

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

BOOK OF ABSTRACTS



Prof. Giuseppe Scutero
University of Palermo
Department of Palermo, Italy



Prof. Antonina Piccinini
University of Palermo
Department of Palermo, Italy



Prof. Luigi Di Stefano
University of Palermo
Department of Palermo, Italy

Plenary lectures

**Modeling and simulation of soil-structure-vehicle
interaction of railway bridges subjected to high-speed trains**

Christoph Adam

Head of the Department of Basic Sciences in Engineering Sciences at Universität Innsbruck, Austria

Abstract

Bridge structures for high-speed trains are exposed to significant dynamic loading during the train passage. The main source of bridge resonance are the repetitive axle loads moving with critical speeds, which are transferred through the vehicle wheels to the structure, rail irregularities, and wheel hunting oscillations. In general, in a state of resonance the load bearing capacity of railway bridge structures is satisfied, however, the admissible bridge deck acceleration is exceeded. Large bridge deck accelerations may lead to ballast instability and to train derailment, and thus, it is often the limiting factor in the dynamic design of railway bridges. Bridge, subsoil, track, and high-speed train represent an uncertain interacting dynamic system of high complexity with, in general, time-dependent system matrices. Thus, full reliability assessment of this system can only be conducted efficiently in an interdisciplinary approach, bringing together the disciplines of structural mechanics, engineering mathematics, and high performance computing. This contribution provides a summary on modeling issues of uncertain bridge-train interaction, its efficient simulation, and an outline of pros and cons of different strategies is provided.

Nano-Scale Mechanical Systems: Recent Trends in Nano-Structural Mechanics

Raimondo Luciano

Department of Engineering, University of Naples Parthenope, Napoli, Italy

Abstract

Nanotechnology is the understanding of matter at dimensions between approximately 1 and 100 nanometers. At nanoscale level, unusual physical, chemical and biological properties may be observed and for these particular properties, nanomaterials are spreading all over: in electronic, biotechnology and nanostructure applications. When the sizes are small and comparable to crystal or molecular distances, size effect in mechanical behaviour is detected, and it cannot be neglected when the behaviour analysis is performed. Therefore, classical continuum mechanics cannot be used, due to its scale-free character: rather, atomistic models and Generalised Continuum Theories (GCTs) have to be used. It is worth noticing that, since atomistic modelling is quite time consuming, size-dependent continuum mechanics approaches are widely employed to explain the size-dependent mechanical behaviour. Lattice-based nonlocal models, Eringen's nonlocal models, gradient theory of elasticity, strain- and stress-driven nonlocal models, and peridynamic theory are some of the most widely known and accepted GCTs. In the context of the stress-driven nonlocal model, it has been successfully applied to solve numerous engineering problems, such as: static bending behaviour, buckling and free transverse vibrations of nanobeams.

The present research work is dedicated to the theoretical modelling of nanomaterials with particular attentions to Carbon NanoTubes. More precisely, the two-phase local/nonlocal Stress-Driven integral model is presented. Firstly, such a model is applied to nanobeams free vibrations problems, with particular attention to the determination of the nanobeam natural frequency. Then, it is used to analyse the small-scale effect on the Mode I fracture behaviour of both edge- and centrally-cracked nanobeams, showing a decreasing of the energy release rate by increasing the nonlocality, with a consequent superior advantage in terms of fracture performance of nanobeams with respect to large-scale beams.

A universe of models and data -- multilevel methods, multifidelity methods and beyond

Carsten Proppe

Chair of Engineering Mechanics, Karlsruhe Institute of Technology, Karlsruhe, Germany

proppe@kit.edu

Due to the advancing possibilities of modeling, computing technology and data acquisition, today a variety of simulation models and data is available that is nearly unmanageable. This diversity in turn opens up new possibilities for the development of computational methods in which information from different sources and of different quality is merged in order to further increase the efficiency of computational procedures. This is particularly important for outer-loop applications, which not only require a large number of model evaluations, but also a careful consideration of the mutual influences between model creation and refinement on the one hand and the quality of the outer-loop result on the other.

The lecture presents important model classes, points out possibilities for structuring the model and data universe and gives an overview of multilevel and multifidelity information fusion methods for a selected outer-loop application, namely the computation of the failure probability in the context of reliability assessment. Furthermore, the potential of machine learning to automate the use of models and to further increase the computational efficiency is highlighted.

Invited keynote lectures

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Title: Probabilistic Approaches for Uncertainty Quantification with Sparse and Interval Data

Author(s): Sankaran Mahadevan*

Department of Civil & Environmental Engineering, Vanderbilt University, Nashville, USA.
sankaran.mahadevan@vanderbilt.edu

Keyword(s): Sparse data, interval data, uncertainty quantification, aleatory, epistemic

Abstract

This presentation discusses several alternative probabilistic approaches to characterize the uncertainty in the presence of sparse and interval data. Both parametric and non-parametric approaches are investigated. Two methods for constructing families of distributions are explored within the parametric approach. The first method is to use a flexible 4-parameter distribution family, such as the Johnson distribution family, which allows the data to dictate the shape of the distribution with a variety of forms. In the presence of sparse data, both the distribution shape and the corresponding distribution parameters are uncertain. An optimization-based approach in combination with a jack-knifing technique is developed to estimate the lower and upper bounds of the distribution moments, which are then employed to construct the Johnson family of distributions to describe the sparse data. In the case of a multivariate distribution, the jack-knifing-based optimization technique is further extended to learn the correlation structure in the data.

The second parametric method for constructing families of distributions develops a Bayesian approach to infer the uncertainty regarding the distribution types and associated distribution parameters to represent the available sparse and/or interval data. The resulting family of distributions is constructed as a weighted combination of the candidate distributions, similar to Bayesian model averaging. The weights are inferred based on Bayesian hypothesis testing.

In addition to the above parametric approaches, a non-parametric approach suitable for sparse and interval data. Kernel density estimation is a well-established non-parametric method; however, it is difficult to apply with sparse and/or interval data. An alternative approach is developed in this work, based on maximum likelihood estimation. The non-parametric probability density is defined by the density values at discrete points along the variable coordinate, and several interpolation techniques are explored for constructing the entire distribution. The likelihood of the observed sparse data is then estimated, and the density values are estimated by maximizing the likelihood.

In the presence of sparse and/or interval data, the resulting uncertainty characterization combines both aleatory and epistemic uncertainty. An approach is developed to separate the contributions of aleatory and epistemic uncertainty on the overall uncertainty. This approach introduces an auxiliary variable, based on the probability integral transform, to achieve the separation not only in the input uncertainty characterization but also to maintain the separation through uncertainty propagation in a system model. Further, variance-based sensitivity analysis is employed to quantify the relative contributions of the aleatory and epistemic uncertainty sources to the overall uncertainty. The above parametric and non-parametric approaches are examined with respect to the delineation of aleatory and epistemic uncertainty and presentation formats of the corresponding results. The proposed techniques are demonstrated with a set of challenge problems developed at Sandia National Laboratories and NASA, with respect to both input uncertainty characterization and uncertainty propagation to the output.

Invited Lecture Prof. Rainer Helmig

Title

Coupled Free and Porous-Medium Flow Processes – Models, Concepts and Analysis-

Author

Prof. Rainer Helmig

Institute for Modelling Hydraulic and Environmental Systems (IWS)

Chair of Hydromechanics and Modelling of Hydrosystems

Universitaet Stuttgart, Pfaffenwaldring 61, 70569 Stuttgart

email: rainer.helmig@iws.uni-stuttgart.de

Co-Authors

Martin Schneider, Edward Coltman, Anna Mareike Kosteletzky, Maziar Veyskarami ,
Hanchuan Wu, Costanza Arico'

Abstract

Coupled systems of free flow adjacent to a porous-medium appear ubiquitously in nature and in technical applications. Examples for interface-driven transport and exchange processes include soil evaporation, fuel cell water management or food drying.

One of the key challenges for coupled free flow and porous-medium flow arises from the fact that the overall effective behaviour depends strongly on interface processes that occur on small spatial scales (pore scale), although the overall system of interest is often too large to resolve these processes explicitly in detail. REV-scale models are usually not able to capture all the relevant physical processes for such coupled systems. In addition, pore-scale interface roughness, macro-scale surface topologies, and boundary layers strongly influence the flow behaviour inside the porous medium and the free-flow region near the common interface. Pore-scale models are in turn not suitable for large-scale problems because of the high computational costs involved, rendering them applicable only to model domains in the range of micrometres to centimetres. For the accurate description of interface phenomena, it is therefore necessary to develop model concepts that combine information gained through pore-scale and REV-scale models.

In this lecture, we will:

- explain the relevant processes of mass, momentum and energy transfer at the interface between a free-flow and a porous-media system;
- present a conceptual model for coupled single-phase free flow and two-phase porous-medium flow with a detailed description of the models in the free flow and in the porous medium;
- provide a new coupling concept for modelling coupled porous-medium and free flow with application to evaporation and salt-precipitation processes. A comparison study will show the advantages and disadvantages in comparison with classical approaches;
- present various numerical examples that will illustrate the influence of soil-moisture processes in the subsurface on the groundwater budget and quality.

The results will be compared and discussed with experimental measurements on different scales.

STRUCTURAL TESTING AT THE MICROMETER AND NANOMETER SCALES

Roberto Ballarini
University of Houston

Abstract

I will summarize the research that my students, post-docs and I have been conducting over the past three decades on the use of Microelectromechanical Systems (MEMS) devices to study the strength, stiffness, fracture toughness, fatigue behavior, subcritical crack growth, and viscoelasticity of numerous materials at micrometer and nanometer scales. The three types of devices, fabricated using standard MEMS processing techniques, have characteristic dimensions comparable to typical MEMS components. The first involves a specimen that is fully integrated with simultaneously fabricated electrostatic actuators that provide sufficient force and displacement to ensure failure under monotonic or cyclic loading. The second is similar but it relies on a piezoelectric drive to apply force and displacement to specimens submerged in liquid. The third is a “passive device” in which force is achieved through the residual stresses that develop during processing. With all these micro-testing machines the entire experiment takes place on-chip, eliminating the difficulties associated with attaching the specimen to an external loading source. Illustrative results are presented for: polycrystalline silicon, silicon carbide and other materials used to fabricate MEMS devices; individual collagen fibrils; carbon nanotubes; and carbon nanotube/epoxy composites.

Conference Abstracts

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Title: The stochastic differential calculus for non-Gaussian delta-correlated input: the Di Paola-Falsone calculus after thirty years

Author(s): Giovanni Falsone

Engineering Department, University of Messina, Messina, gfalsone@unime.it

Keyword(s): stochastic differential calculus, non-Gaussian delta-correlated process, stochastic Ito integral, corrective coefficient terms, Fokker-Plank equation, Di Paola-Falsone calculus.

Abstract

About thirty years ago, a paper was published whose fundamental topic was the extension of the Ito differential calculus, holding in the case of parametric white noise excitations, to the case of non-Gaussian delta-correlated parametric inputs [1]. It was shown that for Gaussian white noise the presence of some corrective terms is necessary to obtain the same results of the Stratonovich approach (Wong-Zakai terms) , even in the case of delta correlated inputs some corrective terms are necessary. They were named Di Paola-Falsone terms [2] and represent the generalization of the Wong-Zakai ones when the inputs are non-Gaussian. Soon, the Ito differential rule was generalized to non-normal delta-correlated inputs, as well as the Fokker Plank equation. In the following years, this calculus was acknowledged by many stochastic researcher in the fields of Mathematics, Physics and Mechanics [3]. Even in these last years, many applications can be find in literature in the field of aerospace engineering, mechanic engineering, but also of genetic sciences, natural sciences, financial sciences, medicine. Thus, it can be affirmed that the Di Paola-Falsone stochastic differential calculus is still very actual.

References

- [1] M. Di Paola, G. Falsone, Stochastic Dynamics of Non-Linear Systems Driven by Non-Normal Delta-Correlated Processes, Journal of Applied Mechanics, Vol.60, pp.141-148. (1993),
- [2] X. Sun, X. Li, Y. Zheng, Governing equations for probability densities of Marcus stochastic differential equations with Lévy noise, Stochastics and Dynamics, Vol.17 (05). (2017)..
- [3] X. Li, J. Gu, W. Xu, F. Ma, Stochastic stability of viscoelastic systems under Gaussian and Poisson white noise excitations, Nonlinear Dynamics, Vol. 93(3), pp. 1579-1588 (2018),

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Title: Fragility Curves for Wooden Houses in Japan Based on Integrated Damage Data from the 2016 Kumamoto Earthquake

Author(s): Fumio Yamazaki^{*1}, Kazuaki Torisawa²

¹ *National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan. Email: fumio.yamazaki@bosai.go.jp*

² *Kanto Gakuin University, Yokohama, Japan. Email: tori@kanto-gakuin.ac.jp*

Keyword(s): the 2016 Kumamoto earthquake, building damage, peak ground velocity, fragility curve

Abstract

A series of earthquakes hit Kumamoto Prefecture, Japan, on April 14 and 16, 2016. After the 2016 Kumamoto earthquake, municipal governments carried out building damage surveys in order to issue disaster-victim certificates [1]. The building damage by the earthquake was most serious in Mashiki Town, which is located closest to the source region, and Uki City, about 20-50 km from the causative fault, was moderately affected. The authors have developed fragility curves for wooden houses using damage survey data from Mashiki Town [2] and Uki City [3] governments independently. The fragility curves for Mashiki Town rise sharply at low peak ground velocity (PGV) levels because of the lack of damage data in the low PGV range. On the contrary, the fragility curves for Uki City show a lower damage ratio for the same PGV level. In this study, we integrated the damage survey data of the two municipalities, and constructed fragility curves with respect to the structural material and construction period for the estimated PGV values. The correlation coefficient showed a strong positive correlation of approximately 0.9 for the integrated dataset. The proposed fragility curves were then compared with existing ones developed from the data in other Japanese earthquakes.

References

- [1] Cabinet Office of Japan, "Operational guideline for damage assessment of residential buildings in disasters," <http://www.bousai.go.jp/taisaku/pdf/shishinall.pdf>, 2013 (in Japanese) [accessed May 1, 2021]
- [2] Yamazaki F., Suto T., Liu W., Matsuoka M., Horie K., Kawabe K., Torisawa K., Inoguchi M., "Development of fragility curves of Japanese buildings based on the 2016 Kumamoto earthquake," Proceedings of the 2019 Pacific Conference on Earthquake Engineering, paper ID 228, Auckland, New Zealand, 2019.
- [3] Torisawa K., Horie K., Matsuoka M., Inoguchi M., Yamazaki F., "Fragility curves of wooden building based on the 2016 Kumamoto earthquake damage in Uki City," Proceedings of the 17th World Conference on Earthquake Engineering, 8a-0031, 10p, Sendai, Japan, 2020.

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Title: SPH modelling of high-density ratio multiphase flows with complex interfaces

Author(s): Nicolò Salis^{*1}, Alessandro Reali^{1,2}, Sauro Manenti^{1,2}.

¹ Department of Civil Engineering and Architecture DICAr, University of Pavia, Pavia, Italy, nicolo.salis01@universitadipavia.it

² Water Research Centre CRA, University of Pavia, Pavia, Italy

Keyword(s): SPH, multiphase flow,

Abstract

Lagrangian particle methods provide a versatile tool to model complex flows. The Lagrangian discretization of the governing equations lacks the advection terms, thus avoiding numerical diffusion and making particle methods highly suitable to model advection-dominated flows [1]. Free surfaces and interfaces between phases are implicitly handled with no need for further conditions. The absence of a topological connection gives to the particle methods an advantage when modelling fast and large domain deformations as well as fluid coalescence and split. In this work, the Weakly Compressible Smoothed Particle Hydrodynamics (SPH) method is considered. The model [4] is developed independently by introducing relevant modifications in the original (FOSS) model SPHERA v.9.0.0 (RSE SpA) [3]. In [1,2] an alternative formulation of the standard SPH is presented to model multiphase flow with high density ratio. In this work a particle shifting algorithm and a Riemann solver are used to avoid the formation of non-physical voids and assure interface sharpness. The model is validated on a variety of multiphase test cases (bubbly flows, Taylor-Rigley Instability, dam break and tank sloshing) showing a wide range of possible applications, including more complex multiphase flows of interest in the field of applied engineering.

References

- [1] Salis, N., Luo, M., Reali, A., & Manenti, S. (2022). Wave generation and wave–structure impact modelling with WCSPH. *Ocean Engineering*, 266, 113228.
- [2] Salis N., Franci A., Idelsohn S., Reali A. and Manenti S. Lagrangian particle-based simulation of waves: A comparison of SPH and PFEM approaches. Subm. to *Engineering with Computers*
- [3] SPHERA (RSE SpA) <https://github.com/GiordanoAgateRSE/SPHERA> (2023)
- [4] Derived code https://github.com/ncsalis/SPHERA/tree/SPHERA_v9.0.0_NS_2P (2022)

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Title: Internal solitary wave trains: interaction and grouping into multi-humped configurations

Authors: Giovanni La Forgia¹, Giampiero Sciortino², Valentina Lombardi³, Pietro Prestininzi^{*2}

¹*Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, 03043, Cassino (FR), Italy, giovanni.laforgia@unicas.it*

²*Department of Civil, Computer Science and Aeronautical Technologies Engineering, University of Rome "Roma Tre", 00146, Rome, Italy, giampiero.sciortino@uniroma3.it; pietro.prestininzi@uniroma3.it*

³*Institute for Environmental Protection and Research (ISPRA), 00144, Rome, Italy, valentina.lombardi@isprambiente.it*

Keyword(s): Multi-humped solitary waves, Numerical simulations, Interfacial solitons, Solitary waves interaction

Abstract

Internal Solitary Waves (ISWs) propagate as large-amplitude undulations of the pycnocline in stratified geophysical fluids, being periodically generated by the interaction between tidal flows and seabed topography.

In this study, the existence in a realistic environment of multi-humped Internal Solitary Waves (ISWs), whose features are compliant with the non-linear theory of multi-humped solitons, is numerically confirmed. Our findings back up field Synthetic Aperture Radar (SAR) observations of ISW packets propagating in the stratified coastal oceans.

Numerical experiments are aimed to generate, through a lock-release mechanism, an originally rank-ordered train of ISWs in a density stratified two-layers system. The velocity field in the wake of leading ISW is found to promote the acceleration and the steepening of the trailing waves, inducing an accretive ISWs grouping. By means of such a long-range interaction, ISWs group into a multi-humped arrangement sharing the shape and travelling as a whole. Results are consistent with the recent theory proposed by La Forgia and Sciortino [1] for ISW propagating through moving, interfacial, stratified environments. Once grouped together, indeed, the Froude number is found to decrease as the number of ISWs composing the packet increases, depicting the occurrence of a Froude cascade process.

References

[1] La Forgia G., Sciortino G., "Free-surface effects induced by internal solitons forced by shearing currents", *Physics of Fluids*, 33 (7), 072102, (2021).

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Title: A comparison between commercial devices for energy recovery in a real Water Distribution Network

Author(s): Gabriella Balacco^{*1}, Michele Stefanizzi², Gaetano D. Fiorese³, Domenico Filannino², Marco Torresi², Orazio Giustolisi¹

¹ Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh), Polytechnic University of Bari, Bari, Italy, GB: gabriella.balacco@poliba.it; OG: orazio.giustolisi@poliba.it

² Department of Mechanics, Mathematics and Management (DMMM), Polytechnic University of Bari, Bari, Italy, MS: michele.stefanizzi@poliba.it; DF: Domenico.filannino@poliba.it; MT: marco.torresi@poliba.it

³ Department of Agricultural and Environmental Sciences, University of Bari Aldo Moro, Bari, Italy, gaetano.fiorese@uniba.it

Keyword(s): Water Distribution Network, Energy recovery, Hydroelectric energy

Abstract

The scarcity of water resources is a known and worldwide issue. Europe has promoted numerous actions (Directive 2000/60/CE [1], Directive 2020/2184 [2]) aimed at reducing water wastage and losses, as well as identifying first the highest quality water resources and allocating the others to irrigation and industry uses. For the same reasons, interest in Water Distribution Network (WDN) management has greatly increased over the past two decades. In this context, EU have been adopted numerous initiatives supported by massive investments in WDN asset management, e.g. Next generation EU [3] is funding actions in Italy to support the sustainable use of water through the digital transition. On one hand, all these investments represent unprecedented opportunities for water companies to improve the quality of WDN service. On the other hand, the digital transition in the WDN industry can provide processes and products to support engineers in making effective and efficient asset management planning decisions based on structured, verifiable and replicable workflows [4].

Energy is also a key issue for EU. The European Green Deal [5] aims to move the EU towards a green transition, aiming to achieve climate neutrality by 2050.

Water-Energy Nexus is one of the pillars of this challenge. The idea is to scientifically support the Water Utilities with concrete but ambitious ideas. A change of perspective can lead to strengthening the Water Energy Nexus, which can lead to achieving the double target through a chain of actions: reduction of water losses and production of clean energy at zero cost.

This study was inspired by the support for the design of district metering areas (DMAs), pressure control, hydraulic monitoring and rehabilitation of the Water Distribution Network (WDN) in Bari, the capital town of the Apulia Region (Italy). It was based on the advanced modelling of the hydraulic behaviour of individual aqueducts, i.e. the calibration of a design model with an innovative paradigm based on water balances, integrating pressure-dependent volumetric losses into the hydraulic analyses [6]. As part of this revision and rationalisation process, we wanted to test the feasibility and economic viability of replacing the current 16 Pressure Reduction Valves (PRVs) present now in the WDN of Bari with an equal number of commercial devices for energy recovery.

Several studies have demonstrated as the energy recovery from a WDN should represent an important alternative to the massive use of PRVs [7, 8, 9, 10]. Nowadays, it is a useful and viable alternative to produce clean energy that is otherwise lost. Some uncertainties are still related to the application of Pumps as Turbines (PATs). Indeed, some limits and mistrusts by water utility operators are due to the absence of catalogue curves of the major parts of pumps running as turbines since this would require the pump to be also tested in turbine mode operation [11]. However, in the last ten years, several

researchers [12, 13, 14] have investigated PATs through experimental, theoretical and numerical studies. Where experimental curves in reverse mode were not available, a strong effort by the research community aimed to develop models able to predict the Best Efficiency Point (BEP) and the characteristic curve of the PAT by knowing the BEP of the pump, retrieved from catalogues [11].

Though, in the last few years, the number of PATs, hydraulic microturbines or valves capable of producing energy in a WDN by exploiting hydraulic load in excess has increased considerably.

In this framework, this study reports on the selection and characteristics of the most appropriate device for each of the PRVs present in the WDN of Bari. The choice was based on the analysis of the hourly flow rates for every node and the pressure in excess available to be converted into energy. For each node, the selection was established on the compatibility of the individual commercial device with the hydraulic conditions present (i.e., flow rate and pressure ranges). The objectives were to maximise the daily power output and define how to set the by-pass hydraulic branch to control the flow rates at the device inlet.

This study represents the *last mile* in making WDNs more efficient and sustainable energy systems, in accordance with the goals of the Green Deal. The aim was to identify the most suitable commercial device for each individual situation through an advanced hydraulic approach that maximised energy production depending on the performance of the device.

References

- [1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, (2000).
- [2] Directive 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast), (2020).
- [3] Call REACT-UE <https://ponir.mit.gov.it/documentazione/gestione-e-attuazione/manifestazioni-di-interesse-react>.
- [4] Laucelli D., Spagnuolo S., Rinaldi A., Perrone G., Berardi L., Giustolisi O., "A complete digital water experience to support real leakage management planning". IOP Conf Ser Earth Environ Sci., (2023).
- [5] Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions The European Green Deal, COM/2019/640 final (2019).
- [6] Berardi L., Simone A., Laucelli D., Giustolisi O., "Feasibility of Mass Balance Approach to Water Distribution Network Model Calibration". In: Procedia Engineering, (2017).
- [7] Balacco G., Binetti M., Caporaletti V., Gioia A., Leandro L., Iacobellis V., Sanvito C., & Piccinni A.F. "Innovative mini-hydro device for the recharge of electric vehicles in urban areas". International Journal of Energy and Environmental Engineering, (2018).
- [8] Morani MC, Simão M, Gazur I, et al. Pressure Drop and Energy Recovery with a New Centrifugal Micro-Turbine: Fundamentals and Application in a Real WDN. Energies. Published online 2022. doi:10.3390/en15041528
- [9] Sinagra M., Sammartano V., Morreale G., Tucciarelli T., "A new device for pressure control and energy recovery in water distribution networks". Water (Switzerland) (2017).
- [10] Ferrarese G., Malavasi S., "Perspectives of water distribution networks with the greenvalve system". Water (Switzerland). (2020).
- [11] Stefanizzi M., Capurso T., Balacco G., Binetti M., Camporeale S. M., & Torresi M., "Selection, control and techno-economic feasibility of Pumps as Turbines in Water Distribution Networks". Renewable Energy. (2020).
- [12] Derakhshan S., Nourbakhsh A., "Experimental study of characteristic curves of centrifugal pumps working as turbines in different specific speeds". Exp Therm Fluid Sci. (2008).
- [13] Nautiyal H., Kumar A., Yadav S., "Experimental Investigation of Centrifugal Pump Working as Turbine for Small Hydropower Systems". Energy Sci Technol. (2011).
- [14] Barbarelli S., Amelio M., Florio G., "Experimental activity at test rig validating correlations to select pumps running as turbines in microhydro plants". Energy Convers Manag., (2017).

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Title: Water Loss Estimation and Pipe Deformation in Water Distribution Network: Laboratory and Numerical experiments

Author(s): Mauro De Marchis¹, Federica Bruno¹, Domenico Saccone¹, Fabrizio Traina¹, Enrico Napoli²

¹ *Kore Water Lab, Faculty of Engineering and Architecture, University of Enna Kore, Enna, Italy, mauro.demarchis@unikore.it; Federica.bruno3@unikorestudent.it*

² *Dipartimento di Ingegneria, Università degli Studi di Palermo, Palermo, Italy, enrico.napoli@unipa.it*

Keyword(s): Leakage, pipe deformation, RANS simulations, Water distribution network

Abstract

Water leaks in pipes can lead to significant water wastage, as well as increased costs for energy and maintenance. In addition, leaks can lead to low pressure conditions, which can create a risk of contamination in the water supply. The amount of water lost through a leak is affected by the pressure in the distribution network, which can vary depending on factors such as the location and size of the leak, as well as the overall condition of the pipe network. Identifying and repairing leaks in a timely manner is essential to minimizing the environmental, financial, and health impacts of water leakage in a distribution system.

In order to effectively control water leakage, it is important to accurately model the hydraulic behaviour of the pipeline and the leak itself. This requires an understanding of the relationship between the operating conditions of the pipeline and the flow rate of the leak. Accurately modeling the behaviour of leaks in both rigid and deformable pipes is essential to accurately estimate the cost-effectiveness of various techniques for controlling leakage, such as pressure reduction. The development of advanced hydraulic models capable of capturing the complex behaviour of leaks in different types of pipes is an ongoing area of research in water distribution systems engineering.

Despite the efforts made to develop a comprehensive theory for water leaks in pipes, the research in this field is still ongoing and requires further investigation. There are various studies in the literature that focus on developing physically meaningful hydraulic models for pressure-dependent leaks in pipes. These models are intended to accurately predict the behaviour of water leaks under different operating conditions.

To investigate on the head-area leakages and on the head-discharge relationships, some laboratory experiments were reproduced numerically by means of a commercial software Ansys, able to simulate both the fluid dynamics and the structural analysis. Basically, the flow field inside the pipe was simulated using the Fluent software module, whereas the deformation analysis was studied using the toolbox of Ansys known as Mechanical.

In order to investigate the relationship between the leak outflow and the water head as a function of the crack shape, several experiments were conducted considering cracks of different shape and size. Specifically, two set of cracks were investigated: circular and rectangular transversal cracks. The two sets of experiments were designed with the aim to have different geometries maintaining almost the same leak area: for example, the test cases T_1 with a rectangular burst of 1.5×10 mm, has an area $A_0=0.007$ equal to that considered in the test case C_1 (circular track), having a diameter equal to $D=4.35$ mm. For each experimental test the head at the inlet node of the network was modified in the range 1.0 to 5 bar, with a step of 0.2 bar, in order to have a detailed variation of the leak outflow as a function of the water head.

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Title: Bayesian identification of brackish water infiltration by Lagrangian sensors

Author(s): Gabriele Freni¹, Mariacrosetta Sambito¹,

¹ *Facoltà di Ingegneria ed Architettura, Università degli Studi di Enna "Kore", Enna, Italia, gabriele.freni@unikore.it*

² *Facoltà di Ingegneria ed Architettura, Università degli Studi di Enna "Kore", Enna, Italia, mariacrosetta.sambito@unikore.it*

Keyword(s): bayesian approach; brackish water infiltration; lagrangian sensors; optimal deploy; urban drainage systems

Abstract

The problem of water quality has always aroused considerable interest within the scientific community, as it is closely connected with the risks associated with public health [1, 2, 3] and environmental problems [4]. For this reason, many researchers have applied different methodologies to monitor the water quality parameters (chemicals and biologicals) of water distribution networks (WDN) and urban drainage systems (UDS) [5, 6, 7]. The latter can be a helpful tool to check the input values to the sewage treatment plants to monitor the process removal efficiency. To monitor the numerous chemical and biological parameters that can come into play in contamination episodes, different types of technologies and sensors have been studied and developed in the literature, which find application in most cases within WDN. According to the review, from the electronic point of view, sensors work with the same standards in WDN and UDS. This feature allows for using different types of sensors on the same monitoring frame enabling a more extensive choice on the market [8]. From the measurement point of view, on the other hand, they differ according to the parameters studied, timing and accuracy of measures. Some parameters (temperature or pH) can be measured directly using specific technologies. In contrast, other parameters such as salinity or dissolved matter concentration are measured through indirect measurements obtained from redox potential, conductivity measurement, turbidity or a combination [9].

The development of new computational algorithms, technological improvement of new measuring instruments and the creation of reliable and economical microcontrollers allow the researchers to develop new monitoring techniques. Passing from discontinuous monitoring, in which the measurements are carried through levies of a sample at specific points of the networks, to continuous real-time tracking at strategic points of the networks through the development of algorithms able to identify any contamination within networks [10], a critical issue that allowed technological innovation was the introduction of a new science called the Internet of Things (IoT) allowing sensors to be continuously accessible and data to be retrieved on demand. IoT can be defined as the application of simple devices connected via the internet to improve system quality [11]. This science has developed in recent years due to simple and inexpensive hardware development. Through microcomputers such as Raspberry Pi and microcontrollers such as Arduino, it was possible to create IT solutions to interact with operators and computers directly.

IoT has evolved so much that its definition has changed compared to the original. We mean all the technologies developed on the "things" for IoT. This technology aims to improve the classical use of things by providing an internet connection. This technology can enhance the potential of any object, instrument or sensor connected to a telecommunications network. Therefore, this science aims to simplify everything, from the simple ordinary life tool to the most complex sensor. It has been demonstrated [12] how this approach can help reach the concept of digitalised industry.

Lagrangian sensors are monitoring platforms that do not require a stable installation but are deployed in the current and transported by the water. Sensors collect and transmit data in real time, and they are recovered at the end of the pipe. The cost of the sensors is usually low as the risk of losing or damaging them is high.

The proposed methodology incorporates several sources of information, including network topology, flows and non-formal “grey” information about the possible locations of contamination sources. For the solution to this problem, two main components are required: a calibrated model for hydraulic and water quality simulations in sewer systems (EPA SWMM model) and a Bayesian solver for likelihood estimation and probability update. Using the Bayesian approach, new information is incorporated into the approach once available, allowing the operator to gain insight into the system once contamination events are detected and identified. In this way, the approach is suitable for solving problems in which data are initially piecemeal, and the operator plans to improve the monitoring strategy.

References

- [1] M. Sambito and G. Freni, “Optimal positioning of water quality sensors in a sewer during dry and wet weather,” in AIP Conference Proceedings, 2020.
- [2] S. Piazza, M. Sambito and G. Freni, “Experimental evidence of diffusion and dispersion impact on optimal positioning of water quality sensors in distribution networks,” in AIP Conference Proceedings, 2021.
- [3] M. Sambito and G. Freni, “Strategies for improving optimal positioning of quality sensors in urban drainage systems for non-conservative contaminants,” *Water (Switzerland)*, vol. 13, no. 7, 2021.
- [4] M. Sambito, A. Severino, G. Freni and L. Neduzha, “A systematic review of the hydrological, environmental and durability performance of permeable pavement systems,” *Sustainability (Switzerland)*, vol. 13, no. 8, 2021.
- [5] N. Olikar and A. Ostfeld, “Inclusion of Mobile Sensors in Water Distribution System Monitoring Operations,” *Journal of Water Resources Planning and Management*, vol. 142, 2016.
- [6] M. Weickgenannt, Z. Kapelan, M. Blokker and D. A. Savic, “Optimal Sensor Placement for the Efficient Contaminant Detection in Water Distribution Systems,” *Water Distribution Systems Analysis*, 2008.
- [7] M. Sambito, C. Di Cristo, G. Freni and A. Leopardi, “Optimal water quality sensor positioning in urban drainage systems for illicit intrusion identification,” *Journal of Hydroinformatics*, vol. 22, no. 1, pp. 46-60, 1 January 2020.
- [8] K. Wang, X. Wen, D. Hou, D. Tu, N. Zhu and P. Huang, (2018) “Application of least-squares support vector machines for quantitative evaluation of known contaminant in water distribution system using water quality parameters” *Sensors*, n. 18.4, p. 938.
- [9] S. Piazza, M. Sambito, R. Feo, G. Freni and V. Puleo, “Optimal positioning of sensors in water distribution networks: comparison of numerical and experimental results,” *Computing and Control for the Water Industry*, 2017.
- [10] S. Piazza, E. J. M. Blokker, G. Freni, V. Puleo and M. Sambito, “Impact of diffusion and dispersion of contaminants in water distribution networks modelling and monitoring,” *Water Supply*, vol. 20, no. 1, pp. 46-58, 2020.
- [11] L. Atzori, A. Iera and G. Morabito, “Understanding the Internet of Things: definition, potentials, and societal role of a fast-evolving paradigm,” *Ad Hoc Networks*, vol. 56, pp. 122-140, 2017.
- [12] F. Wortmann and K. Flächter, “Internet of things,” *Business & Information Systems Eng.*, vol. 57, no. 3, pp. 221-224, 2015.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Uncertainty propagation on the thunderstorm gust response factor via interval analysis

Authors: Luca Roncallo^{*1}, Federica Tubino², Alba Sofi³, Giuseppe Muscolino⁴

¹*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy, luca.roncallo@edu.unige.it*

²*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy, federica.tubino@unige.it*

³*Department of Architecture and Territory, University of Reggio Calabria, Reggio Calabria, Italy, alba.sofi@unirc.it*

⁴*Department of Engineering, University of Messina, Messina, Italy, giuseppe.muscolino@unime.it*

Keywords: Gust response factor; Interval analysis; Thunderstorms outflows

Abstract

The maximum wind-excited response of structures and equivalent static wind loading are normally estimated through the gust response factor technique, relying on stationarity hypothesis that applies to synoptic events. In view of its handiness and reliability, this approach was generalized to the non-stationary case of thunderstorm outflows, based on an Evolutionary Power Spectral Density (EPSD) model, defined as a function of suitable thunderstorm parameters [1], and a closed-form solution was proposed able to account the induced transient dynamic effects [2]. Despite the potential of the approach, its applicability is undermined by the choice of the parameters describing the thunderstorm EPSD model, which may vary from one thunderstorm to another. Starting from a large number of thunderstorm records, possible ranges of variation of such parameters were derived, along with a preliminary sensitivity analysis of the thunderstorm gust response factor [3].

In this study, the propagation of uncertainties of thunderstorm and structural parameters on the thunderstorm gust response factor is studied within a non-probabilistic framework through improved interval analysis [4]. Specifically, starting from the thunderstorm data available and the closed-form solution proposed by the authors [2], suitable bounds of the relevant parameters are defined, and the interval analysis is applied to obtain the corresponding bounds of the thunderstorm gust response factor on varying both the thunderstorm parameters and the dynamic properties of the structure [4,5]. The possibility of deriving analytically the interval of variation of the gust factor will also be explored.

References

- [1] Roncallo L., Solari G., Muscolino G., Tubino F., "Maximum dynamic response of linear elastic SDOF systems based on an evolutionary spectral model for thunderstorm outflows", *Journal of Wind Engineering and Industrial Aerodynamics*, 224, 104978, (2022).
- [2] Roncallo L., Tubino F., "Thunderstorm Gust Response Factor: a closed-form solution", *Journal of Wind Engineering and Industrial Aerodynamics*, tentatively accepted, (2023).
- [3] Roncallo L., Tubino F., "Thunderstorm Gust Response Factor: general tendencies and sensitivity analysis", *Journal of Wind Engineering and Industrial Aerodynamics*, 236, 105376, (2023).
- [4] Muscolino G., Sofi A., "Stochastic analysis of structures with uncertain-but-bounded parameters via improved interval analysis", *Probabilistic Engineering Mechanics*, 28, 152-163, (2012).
- [5] Muscolino G., Sofi A., Giunta F., "A Sensitivity-Based Approach for Reliability Analysis of Randomly Excited Structures With Interval Axial Stiffness", *Journal of Risk and Uncertainty in Engineering Systems*, 6, 041008-1, (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A hybrid continuous/discontinuous multiscale approach for analyzing damage localization phenomena in anisotropic composite microstructures

Author(s): Daniele Gaetano¹, Fabrizio Greco², Lorenzo Leonetti^{*3}, Arturo Pascuzzo⁴

¹ Department of Civil Engineering, University of Calabria, Rende, Italy, daniele.gaetano@unical.it

² Department of Civil Engineering, University of Calabria, Rende, Italy, fabrizio.greco@unical.it

³ Department of Civil Engineering, University of Calabria, Rende, Italy, lorenzo.leonetti@unical.it

⁴ Department of Civil Engineering, University of Calabria, Rende, Italy, arturo.pascuzzo@unical.it

Keyword(s): multiscale modeling, damage localization, failure analysis, composite microstructures

Abstract

In this work, a novel finite element-based multiscale approach is proposed for investigating damage localization phenomena in general anisotropic composite microstructures, while keeping a high accuracy level and low computational costs at the same time. Such an approach, which relies on a continuous/discontinuous nonlinear homogenization scheme, has the main advantage to overcome the mesh sensitivity problems usually experienced by purely continuous homogenization techniques after the occurrence of macroscopic strain localization [1].

The key ingredient of the proposed approach is a microscopically informed traction-separation law for the cohesive interfaces embedded in the volumetric mesh at the macroscopic scale, which is extracted in an “off-line” computational stage from the nonlinear homogenized behavior of either a suitably identified Repeating Unit Cell (for periodic microstructures) or Representative Volume Element (for random microstructures) subjected to several macroscopic strain histories. Such an approach is highly efficient, as it does not require costly nested finite element computations as in FE² methods [2]. In the present strategy, general nonlinear constitutive laws at either bulk or interface level are allowed to be adopted at the microscopic scale, whereas a Diffuse Interface Model is used for representing arbitrary cracks at the macroscopic scale, according to the formulation proposed in [3] by some of the authors. The proposed multiscale approach has been successfully validated via suitable comparisons with Direct Numerical Simulations (DNSs), with specific reference to a series of case studies, involving periodic microstructures exhibiting a strain-softening anisotropic damage behavior. As an interesting application of the proposed approach, the investigation of failure phenomena in brick-and-mortar architected materials (such as nacre-like bioinspired composites [4]) is also presented.

References

- [1] Belytschko T., Song J.-H., “Coarse-graining of multiscale crack propagation,” *International Journal for Numerical Methods in Engineering*, 81, 537–563 (2010).
- [2] Geers M.G.D., Kouznetsova V.G., Brekelmans W.A.M., “Multi-scale computational homogenization: Trends and challenges,” *Journal of Computational and Applied Mathematics*, 234, 2175–2182 (2010).
- [3] De Maio U., Greco F., Leonetti L., Luciano R., Nevone Blasi P., Vantadori, S., “A refined diffuse cohesive approach for the failure analysis in quasibrittle materials—part I: Theoretical formulation and numerical calibration,” *Fatigue & Fracture of Engineering Materials & Structures*, 43(2), 221–241 (2020).
- [4] Greco F., Leonetti L., Pranno A., Rudykh, S., “Mechanical behavior of bio-inspired nacre-like composites: A hybrid multiscale modeling approach,” *Composite Structures*, 233, 111625 (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A multiphase approach to peridynamics

Author(s): Federico Cluni^{*1}, Vittorio Gusella¹, Dimitri Mugnai², Edoardo Proietti Lippi³, Patrizia Pucci³

¹Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, {federico.cluni,vittorio.gusella}@unipg.it

²Department of Ecological and Biological Sciences, University of Tuscia, Viterbo, Italy, dimitri.mugnai@unitus.it

³Department of Mathematics and Informatics, University of Perugia, Perugia, Italy, {edoardo.proiettilippi,patrizia.pucci}@unipg.it

Keyword(s): Peridynamics, fractional Laplacian, mixed local and nonlocal operators, variational methods, numerical methods.

Abstract

Starting from the seminal works of Eringen [1-2], there has been an increasing interest in the analysis on nonlocal response of elastic bodies [3-4], which is intrinsic to composite materials [5]. The approach proposed by Eringen is based on the differentiation of the phenomenological law, which can be an issue in case of discontinuities. In order to overcome this problem, Silling [6] proposed a different approach based on peridynamics, where the balance equation is written with an operator which accounts for nonlocal behavior.

In the present work a model able to describe the nonlocal behavior of an elastic body is proposed by a peridynamic approach. In particular, we consider a two-phase medium, with a local behavior modelled through ordinary Laplacian and a nonlocal behavior modelled by a regional fractional Laplacian of order s . It is possible to vary the mixture relation between the two phases in order to achieve a better description of the mechanical response. A parametric analysis to assess the influence of the order s , the mixture law and linear restraints is proposed.

Both linear and nonlinear load are considered. The problem is solved through a numerical approach which estimates the regional fractional Laplacian by means of its singular integral representation which can be interpreted in the context of finite differences. Some numerical results are presented and compared with those which employ a different nonlocal operator, both in statics and dynamics [7-8].

References

- [1] Eringen A.C. "On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves," Journal of Applied Physics, 54 (9), 4703-4710, 1983.
- [2] Eringen A.C., Edelen D.G.B., "On nonlocal elasticity", International Journal of Engineering Science, 10 (3), 233-248, 1972.
- [3] Vaccaro M.S., Pinnola F.P., Marotti de Sciarra F., Barretta R., "Limit behaviour of Eringen's two-phase elastic beams", European Journal of Mechanics A-Solids, 89, 104315, 2021.
- [4] Di Matteo A., Pavone M., Pirrotta A., "Exact and approximate analytical solutions for nonlocal nanoplates of arbitrary shapes in bending using the line element-less method," Meccanica, 57 (4), 923-941, 2022.
- [5] Silling S.A., "Reformulation of elasticity theory for discontinuities and long-range forces", Journal of Mechanics of Materials and Structures, 9 (2), 245-258, 2014.
- [6] Silling S.A., "Origin and effect of nonlocality in a composite", Journal of the Mechanics and Physics of Solids, 48, 175-209, 2000.
- [7] Autuori G., Cluni F., Gusella V., Pucci P., "Mathematical models for nonlocal elastic composite materials", Advances in Nonlinear Analysis, 6 (4), 355-382, 2017.
- [8] Autuori G., Cluni F., Gusella V., Pucci P., "Longitudinal waves in a nonlocal rod by fractional Laplacian", Mechanics of Advanced Materials and Structures, 27 (7), 599-604, 2020.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Homogenization-Based Analytical Solution for Laminar Flow Problems in Channels Bounded by Rough/Permeable Walls

Author(s): Essam Nabil Ahmed^{*1}, Alessandro Bottaro²

¹ DICCA, Università degli Studi di Genova, Genova, Italy, essameldin.abdo@edu.unige.it

² DICCA, Università degli Studi di Genova, Genova, Italy, alessandro.bottaro@unige.it

Keyword(s): laminar channel flow; rough wall; porous substrate; homogenization; effective conditions

Abstract

The study of the laminar, plane Poiseuille flow in smooth channels has been a thoroughly studied problem in fundamental fluid mechanics. In the present work, a generalised version of this problem is considered. The steady, incompressible, laminar flow in a channel bounded by rough/permeable walls is targeted for upscaling via the homogenization technique; the presence of the structured surfaces/substrates on the channel flow behaviour is macroscopically mimicked by imposing second-order accurate *effective* boundary conditions (expressed in terms of a small parameter ε representing the ratio between the microscopic length scale and half the channel height) for the velocity at fictitious interfaces between the structured surfaces and the channel flow region. In the fully developed region, provided that the macroscopic pressure gradient driving the flow through the channel is aligned with one of the principal axes with regard to the Navier-slip tensors of the walls, one can solve for a one-directional channel flow—i.e., the macroscopic pressure gradient applied in X yields a streamwise velocity $U = U(Y)$ subject to Robin boundary conditions describing the slip velocity at the bottom ($Y = 0$) and top ($Y = 2$) boundaries—seeking an analytical solution of the reduced Navier-Stokes equation. Such a macroscopic counterpart of the physical channel flow is indicated here as the *Generalized Poiseuille* flow. The analytical solution obtained was validated against full feature-resolving simulations of laminar flow through channels bounded by two-/three-dimensionally structured walls, of either highly ordered or random textures, where the accuracy and the applicability range of the model were analysed.

The analysis conducted crowns the efforts devoted in recent years to the implementation of the multiscale homogenization theory in relevant physical problems (cf., for instance, refs. [1–4]), bridging a gap between basic and applied fluid mechanics when flows over natural/engineered surfaces are encountered, and providing a low-cost framework for preliminary understanding of the macroscale features of such flows. Moreover, this study opens up prospects for generating homogenization-based counterparts of other classical flow problems such as Couette flow and Hagen-Poiseuille flow—a new family which can enrich the existing group of known exact solutions of the Navier-Stokes equations and which may serve for the validation of newly developed CFD codes.

References

- [1] Jiménez Bolaños S., Vernescu B., “Derivation of the Navier slip and slip length for viscous flows over a rough boundary,” *Physics of Fluids*, 29, 057103, (2017).
- [2] Bottaro A., “Flow over natural or engineered surfaces: an adjoint homogenization perspective,” *Journal of Fluid Mechanics*, 877, P1, (2019).
- [3] Bottaro A., Naqvi S.B., “Effective boundary conditions at a rough wall: a high-order homogenization approach,” *Meccanica*, 55, 1781–1800, (2020).
- [4] Naqvi S.B., Bottaro A., “Interfacial conditions between a free-fluid region and a porous medium,” *International Journal of Multiphase Flow*, 141, 103585, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Assessing the mechanical stimuli of bone remodeling through multiscale, micromechanics-inspired modeling

Author(s): Stefan Scheiner^{*1}, Christian Hellmich¹, and Nenad Filipovic²

¹ Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria, stefan.scheiner@tuwien.ac.at

² Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia

Keyword(s): bone remodeling, mechanoregulation, pressure, fluid flow, piezoelectric

Abstract

Qualitatively, the effects of mechanical loading acting onto bone on the bone metabolism are well-known. A certain “normal” load level is needed in order to maintain the amount of bone tissue required for providing a sufficient load-carrying capacity. If the actual load level is too low, bone tissue is lost (leading to thinner and/or more porous bones), whereas additional bone tissue may accumulate if the load level consistently exceeds the normal level. However, the bone research community has been pondering for decades over the question which mechanisms are eventually responsible for this behavior; and in particular which mechanical stimulus is able to steer the biology of bone towards anabolic or catabolic regimes. In this respect, several hypotheses were brought forward – however, their relevance has long remained unclear because of the impossibility of testing them in vivo. This contribution presents continuum microporomechanics-inspired modeling approaches, developed over the past few years, which allow for computing, quantitatively, the magnitudes of several of the proposed mechanobiological stimuli, including mechanical excitation of cells and other biological factors in bone by means of hydrostatic pressure, fluid flow-induced shear stresses, and piezoelectric effects [1,2]. Rigorously considering to that end the hierarchical organization of bone tissue, it has turned out that hydrostatic pressure appears to be of major importance for the mechanobiology of bone, whereas the other stimuli probably play less prominent roles. Notably, the presented models can be (and have already been) straightforwardly utilized, e.g., for integration in structural simulations of bone organs. This has been recently demonstrated via the European project SGABU [3], where a publicly accessible computational platform has been developed, integrating micromechanics-based models of biological tissues. The general functioning of this platform is briefly presented as well.

References

- [1] Scheiner, S. and Pivonka, P. and Hellmich, C. Poromicromechanics reveals that physiological bone strains induce osteocyte-stimulating lacunar pressure. *Biomechanics and Modeling in Mechanobiology* (2016), 15: 9-28.
- [2] Estermann, S.-J. and Scheiner, S. Multiscale modeling provides differentiated insights to fluid flow-driven stimulation of bone cellular activities. *Frontiers in Physics* (2018), 6: 76.
- [3] Increasing scientific, technological and innovation capacity of Serbia as a Widening country in the domain of multiscale modelling and medical informatics in biomedical engineering. Call H2020-WIDESPREAD-2020-5, Grant ID 952603 (2020-2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Atlas-based Quantification of the Biomechanics of Patients with Transcatheter Aortic Valve Replacement

Author(s): Chiara Catalano^{*1}, Roberta Scuoppo^{*1}, Stefano Cannata², Caterina Gandolfo², Salvatore Pasta^{1,2}

¹ Department of Engineering, University of Palermo, Palermo, Italy, email: salvatore.pasta@unipa.it

² Department for the Treatment and Study of Cardiothoracic Diseases and Cardiothoracic Transplantation, IRCCS-ISMETT, Palermo, Italy

Keyword(s): statistical shape analysis, finite-element analysis, transcatheter aortic valve replacement

Abstract

Transcatheter aortic valve replacement (TAVR) is increasingly used to treat patients with severe aortic (AS) stenosis who are deemed inoperable or at high risk for surgical aortic valve repair [1-3]. Atlas-based analyses of patients underwent transcatheter heart valve interventions appears promising to understand the mechanistic link between the device and human host. The construction of probabilistic atlases is based on statistical shape modelling (SSM) to assess key anatomic features for a given patient population. Such an approach is relevant to study the complex nature of the calcific aortic valve leaflets and aortic root shape of patients with TAVR. This study was carried out to develop a SSM of the aortic root with calcific valve leaflets, and then assess the structural heart mechanics by finite-element analysis starting from the deformation of the mean template for specific shape boundaries (i.e., ± 1.5 standard deviation). Simulations will be used to quantify the final deformed shapes of the implanted device for different principal shape modes. The atlas-based disease assessment can represent a powerful tool to reveal important insights on TAVI, especially for patients who have borderline anatomies and thus challenging clinical decision making. The utilize of SSMs for creating probabilistic patient cohorts can facilitate the understanding of the heterogenous nature of the aorta or improve the way we design the next generation of transcatheter heart valves.

References

- [1] Mylotte D, et al. Transcatheter heart valve failure: a systematic review. Eur Heart J 2015; 36(21): 1306-27.
- [2] Arai T, et al. The feasibility of transcatheter aortic valve implantation using the Edwards SAPIEN 3 for patients with severe bicuspid aortic stenosis. J Cardiol 2017; 70(3-4): 220-24.
- [3] Braghiroli J, et al. Transcatheter aortic valve replacement in low risk patients: a review of PARTNER 3 and Evolut low risk trials. Cardiovascular diagnosis and therapy 2020; 10(1): 59-71.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Uncertainty quantification of dynamic cerebral autoregulation in cardiovascular disease: A Bayesian compressive sampling approach

Author(s): Leonidas Taliadouros^{*1}, Maria I. Katsidoniotaki¹, Ioannis A. Kougoumtzoglou¹, Eliza C. Miller² and Randolph S. Marshall¹²

¹ *Department of Civil Engineering & Engineering Mechanics, Columbia University, New York, USA*

² *Neurology-Stroke Division, Neurological Institute of New York, Columbia University Medical Center, New York, USA*

Keyword(s): precision medicine; physiological mechanism; dynamic cerebral autoregulation; uncertainty quantification; nonlinear system; compressive sampling

Abstract

Dynamic cerebral autoregulation (DCA) refers to the normal physiological capacity for cerebral arterioles to rapidly adjust caliber in response to blood pressure (BP) shifts, thereby ensuring constant cerebral blood flow (CBF) over a wide range of BP values. DCA dysfunction is associated with a number of cardiovascular diseases, and thus, devising precise and accurate techniques for DCA analysis, monitoring and control is of growing importance to patient care. This may allow for targeted and personalized management of blood pressure in patients with acute cardiovascular disease.

Current state-of-the-art methods for DCA modeling and analysis typically employ continuous bedside monitoring of BP and CBF to identify an input-output relationship between the two variables (e.g., [1]). However, most of these methods rely on strong and often unrealistic assumptions (such as linearity of the input-output relationship and stationarity of the measured data), and/or lack any predictive capabilities, and/or employ exceedingly large and complex parameterizations that reduce the interpretability of the model and provide limited insight regarding the autoregulation mechanism. Overall, there is a critical need for better methods to provide precise, accurate, real-time, and easily interpretable quantification of impaired DCA function in a wide range of cardiovascular diseases.

In this paper, a data-driven technique based on Bayesian compressive sampling [2] is developed to be used both for sparse modeling of dynamic cerebral autoregulation (DCA) and for rapid diagnosis and control of impaired DCA function. The proposed technique exhibits significant novelty and advantages compared to current state-of-the-art approaches, including (1) Predictive capabilities used for rapid, real-time, and accurate diagnosis and control of impaired DCA; (2) Uncertainty quantification of the model predictions, providing clinicians with a measurable confidence degree when employing the methodology as a diagnostic tool for assessing DCA performance; (3) Precision by tailoring the model to a specific patient/disease; (4) Robustness subject to incomplete data, allowing for reliable predictions even if the measured BP-CBF time-histories have missing data.

References

- [1] Miller E., Dos Santos K. R. M., Marshall R. S., Kougoumtzoglou I. A., 2020. Joint time-frequency analysis of dynamic cerebral autoregulation via generalized harmonic wavelets, *Physiological Measurement*, vol. 41: 024002: 1-11.
- [2] Kougoumtzoglou I. A., Petromichelakis I., Psaros A. F., 2020. Sparse representations and compressive sampling approaches in engineering mechanics: A review of theoretical concepts and diverse applications, *Probabilistic Engineering Mechanics*, vol. 61, 103082: 1-20.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Computational study of retinal blood flow coupled to a global circulation model

Author(s): Alessia Casalucci^{*1}, Rodolfo Repetto¹, Lucas Müller², Annunziato Siviglia³, Eleuterio Toro³

¹ Department of Civil, Chemical and Environmental Engineering, University of Genoa, Italy, alessia.casalucci@edu.unige.it

² Department of Mathematics, University of Trento, Italy, lucas.muller@unitn.it

³ Laboratory of Applied Mathematics, DICAM, University of Trento, Italy

Keyword(s): Retinal circulation, Flow simulation, Mathematical model, Circulatory system

Abstract

The retina is one of the most metabolically active tissues in the body. A well-organized ocular vascular system adapts to meet the metabolic requirements of the retina to ensure visual function. The retina is supplied mainly by the central retinal artery that travels along the inferior margin of the optic nerve sheath. It then enters the eye through the center of the optic nerve and branches to form three capillary layers [1]. Blood drains from the capillary bed into retinal veins that eventually converge into the central retinal vein, which runs through the optic nerve into the cavernous sinus. The flow in these vessels is directly affected by the intraocular pressure (IOP) in the eye, the cerebrospinal fluid pressure (CSFP) in the optic nerve and intracranial pressure (ICP) in the cavernous sinus.

We present a detailed geometric multiscale model for the retinal circulation, involving arteries, veins and microvasculature. The topology of arterial and venous networks is extracted using the Automated Retinal Image Analyzer (ARIA) [2] from medical images included in the Digital Retinal Images for Vessel Extraction (DRIVE) [3] (Fig. 1). Terminal points of large/medium arteries are coupled to the venous network via lumped parameter models representing the microcirculation. The constructed model is coupled to an existing closed-loop global multiscale human circulation model, which comprises a 1-D representation of major arteries and veins and lumped-parameters models of the microcirculation, heart, pulmonary circulation and cerebrospinal fluid [4,5] (Fig. 2).

Our model reproduces blood flow and pressure wave propagation in the retinal network. Moreover, it constitutes a first step towards the study of the relationship between IOP and ICP. The present model represents a framework that can be used to study various pathological conditions that regard the interaction of the eye vasculature with other fluids (such as glaucoma).

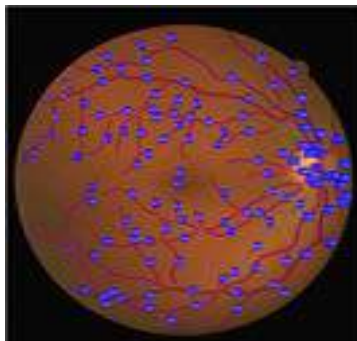


Figure 1: Segmentation of major retinal vessels with ARIA [2]

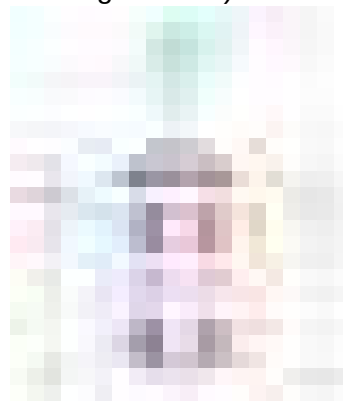


Figure 2: Representation of the global model for the full human blood and cerebrospinal circulation [5].

References

- [1] Netter FH, Atlas of Human Anatomy, Elsevier Health Sci, Philadelphia, 2006.
- [2] Bankhead et al. PLoS ONE 7(3): e32435, 2012.
- [3] J. Staal et al, in IEEE Transactions on Medical Imaging, vol. 23, no. 4, pp. 501-509, 2004.
- [4] Müller et al, Int J Numer Method Biomed Eng, 30(7):681–725, 2014.
- [5] Toro et al, Int J Numer Method Biomed Eng, e3532, 2021.

EMI 2023 International Conference

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Title: From cine-MRI to Computational Models of Blood Flow in the Right Heart

Author(s): Francesca Renzi^{*1}, Marco Fedele², Vincenzo Giambruno³, Alfio Quarteroni^{2,4}, Giovanni Puppini⁵, Giovanni Battista Luciani³, Christian Vergara⁶.

¹ Department of Surgery, Dentistry, Pediatrics, and Obstetrics/Gynecology University of Verona, Verona, Italy, francesca.renzi@univr.it

² MOX, Department of Mathematics Politecnico di Milano, Milano, Italy, marco.fedele@polimi.it, alfio.quarteroni@polimi.it

³ Division of Cardiac Surgery, Department of Surgery, Dentistry, Pediatrics, and Obstetrics/Gynecology University of Verona, Verona, Italy, vincenzo.giambruno@univr.it, giovanni.luciani@univr.it

⁴ Ecole Polytechnique Fédérale de Lausanne Rte Cantonale, Lausanne, Switzerland

⁵ Department of Radiology University of Verona, Verona, Italy, giovanni.puppini@aovr.veneto.it

⁶ LaBS, Dipartimento di Chimica, Materiali e Ingegneria Chimica "Giulio Natta", Politecnico di Milano, Milano, Italy, christian.vergara@polimi.it

Keyword(s): Right heart, cine-MRI, CFD

Abstract

Clinical interest in the right side of the heart (RH) has increased significantly due to the awareness that changes in right cardiac structure and function have prognostic implications in several congenital and acquired heart diseases, such as Tetralogy of Fallot, pulmonary hypertension or tricuspid regurgitation [1]. Many of such diseases affect blood dynamics, and Computational Fluid Dynamics (CFD) models are proven to be valid tools for the quantitative and non-invasive analysis of blood pressures, velocities, and wall shear stresses, which is crucial to improve the understanding of RH functioning. In this work, we develop a complete patient-specific CFD model of the complete beating RH, including both chambers and valves, where the wall displacement and the RH geometry are reconstructed from images. We developed a flexible method, called Multi-Image Morphing based (MIM) technique, that is able to merge the information coming from different MR acquisition series and applies a morphing procedure to reconstruct the cardiac volumes and motion requiring minimal user contribution. In the reconstructed moving RH geometries we performed CFD simulations, solving the Navier-Stokes equations in an Arbitrary Lagrangian-Eulerian framework where the domain moves according to the reconstructed displacement field. The reconstructed valves are modeled as surfaces immersed in the fluid dynamics domain by the Resistive Immersed Implicit Surface (RIIS) [2] method. We assessed the accuracy of the MIM technique by comparing the reconstruction results with the original images and we analyzed the CFD results to assess the reliability of our computational model to answer specific clinical questions.

References

- [1] Domitrescu S. I., Tintoiu I. C., Underwood M. J., "Right heart pathology: from mechanism to management", Springer, 2018.
- [2] Fedele M., Faggiano, E., Dedè L., Quarteroni A., "A patient-specific aortic valve model based on moving resistive immersed implicit surfaces", Biomechanics and modelling in mechanobiology, 16, 1779-1803, 2017.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Blood Flow Simulation in an Improved Blalock-Taussig Shunt in Patient Specific Geometries

Author(s): Ramesh K. Agarwal

*Mechanical Engineering and Materials Science, Washington University in St. Louis, St. Louis, USA
rka@wustl.edu*

Keyword(s): Reynolds-Averaged Navier-Stokes Equations, Turbulence Modelling,

Abstract

Blalock-Taussig (BT) Shunt is a palliative surgical procedure used during a Norwood surgery on a newborn baby suffering from cyanotic heart defects. The BT Shunt can increase blood flow in patients' pulmonary artery which can ease the "Blue Baby Syndrome." Currently used BT Shunts do not produce a balanced flow distribution to the pulmonary arteries (PAs) which can cause high wall shear stress (WSS) and blood flow separation resulting in blood clots. A modified BT Shunt was designed to partially solve this problem. The modified BT Shunt is shown by numerical simulations to have the ability to better control the flow distribution between Innominate Artery (IA) and PAs with lower and gradually varying WSS and with improved flow balance to the left and right pulmonary artery at the T-junction of the shunt.

The goal of this paper is to computationally evaluate the steady flow in the modified BT shunt model between innominate and pulmonary artery using a patient specific aorta model. The simulations are performed using the commercial CFD software ANSYS Fluent. The improved modified BT shunt is connected between IA and PA. A change in the length of the shunt can be made to fit it under different conditions of actual patients. In numerical simulations, a full geometry of patient's aorta is considered. Results for different lengths of the shunt are compared to determine the length that generates the lowest WSS and improved flow distribution to the PAs. It is found that the length of nearly 26mm creates lower WSS and flow rate difference between the two sides of PA at the T-junction attachment of the shunt. A sophisticated computational model was created using Solidworks and Blender software to create the realistic geometry which included the IA, PA and modified BT shunt. The numerical simulations provide details of the flow field including velocity and pressure field, WSS, and blood damage. Several parameters in shunt design weigh heavily in reducing the thrombosis. This study demonstrates how CFD can be effectively utilized in the design of a medical device such as BT shunt to improve the clinical outcomes in patients.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Multiscale approach for modeling the elastic and fracture properties of nanomodified epoxy resins

Author(s): Greta Ongaro^{*1}, Razie Izadi¹, Marco Pingaro¹, Patrizia Trovalusci¹, and Roberta Bertani²

¹ *Department of Structural and Geotechnical Engineering, Sapienza University of Rome, v. A. Gramsci 53, Rome 00197, Italy, greta.ongaro@uniroma1.it, razie.izadi@uniroma1.it, marco.pingaro@uniroma1.it, patrizia.trovalusci@uniroma1.it*

² *Department of Industrial Engineering, University of Padova, v. F. Marzolo 9, Padova 35131, Italy, roberta.bertani@unipd.it*

Keyword(s): Multiscale approach, Molecular Dynamics, Peridynamics, Virtual Element Method, Polymer-based nanocomposites, Experimental tests

Abstract

The interest of the scientific community has recently been attracted by nanomodified epoxy resins, since they exhibit enhanced mechanical and barrier properties, and superior performance in terms of thermal stability and flame retardancy. Experimental characterization and numerical modeling of the overall mechanical properties of nanocomposites is therefore of fundamental importance to increase their reliability and expand their application fields. In this work, a multiscale framework is implemented to estimate the elastic and fracture properties of polymer-based nanocomposites. The approach, which spans three length scales from atomistic to macroscopic descriptions, is supported by experiments. Molecular dynamics simulations (MD) are performed at the atomistic level to determine the elastic properties and fracture toughness of unit cells (UCs) consisting of cross-linked epoxy resin and nanoclay layers [1]. The results obtained by the atomistic simulations are then used as input for the peridynamic (PD) analysis at the upper scale. A further outcome of MD simulations is the characterization of the morphology and mechanical parameters of the interphase layer. These data are then employed in a statistical homogenization approach (SH) which is implemented to determine the effective elastic modulus of a representative volume element (RVE) consisting of epoxy resin and randomly distributed nanofillers [2]. At the final scale of the numerical procedure, the results obtained by MD and SH simulations are employed in a classical continuum mechanics-peridynamics (CCM-PD) coupling strategy implemented to estimate the fracture toughness of the nanocomposites [3]. In the coupled model, the CCM region is described as fully homogeneous, whereas the small-scale heterogeneity of the crack tip region is modeled through the recently proposed intermediately-homogenized peridynamic model. For the experimental characterization, specimens made of epoxy resin nanomodified through the addition of different inorganic nanoclays are subjected to tensile and fracture tests. Comparison to experimental data confirms the capability of the multiscale approach to properly model the effective elastic modulus and fracture toughness of nanocomposites.

References

- [1] Izadi R., Ghavanloo E., Nayeibi A., "Elastic properties of polymer composites reinforced with C60 fullerene and carbon onion: Molecular dynamics simulation", *Physica B: Condensed Matter*, Vol. 574, 311636, (2019).
- [2] Pingaro M., Reccia E., Trovalusci P., Masiani R., "Fast statistical homogenization procedure (FSHP) for particle random composites using virtual element method", *Computational Mechanics*, Vol. 64, pages 197-210, (2019).
- [3] Ongaro G., Bertani R., Galvanetto U., Pontefisso A., Zaccariotto M., "A multiscale peridynamic framework for modelling mechanical properties of polymer-based nanocomposites", *Engineering Fracture Mechanics*, Vol. 274, 108751, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Buckling Property of Woven Fabric Composite Laminate with a Small Number of Plies

Author(s): Keishiro Yoshida^{*1}, Tatsuya Kitao², Keita Oda³

¹ *Department of Aeronautics, Kanazawa Institute of Technology, Nonoichi, Japan,
k-yoshida@neptune.kanazawa-it.ac.jp*

² *School of Mechanical Engineering, Kanazawa Institute of Technology, Nonoichi, Japan*

³ *Department of Aeronautics, Kanazawa Institute of Technology, Nonoichi, Japan*

Keyword(s): plain weave fabric, composite, buckling, laminate, inhomogeneity

Abstract

Composite materials represented by carbon fiber reinforced plastics are increasingly applied to structural members in many engineering fields. Composite materials reinforced with woven fabrics are often used for curved shape structures because of their conformability with a complex shape. Composite materials are usually used as laminates. When evaluating the mechanical property of the laminate, each lamina is often treated as a homogeneous material. However, the intralaminar inhomogeneity is more significant in woven fabric composites than in unidirectional fiber reinforced composites because yarns are interwoven within each ply and the thickness of each yarn which takes up in the thickness of each ply is relatively large in a woven fabric composite. The intralaminar inhomogeneity may affect the mechanical properties of laminates, especially laminates with a small number of plies.

Sugiyama K. et al. [1] conducted numerical multiscale analysis, the procedure of which is described in Refs. [2, 3], to investigate the effective laminate stiffness and the in-plane compression buckling property of plain weave fabric composite laminates with different number of plies. The intralaminar inhomogeneity was considered in the multiscale analysis. Sugiyama K. et al [1] also conducted the buckling test to experimentally confirm the validity of the analysis results. However, regarding the buckling analysis, a simplified analysis was performed which did not accurately include some of the stiffnesses of the laminate. Regarding the experiment, it is suspected that the excessive initial imperfection occurred in the buckling test of the laminates with a small number of plies. It is desirable to improve the analysis model and the experimental method.

In this study, regarding the buckling analysis, the user-subroutine is utilized to accurately include all the stiffnesses of the laminate in the analysis model. Regarding the experiment, loading fixtures dedicated to test specimens of 1-ply lamina and 2-ply laminate are newly prepared. It is confirmed through the numerical and experimental investigations that the reduction of the apparent elastic modulus, especially the reduction of the apparent bending modulus, in the 1-ply lamina or 2-ply laminate also causes a reduction of its buckling load.

References

- [1] Sugiyama K. et al., "Buckling Property of Plain Weave Fabric Composite Laminate Considering Intralaminar Inhomogeneity" in Proc. 22nd International Conference on Composite Materials, Melbourne, Aug.11-16, No. 2312-6 (2019).
- [2] Yoshida K. et al., "Effect of the Number of Laminated Plies on Elastic Properties of Plain-Weave Fabric Composite Laminates", Materials System, Vol.36, pp.17-23 (2019).
- [3] Yoshida K. et al., "Numerical Analysis of Bending and Transverse Shear Properties of Plain-Weave Fabric Composite Laminates Considering Intralaminar Inhomogeneity", Advanced Composite Materials, Vol.26, no.2, pp.135-156 (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Computational thermo-elastic steady-state homogenization of polycrystals by boundary elements

Author(s): Ivano Benedetti^{*1}, Alberto Milazzo²

¹ *Department of Engineering, University of Palermo, Palermo, Italy, ivano.benedetti@unipa.it*

² *Department of Engineering, University of Palermo, Palermo, Italy, alberto.milazzo@unipa.it*

Keyword(s): Polycrystalline materials, Steady-state thermo-elasticity, Computational homogenization, Computational micro-mechanics, Multiscale materials modelling, Boundary element method

Abstract

A framework for steady-state thermo-elastic analysis of polycrystalline materials is proposed [1]. The method is formulated at the scale of the individual grains and it is based on the explicit representation, through generalized Voronoi tessellations, of the micro-structural morphology. The steady-state thermo-elastic behaviour of the individual grains is expressed in integral form. The presence of volume integrals induced by the inherent physics of the thermo-elastic coupling is addressed through a Dual Reciprocity Method (DRM), which allows recasting the formulation in terms of boundary integrals only. This aspect allows employing the Boundary Element Method as numerical solver, with the associated benefits in terms of data preparation, pre-processing and overall computational costs [2]. The method is applied to homogenise the conductivity and thermo-elastic constants of polycrystalline silicon carbide and alumina, two widely employed ceramic materials. The obtained results confirm the accuracy of the formulation and suggest applications in multiscale formulations as well for the analysis and design of micro-mechanical devices.

References

- [1] Benedetti I., "An integral framework for computational thermo-elastic homogenization of polycrystalline materials". *Computer Methods in Applied Mechanics and Engineering*, 407, 115927, 2023
- [2] Benedetti I., Gulizzi V., Milazzo A., "A microstructural model for homogenisation and cracking of piezoelectric polycrystals", *Computer Methods in Applied Mechanics and Engineering*, 357, 112595, 2019

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Advances of a GA-based optimization procedure for seismic upgrading of RC structures

Author(s): Francesco Nigro^{*1}, Enzo Martinelli²

¹ Department of Civil Engineering, University of Salerno, Salerno, Italy, fnigro@unisa.it

² Department of Civil Engineering, University of Salerno, Salerno, Italy, e.martinelli@unisa.it

Keyword(s): Seismic upgrading, FRP jacketing, Steel bracings, Optimization, Genetic Algorithms.

Abstract

In the last decades, among the various Artificial Intelligence (AI) techniques, Genetic Algorithms (GAs) have been proven as an effective and flexible solution for solving optimization problems in various fields of applied sciences, including the case of structural and seismic engineering [1].

Focusing on the seismic upgrading of existing RC structures, it should be noted that this kind of design problem can be solved adopting an appropriate combination of member-level and structure-level techniques, although design rules are rarely available for supporting engineers in a similar choice. Thus, the choice of the most suitable intervention results to be a complex technical challenge for engineers, since theoretically infinite combinations of various upgrading solutions could accomplish the desired structural performance. Nevertheless, a similar choice is unlikely to be regarded as an optimization problem, although GAs may help to find the “fittest” upgrading solution, with regard to one predefined optimization criterion (e.g. the initial cost of intervention).

The aim of the presentation consists in outlining the latest advances in the implementation of a recently-formulated Genetic Algorithm (GA) procedure for an “optimal” upgrading of existing Reinforced Concrete (RC) structures. More specifically, the procedure is intended at selecting the cheapest technically feasible and code compliant solution among those which can be figured out by combining FRP jacketing of RC columns (as a member-level technique) and the introduction of steel bracings (as a structure-level technique). The current implementation considers the “best” combination as the one requiring the lowest intervention costs, including demolition and reconstruction operations of the non-structural parts concerned with the realization of both member- and structure-level techniques, the direct cost of materials and workman force and (last, but not least) the cost of a possible upgrading of foundations. At each “generation” of the procedure, a “population” of potential upgrading solutions is evaluated with respect to a previously-defined objective function. Then, the three main genetic operators (selection, crossover and mutation) are handled to simulate the driving mechanisms of the evolution of species, resulting in the “survival of the fittest” rule. As a consequence, at each iteration the cost-effectiveness of the technically-admissible solutions is increased [2].

The presentation will focus on the parameters controlling the aforementioned genetic operators that have an impact on the resulting computational efficiency and the actual capability of the procedure to pick the most cost-effective solution, showing some recent improvements obtained in terms of computational efficiency.

References

- [1] Di Trapani F., Sberna A. P., Marano G. C., “Cost and EAL based optimization for seismic reinforcement of RC structures”, *Procedia Structural Integrity*, Volume 33, Pages 917-924, ISSN 2452-3216, (2021). <https://doi.org/10.1016/j.prostr.2021.10.102>.
- [2] Nigro F., Falcone R., Martinelli E., “Seismic upgrading of RC structures through an optimization procedure based on Genetic Algorithm”, *Procedia Structural Integrity*, Volume 44, Pages 1704-1711, ISSN 2452-3216, (2023). <https://doi.org/10.1016/j.prostr.2023.01.218>.

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Palermo, Italy, August 27 - 30, 2023

Title: Structural optimization for designing sustainable structures under seismic condition

Author(s): Emanuele Crespino^{*1}, Sigrid Adriaenssens², Aginaldo Fraddosio¹, Carlo Olivieri^{2,3}, Mario Daniele Piccioni¹

¹ Department of Architecture, Construction and Design (ArCoD), Politecnico di Bari, Via Orabona, 4, 70125, Bari (BA), Italy (e.crespino@phd.poliba.it, aginaldo.fraddosio@poliba.it, mariodaniele.piccioni@poliba.it)

² Department of Civil and Environmental Engineering, Princeton University, Princeton, 08544, NJ, United States (sadriaen@princeton.edu)

³ Department of Civil Engineering (DICIV), University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano (SA), Italy (colivieri@unisa.it)

Keyword(s): Form-finding, Structural optimization, Concrete shells, Sustainable structures; Seismic engineering

Abstract

The construction industry has a high consumption of non-renewable resources and energy, resulting in significant CO₂ emissions. Especially in case of large-span structures in seismic areas like, e.g., commercial and exposition buildings, train and ferry-boat stations there is a pressing need of more sustainable structural design approaches. To offer a possible solution to this problem, we stress the high efficiency of shell structures, and employ form-finding and structural optimization tools. In particular, we propose a new hybrid approach coupling a concrete shell to a suspended, long-period steel structure, that substantially behave like a structure isolated-from-the-above, thus enhancing the overall efficiency of the system. This highly efficient structure turns out to also meet architectural quality standards. The simultaneous consideration of shape and structure in the design is therefore an effective way for achieving the "firmitas" and "venustas" properties as theorized by Vitruvius.

This new sustainable design strategy is applied for the conceptual design of a train station in Catanzaro, one of Italy's most seismic areas. We compare two different design approaches. The first involves two sequential steps: a form finding process for a mainly compressed concrete shell under the self-weight, and then a sizing optimization process that adjusts the shell's thickness to withstand mostly in compression also the weight of the steel-suspended structure. The second design approach consists in the form finding of the concrete under both the self-weight and the weight of the steel structure. The latter generates a highly variable and significantly corrugated shell, optimized for the concentrated loads transmitted by the steel ties.

The form-finding study is performed using Grasshopper and Kangaroo 2 in Rhinoceros 6 software, thus by employing the Dynamic Relaxation method. The sizing optimization is carried out using Altair Hyperworks software through the Feasible Direction Method (MFD).

The optimized structures (first and second design approach) are then analyzed under seismic loads through a full-dynamic time-history analysis using linear finite element method, considering the action of three acceleration components. It is shown that the addition of seismic loads involves a relatively low increase in stresses for both the reinforced concrete shell and the steel suspended structure. In particular, the reinforced concrete shell requires the minimum quantity of steel reinforcement allowed by the structural codes, except for areas of limited size. Additionally, it is found for the suspended steel structure that the maximum displacements and inter-storey drift are comparable to those of structures equipped with base isolation devices.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Free vibrations of shear deformable beams and frames in presence of multiple cracks

Authors: Francesco Cannizzaro^{*1}, Ilaria Fiore², Salvatore Caddemi³, Ivo Calio⁴

¹ *Dipartimento di Ingegneria Civile e Architettura, Catania, Italy, francesco.cannizzaro@unict.it*

² *Dipartimento di Ingegneria Civile e Architettura, Catania, Italy, ilaria.fiore@unict.it*

³ *Dipartimento di Ingegneria Civile e Architettura, Catania, Italy, salvatore.caddemi@unict.it*

⁴ *Dipartimento di Ingegneria Civile e Architettura, Catania, Italy, Ivo.calio@unict.it*

Keyword(s): Timoshenko beam, multiple cracks, distributional model, free vibrations, dynamic stiffness matrix

Abstract

The presence of concentrated damage, such as cracks, along beams causes singularities in the response parameters. In the adopted model, the problem is usually dealt with by splitting the integration domain and by imposing suitable transition conditions at the singularity occurrence [1].

When cracks occur along shear deformable beams, due to first and second crack growth mode, the response is characterized by discontinuities both of the rotation and transversal displacement functions.

In case of appearance of multiple cracks the subdivision of the integration domain made become very inconvenient and for this reason a recurrence procedure of the relevant governing equations to link the subdomain has been devised [2].

For the vibration modes of the multi-cracked Timoshenko beam model, an explicit closed form expression, based on a flair of the influence on the solution of the rotation discontinuity between subsequent subdomains, has been proposed in the literature [3].

In this work, an exact distributional model able to extend the free vibration Timoshenko governing equations by embedding the effect of multiple cracks is formulated. In particular, additional distributional terms dependent on the rotation and transversal displacement discontinuities are introduced. The equations of the multi-cracked Timoshenko beam are correctly integrated over a single integration domain spanning along the entire beam length. Novel explicit closed form solutions of the free vibration modes are presented and the natural frequency characteristic equations dependent on the boundary conditions are derived.

The presented formulation allows the explicit derivation of the frequency dependent dynamic stiffness matrix for the multi-cracked Timoshenko beam that can be adopted, by means of an appropriate assemblage, to analyze shear deformable damaged frames.

References

- [1] Chondros T.G., Dimarogonas A.D., "Influence of cracks on the dynamic characteristics of structures," Journal of Vibration, Acoustics, Stress and Reliability in Design, 111, 251-256, (1989).
- [2] Li Q.S., "Vibratory characteristics of Timoshenko beams with arbitrary number of cracks," Journal of Engineering Mechanics, 129(11), 1355-1359, (2003).
- [3] Khiem N.T., Hung D. T., "A closed-form solution for free vibration of multiple cracked Timoshenko beam and application," Vietnam Journal of Mechanics, 39(4), 315-328, (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Efficient stochastic response determination of nonlinear systems based on a reduced-order formulation of the Wiener path integral technique in conjunction with high-performance computing strategies

Author(s): Ketson R. M. dos Santos^{*1}, Ioannis A. Kougiumtzoglou².

¹*Department of Civil, Environmental, and Geo- Engineering, University of Minnesota, Minneapolis, USA, dossantk@umn.edu*

²*Department of Civil Engineering and Engineering Mechanics, Columbia University, New York, USA, ikougium@columbia.edu*

Keyword(s): Wiener path integral, Rayleigh-Ritz, high-performance computing.

Abstract

The Wiener path integral (WPI) technique for determining the stochastic response of diverse nonlinear dynamical systems relates to treating the system response joint transition probability density function (PDF) as a functional integral over the space of all possible paths connecting the initial and the final states of the response vector [1-2]. Further, the functional integral is evaluated, ordinarily, by resorting to an approximate approach that considers the contribution only of the most probable path. This corresponds to an extremum of the functional integrand and is determined by solving a functional minimization problem that takes the form of a deterministic boundary value problem. Recently, to increase the computational efficiency associated with the WPI technique, a reduced-order WPI variational formulation was developed in [3]. This reduced-order formulation can be construed as an approximation-free dimension reduction approach that renders the associated computational cost independent of the total number of stochastic dimensions of the problem. Concisely stated, the technique can determine directly any lower-dimensional joint response PDF corresponding to a subset only of the response vector components by utilizing an appropriate combination of fixed and free boundary conditions. In this paper, for the computational cost of the reduced-order WPI formulation to decrease even further, various efficient solution strategies are explored based on high-performance computing tools, such as parallel processing schemes, shared-memory architectures and graphics processing units (GPUs) technology. An indicative numerical example is considered for assessing the performance of the proposed solution strategies. Comparisons with pertinent Monte Carlo simulation data are included as well.

References

- [1] Kougiumtzoglou I. A., Spanos P. D., "An analytical Wiener path integral technique for non-stationary response determination of nonlinear oscillators," *Probabilistic Engineering Mechanics*, 28, 125-131, (2012).
- [2] Kougiumtzoglou I. A., "A Wiener path integral solution treatment and effective material properties of a class of one-dimensional stochastic mechanics problems", *ASCE Journal of Engineering Mechanics*, 143 (6), 04017014, (2017).
- [3] Petromichelakis I., Kougiumtzoglou I. A., "Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries," *Proceedings of the Royal Society A*, 476, 20200385 (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Stochastic response determination of an array of coupled nonlinear micromechanical oscillators based on an efficient reduced-order formulation of the Wiener path integral technique

Author(s): Maria I. Katsidoniotaki^{*1}, Ioannis Petromichelakis¹, Ioannis A. Kougoumtzoglou¹

¹ *Department of Civil Engineering & Engineering Mechanics, Columbia University, New York, USA*

Keyword(s): Wiener path integral, Nonlinear system, Stochastic dynamics, Nanomechanics

Abstract

The stochastic response of a multi-degree-of-freedom nonlinear dynamical system is determined efficiently based on a recently developed, approximation-free, reduced-order formulation of the Wiener path integral (WPI) technique [1]. The system can be construed as a representative model of electrostatically coupled arrays of micromechanical oscillators, and relates to an experiment performed by Buks and Roukes [2]. Compared to alternative modeling and solution treatments in the literature [2-4], the paper exhibits the following novelties. First, typically adopted linear, or higher-order polynomial, approximations of the nonlinear electrostatic forces are circumvented. Second, for the first time, stochastic modeling is employed by considering a random excitation component representing the effect of diverse noise sources on the system dynamics. Third, the resulting high-dimensional, nonlinear system of coupled stochastic differential equations governing the dynamics of the micromechanical array is solved based on the WPI technique for determining the response joint probability density function. Comparisons with pertinent Monte Carlo simulation data demonstrate a quite high degree of accuracy and computational efficiency exhibited by the WPI technique. Further, it is shown that the proposed model can capture, at least in a qualitative manner, the salient aspects of the frequency domain response of the associated experimental set-up.

References

- [1] Petromichelakis I, Kougoumtzoglou IA. Addressing the curse of dimensionality in stochastic dynamics: a Wiener path integral variational formulation with free boundaries. *Proc Royal Soc A*. 2020; 476:20200385.
- [2] Buks E, Roukes L. Electrically tunable collective response in a coupled micromechanical array. *Microelectromechanical systems*. 2002; 11: 802-807.
- [3] Lifshitz R, Cross MC. Response of parametrically driven nonlinear coupled oscillators with application to micromechanical and nanomechanical resonator arrays. *Physical Review*. 2003; 67: 134302-13.
- [4] Zhu J, Ru CQ, Mioduchowski A. High-order subharmonic parametric resonance of multiple nonlinearly coupled micromechanical nonlinear oscillators. *Acta Mechanica*. 2010; 212: 69-81.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Solving Partial Differential Equations with Quantum Approximate Bayesian Optimization Algorithm

Author(s): Jungin E. Kim¹, Jinhwan Sul¹, Yan Wang^{*1}

¹ School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA, yan-wang@gatech.edu

Keyword(s): Quantum Computing; Quantum Approximate Optimization Algorithm; Partial Differential Equation; Uncertainty Quantification

Abstract

Quantum computing is an emerging new computational paradigm of solving difficult problems, including optimization [1, 2] and simulation [3], where quantum superposition is utilized for parallel searching of solutions. To make quantum computing useful for engineering, new quantum algorithms and methods are needed to solve partial differential equations (PDEs). In this research, we propose a new approach to solve PDEs based on a recently developed quantum approximate Bayesian optimization algorithm (QABOA) [4,5]. QABOA is a hybrid quantum-classical optimization approach. In the quantum circuit, a sequence of phase-separating and mixer operators are applied in an alternating fashion, while the hyperparameters of the quantum circuit are optimized with Bayesian optimization. The phase-separating Hamiltonian encodes the objective function to be optimized, whereas the mixer Hamiltonian perturbs the quantum system. The consideration of uncertainty in the quantum circuit can improve the convergence. To apply QABOA to solve PDEs, the differential equations are first linearized with the finite-difference approach. The linear system is solved by minimizing the difference between the vectors on two sides of the linear equations. The corresponding phase-separating Hamiltonian for QABOA is designed based on the coefficient matrix and right-hand side vector. Auxiliary equations are added to the linear system so that the Hamiltonian is of size 2^n by 2^n where n is the number of qubits. The proposed approach is demonstrated with the Poisson equation and diffusion equation.

References

- [1] Wang, Y., Kim, J. E., Suresh, K., "Opportunities and challenges of quantum computing for engineering optimization," ASME Journal of Computing and Information Science in Engineering, Vol. 23, No.6, (2023).
- [2] Wang, Y., "Global optimization with quantum walk enhanced Grover search," Proceedings of ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference p. V02BT03A027, (2014).
- [3] Wang, Y., "Simulating stochastic diffusions by quantum walks," Proceedings of ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, p. V03BT03A053, (2013).
- [4] Wang, Y., "A quantum approximate Bayesian optimization algorithm for continuous problems," Proceedings of 2021 IISE Annual Conference & Expo, p. 235–240 (2021).
- [5] Kim, J. E., Wang, Y., "Quantum approximate Bayesian optimization algorithms with two mixers and uncertainty quantification," IEEE Transactions on Quantum Engineering, (under review).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Flextegrity and sheartegritty demonstration models for the multiscale analysis of structured materials and metamaterials

Authors: Gianni Royer-Carfagni^{*1}, Claudio Boni²

¹ Department of Engineering and Architecture, University of Parma, Parma, Italy, gianni.royer@unipr.it

² Department of Engineering and Architecture, University of Parma, Parma, Italy, claudio.boni@unipr.it

Keywords: multiscale analysis; structured material; metamaterial; flextegrity; sheartegritty; prototype.

Abstract

In structured materials, the macroscopic response to external actions is dictated by the underlying hierarchical organization of microscopic elements in mutual interaction. Remarkable examples are Carbon NanoTube (CNT) fibers, fullerites and biomaterials like nacre. Their macroscopic mechanical stiffness and strength not only result from the straining of the elements, but also from their reciprocal displacement and/or rotation, providing for the onset of internal disarrangements. The nature of the interaction forces can be very different in type (van der Waals, elastic bridging, direct contact), but in general they can be effectively caught within the paradigm of cohesive and frictional interaction between wavy surfaces. This represents a phenomenological model, which may forgo a faithful mimetic description of the real nature of microscopic interactions, but can describe the macroscopic empirical findings consistently with a fundamental theory, while suggesting possible directions of research. It is useful, from both a pedagogical and speculative point of view, to conceive simple phenomenological models for structured materials based on fundamental laws, since they can demonstrate the actual mechanisms of deformation and possibly inspire novel metamaterials.

The recently proposed concepts of *flextegrity* [1,2] and *sheartegritty* [3,4] appear to be a convenient rationale to conceive demonstration models, which can materialize in the manufacturing of macroscopic prototypes amenable of testing. The concept is that of segmental structures whose segments, held together by prestressed tendons, are in contact on properly-shaped surfaces, such that the deformation mechanism involves the relative rotation and/or the reciprocal sliding of the segments. A wide category of macroscopic nonlinear constitutive laws is determined not only by the cohesive/frictional nature of the contact, but even more so by the geometry of the contact profiles, as demonstrated for nacre-inspired materials in a recently published work co-authored by Roberto Ballarini [3]. The model takes into account average contact laws, active on the mean contact plane, which allows to elegantly bypass the difficulties of contact localization.

Here, we present demonstration models, and the corresponding tests on 3D-printed prototypes, for various structured materials, such as lamellar materials, spun CNT fibers and spatial lattices with underlying kinematic skeleton. These can inspire metamaterials at the micro-scale, although applications in architecture, aerospace, medicine are also possible at the macroscale.

References

- [1] Boni C., Silvestri M., Royer-Carfagni G., "Flexural tensegrity of segmental beams", *Proceedings of the Royal Society A*, 476(2237), 20200062, (2020).
- [2] Boni C., Royer-Carfagni G., "Flextegrity simple cubic lattices", *Proceedings of the Royal Society A*, 479(2270), 20220637, (2023).
- [3] Ballarini R., Boni C., Royer-Carfagni G., "Geometry of sliding lamellae dictates the constitutive properties of nacre-like hierarchical materials", *Journal of the Mechanics and Physics of Solids*, 167, 105000, (2022).
- [4] Boni C., Royer-Carfagni G., "A Gedankenmodell for the tensile response of carbon nanotube fibers", submitted for publication, available at SSRN 4332079.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Total drag estimation of turbulent flow over industrial rough surfaces

Author(s): Federica Bruno¹, Mauro De Marchis^{*1}, Stefano Leonardi²

¹ Kore Water Lab, Faculty of Engineering and Architecture, University of Enna Kore, Enna, Italy, (mauro.demarchis@unikore.it; federica.bruno3@unikorestudent.it)

² Department of Mechanical Engineering, University of Texas at Dallas, Richardson, Texas, USA

Keyword(s): Roughness, DNS simulations, Drag estimation,

Abstract

Roughness plays an important role in many fields of study, including physics, engineering and environmental science, among others. Most surfaces are naturally rough and understanding the irregularity is important in engineering applications, such as in marine environment, aerospace and automotive as it can impact system performance. For example, the rough surface on airplane wings or ship hulls can affect fuel efficiency leading to a huge cost increase. Additionally, in environmental science, roughness affects several natural processes, such as erosion, sediment transport, and water flow over river beds. Therefore, understanding the roughness effects may help to predict and mitigate environmental hazards, such as flooding or landslides.

Several researches focused the attention on the effect induced by roughness having different shape and distribution. Despite of this, unfortunately, a universal law is not yet fully understood.

One of the main challenges of the last decade was the prediction of drag and roughness function based on surface topography. Basically, several efforts have been made to find a statistical descriptor of the roughness geometry able to replace the classical equivalent sand grain roughness k_s . In fact, k_s is more a hydraulic property than a geometrical scale of the surface, which could be measured, and the estimation of its value requires knowledge of the mean velocity profile. Because of the stochastic nature of surface roughness, it can be difficult to derive a universal correlation between roughness effects and surface geometrical properties. Roughness, in fact, is characterized by peaks and cavities of different heights, which oscillate around an average value. It is widely accepted that the impact of surface texture depends on a range of factors such as the size, distribution, density, shape and/or slope of surface features. As a result, it is important to consider these factors when developing a universal parameter.

In this study, Direct Numerical Simulations have been performed to analyze a set of 2D rough surfaces, both regularly or irregularly distributed, using triangle-shaped elements. The aim of the research is to find a physical parameter representative of the whole rough shape. In order to this, seven geometries with different shapes but similar effective slope ES, skewness, and kurtosis have been investigated. The study pointed out how different roughness shapes, having the same effective slope or mean roughness height or skewness, ecc. can result in different values of drag and roughness function. This particular behaviour can be attributed to the importance of the highest pinnacles above the roughness sublayer as well as to the effect of the wake induced by these local peaks of roughness.

Based on the numerical experiments, a new geometrical parameter called Effective Distribution ED was introduced. This parameter is based on the Effective Slope, on the height of the highest pinnacles and on the wake induced by these pinnacles. A linear correlation has been observed for all the analysed cases, showing the ability of the proposed parameter to predict the roughness effect on turbulent flow.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Data-driven models for water distribution networks: A promising Machine Learning approach for improving efficiency and sustainability

Author(s): Gabriele Restuccia^{*1,3,a}, Ilenia Tinnirello^{1,3,a}, Fulvio Lo Valvo^{1,a}, Giacomo Baiamonte^{1,a}, Domenico Garlisi^{2,3,a}, Costantino Giaconia^{1,3,a}

¹ *Department of Engineering, University of Palermo, Viale delle Scienze, edificio 7, Palermo, Italy*

² *Department of Mathematics and Computer Science, University of Palermo, Via Archirafi 34, Palermo, Italy*

³ *CNIT, Viale G.P. Usberti, n. 181/A, Parma, Italy*

^a *{name}.{surname}@unipa.it*

Keyword(s): Smart Water Distribution Network (SWDN), LoRaWAN, Vibrations sensors

Abstract

Water is one of the most important natural resources that humans rely on for survival. However, in recent years, the global water consumption has increased significantly, while the world is facing a global water deficit primarily due to the effects of climate change [1][2]. This has highlighted the urgent need to develop better strategies to preserve this vital resource, particularly in water distribution networks (WDNs), which are often inefficient and wasteful. To address this issue, data-driven models have emerged as a promising approach that utilizes analytical models and low power wide area networks (LPWANs) to monitor and evaluate water distribution networks in near-real-time. Analytical models can be used to evaluate the exact water flows at each point of a WDN as a function of the network topology, water sources, and demand. However, these models require complete information about the positions, elevations, and construction materials of the junctions, pipes, and pumps that make up the WDN. This can be challenging to obtain, especially if we consider that topology can change over time because of water leaks or other evolution of the water pipes. To address these challenges, it is important to rely on a monitoring system integrated into the WDSN. LPWAN technologies, such as LoRaWAN, are emerging as a promising solution for implementing connected water meters in near-real-time. Innovative sensing elements can be also deployed on pipes to improve the network monitoring, especially when meters are too sparsely distributed. The data collected from the monitoring system can be exploited for building a data-driven model of the network, able to relate the measurements (such as pressure and water demand values) to the water flows available at each node. The model can be exploited for identifying variations in the network topologies due to unexpected events (such as new leakage points) as a function of the prediction error. In particular, we present a new approach that combines classification and neural networks to predict leaks with a high level of generalization in a WDN. For training the model, we consider a neural network devised to model the WND, as a function of the desired flows, the actual flows, the pressure, and the elevation for each node; a linear classifier, working on the errors between the neural network predictions and the real measurements available at the metering points. To validate the proposed approach, we use the Water Network Tool for Resilience (WNTR), a Python package designed to simulate and analyse the resilience of water distribution networks based on EPANET (US Environmental Protection Agency water NETwork, which is an open-source software for modelling hydraulic and quality dynamics of a water distribution system). Overall, data-driven models have significant potential to improve the efficiency and sustainability of water distribution networks [3]. The approach presented in this work is an important step toward developing more accurate and generalizable models that can help in addressing the anomaly detection in WDNs.

References

- [1] WWAP: World Water Assessment Programme, The United Nations world water development report 2020: water and climatechange:WWDR2020,978-92-3-100371-https://unesdoc.unesco.org/notice?id=p::usmarcdef_0000372985
- [2] Europe's Water in Figures An overview of the European drinking water and waste water sectors 2021 edition EurEau ISBN 978-2-9602226-3-0.
- [3] G. Restuccia, G. Baiamonte, D. Garlisi, C. Giaconia, F. Lo Valvo, I. Tinnirello, "A distributed analysis of vibration signals for leakage detection in Water Distribution Networks", AIMETA 2022

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Numerical study of noise reduction by air-sheet barriers in water

Author(s): Naira Hamid^{*1}, Giovanni Petris¹, Marta Cianferra¹, Vincenzo Armenio¹

¹ *Earth Science, Fluid-Dynamics, and Mathematics. Interactions and Methods, Trieste, Italy.*

Keyword(s): hydroacoustics, bubbly liquids, bubble barriers

Abstract

The drastic increase in undersea noise pollution has permuted the balance of marine life. In order to stabilize the ecological impact, various noise reduction techniques have been investigated. Among the different recommended solutions, the air-bubble barriers nowadays are widely used for mitigating impulsive sound waves and it ensures the reduction of the impact of such aggressive sounds on the ecosystem [1]. In this work, we examine the reduction of acoustic impulses in a layered fluid, by considering a monopole sound source that generates spherical acoustic waves and solving the wave equation for the acoustic pressure by employing a second-order accurate finite difference method (FDTD) [2]. In our case study, we considered a 3D numerical domain that is archetypal of a water system bounded by a top reflecting surface. The reflecting surface is simulated through the use of a Neumann boundary condition at the top, whereas the PML condition is set at the open boundaries [2]. We analyze the acoustic response by placing the monopole source at the center of the domain, far from the interface, first considering a homogeneous medium and afterward, in the heterogeneous medium where the density close to the top boundary is derived from a Direct numerical simulation of a turbulent plane channel flow for a mixture of air and water. We consider different frequencies and analyze the ratio of acoustic pressure amplitudes of heterogeneous media to homogeneous media at the top surface against the ratio between the sound source wavelength and the thickness of the air-water mixture. We observe a general reduction of the acoustic pressure at the solid reflecting surface by some orders of magnitude when an air sheet is present. Our next step is to simulate the real problem domain involving air-water mixtures using Wall Modelled Large Eddy Simulation. Results will be presented and discussed at the Conference.

References

- [1] Tsouvalas A, Metrikine A V, "Noise reduction by the application of an air-bubble curtain in offshore pile driving", *Journal of Sound and Vibration*, 371, 2016.
- [2] Petris G, Cianferra M, Armenio V, "A numerical method for the solution of the three-dimensional acoustic wave equation in a marine environment considering complex sources", *Ocean Engineering*, 256, 2022.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Computational Methods for Wave Dispersion Analysis in Stress-Driven Nonlocal Rayleigh Beam Lattices

Authors: Andrea Francesco Russillo, Giuseppe Failla*, Gioacchino Alotta

Department of Civil, Energy, Environmental and Materials Engineering (DICEAM), University of Reggio Calabria, Italy, andreafr.russillo@unirc.it, giuseppe.failla@unirc.it, gioacchino.alotta@unirc.it

Keywords: small-size beam lattice, stress-driven nonlocal elasticity, Rayleigh beam, size effects, dynamic-stiffness method, finite-element method.

Abstract

Small-size structures are of great interest in many real-life applications, as documented by the number of recent publications in this field [1,2]. This study deals with 2D small-size Rayleigh beam lattices, where size effects are modelled by the stress-driven nonlocal elasticity theory [3-5]. The aim is to present two novel computational approaches for elastic wave propagation analysis [6]. In a first dynamic-stiffness approach, each lattice member is modelled by a unique two-node beam element, the exact dynamic-stiffness matrix of which is built solving in closed analytical form the stress-driven differential motion equations. In a second finite-element approach, each lattice member is discretized by an increasingly refined mesh of two-node beam elements; in this case, the stiffness and mass matrices of the lattice member are obtained from shape functions built from the exact solutions of the stress-driven differential equations for static equilibrium. Advantages of the two approaches are compared and discussed. Dispersion curves are calculated for a typical planar lattice, investigating the role of nonlocality.

References

- [1] Romano G., Barretta R., "Nonlocal elasticity in nanobeams: The stress-driven integral model," *International Journal of Engineering Science*, 115, 14-27, (2017).
- [2] Romano G., Barretta R., "Stress-driven versus strain-driven nonlocal integral model for elastic nano-beams," *Composites Part B: Engineering*, 114, 184-188, (2017).
- [3] Romano G., Barretta R., Diaco M., Marotti de Sciarra F., "Constitutive boundary conditions and paradoxes in nonlocal elastic nanobeams," *International Journal of Mechanical Sciences*, 121, 151-156, (2017).
- [4] Thai H.-T., Vo T.P., Nguyen T.-K., Kim S.-E., "A review of continuum mechanics models for size-dependent analysis of beams and plates," *Composite Structures*, 177, 196-219, (2017).
- [5] Ghayesh M.H., Farajpour A., "A review on the mechanics of functionally graded nanoscale and microscale structures," *International Journal of Engineering Science*, 137, 8-36, (2019).
- [6] Russillo A.F., Failla G., "Wave propagation in stress-driven nonlocal Rayleigh beam lattices," *International Journal of Mechanical Sciences*, 215, 106901, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Steady vibration problems in the coupled theory of thermoviscoelasticity for triple porosity materials

Author(s): Maia M. Svanadze¹, Merab Svanadze^{*2}

¹ *Faculty of Exact and Natural Sciences, Tbilisi State University, Tbilisi, Georgia, maia.svanadze@gmail.com*

² *Institute of Fundamental and Interdisciplinary Mathematic Research, Ilia State University, Tbilisi, Georgia, svanadze@gmail.com*

Keyword(s): Thermoviscoelasticity, triple porosity materials, potential method, existence and uniqueness theorems

Abstract

In this talk, the linear coupled theory of thermoviscoelasticity for Kelvin-Voigt materials with triple-porosity is considered and the basic internal and external boundary value problems (BVPs) of steady vibrations are investigated. Namely, the fundamental solution of the system of steady vibration equations of the considered theory is constructed. The uniqueness theorems for the solutions of the BVPs of steady vibrations are proved. The surface and volume potentials are constructed and their basic properties are established. The BVPs are reduced to the always solvable singular integral equations. The existence theorems for classical solutions of the internal and external BVPs of steady vibrations are proved by means of the potential method (for details on the potential method see [1]).

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References

- [1] Svanadze, M., "Potential method in the linear theory of viscoelastic materials with voids," Journal of Elasticity, Vol. 114, pp. 101-126, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A viscoelastic nonlocal model for microtubules used as vibrational biosensors

Authors: Francesco Paolo Pinnola, Francesco Marotti de Sciarra

Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy,
francescopaolo.pinnola@unina.it, marotti@unina.it

Keywords: viscoelasticity, nonlocality, dynamic analysis, microtubules

Abstract

Dynamic vibration analysis of microtubules (MTs) in a cytosolution is presented. These biological components are cylindrical elements composed by globular proteins that constitute the main part of the cellular cytoskeleton. Simulating their vibrations caused by external physical and electromechanical inputs is crucial to describe the mechanical behavior of the eukaryotic cell [1]. These MTs can be modeled as beam elements surrounded by viscous environment (cytosol) taking into account some specific mechanical phenomena. Specifically, the presented model takes into account the size effect, typical at the micro-scale, by means of a nonlocal stress-driven integral relation [2]. Moreover, the rheological phenomena related to the MTs and the surrounding environment are considered with the aid of the fractional-order viscoelasticity obtaining a versatile time-dependent nonlocal constitutive law [3]. In this way damping effect is related to the internal constitutive characteristics of the MTs and to their interactions with the surrounding cytosol. The resulting dynamical problem is solved by means of a specific modal decomposition procedure, i.e., introducing the proper continuous shape functions of nonlocal structural element, evaluating the steady-state response and providing results in terms of power spectra. Presented numerical results and parametric analysis showing the influence of nonlocality and viscoelasticity in the mechanical response. Numerical and theoretical outcomes can help recent advanced monitoring methods to identify physiological or pathological state of the living cells [4].

References

- [1] Li S., Wang C., Nithiarasu P., "Electromechanical vibration of microtubules and its application in biosensors", *Journal of the Royal Society Interface*, 16(151), 20180826, (2019).
- [2] Pinnola F.P., Vaccaro M. S., Barretta R., Marotti de Sciarra F., "Random vibrations of stress-driven nonlocal beams with external damping", *Meccanica*, 56, 1329-1344, (2021).
- [3] Pinnola F.P., Barretta R., Marotti de Sciarra F., Pirrotta, A., "Analytical Solutions of Viscoelastic Nonlocal Timoshenko Beams", *Mathematics*, 10(3), 477, (2022).
- [4] Pokorný J., Vedruccio C., Cifra M., Kučera O., "Cancer physics: diagnostics based on damped cellular elastoelectrical vibrations in microtubules", *European Biophysics Journal*, 40(6), 747-59 (2011).

Title: A framework for data-driven multi-scale parametrizations in coupled porous media and free-flow systems

Authors: Edward Coltman¹, Martin Schneider¹, Rainer Helmig¹

⁽¹⁾ Institute for Modeling Hydraulic and Environmental Systems, University of Stuttgart

Keywords: data-driven, scale-bridging, coupled systems, machine learning, metrics

Abstract: Presented is a framework for the data-driven determination of multi-scale parametrizations for coupled porous media and free-flow systems.

Simulations of flow and transport in coupled porous media and free-flow systems can become very complex when realistic applications are considered [1, 2]. Evaluations of these systems at the REV scale, although efficient when using modern discretization methods [5], require well defined parameters that represent pore-scale phenomena to maintain their accuracy. Determining the optimal parameters for these models requires expensive pore-scale calculations [6]. This work outlines a series of four steps where these parameters can be calculated, as outlined in Figure 1, and further explained in [3].

First, evaluations of a system are evaluated at the pore scale. Next, these solutions are averaged and evaluated against REV scale models with closure or dispersion terms. The calculation of optimal parameters minimizing the difference between these scales can then be generalized using a specialized convolutional neural network. Finally, the results and physical meaning of these parametrizations can be further investigated using a correlation analysis to descriptive pore metrics. All simulations are performed using the numerics simulator DuMu^x [4].

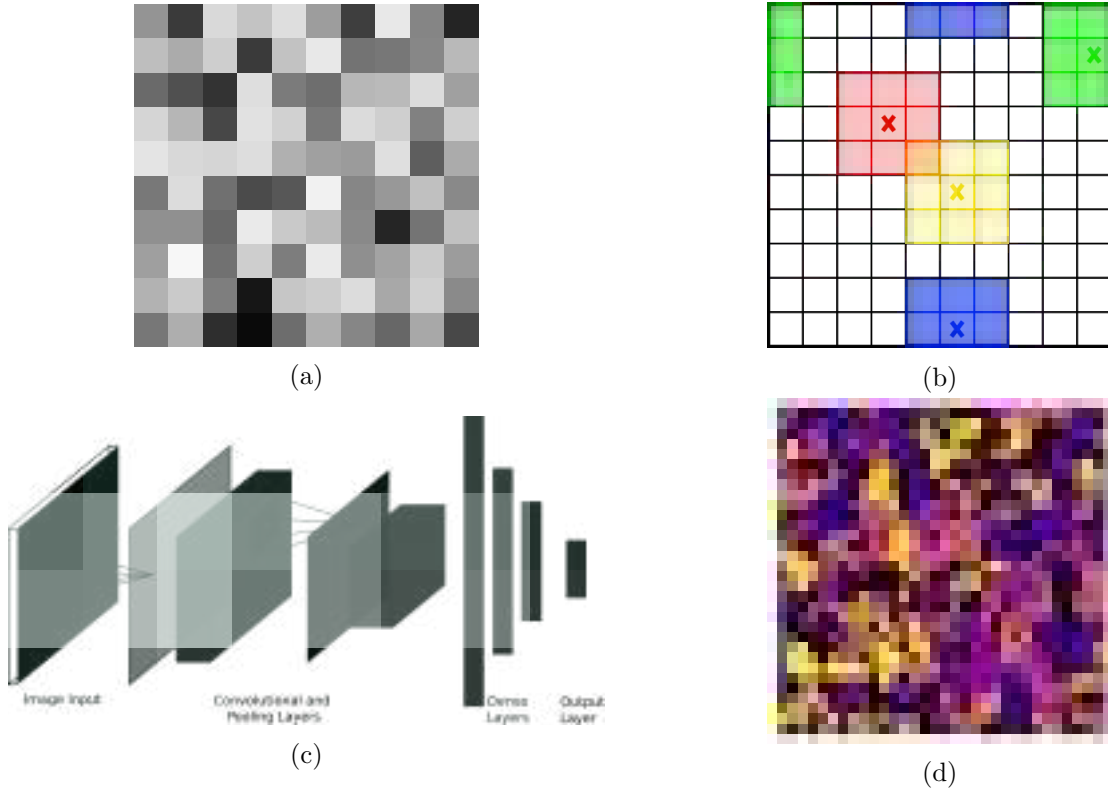


Figure 1: Framework outline: (1a) Pore-scale simulations, (1b) Averaging and closure term evaluation, (1c) generalizations via a CNN, (1d) evaluation of descriptive metrics.

References

- [1] L. M. Bahlmann, K. M. Smits, K. Heck, E. Coltman, R. Helmig, and I. Neuweiler. Gas component transport across the soil-atmosphere interface for gases of different density: Experiments and modeling. Water Resources Research, 56(9):e2020WR027600, 2020.
- [2] E. Coltman, M. Lipp, A. Vescovini, and R. Helmig. Obstacles, interfacial forms, and turbulence: A numerical analysis of soil-water evaporation across different interfaces. Transport in Porous Media, 134:275–301, 2020.
- [3] Edward Coltman, Martin Schneider, and Rainer Helmig. A dumux framework for data-driven multi-scale parametrizations. arXiv, 2023.
- [4] T. Koch, D. Gläser, K. Weishaupt, S. Ackermann, M. Beck, B. Becker, S. Burbulla, H. Class, E. Coltman, S. Emmert, T. Fetzer, C. Grüninger, K. Heck, J. Hommel, T. Kurz, M. Lipp, F. Mohammadi, S. Scherrer, M. Schneider, G. Seitz, L. Stadler, M. Utz, F. Weinhardt, and B. Flemisch. DuMux 3 – an open-source simulator for solving flow and transport problems in porous media with a focus on model coupling. Computers & Mathematics with Applications, 2021.
- [5] M. Schneider, D. Gläser, K. Weishaupt, E. Coltman, B. Flemisch, and R. Helmig. Coupling staggered-grid and vertex-centered finite-volume methods for coupled porous-medium free-flow problems. Journal of Computational Physics, Accepted, in Production, 2023.
- [6] B. D. Wood, F. Cherblanc, M. Quintard, and S. Whitaker. Volume averaging for determining the effective dispersion tensor: Closure using periodic unit cells and comparison with ensemble averaging. Water Resources Research, 39(8), 2003.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Fluid-Structure Interaction in Reverse Osmosis membrane modules

Authors: Giuseppe Battaglia^{*1}, Luigi Ranieri², Bastiaan Blankert², Giorgio Micale¹, Cristian Picioreanu²

¹ *Dipartimento di Ingegneria, Università degli Studi di Palermo, Palermo, Viale delle Scienze, 90128, Italy*

² *Water Desalination and Reuse Center (WDRC), Biological and Environmental Science and Engineering Division (BESE), King Abdullah University of Science and Technology (KAUST), Thuwal, 23955-6900, Saudi Arabia*

Keywords: Membrane deformation, structural mechanics, computational fluid dynamics, Darcy flow

Abstract

Reverse osmosis (RO) is the most efficient desalination technology that produces up to 65.5 million m³/day of clean water from seawater or brackish water [1]. In the process, an applied pressure is employed to overcome the osmotic pressure arising at the surfaces of a semi-permeable membrane placed between a concentrated and a dilute aqueous solution. The net pressure induces a water passage from the concentrated solution (feed solution) into the dilute one (permeate solution). In RO units, spacers are adopted to keep membranes separated and define the channels where solutions flow. However, spacers induce hydraulic pressure drops that influence the net pressure driving force of the process. In the literature, numerous studies were mainly focused on feed spacer geometries. Conversely, the permeate-side characteristics have been mainly ignored. Membrane compaction and membrane intrusion in permeate channels (or membrane deformation) can occur in RO units. Membrane compaction has been investigated, while membrane deformation has always been neglected. Kleffner et al. have debated the impact of membrane deformation on RO performances, estimating a possible water flux reduction of ~15 % during High-Pressure RO operations (120 bar) [2]. The present work aims at developing the first fluid-structure interaction modelling tool able to assess the influence of membrane deformation on the permeate side of RO units and its impact on process performance. One-way coupled 3-D mechanical and fluid dynamics simulations were conducted using a Finite Element/Finite Volume method (Ansys Mechanical® and Ansys Fluent®). The study was performed at the low scale of a periodic repetitive unit of a membrane-permeate spacer assembly. Membrane and spacer mechanical characteristics were determined by conducting a parametric study exploiting experimental data. Specifically, a purposely designed experimental set-up was developed at the Water Desalination and Reuse Center of the King Abdullah University of Science and Technology to measure pressure losses in permeate channels and, at the same time, to optically record pressure-induced membrane deformations at different applied pressures. Permeate channel volume decreased by 2.3 times under an applied pressure of 57 bar, causing pressure losses to increase up to 20 times with respect to the undeformed configuration. In future works, the low-scale data will be implemented into higher-scale models (treating the membranes as porous media) to address the impact of membrane deformation on RO performance.

References

- [1] Jones E., Qadir M., van Vliet M., Smakhtin V., Kang S., "The state of desalination and brine production: a global outlook", *Science of The Total Environment*, Vol 657, pages 1343-1356, (2019).
- [2] Kleffner C., Braun G., Antonyuk S., "High-Pressure Reverse Osmosis for Industrial Water Recycling: Permeate-Sided Pressure Drop as Performance-Limiting Factor", *Chemie Ingenieur Technik*. Vol 93, pages 1352–1358, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A Finite Element approach to address the 3D coupled thermo-mechanical and neutron diffusion problem on cementitious materials

Authors: Jiangkun Zhang¹, Beatrice Pomaro^{*1}, Gianluca Mazzucco¹, Beaudin Freinrich Dongmo¹, Valentina Salomoni², Carmelo Majorana¹

¹ *Department of Civil, Environmental and Architectural Engineering, University of Padova, Via F. Marzolo 9, 35131 Padova, Italy, jiangkun.zhang@phd.unipd.it, beatrice.pomaro@unipd.it, gianluca.mazzucco@unipd.it, beaudinfreinrich.dongmo@phd.unipd.it, carmelo.maiorana@unipd.it*

² *Department of Management and Engineering, University of Padova, Stradella S. Nicola 3, 36100 Vicenza, Italy, valentina.salomoni@unipd.it*

Keywords: Multiphysics; Multiscale; Coupled problems; Finite Elements; Irradiated concrete

Abstract

Concrete is an attractive material for nuclear radiation shielding purposes [1]. Structural and integrity assessment of biological shielding during the operational life of nuclear facilities invokes the study of the interrelated physical mechanisms taking place in the absorbing medium during irradiation. This work pursues the idea to address the problem via a deterministic approach, formulated within the framework of continuous numerical methods. Specifically, a Finite-Element based formulation for cementitious materials at in-service irradiation conditions is proposed. The model combines thermo-mechanical, and neutron diffusion processes. The mathematical problem resorts to a two-group neutron diffusion theory to tackle the particle transport problem [2]. The heat conduction theory takes into account the transition of fast to thermal neutrons, and the heat rise due to the thermalization process of the fast neutron flux during radiation absorption. The interaction between the thermal, and the radiation field with the mechanical field reflects on both, thermal expansion, and radiation-induced volume expansion [3] effects on concrete. The weak formulation of the system of governing equations is derived via a Galerkin approach. Discretization in time is accomplished by using an implicit finite difference scheme. The strong problem is, then, reconducted to the solution of a nonlinear system of ordinary differential equations, for which a monolithic solution is sought, iteratively, via a Newton Raphson scheme in terms of the state variables of the problem. The performance of the model is checked through the results provided by theoretical models available in the literature [4]. For the purposes of investigating material durability, the proposed numerical formulation is extended to the mesoscale. From the results obtained at this scale, considerations are made on the aggregate, and macropores distribution in relation to heat, and particle fluxes.

References

- [1] Kaplan M.F., Concrete radiation shielding: Nuclear physics, concrete properties, design, and construction, John Wiley & Sons Ltd, New York (1989).
- [2] Price B.T., Horton C.C., Spinney K.T., Radiation shielding, Pergamon Press, London (1957).
- [3] Kontani O., Ichikawa Y., Ishizawa A., Takizawa M., Sato O, "Irradiation effects on concrete structures", book chapter 27, 459-473. In: Infrastructure systems for nuclear energy, John Wiley & Sons Ltd (eds T.T.C. Hsu, C.-L. Wu and J.-L. Li) (2014).
- [4] Jing Y., Xi Y., "Modeling long-term distribution of fast and thermal neutron fluence in degraded concrete biological shielding walls", Construction and Building Materials, 292, 123379, 2021.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Large Scale Biomimicry Impact of Three-Dimensional Annulus Shape and Leaflet Lateral Profile on Engineered Mitral Valve Mechanics, a Numerical Analysis

Author: Elisa Lanzalaco^{1,2}, Joan Dario Laubrie Soto², Federica Cosentino², Giuseppe Raffa³, Michele Pilato³, Vincenzo La Carrubba¹, Antonio Pantano¹, Antonio D'Amore^{2,4}.

¹ *University of Palermo, Palermo, Italy*

² *Fondazione Ri.MED, Via Bandiera 11, Palermo, Italy*

³ *ISMETT, UPMC, Italy*

⁴ *McGowan Institute for Regenerative Medicine, University of Pittsburgh, Pittsburgh, USA*

Keywords: Mitral Valve, Annulus, Biomimicry, Prosthetic Devices, Numerical Analysis, Chordae Tendineae

Abstract

One of the leading causes of morbidity and mortality in the Western industrialized countries is heart valve disease [1]. The incidence of these valve diseases in the USA is estimated as 2.5% [2]. The American Heart Association shows that over 4 million people in the USA suffer from Mitral Valve (MV) disease with an annual increase of about 350.000 new cases [3]. To date, the valve repair and replacement market are estimated to be worth \$2.8 billion, with a projected compound annual growth rate of 9.1% [4].

Currently, several prosthetic devices are used for the repair of the mitral valve, which is characterized by different anchoring mechanisms to ensure good positioning, coaptation, and limited perivalvular leak. However, all the commercial devices are characterized by three leaflets, and this is associated with an alteration of the blood flow. In addition, mitral valve dynamism is neglected by a flat annulus configuration [5]. Due to the complexity of the MV, only a limited number of groups are developing numerical methods including the chordal apparatus like Khaligi et al. [6]. However, none of them has standardized the chordal apparatus.

The MV has a complex and dynamic anatomical structure, consisting of two asymmetric leaflets, a 3D saddle shape annulus, chordae tendineae (CT), and papillary muscles (PM). Damage of any of these components can lead to mitral regurgitation, which consists of mitral valve incontinence.

We performed numerical simulations on two different models of MV. In the first, the leaflets were modelled as described in detail by Jiang et al. 2004 [7]. Instead, the second was modelled with a physiological-inspired lateral profile and with an annulus based on the Edwards Lifesciences Annuloplasty Ring patent [8].

The simulations were performed on Abaqus using the Neo Hookean model to describe the material behavior. Connector elements (axial) were used for simulating the CT that connected the PM and the leaflet. The systolic phase was simulated by applying pressure on the outer surface, ranging from 7.5 mmHg to 120 mmHg, for a duration of 0.35 seconds. Similarly, the diastolic phase was simulated by applying pressure of 7.5 mmHg on the inner surface, for a duration of 0.65 seconds.

In this study, we investigated the impact of the number of chordae tendineae on the valve mechanisms. To accomplish this, we varied the number of chordae tendineae to 2, 6 and 8 to determine the resulting stress and strain through Finite Element Method (FEM).

To assess the impact of chordae tendineae variation on ΔS (difference between the maximum and the minimum in plane principal stress) we conducted a One-Way ANOVA analysis on two different models. Our results showed that the first model with $n=2$ chordae tendineae is statistically significant compared to the model with $n=6$ and $n=8$. However, we did not find any statistically significant differences in strain between the different models.

In the second model, which incorporated a physiological inspired lateral profile, we found that, for the stress distribution, the configuration with $n=2$ chordae tendineae is statistically significant compared to the configuration with $n=6$. This result was consistent with the differences observed for the strain distribution between the two configurations.

Our study showed that the number of chordae tendineae had a significant impact on the stress and strain distribution in both models. We did not observe any statistically significant difference in stress and strain between models with $n=6$ and $n=8$ chordae tendineae. Based on these findings, we can conclude that the model with $n=6$ chordae tendineae would be the best option due to its simplified fabrication process.

Furthermore, our simulations indicated that the commissural zone and the area around the chordae tendineae are the most stressed regions of the valve in both models.

References

- [1] K. Maganti, V.H. Rigolin, M.E. Sarano, and R.O. Bonow, "Valvular Heart Disease: Diagnosis and Management", Mayo Clin Proc, vol. 85, fasc. 5, pp. 483–500, 2010
- [2] B. Iung and A. Vahanian, "Epidemiology of valvular heart disease in the adult", Nat Rev Cardiol, vol. 8, fasc. 3, pp. 162–172, 2011
- [3] E. J. Benjamin et al., "Heart Disease and Stroke Statistics-2017 Update: A Report From the American Heart Association", Circulation, vol. 135, folder. 10, pp. e146–e603, 2017
- [4] Edwards Lifesciences 2015 year report
- [5] L. Gheorghe et al., "Current Devices in Mitral Valve Replacement and Their Potential Complications", Frontiers in Cardiovascular Medicine, vol. 7, 2020
- [6] A.H. Khalighi, A. Drach, C.H. Bloodworth, E.L. Pierce, A.P. Yoganathan, R.C. Gorman, J.H. Gorman, M.S. Sacks "Mitral Valve Chordae Tendineae: Topological and Geometrical Characterization" Ann Biomed Eng. 2017
- [7] H. Jiang, G. Campbell, D. Boughner, W.K. Wan, M. Quantz "Design and manufacture of a polyvinyl alcohol (PVA) cryogel tri-leaflet heart valve prosthesis" Med Eng Phys. 2004
- [8] O. Alfieri, A. F. Carpentier, F. Maisano, A. Redaelli, e P. M. McCarthy, "Annuloplasty rings", US20190117398A1, 2019

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A MicroCT *in situ* protocol to reveal the structure-function relation in electrospun hierarchical scaffolds for tendon/ligament regeneration

Author(s): Gregorio Marchiori^{*1,2}, Alberto Sensini³, Nicola Sancisi⁴, Gianluca Tozzi⁵, Massimiliano Zingales⁶, Gaia Prezioso⁶, Andrea Zucchelli⁴, Gianluca Giavaresi¹

¹ Surgical Sciences and Technologies, Rizzoli Orthopaedic Institute, Bologna, Italy, gregorio.marchiori@ior.it

² Ingegneria dell'Informazione, University of Brescia, Brescia, Italy, g.marchiori002@unibs.it

³ CTR and cBITE of MERLN Institute for Technology-Inspired Regenerative Medicine, Maastricht University, Maastricht, The Netherlands, alberto.sensini@maastrichtuniversity.nl

⁴ Industrial Engineering, University of Bologna, Bologna, Italy, nicola.sancisi@unibo.it

⁵ School of Engineering, University of Greenwich, Chatham Maritime, UK, G.Tozzi@greenwich.ac.uk

⁶ Ingegneria, University of Palermo, Palermo, Italy, massimiliano.zingales@unipa.it

Keyword(s): electrospun hierarchical tendon/ligament scaffolds; microCT; *in situ* tensile test

Abstract

Electrospun PLLA/collagen bundles (SB) and hierarchical structures (EHS) are under research as bioinspired tendon-ligament scaffolds [1]. Understanding how the hierarchical structure evolves with increasing strain is of the utmost importance to relate scaffold design and function. With this aim, a microCT *in situ* uniaxial loading protocol was developed. Firstly, to define reference mechanical characteristics, 4 SB and 4 EHS were tested with a monotonic ramp to failure at 0.33 %/s of strain rate. Then, 3 SB and 3 EHS underwent the microCT *in situ* test. Samples were submerged in PBS for two minutes before clamping for tensioning in the microCT apparatus (Skyscan 1172, Bruker, Belgium). After microCT scan at the minimum strain allowed by the load cell sensitivity (0.45 Newton, corresponding to 2% strain for SB and 0% strain for EHS), progressive strains were imposed (SB: 3-4-5-7-9%; EHS: 1.5-3-5-7%). Each strain was followed by 15 minutes stress-relaxation, to exhaust viscous phenomena, before each microCT acquisition. SB were scanned at a voxel size of 13 μm , with no filter and an x-ray tube voltage of 40 kV. Scanning protocol for EHS was the same, except for a higher spatial resolution (9 μm) to discriminate between different internal hierarchical levels. The region of interest (ROI) selection and morphometric analysis were performed using SkyScan CT-Analyser software. ROI extended for 6 mm in length, 2 mm below the superior fixed clamp, to avoid metal artefacts. The microCT *in-situ* test reported strain-load curves consistent with reference mechanical characterizations, confirming that the procedure did not alter the scaffold original mechanics, allowing the study of the evolution of their internal structure. Bundle tortuosity decreased and alignment along the mechanical axis increased with strain for EHS, while not for SB, probably because SB extensively overpassed the yielding point during the *in-situ* test. Contraption with increasing strain was common for both kinds of samples, as expected, but corresponded to a decrease in porosity only for SB (intra-bundle), while the presence of voids increased for EHS (inter-bundle). The microCT *in situ* mechanical test successfully allowed investigation, for the first time, of the relation between microstructure and mechanics of electrospun scaffolds. This protocol will be fundamental for future Digital Volume Correlation studies, for obtaining unprecedented information to design the future generations of scaffolds for tissue engineering.

References

[1] Sensini A., Cristofolini L., Zucchelli A., Focarete M.L., Gualandi C., De Mori A., Kao A.P., Roldo M., Blunn G., Tozzi G., "Hierarchical electrospun tendon-ligament bioinspired scaffolds induce changes in fibroblasts morphology under static and dynamic conditions", Journal of Microscopy, 277(3):160-169 (2020)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Homogenization of osmotic flows across thin permeable membranes

Author(s): K. Wittkowski^{*1}, E. C. Giordano², P. G. Ledda³, F. Gallaire⁴, G. A. Zampogna⁵.

¹ LFMI, École Polytechnique Fédérale de Lausanne, Lausanne, CH, kevin.wittkowski@epfl.ch

² DICCA, Università degli Studi di Genova, Genova, IT, giordano.edo@libero.it

³ DICAAR, Università degli Studi di Cagliari, Cagliari, IT, piergiuseppe.ledda@unica.it

⁴ LFMI, École Polytechnique Fédérale de Lausanne, Lausanne, CH, francois.gallaire@epfl.ch

⁵ LFMI, École Polytechnique Fédérale de Lausanne, Lausanne, CH, giuseppe.zampogna@epfl.ch

Keyword(s): homogenization, osmosis, porous membranes

Abstract

Osmotic flows through permeable membranes allow the correct functioning of living systems, such as corneal endothelial pump [1], retinal pigment epithelium [2], and filtration in kidney tubules [3]. In the present contribution, we develop via a homogenization-based methodology [4,5] a macroscopic predictive model describing the flow of a solvent driven by a solute concentration gradient across a semi-permeable thin membrane. The homogenization of the Stokes-Nernst-Planck system leads to effective flux and stress jump conditions across the membrane, modelled as a smooth interface separating two distinct fluid domains. Several coefficients quantify the solvent stress and solute flux jumps, each associated with a specific membrane property, i.e., the solvent permeability and slip, the solute effective diffusion, and the osmotic transport coefficient. These coefficients stem from the solution of problems obtained through the homogenization procedure and are valid within a microscopic unit cell, the elementary building block of the membrane structure. The model developed is implemented numerically and validated against simulations of the Stokes-Nernst-Planck system solved at all scales present in the problem. The connection of our macroscopic model with the Kedem-Katchalsky law [6], which requires phenomenological coefficients with little predictive power, is discussed. Our model provides a rigorous, quantitative, and efficient way to describe, predict and optimize flows through osmotic membranes, with disparate applications in biological fluid mechanics.

References

- [1] Bonanno J.A., "Molecular mechanisms underlying the corneal endothelial pump", *Experimental Eye Research*, 95(1), 2-7, (2012).
- [2] Dvoriashyna, M., Foss, A.J.E., Gaffney, E.A., Jensen, O.E., Repetto, R., "Osmotic and electroosmotic fluid transport across the retinal pigment epithelium: A mathematical model", *Journal of Theoretical Biology*, 456, 233-248, (2018).
- [3] Kiil, F., "Mechanism of osmosis", *Kidney International*, 21, 303-308, (1982).
- [4] Zampogna, G.A., Gallaire, F., "Effective Stress Jump across membranes", *Journal of Fluid Mechanics*, 892, A9, (2020).
- [5] Zampogna, G.A., Ledda, P.G., Gallaire, F., "Transport across thin membranes: Effective solute flux jump", *Physics of Fluids*, 34, 083113, (2022)
- [6] Kedem, O., Katchalsky, A., "Thermodynamic analysis of the permeability of biological membranes to non-electrolytes", *Biochimica et Biophysica Acta*, 27, 229-246, (1958).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A fluid structure interaction model of the vibration frequencies of the eye bulb

Authors: Giuseppe Tomassetti^{*1}, Nicoletta Tambroni², Rodolfo Repetto²

¹*Department of Industrial, Electronic and Mechanical Engineering, Rome 3 University, Rome, Italy, giuseppe.tomassetti@uniroma3.it*

²*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy, nicolella.tambroni@unige.it, rodolfo.repetto@unige.it*

Keyword(s): ocular vibrations, fluid-structure interaction, natural frequencies.

Abstract

The human eye is a pressurised organ consisting of a solid elastic shell (the corneo-scleral shell) containing a gel like substance (the vitreous humour). The intraocular pressure (IOP) is regulated by a delicate balance between fluid production by a specialised tissue named the ciliary body and resistance its drainage from the eye, into the venous system. IOP is an important clinical parameter as it is well know that high IOP values correlate with the occurrence of open angle glaucoma, a sight threatening disease and the leading cause of blindness in developed countries. IOP is routinely measured with Goldmann contact tonometers: the force required to flatten a portion of the cornea is measured and it is related to the IOP through empirical relationships. In recent years, there has been a growing interest in non-contact pressure measuring techniques and acoustic tonometry is among the most promising. The eye bulb is excited with acoustic waves and the vibration frequency of the ocular shell is measured, which allows the operator to identify natural frequencies of oscillation. The oscillation frequencies have been shown to be closely correlated to IOP, both in experimental [1,2] and numerical works [3,4]. However, a complete mechanical model that properly accounts for the interaction between the elastic corneo-scleral shell and the viscoelastic vitreous humour is still missing. We propose such a model, describing the eye wall as a spherical, prestressed elastic shell, containing a viscoelastic material. We study the eigenfrequencies of the system and the corresponding eigenfunctions, by expanding the solution in terms of vector spherical harmonics. The model allows us to single out the role of the parameters involved in the problem. IOP and Young's modulus of the shell strongly influence the vibration frequencies, whereas the vitreous rheological properties mostly influence damping.

References

- [1] Kim, D. et al. "A Pilot Study for Intraocular Pressure Measurements Based on Vibroacoustic Parameters". *Scientific Reports* 11, no. 1 (2021).
- [2] Shih, P. et al. "Eye Orbit Effects on Eyeball Resonant Frequencies and Acoustic Tonometer Measurements". *Scientific Reports* 12, no. 1 (2022).
- [3] Aloy, M. Á. Et al. "Estimation of the Mechanical Properties of the Eye through the Study of Its Vibrational Modes", *PLOS ONE* 12, no. 9 (2017)
- [4] Shih, P. and Yi-Ren G. "Resonance Frequency of Fluid-Filled and Prestressed Spherical Shell—A Model of the Human Eyeball". *The Journal of the Acoustical Society of America* 139, no. 4 (2016).

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Effect of Heart Contraction on Coronary Arteries' Flow Rate

Seyyed Mahmoud Mousavi^{*1}, Gianluca Zitti², Jolanda J. Wentzel³, Marco Pozzi⁴, Maurizio Brocchini⁵

¹ Department of Construction, Civil Engineering, and Architecture, Polytechnic University of Marche, Ancona, Italy, s.m.mousavi@pm.univpm.it

² Department of Construction, Civil Engineering, and Architecture, Polytechnic University of Marche, Ancona, Italy, g.zitti@staff.univpm.it

³ Department of Cardiology, Biomechanical Engineering, Erasmus MC, Rotterdam, Netherlands, j.wentzel@erasmusmc.nl

⁴ Department of Pediatric and Congenital Cardiac Surgery and Cardiology, United Hospital, Ancona, Italy, marco.pozzi@ospedaleiriuniti.marche.it

⁵ Department of Construction, Civil Engineering, and Architecture, Polytechnic University of Marche, Ancona, Italy, m.brocchini@staff.univpm.it

Keyword(s): Coronary artery perfusion, heart contractility, numerical simulations

Abstract

While the heart pumps blood into our vessels, coronary arteries feed blood into the heart itself; this highlights the importance of accurate simulation of coronary artery perfusion. Numerical simulations can provide rich insight into coronary perfusion. Coronary artery flow, however, is a complex phenomenon particularly because of the influence of heart contractions. In the literature, it is hypothesized that ventricular contractions impede coronary perfusion [1][2][3]. In this research, we are simulating coronary perfusion with the ANSYS CFD software package. We are trying to simulate the effect of heart contraction on coronary perfusion in contrast to 1D models, which artificially apply an impedance downstream of the coronary flow. Moreover, this will help to better understand how we can imply in vitro the effect of heart contraction on coronary artery flow rates. We simulate the coronary vessels with flexible walls and apply heart pressure on the circumference of the coronary vessels to mimic the effects of the intramyocardial pressure on coronary perfusion. The results of our numerical fluid-structure interaction (FSI) simulations indicate that the peak coronary blood flow in the systolic phase is approximately %15 lesser compared to the case without heart contractility effects.

References

- [1] R. Krams, A. C. T. A. van Haelst, P. Sipkema, and N. Westerhof, "Can coronary systolic-diastolic flow differences be predicted by left ventricular pressure or time-varying intramyocardial elastance?," *Basic Res. Cardiol.*, vol. 84, no. 2, pp. 149–159, 1989, doi: 10.1007/BF01907924.
- [2] R. Krams, P. Sipkema, and N. Westerhof, "Varying elastance concept may explain coronary systolic flow impediment," *Am. J. Physiol. Circ. Physiol.*, vol. 257, no. 5, pp. H1471–H1479, 1989.
- [3] R. Krams, P. Sipkema, J. Zegers, and N. Westerhof, "Contractility is the main determinant of coronary systolic flow impediment," *Am. J. Physiol. Circ. Physiol.*, vol. 257, no. 6, pp. H1936–H1944, 1989.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Investigating elastic- and entropic-driven rupture mechanisms of biomembranes

Authors: Salvatore Buonocore^{*1}, Rosario Capozza², Francesco De Angelis¹

¹ *Istituto Italiano di Tecnologia (IIT), Via Morego 30, 16163 Genova, Italy*

² *Institute for Infrastructure and Environment, School of Engineering, The University of Edinburgh, Edinburgh EH9 3JL*

Keyword(s): Biomembranes rupture, Elastic- vs entropic-dominated regimes, Continuum mechanics coupled with Brownian-like hydrodynamic fluctuations, Drug delivery

Abstract

Biomembranes are characterized by several elastic parameters that appropriately describe the energetics of their deformation under thermal fluctuations [1]. When their structure is quasi-two-dimensional (namely lipid bilayer 4-5 nm thick), several recent studies [1, 2] showed that their disruption, at finite temperature, can be driven either by elastic or entropic forces depending on their size. However, what happens for thicker and larger structures? Using Continuum finite element simulations coupled with Brownian-like hydrodynamic fluctuations, we show that the entropic contribution to the dynamics and rupture of biomembranes at finite temperature can be the dominant mechanism not only for structures few nanometers thick but also for thicker larger structures (of the order of several μm). The results of this work can help shedding light on the dynamic and failure modes of biomembranes that are key in tissue engineering and drug delivery. The most remarkable advantage of the proposed computational approach is the possibility of analyzing dynamical processes of bio-structures spanning dimensional and temporal intervals ranging from nanometers to micrometers and from nanoseconds to microseconds, in a computationally stable and efficient manner. In these spatial and temporal ranges, the Molecular Dynamics approach is not a viable route.

References

- [1] David Boal, David H. Boal, *Mechanics of the Cell*. Cambridge University Press, 2012.
- [2] Rosario Capozza, Luca Giomi, Carlo A. Gonano, and Francesco De Angelis, *How to puncture a biomembrane: elastic versus entropic rupture*, *arXiv preprint: 1911.05557* (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Bearing capacity of truss lattice structures

Author(s): Mattia Schiantella^{*1}, Federico Cluni¹, Vittorio Gusella¹

¹ *Department of civil and environmental engineering, University of Perugia, Italy,
mattia.schiantella@unipg.it, federico.cluni@unipg.it, vittorio.gusella@unipg.it*

Keyword(s): Limit Analysis, truss lattice structures, meta-materials

Abstract

Truss lattice structures are becoming more popular given the increased ability to generate small scale structures with remarkable accuracy thanks to the spread of 3d printing and other innovative techniques [1].

Since these trusses are very thin, most of the space in this system is empty, therefore the overall density is very low even though the constituent elements have a high density.

This kind of structure exhibits great strength combined with significant material savings as shown in [2] and [3] by experimental tests.

In [4] it is shown that for a discrete truss lattice structure it is possible to derive an equivalent continuum model through scale bridging techniques

In this work, the failure load of such systems is evaluated by mean of an upper bound limit analysis.

The solution to this problem has instead an analogy with the one obtained for the continuum upper bound limit analysis in plane strain conditions such as Discontinuity Layout Optimization [5], [6].

References

- [1] Dong L., Deshpande V., Wadley H, "Mechanical response of Ti-6Al-4V octet-truss lattice structures", International Journal of Solids and Structures, 60-61, 107-124, (2015).
- [2] Quegeillalt D., Wadley H, "Cellular metal lattices with hollow trusses", Acta Materialia, 53(2), 303-313, (2005).
- [3] O'Masta M.R et al "The fracture toughness of octet-truss lattices", Journal of the Mechanics and Physics of Solids, 98, 271-289, (2017).
- [4] Desmoulins A., Kochmann D.M., "Local and nonlocal continuum modelling of inelastic periodic networks applied to stretching-dominated trusses", Computer Methods in Applied Mechanics and Engineering, 313, 85-105, (2017).
- [5] Smith, C.C., Gilbert, M., "Application of discontinuity layout optimization to plane plasticity problems," Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 463, 2461-2484, 2007.
- [6] Schiantella, M., Cluni, F., and Gusella, V., "Parametric Analysis of Failure Loads of Masonry Textures by Means of Discontinuity Layout Optimization (DLO)." Materials 15 (10): 3691, (2022)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Coupling Virtual Element Method (VEM) and Interface Elements for modelling fracture propagation in Grain Boundaries materials

Author(s): Crisitina Gatta¹, Marco Pingaro^{*1}, Daniela Addressi¹, Patrizia Trovalusci¹

¹ Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy,
crisitina.gatta@uniroma1.it
marco.pingaro@uniroma1.it
daniela.addressi@uniroma1.it
patrizia.trovalusci@uniroma1.it

Keyword(s): Virtual Element Method, VEM, interface finite elements, polycrystalline composites, nonlinear behaviour, fracture.

Abstract

The aim of this work is to study nonlinear behaviour of polycrystalline material with particular focus on Ceramic Metal Composite (CMC) material [1]. These kind of materials are widely use in a large range of engineering applications for their thermomechanical characteristics. Here we propose a coupling approach between the innovative method of Virtual Element (VE) [2] and Interface Finite Element [3] considering the damage located in the interfaces between the grains. Combing this two approaches seems be a very promising technique for modelling this kind of materials avoiding to mesh each grains with a reduction of the computational burden without lack of precision in terms of global behaviour.

The key idea is to model the grains with one single element and interpose between the grains border nonlinear zero thickness interface elements. The nonlinearity is concentrated in the interfaces in which, commonly, the cracks grow. Some benchmarks shown the reliability of the proposed strategy. Furthermore, a sensitivity analysis at varying the volume fraction of the metallic phase and the microstructure will be presented. All the numerical results are performed using Alumina/Zirconia ($\text{Al}_2\text{O}_3/\text{ZrO}_2$) composite has paradigmatic examples of CMC material.

Acknowledgments

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References

- [1] Sadowski, T., "Modelling of damage and fracture processes of ceramic matrix composites under mechanical loading", Multiscale modeling of complex materials: phenomenological, theoretical and computational aspects, 151–178 (2014).
- [2] Pingaro, M., Reccia, E., Trovalusci, P., Masiani. R., "Fast statistical homogenization procedure (FSHP) for particle random composites using virtual element method", Computational Mechanics, 64, 197–210, (2019).
- [3] Addressi, D., Gatta, C., Marfia, S., Sacco, E., "Multiscale analysis of in-plane masonry walls accounting for degradation and frictional effects", International Journal for Multiscale Computational Engineering, **18** 159–180 (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Dynamic characterization and shake-table experimental validation of an innovative base-isolation device for seismic protection of statues

Author(s): Giacomo Navarra^{*1}, Francesco Lo Iacono¹, Elena Alberti¹, Maria Oliva¹

¹ Faculty of Engineering and Architecture, Kore University of Enna, Enna, Italy,

Emails: giacomo.navarra@unikore.it, francesco.loiacono@unikore.it, mariagraziaelena.alberti@unikorestudent.it, maria.oliva@unikore.it.

Keyword(s): Cultural Heritage, Seismic protection, Shake-table tests, Base isolation, Museum contents

Abstract

Monuments and statue-like objects have revealed a poor dynamic behaviour during past major earthquakes occurred in the Mediterranean area in the last decades. A large research activity has been devoted over the years to the mitigation of seismic effects in historic building, while seismic protection of museum contents has not received the same attention despite their inestimable value. Analytical studies on the non-linear dynamic experienced by statue-like objects during earthquakes as well as experimental investigations on small-scale models can be found in literature [1], but experimental works in realistic earthquake scenarios aiming at assessing the seismic mitigation level of protection devices in real-scale still remain limited. Among the several mitigation techniques explored by researchers, the base isolation has resulted to be very effective for the seismic protection of statue-like items, providing low lateral stiffness, adequate damping and self-center capability. This research work presents preliminary results of an extensive test campaign for the characterization of the dynamical behavior and the seismic protection level of an innovative 2D base-isolation device through full-scale shake table tests carried out at the L.E.D.A. (Laboratory of Earthquake engineering and Dynamic Analysis) Research Institute at the “Kore” University of Enna, Italy [2]. The device consists of a series of multiple articulated quadrilateral mechanism elements, patented as KSJ (Kinematic Steel Joint), that allows the free movements of a rigid base in both horizontal directions, providing pendulum-like behavior and re-centering capabilities due to its kinematic features. Broadband random noise and selected natural earthquake acceleration time-histories have been firstly applied by varying load conditions and different intensities in order to characterize the dynamics of the device. Hence, shake-table tests on a full-scale replica of the 2.24 m tall statue of the Goddess of Morgantina, selected due to its peculiar story and its significance, have been performed to assess the seismic protection level in a high realistic earthquake scenario [3]. On the basis of experimental results, a simple friction pendulum analytical model has been finally derived and calibrated for design purposes.

References

- [1] Calì I., Marletta M., “Passive control of the seismic rocking response of art objects”, *Engineering Structures*, 25(8), p. 1009–1018, (2003).
- [2] Castelli F., Lentini V., Lo Iacono F., Navarra, G., “Shake-table tests for the dynamic characterisation of an innovative isolator for seismic protection of statues” in *Geotechnical Engineering for the Preservation of Monuments and Historic Sites III*, pp. 389–400. CRC Press, London, (2022)
- [3] Alberti E., Ausenda G., Castino M.C., Lo Iacono F., Navarra G., “Seismic protection of the Goddess of Morgantina statue through an innovative base-isolation device: validation by Shake-table tests” in Cimellaro, G.P. (eds) *Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures*. 17th WCSI, Torino (Italy), 12-16 September 2022. *Lecture Notes in Civil Engineering*, vol 309. Springer, Cham., p. 717-725, (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Numerical modeling of the seismic response and damage of full-scale masonry arches and vaults

Author(s): Roberta Scungio^{*1}, Chiara Pepi¹, Massimiliano Gioffrè¹

¹ *Department of Civil and Environmental Engineering, University of Perugia, Italy, roberta.scungio@studenti.unipg.it, chiara.pepi@unipg.it, massimiliano.gioffre@unipg.it*

Keyword(s): Masonry arches, masonry vaults, numerical modeling, dynamic response

Abstract

The safety of masonry arches and vaults is a prominent topic in the preservation of the architectural European heritage. These structures are prone to damage caused by both static and dynamic extreme loads. Predicting the structural behavior to guarantee the safety of such structures is a complex task and a number of methods have been proposed in the literature in the last decades.

Within this context, combining numerical approaches to experimental investigations can lead to digital twins for accurate structural response and damage estimations. Given to cost and time limitations, often the response obtained with numerical models has been compared with the experimental response of scaled structural specimens. The obtained results were therefore influenced by the used scale [1-2].

In this paper, the large data set with experimental dynamic results on full-scale masonry arches and vaults [3-4] is used to calibrate micro-mechanical numerical models that can be used to describe both the dynamic response and the observed damage.

References

- [1] Bianchini N., Mendes N., Calderini C., Lourenço P. B., "Modelling of the dynamic response of a reduced scale dry joints groin vault", *Journal of Building Engineering*, 66, 105826. (2023)
- [2] Gaetani A., Bianchini N., Lourenço P. B., "Simplified micro-modelling of masonry cross vaults: Stereotomy and interface issues", *International Journal of Masonry Research and Innovation*, 6, 97-125. (2021)
- [3] Gioffré M., Vincenzini A., Cavalagli N., Gusella V., Caponero M. A., Terenzi A., Pepi C. "A novel hemp-fiber bio-composite material for strengthening of arched structures: Experimental investigation." *Construction and Building Materials*, 308, 124969. (2021).
- [4] Gioffré M., Navarra G., Cavalagli N., Iacono F. L., Gusella V., Pepi C. "Effect of hemp bio composite strengthening on masonry barrel vaults damage". *Construction and Building Materials*, 367, 130100. (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Preliminary experimental tests and numerical modelling of an innovative base isolation system.

Author(s): Francesco Lo Iacono^{*1}, Giuseppe Mugnos¹, Giacomo Navarra¹, Alessandro Bianchi², Roberto Giacchetti³.

¹ Faculty of Engineering and Architecture, University of Enna Kore, Enna, Italy,

Emails: francesco.loiacono@unikore.it, giuseppe.mugnos@unikorestudent.it, giacomo.navarra@unikore.it.

² Gea Soc. Coop. Prevenzione Rischio Sismico, Ancona, Italy, a.bianchi@geacoop.eu.

³ Studio Tecnico Ing. Roberto Giacchetti, Ancona, Italy, robertogiacchetti@libero.it.

Keyword(s): Seismic base isolation, Experimental test, Shaking table seismic test.

Abstract

Seismic hazard is undoubtedly one of the most important causes of damage on civil structures and, very often, it is the cause for the loss of lives and goods as recently showed during the 7.8 Mw earthquake that struck southern and central Turkey and northern and western Syria, in February 2023. In the last decades, several generations of researchers devoted their efforts to study the most suitable seismic protection strategies, and, amongst others, seismic isolation has been proved to be one of the most effective and reliable [1].

Seismic isolation is a method of protecting a building from major earthquakes by installing some isolation and energy absorbing devices between the building superstructure and its foundation. Nowadays, many different isolation devices are present in the market with different mechanical properties and costs.

The present work reports the results of a preliminary experimental campaign carried out taking advantage of the 6-DOF shaking table system of the L.E.D.A. (Laboratory of Earthquake engineering and Dynamic Analysis) Research Institute at the “Kore” University of Enna, Italy [2]. The tests activities concerned an innovative seismic isolation system, named and patented as Double Raft, consisting of two foundation slabs in reinforced concrete. The lower slab made integral with the shaking table, can contain the upper one inside, on which a 1:2 scale steel frame with two elevations has been connected.

Two layers of Teflon sheets each 5 mm thick are interposed between the two foundations, to decrease the grazing friction between the two slabs and thus create a seismic isolation system at the base. To limit lateral movements, a system of steel springs was interposed between the walls of the lower slab and the upper slab. Upon assembly, the springs were preloaded to offer stiffness in both directions of the horizontal components of the relative displacement between the two slabs.

Random noise and 3D seismic experimental tests have been applied to the system under investigation and the experimental data are elaborated to develop an analytical model of the system, to verify the functioning of the proposed isolation system and to assess the seismic protection level offered.

References

[1] AA VV, Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Springer, Cham, (2023).

[2] Lo Iacono, F., Navarra, G., Oliva, M., Cascone, D., “Experimental Investigation of the Dynamic Performances of the LEDA Shaking Tables System” in Proceedings of the 23rd Conference of the Italian Association of Theoretical and Applied Mechanics, AIMETA 2017, Salerno, 4-7 September 2017, 5, pp. 897–915 (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Cost and embodied carbon-based optimization of seismic retrofit of RC frame structures using evolutionary algorithms

Author(s): Fabio Di Trapani^{*1}, Antonio P. Sberna², Josephine V. Carstensen³, Giuseppe C. Marano⁴

¹*Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Turin, Italy, fabio.ditrapani@polito.it*

²*Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Turin, Italy, antonio.sberna@polito.it*

³*Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, USA, jvcar@mit.edu*

⁴*Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Turin, Italy, giuseppe.marano@polito.it*

Keyword(s): embodied carbon, optimization, genetic algorithms, retrofitting, reinforced concrete

Abstract

Seismic retrofitting interventions for reinforced concrete structures are generally associated with noticeable costs, significant invasiveness, and relevant downtime. The environmental impact of such interventions is not generally considered a design parameter, although there is a pressing need for reducing CO₂ emissions in the field of civil engineering [1,2]. Recent studies [3,4] proved that automated seismic retrofit design can be effectively carried out using computational intelligence for a cost-based optimal design. However, the minimum cost-based design does not necessarily entail low carbon emissions. In this frame of reference, this study proposes a genetic algorithm-based framework for the embodied carbon-based optimization of different typologies of retrofitting techniques. The framework provides an automated design of seismic retrofit (topology and sizing) of reinforced concrete columns, to upgrade an RC structure to resist the current design code seismic demands. The Global Warming Potential (GWP) is used as an effective measure of the embodied carbon emissions associated with each reinforcement technique. The case study test of a typical non-seismically conforming reinforced concrete building structure is investigated. GWP optimization is carried out considering four different possible retrofitting techniques (steel jacketing, concrete jacketing, FRP jacketing, and steel bracing). The optimal results are finally compared in terms of environmental impact and associated economical costs. Results will show that the proposed framework could be used as an effective tool for a sustainable design of seismic retrofit of existing reinforced concrete frame structures.

References

- [1] Clemett N, Carols Gallo WW, O'Reilly, Gabbianelli G, Monteiro R. Optimal seismic retrofitting of existing buildings considering environmental impact. *Engineering Structures* 2022, 250: 113391.
- [2] Ching E, Carstensen JV. Truss topology optimization of timber–steel structures for reduced embodied carbon design. *Engineering Structures* 2022, 252: 113540.
- [3] Di Trapani F, Sberna AP, Marano GC. A new genetic algorithm-based framework for optimized design of steel-jacketing retrofitting in shear-critical and ductility-critical RC frame structures. *Engineering Structures* 2021, 243:112684.
- [4] Di Trapani F, Sberna AP, Marano GC. A genetic algorithm-based framework for seismic retrofitting cost and expected annual loss optimization of non-conforming reinforced concrete frame structures. *Computers and Structures*. 2022; 271:106855.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Iterative partial stiffening process for the reduction of shell buckling

Author(s): Alex SEITER^{1*}, Thorsten POFAHL¹, Martin TRAUTZ¹

¹ *Chair of Structures and Structural Design, RWTH Aachen University, Aachen, Germany, seiter@trako.arch.rwth-aachen.de*

Keyword(s): shell-buckling, metal spatial structures, lightweight structures, structural optimization, metal-forming, additive manufacturing

Abstract

Metallic semi-finished sheet products offer enormous potential for lightweight construction, which are being extensively exploited in the automotive and aerospace industries. The basic idea is to respond to buckling phenomena by a bending-active behavior of the shell cross-section [1, 2].

This behavior can be reached by embossing or applying microstructures on single layers [3] and even enhanced by connecting two layers together with embossed shear stiffeners [4]. A major challenge lies in the calculation of the required stiffeners location with its orientation to ensure stability, as well as stiffening level of the structure. Because of excessive design space and limited control abilities, parameter studies are unsuitable and non-robust.

To determinate an optimized structure, an iterative process is implemented in the stability investigation. Within this algorithm, the stiffness gets iteratively increased only within relevant surface domains of the structure. These domains are defined by the determination of stress intensities, curvature ratios and the maximum deformation location due to buckling of given shell models under defined boundary conditions and loads. The iterative partial stiffening process (IPSP) allow to translate the required calculated stiffness into the factual stiffeners lay-out (single layer or multilayer structures) to obtain overall stable thin sheet structure.

References

- [1] M. Widmann, Herstellung und Versteifungswirkung von geschlossenen Halbrundsicken, Berlin: Springer, 1984.
- [2] D. Emmrich, "Entwicklung einer FEM basierten Methode zur Gestaltung von Sicken für biegebeanspruchte Leitstützstrukturen im Konstruktionsprozess," IPEK, no. 13, 2005.
- [3] T. Pofahl, A. Seiter, M. Trautz, L.-M. Reitmaier, D. Bailly and G. Hirt, "Form Finding of Sheet Metal Shell by generative Design and multi-objective Optimization according to the Principle of Structural Morphology," in Advances in Architectural Geometry (AAG), University of Stuttgart, 04.-07. October 2023.
- [4] A. Seiter, T. Pofahl, M. Trautz, L.-M. Reitmaier, D. Bailly and G. Hirt, "Sheet Metal Shells," in 14. Baustatik Baupraxis. 23. und 24. März 2020, Universität Stuttgart / Herausgeber: Manfred Bischoff, Malte von Scheven, pp. 439-446, Universität Stuttgart, 2020.).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Research on Intelligent Design Method for Structural Topology of Complex Architectural Plans

Author(s): Chong Zhang^{*1}, Chen Wang², Muxuan Tao³, Jiansheng Fan⁴

¹ Department of Civil Engineering, Tsinghua University, Beijing, China, xixizhongyu@126.com

² Department of Civil Engineering, Tsinghua University, Beijing, China, qtwjy309@163.com

³ Department of Civil Engineering, Tsinghua University, Beijing, China, taomuxuan@tsinghua.edu.cn

⁴ Department of Civil Engineering, Tsinghua University, Beijing, China, fanjsh@tsinghua.edu.cn

Keyword(s): Structural topology, Graph generation model, Data-driven model, Generative adversarial network, Intelligent design method

Abstract

In order to achieve automatic generation of structural topology for complex architectural plans, this study proposes an intelligent design method based on graph generation models. The method assists designers in generating structural topologies quickly and efficiently. Firstly, an undirected graph data structure is used to describe the structural plans, and the structural topology generation problem is transformed into a problem of generating the adjacency matrix of an undirected graph. A dataset of 200 complex architectural plans and structural plans is collected, and digital image processing methods are used to recognize the structural plans and convert them into corresponding digital representations. Then, a generative adversarial network architecture is used to generate the adjacency matrix, with a multi-layer perceptron as the generator and a graph neural network as the discriminator to determine the authenticity of the generated adjacency matrix. Numerical experiments show that this intelligent design method for structural topology can automatically generate reasonable topologies for complex architectural plans and provide good preliminary design solutions for structures.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Allied Denoising Convolutional Neural Network for State-of-Health Estimation for Lithium-Ion Batteries

Author(s): Sun Geu Chae^{*1}, Suk Joo Bae²

¹ *Department of Industrial Engineering, Hanyang University, Seoul, South Korea, sgchae@psm.hanyang.ac.kr*

² *Department of Industrial Engineering, Hanyang University, Seoul, South Korea, sjbae@hanyang.ac.kr*

Keyword(s): Health Monitoring, Deep Learning, Capacity Estimation, Automated Feature Learning

Abstract

In real-world applications, ambient noise collected from sensors and varying stress level applied on lithium-ion batteries are present. To overcome this difficulty, an allied DnCNN-CNN (Denoising convolutional neural network-convolutional neural network) model is proposed in this paper as a new framework for predicting nonlinear state-of-health degradation of lithium-ion batteries (Li-Ion) under various conditions. In the presence of unknown background noise levels, a denoising CNN is used to improve prediction accuracy. Denoising CNN is learned on noisy data and then used in a residual learning technique to eliminate noise. To verify denoising and state-of-health prediction performance, multiphysics features degradation test data is used to compare vanilla convolutional neural network model, denoising autoencoder model, denoising variational autoencoder, and proposed allied DnCNN-CNN model. The verification and comparison results demonstrate that the proposed allied DnCNN-CNN model in various environments can produce a higher accuracy and robustness than other data-driven methods in estimating the state-of-health of the Li-ion batteries.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Emulsion dynamics in an idealized porous matrix

Author(s): Stefano Miliani^{*1}, Andrea Montessori¹, Michele La Rocca¹, Pietro Prestininzi¹.

¹ *Department of Civil, Computer Science and Aeronautical Technologies Engineering, Roma Tre University, Rome, Italy, [stefano.miliani, andrea.montessori, michele.larocca, pietro.prestininzi]@uniroma3.it*

Keyword(s): Lattice Boltzmann Method, Multiphase flow, Flows in Porous Media, Trapping

Abstract

Recently, important processes in chemical and hydraulic engineering like Enhanced Oil Recovery (EOR) and Soil Remediation (SR) have been object of numerous studies: in particular, it has been demonstrated that the emulsification of the dispersed oil phase inside the soil, using chemicals like surfactants drastically, drastically increase their efficiency [1]. Nonetheless a comprehensive understanding of how such increase is achieved is still missing; the physical modelling of this kind of phenomena may suffers of low repeatability and high costs, thus the adoption of numerical approaches. Among the many numerical methods, the Lattice Boltzmann Method (LBM), which is a mesoscopic approach that can be seen as a discretization of Boltzmann Equation [2], has been widely adopted to study multiphase flows [3-4].

In this study, the multiphase LBM model, proposed by Montessori et al. [3], able to mimic the Short-Range repulsive Forces (SRFs) which may be generated by the presence of surfactants, has been adopted to analyse the dynamics of emulsion flows inside an idealized porous media.

Firstly, the adopted model was validated against experimental data from literature [5]: the experiment consisted in the study of the displacement of droplets, generated by means of a T-junction, inside a porous chamber. The aim of the validation was the reproduction of the different geometrical patterns generated by the variation of two different parameters: the Capillary number and the droplets generation frequency. The comparison between the experimental data and the numerical results confirmed that the presented LBM model is able to correctly reproduce complex droplets behaviour inside a confined geometry. The model was then used to investigate the dynamics of the dispersed oil phase in porous matrix by referring to the variation of the aforementioned Capillary number and the wettability of the solid walls; in particular, the analysis focused on the influence of such parameters on the trapping phenomenon. The study of the dispersed oil mass distribution in velocity illustrated the influence of the Capillary number on the re-mobilization of adhered and trapped oil mass.

Hence, this study demonstrates that proposed LBM model, able to consider SRFs through a minimal approach, allows to give a useful insight into the trapping process and to explore parametric spaces relevant to technical scenarios like EOR and SR.

References

- [1] Perrazzo, A., Tomaiuolo, G., Preziosi, V., Guido, S., "Emulsions in porous media: From single droplet behavior to applications for oil recovery", *Advances in Colloid and Interface Science*, 256, page 305-325, (2018).
- [2] Succi, S., *The Lattice Boltzmann Equation: For Fluid Dynamics and Beyond*, Clarendon Press, Oxford, 2001.
- [3] Montessori, A., Lauricella, M., Tirelli, N., Succi, S., "Mesoscale modelling of near-contact interactions for complex flowing interfaces", *Journal of Fluid Mechanics*, 872, page 327-347, (2019).
- [4] Wei, B., Hou, J., Sukop, M.C., Du, Q., Wang, H. "Flow behaviors of emulsions in constricted capillaries: A lattice Boltzmann simulation study", *Chemical Engineering Science*, 227, page 115925, (2020).
- [5] Jose, B.M., Cubaud, T., "Droplet arrangement and coalescence in diverging/converging microchannels", *Microfluid Nanofluid*, 12, page 687-696, (2012).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Wave propagation modeling in periodic magneto-electro-elastic materials via multi-field continualization

Author(s): Rosaria Del Toro^{*1}, Maria Laura De Bellis¹, Andrea Bacigalupo²

¹ *INGEO, University of Chieti-Pescara, Pescara, Italy*

² *DICCA, University of Genova, Genova, Italy*

e:mail: rosaria.deltoro@unich.it, marialaura.debellis@unich.it, andrea.bacigalupo@unige.it

Keyword(s): magneto-electro-elastic materials, Bloch wave propagation, non-local continua

Abstract

A dynamic multi-field continualization model for magneto-electro-elastic materials characterized by a periodic microstructure is analysed [1]. The governing equations that describe a three dimensional heterogeneous magneto-electro-elastic material are pointed out and, consequently, they are specialized to the peculiar case of a magneto-electro-elastic layered material. By adopting the transfer matrix method and the Floquet-Bloch boundary conditions, the frequency dispersion spectrum is retrieved by solving an eigenproblem, involving a 12x12 transfer matrix endowed with palindromic characteristic polynomial. In particular, by supposing the cubic symmetry of layers, the problems involving longitudinal and transverse elastic waves are uncoupled. Such a case may simplify the treatment and the size of the subproblems to be solved, corresponding to a 4x4 transfer matrix for the longitudinal case, and a 8x8 transfer matrix for the transverse problem, both characterized by palindromic characteristic polynomials [2]. Then, after modeling the magneto-electro-elastic layered material as a set of equally spaced interfaces, a continualization approach is adopted to tackle with the wave propagation in the layered periodic material by matching the Z-transform of the vector collecting the nodal fields to the two-sided Laplace transform of the same vector at the macroscale. Consequently, multi-field integral-type non-local continua as well as multi-field generalized gradient-type (higher-order) non-local continua are identified [3]. Finally, the dispersion curves obtained from the continualization technique and those provided by the Floquet-Bloch theory are compared to test the proposed approach.

References

- [1] Del Toro R., De Bellis M.L., Bacigalupo A., "High frequency multi-field continualization scheme for layered magneto-electro-elastic materials," submitted (2023).
- [2] Del Toro R., Bacigalupo A., Lepidi M., Mazzino A., "Dispersive waves in magneto-electro-elastic periodic waveguides," *International Journal of Mechanical Sciences*, 236, 107759, (2022).
- [3] Bacigalupo A., Gambarotta L., "Identification of non-local continua for lattice-like materials," *International Journal of Engineering Science*, 159, 103430, (2021)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A Dimension Reduction Approach based on the Wiener Path Integral For Determining The Stochastic Response Of Nonlinear Systems With Fractional Derivative Elements

Author(s): Ilias G. Mavromatis^{*1}, Ioannis A. Kougoumtzoglou²

¹ Department of Civil Engineering & Engineering Mechanics, Columbia University, USA, im2580@columbia.edu

² Department of Civil Engineering & Engineering Mechanics, Columbia University, USA, iak2115@columbia.edu

Keyword(s): Stochastic dynamics; nonlinear system, fractional derivative, Wiener path integral, dimension reduction

Abstract

A technique based on the Wiener path integral (WPI) is developed for determining the stochastic response of diverse nonlinear systems with fractional derivative elements. Specifically, a reduced-order WPI formulation is proposed, which can be construed as an approximation-free dimension reduction approach that renders the associated computational cost independent of the total number of stochastic dimensions of the problem. In fact, the herein developed technique can determine directly any lower-dimensional joint response probability density function corresponding to a subset only of the response vector components. This is done by utilizing an appropriate combination of fixed and free boundary conditions in the related variational, functional minimization, problem. Notably, the reduced-order WPI formulation is particularly advantageous for problems where the interest lies in few only degrees of freedom whose stochastic response is critical for the design and optimization of the overall system. The technique can be construed as an extension of the formulation in [1] to account for fractional derivative elements in the system equation of motion. Alternatively, it can be viewed as a generalization of the formulation in [2] to yield enhanced computational efficiency. An indicative numerical example is considered pertaining to a stochastically excited tuned mass-damper-inerter nonlinear system with a fractional derivative element. Comparisons with relevant Monte Carlo simulation data demonstrate the accuracy and computational efficiency of the technique.

References

- [1] Petromichelakis I., Kougoumtzoglou I. A. (2020) Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries. *Proc. of the Royal Society A: Mathematical, Physical and Engineering Sciences* **476**:2243.
- [2] Di Matteo A., Kougoumtzoglou I. A., Pirrotta A., Spanos P. D., Di Paola M. (2014) Stochastic response determination of nonlinear oscillators with fractional derivatives elements via the Wiener path integral. *Probabilistic Engineering Mechanics*, Vol. 38: 127-135.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A low energy and slow timescale control device for the re-tuning of a suboptimal tuned mass damper

Author(s): Anass Mayou^{*1}, Vincent Denoël²

¹ *Structural & Stochastic Dynamics (SSD), University of Liège, Liège, Belgium, anass.mayou@uliege.be*

² *Structural & Stochastic Dynamics (SSD), University of Liège, Liège, Belgium, v.denoel@uliege.be*

Keyword(s): TMD, Retuning, Robustness, Perturbation techniques, Multiple timescale

Abstract

Tuned mass dampers (TMDs) have been widely studied and used for mitigating the structural vibrations induced by environmental loads such as wind, earthquakes, and traffic. However, frequency mistuning of the TMD, which can occur due to uncertainties in the structural parameters or environmental loads, can significantly reduce the efficiency of the system. The *retuner*, a new concept in the field of structural dynamics, is an additional mass-spring system that can be incorporated into the TMD system to enhance its robustness against mistuning.

The retuner consists of a smaller mass-spring system that is connected in series with the primary structure and the TMD. By selecting appropriate parameters for the retuner system, it is possible to restore the original damping of the TMD system even in the presence of mistuning. The design of the retuner system is simple, and the parameters can be chosen based on a simple formula, making it easy to implement and widely applicable.

The application of the retuner system has several advantages. Firstly, it can be used to treat mistuning in existing structures without modifying the TMD system's mass or spring properties. Secondly, it can be used to create a semi-passive control system in newly constructed structures, which is energy-efficient and requires slow timescale retuning. The semi-passive control system operates most of the time in a passive mode, which reduces the energy consumption required for the control.

The results have shown that the retuner system can effectively improve the robustness of the TMD system against mistuning and reduce the structural vibrations induced by environmental loads.

Overall, the retuner system is a promising approach to enhance the robustness of TMDs against mistuning, offering an efficient and low-cost solution for structural vibration control.

References

[1] Mayou, Anass, and Vincent Denoël. "Asymptotic analysis of multiple mode structures equipped with multiple tuned mass dampers." *Journal of Sound and Vibration* 535 (2022): 117104.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Sensitivity of a granular homogeneous and isotropic second-gradient continuum model with respect to uncertainties

Authors: Gabriele La Valle^{*1}, Bilen Emek Abali², Giovanni Falsone³, Christian Soize⁴

¹ *Department of Engineering, University of Messina, Messina, Italy, gablavalle@unime.it*

² *Division of Applied Mechanics, Uppsala University, Uppsala, Sweden, bilenemek@abali.org*

³ *Department of Engineering, University of Messina, Messina, Italy, gfalsone@unime.it*

⁴ *MSME UMR 8208, Université Gustave Eiffel, Marne-la-Vallée, France, christian.soize@univ-eiffel.fr*

Keywords: Granular micromechanics; Higher-order theories; Probabilistic model; MaxEnt approach

Abstract

This work concerns the probabilistic analysis of granular materials. More precisely, this work is devoted to the stochastic modeling of the granular geometric and constitutive microscale parameters associated with grain-pair interactions of an existing granular second gradient model [1]. Such an issue is addressed with a probabilistic methodology that relies on the Maximum Entropy (MaxEnt) principle from Information Theory [2]. After defining and improving the chosen granular second gradient continuum model, it is shown that the involved microscale parameters are statistically independent in micro-homogeneous and micro-isotropic materials. More precisely, the grain-pair distance between two consecutive grains is a uniformly distributed random variable and the specific microscale stiffness parameters are Gamma-distributed random variables. For illustration purposes, a micro-homogeneous, micro-isotropic, macro-homogeneous, and macro-isotropic 2D concrete plate subjected to an axial load is considered. A stochastic solver based on Monte Carlo (MC) numerical simulations is chosen whose convergence is studied. Finally, uncertainties propagation is discussed, and statistical fluctuations of the macro mechanical response are found to be nonnegligible.

References

- [1] Placidi L., Berchiesi E., Misra A., et al., “Micromechanics-based elasto-plastic damage energy formulation for strain gradient solids with granular microstructure”, *Continuum Mechanics and Thermodynamics*, 33, 2213-2241, (2021).
- [2] Soize C., *Uncertainty Quantification*, Springer, Cham (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Mechanical behaviour of polymeric cords used in tyres

Authors: Lucas Pires da Costa^{*1}, Marco Moscatelli¹, Paola Caracino², Claudia Comi¹, Giorgio Novati¹

¹ *Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy,
lucas.piresdacosta@polimi.it*

² *R&D Reinforcement Materials, Pirelli Tyre SpA, Milan, Italy*

Keywords: rayon, reinforcement, tyre, constitutive model, geometrical model, finite elements

Abstract

This work focuses on the mechanical behaviour of rayon yarns and cords, which are used as reinforcement, with various levels of twist, in rubber-based composites such as vehicle tyres. To set up a model able to represent the reinforcement's macroscopic behaviour, an equivalent three-dimensional continuum of cylindrical shape is used with preferential material directions described by geometrical models available in the literature, see e.g., Treloar [1]. The analysis approach proposed in the present contribution makes use of an idealised fibre orientation angle distribution (see e.g., Sibellas et al. [2]), relevant to a generic cross-section, computed as an average along the pitch of the twisted geometry. Locally an elasto-viscoplastic constitutive model is adopted which takes into account the aforementioned fibre orientation angle. A finite element model for such an equivalent continuum is set up. The model is calibrated on the experimental results of untwisted yarn and yarn with a given twist. The validation is done by simulating a series of tests under monotonic and non-monotonic imposed strain histories for yarns with other twist levels and multi-ply cords [3].

The current formulation has been established in the small strain context, but a description of the evolution of the fibre geometry for increasing strain is an essential ingredient for a more realistic representation of the reinforcement behaviour. A finite element procedure that incorporates this aspect is the object of ongoing research.

References

- [1] Treloar L.R.G., "The geometry of multi-ply yarns", *Journal of the Textile Institute Transactions*, Vol 47, page 348-368, (1956).
- [2] Sibellas A., Adrien J., Durville D., Maire E., "Experimental study of the fiber orientations in single and multi-ply continuous filament yarns", *Journal of the Textile Institute*, Vol 111, page 646-659, (2020).
- [3] Caracino P., Agresti S., da Costa L.P., Novati G., Comi C., "The nonlinear behaviour of cords to be used in rayon-rubber composites", in *Proceedings of the European Conference on Constitutive Models for Rubbers*, Milan, Italy, page 472-476, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Diffusion of the aging fluid in a bidimensional homogeneous body

Author(s): Angelo Scrofani^{*1}, Emilio Barchiesi², Bernardino Chiaia³, Anil Misra⁴, Luca Placidi⁵

¹ Dipartimento di Ingegneria e Scienze dell'Informazione e Matematica, Università degli Studi dell'Aquila, L'Aquila, Italy, angelo.scrofani@graduate.univaq.it

² Dipartimento di Architettura, Design e Urbanistica, Università degli Studi di Sassari, Alghero, Italy, ebarchiesi@uniss.it

³ Dipartimenti di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino, Italy, bernardino.chiaia@polito.it

⁴ Civil, Environmental & Architectural Engineering, University of Kansas, Lawrence (KS), USA, amisra@ku.edu

⁵ Engineering Faculty, Università Telematica Internazionale UNINETTUNO, Roma, Italy, luca.placidi@uninettunouniversity.net

Keyword(s): hemivariational method, diffusion, damage, aging

Abstract

Aging related damage for a bidimensional homogeneous body is presented. The aging phenomena are often associated with the diffusion of certain particles which then activate internal chemical action. In this paper, a hemi variational method for a homogeneous and damaged 2-D model [1] is proposed in order to describe damage and deformation in a dam caused by the diffusion of an aging fluid. The proposed model is used to perform a suite of parametric studies. In these studies, the body is subjected not only to the distributed external loads (the dual of displacement) but also to the dual of the concentration of the aging fluid, called external distributed aging fluid influx pressure. The parametric analyses are carried out in terms of diffusivity and damage-concentration coupling. The influx pressure drives the incoming flow of the aging fluid which is coupled with the damage evolution. The results are utilized to predict the evolution of the damage in the dam. The life [2] of the big structures is a crucial point in civil engineering because it is linked with the safeguarding of human life.

References

- [1] Placidi L., Misra A., Barchiesi E. "Two-dimensional strain gradient damage modelling: a variational approach" in Zeitschrift für Angewandte Mathematik und Physik, (Apr. 2018).
- [2] Alexander M., Beushausen H. "Durability, service life prediction, and modelling for reinforced concrete structures-review and critique" in Cement and Concrete Research, page 17-29, (Aug. 2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Approximate Bayesian Computation and surrogate modelling for structural identification of simple structural systems

Authors: Chiara Pepi^{*1}, Silvia Monchetti², Cecilia Viscardi³, Massimiliano Giofrè¹, Gianni Bartoli², Roberta Scungio¹

¹ *Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, chiara.pepi@unipg.it, massimiliano.gioffre@unipg.it, roberta.scungio@studenti.unipg.it*

² *Department of Civil and Environmental Engineering, University of Florence, Italy, silvia.monchetti@unifi.it, gianni.bartoli@unifi.it*

³ *Department of Statistics, Computer Science, Applications, University of Florence, Italy, cecilia.viscardi@unifi.it*

Keyword(s): uncertainty quantification, Approximate Bayesian Computation, surrogate modelling

Abstract

Masonry arches and vaults are typical historic structural components often subjected to asymmetric loading due to seismic action and/or abutments settlements. For this reason, in the last decades, several studies have been carried out to improve the knowledge of masonry arches and vaults structural performance towards seismic loads for their preventive conservation. The structural performance of existing constructions is usually estimated by means of accurate numerical models driven by a set of unknown numerical model input parameters (i.e. geometry, mechanical characteristics, physical characteristics, boundary conditions) that can be estimated by means of deterministic optimization functions aimed at minimizing the distance between the output of a numerical model and the measured dynamic and/or static structural response. In the deterministic setting the uncertainties related to both numerical model input parameters and measurements are completely neglected. In this sense, the Bayesian approach can be used to estimate the unknown numerical model parameters and their associated uncertainties (posterior distributions) updating the model parameters prior knowledge (prior distributions) using current measurements and accounting explicitly for all the source of uncertainties that affect observed quantities (via likelihood functions). Two main drawbacks can be recognized: first, the likelihood function is unknown or too complex to evaluate; second, the computational costs required for the approximation of the posterior distribution can make the problem solution unfeasible. In this work, the numerical models of simple structural system (beams and/or arches) are set up and the unknown input parameters (i.e. mechanical properties and boundary conditions) are inferred by means of Bayesian updating taking as reference the observed structural response (i.e. modal data, strains, displacements) [1-3]. The drawback of intractable likelihood function is faced adopting Approximate Bayesian Computation (ABC); the drawback of high computational costs is overpassed by means of accurate surrogate models (i.e. Polynomial Chaos Expansions, Artificial Neural Network)

References

- [1] Pepi, C., Giofrè, M., Grigoriu, M. D. "Parameters identification of cable stayed footbridges using Bayesian inference." *Meccanica*, 54, 1403-1419, (2019).
- [2] Pepi, C., Giofrè, M., Grigoriu, M. "Bayesian inference for parameters estimation using experimental data." *Probabilistic Engineering Mechanics*, 60, 103025, (2020).
- [3] Monchetti, S., Viscardi, C., Betti, M., Bartoli, G. "Bayesian-based model updating using natural frequency data for historic masonry towers." *Probabilistic Engineering Mechanics*, 70, 103337, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A probabilistic approach for regional post-earthquake damage assessment in bridges using Bayesian networks

Author(s): Pooria Mesbahi^{*1}, Enrique García-Macías², Marco Breccolotti³, Filippo Ubertini⁴

¹ *Department of Civil and Environmental Engineering, University of Perugia, Ph.D. Student, Perugia, Italy, pooria.mesbahi@studenti.unipg.it*

² *Department of Structural Mechanics and Hydraulic Engineering, University of Granada, Assistance Professor, Granada, Spain, enriquegm@ugr.es*

³ *Department of Civil and Environmental Engineering, University of Perugia, Associate Professor, Perugia, Italy, marco.breccolotti@unipg.it*

⁴ *Department of Civil and Environmental Engineering, University of Perugia, Full Professor, Perugia, Italy, filippo.ubertini@unipg.it*

Keyword(s): Bayesian networks; Vulnerability analysis; Fragility curve; Bridge Networks; Structural health monitoring (SHM); Bayesian model updating; Machine learning

Abstract

The ageing degradation of European bridges poses a pressing challenge, and the risks of cascade failures are fostering growing investments across EU countries on rehabilitation and maintenance operations. In this context, since replacing all the obsolete and deficient bridges is financially infeasible, the development of efficient techniques to prioritize interventions becomes a necessity. In this light, condition-based maintenance schemes through Structural Health Monitoring (SHM) systems are particularly well-suited to enable data-informed decision-making. The high costs of installation and maintenance of monitoring equipment, however, represent a major limitation for the scalability of SHM to regional contexts. Nonetheless, given the circumstance that bridges within a region are usually similar in terms of typology and materials, there is a reasonable prospect that evaluating only a limited number of structures it is possible to infer the condition of the regional network, leading to significant economic savings. This idea of transfer learning from the realm of Artificial Intelligence (AI) may be particularly powerful for earthquake risk assessments, with seismic shocks acting as a common degradation agent in the whole network. In these cases, it is essential to develop near-real-time damage assessment techniques capable of estimating uncertainty factors in both seismic demand and structural capacity to enable decision-making and to prioritize recovery and emergency services. According to these assumptions, in this paper a probabilistic damage assessment framework is presented based on a Bayesian network to estimate the post-earthquake condition of bridge networks. On one hand, the proposed framework has the capability to estimate the seismic demands of bridges in the network by propagating the seismic records acquired by a strong motion system. To do so, the monitoring records are used to update a seismic attenuation model in probabilistic terms, thus allowing to propagate this evidence from the epicenter and to extract more accurate estimates of the local demands at unmonitored locations. Afterwards, the proposed approach incorporates a demand-capacity model to calculate the probability of failure of all the assets in the network. To this aim, an incremental dynamic analysis (IDA) is used to obtain the structural capacity, and the resulting fragility curves are utilized for vulnerability analysis of all the bridges in the network. To evaluate the effectiveness of the proposed method, a numerical investigation of the bridges network in the Italian region of Perugia is presented as a validation case study.

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Palermo, Italy, August 27 - 30, 2023

Title: Global sensitivity analysis of metabarriers for seismic surface wave attenuation using surrogate modeling

Author(s): Farhad Zeighami^{*1}, Leonardo Sandoval², Alberto Guadagnini², Vittorio Di Federico¹.

¹ Department of Civil, Chemical, Environmental, and Materials Engineering (DICAM), University of Bologna, Bologna, Italy, farhad.zeighami3@unibo.it, vittorio.difederico@unibo.it

² Dipartimento di Ingegneria Civile e Ambientale, Politecnico di Milano, Milan, Italy, rafaelleonardo.sandoval@polimi.it, alberto.guadagnini@polimi.it.

Keyword(s): Global sensitivity analysis, Surrogate modeling, Metabarriers, Seismic surface waves, Ground vibration attenuation.

Abstract

We investigate the impact of the uncertainty associated with three key mechanical parameters (i.e., soil density, soil shear modulus, and mass of mechanical resonators) on the seismic isolation performance of a metabarrier. The latter constitutes a novel class of elastic metamaterials engineered to attenuate ground-induced vibrations and shield vulnerable structures or infrastructures against seismic surface waves [1]. It relies on a cluster of locally resonant pillars or mechanical resonators installed on the soil surface. Seismic metabarriers are passive isolation devices tailored to operate at specific frequency ranges. Once the motion of incoming surface waves activates the resonators, they can deflect and convert the traveling surface waves into bulk shear waves [2]. Achieving the proper design and implementation of seismic metabarriers requires a comprehensive knowledge of the role played by the model parameters governing soil-barrier dynamic interaction. In this context, global sensitivity analysis (GSA) techniques can be employed to quantify the influence that parameters of seismic metabarriers and their associated uncertainty have on their response [3].

We rely on a two-dimensional numerical model which is developed according to the wave finite element approach [4], and evaluate the dispersion relation and transmission coefficient of a metabarrier interacting with seismic surface waves in the low-frequency regime. Given the heavy computational burden of the numerical model, we rest on a surrogate modeling technique. Our results suggest that the soil shear modulus is the parameter with the most significant influence on the transmission coefficient of the metabarrier across the entire frequency range of interest. We then find that the resonator mass plays a substantial role in the frequency limit close to the operating frequency of the metabarrier [5]. This study provides new insights into the rational design of seismic metabarriers, which can impact several civil engineering areas, including geotechnical engineering, road and railway traffic, and earthquake engineering.

References

- [1] Palermo A., Krödel S., Marzani A., Daraio C., "Engineered metabarrier as shield from seismic surface waves," *Scientific Reports*, 6, 39356, 2016.
- [2] Colquitt D., Colombi A., Craster R., Roux P., Guenneau S., "Seismic metasurfaces: Sub-wavelength resonators and Rayleigh wave interaction," *Journal of the Mechanics and Physics of Solids*, 99, 379–393, 2017.
- [3] Dell'Oca A., Riva M., Guadagnini A., "Global sensitivity analysis for multiple interpretive models with uncertain parameters," *Water Resource Research*, 56(2), 1–20, 2020.
- [4] Palermo A., Vitali M., Marzani A., "Metabarriers with multi-mass locally resonating units for broad band Rayleigh waves attenuation," *Soil Dynamics and Earthquake Engineering*, 113, 265–277, 2018.
- [5] Zeighami F., Sandoval L., Guadagnini A., Di Federico, V., "Uncertainty quantification and global sensitivity analysis of seismic metabarriers," *Engineering Structures*, 277, 115415, 2023.

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EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Bayesian updating of a multi-storey timber building

Authors: Blaž Kurent^{*1}, Noemi Friedman², Boštjan Brank³

¹ Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia, bkurent@fgg.uni-lj.si

² Informatics Laboratory, Institute for Computer Science and Control (SZTAKI), Budapest, Hungary, n.friedman@ilab.sztaki.hu

³ Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia, bbrank@fgg.uni-lj.si

Keywords: Bayesian model updating, timber building, uncertainty quantification, mode pairing, surrogate model

Abstract

Wind-induced vibrations are often a governing design criterion for tall timber buildings [1], which demand an accurate model for predicting the dynamic behaviour of the building. Even a detailed finite element (FE) model developed according to the best engineering judgement may still not satisfy the desired accuracy for predicting dynamic properties, mainly due to uncertainty of material properties and the effects of different building elements [2]. Model updating does not only offer an improved model but may also provide knowledge about uncertain modelling parameters and assumptions.

We will present updating of an FE model of a multi-storey timber building that is based on the experimental modal data. The probabilistic framework that is presented in [3] is adopted for the updating. First, a generalized Polynomial Chaos Expansion [4] is used to create a surrogate model that maps model parameters to the eigenfrequencies and eigenvectors. To overcome the problem of mode switching, a clustering algorithm is used to correctly order the modes. The surrogate model is used to efficiently run uncertainty quantification and sensitivity analysis [5], which are the basis for the selection of parameters for model updating. Finally, the surrogate-based Bayesian model updating using modal data obtained from the in-situ experimental test of the observed building is carried out to reduce the uncertainty of modelling parameters. A Markov chain Monte Carlo [6] method is used to sample from the posterior parameter distribution. The likelihood is derived by stochastic analysis of the experimental results, estimating their uncertainty.

References

- [1] M. Johansson, A. Linderholt, Å. Bolmsvik, K. Jarnerö, J. Olsson and T. Reynolds, "Building higher with light-weight timber structures - The effect of wind induced vibrations," INTER-NOISE 2015 - 44th International Congress and Exposition on Noise Control Engineering, 2015.
- [2] B. Kurent, B. Brank and W. K. Ao, "Model updating of seven-storey cross-laminated timber building designed on frequency-response-functions-based modal testing," Structure and Infrastructure Engineering, 2021.
- [3] B. Kurent, N. Friedman, W. K. Ao and B. Brank, "Bayesian updating of tall timber building model using modal data," Engineering Structures, 266, 114570, 2022.
- [4] D. Xiu, G. E. Karniadakis, "The Wiener-Askey polynomial chaos for stochastic differential equations," SIAM J Sci Comput. 24(2), 619–44, 2002.
- [5] B. Sudret, "Global sensitivity analysis using polynomial chaos expansions," Reliab Eng Syst Saf, 93(7), 964–79, 2008.
- [6] W. K. Hastings, "Monte Carlo sampling methods using Markov chains and their applications," Biometrika, 57(1), 97–109, 1970.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Parametric Algorithm-Aided design of optimal long-span hollow-section steel beams

Author(s): Alessandra Fiore^{1*}, Iris Tarallo¹, Giuseppe Carlo Marano²

¹ ARCOD, Politecnico di Bari, Via Orabona 4, 70125 Bari, Italy, alessandra.fiore@poliba.it

² DISEG, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy, giuseppe.marano@polito.it

Keyword(s): parametric design, structural optimization, size optimization, shape optimization, genetic algorithms, Grasshopper, truss beam, arch beam, network arch, weight minimization

Abstract

This study deals with the parametric Algorithm-Aided design and the optimization of pedestrian steel structures that are particularly significant in the field of civil engineering. Structural optimization is performed by genetic algorithms (GA). In particular, Grasshopper parametric analysis solver is used, by implementing the Galapagos algorithm [1]. The optimization is carried out in terms of both weight and shape [2].

Three models of simply-supported beams, with a span equal to 20 metres, are considered: a truss girder, an arch with orthogonal ropes and a network arch. In the first structure, the design variables are represented by the cross-section and the geometric arrangement of the elements constituting the beam. In the case of the arch and network beams, the design variables are the width of the arch curvature, the cross-section of the different components and the arrangement of internal ropes.

In all optimization procedures the weight of the structure is assumed as the objective function and the attention is focused on hollow circular sections.

The performed analyses show that the network arch represents the optimal model. In fact, it is characterized by normal and bending stresses lower than the other typologies and by the lowest weight and then cost. There is an inverse relationship between the angle of curvature of the top chord and the number of ropes. The cross section of the top chord is bigger than the one of the bottom chord, as well as diagonals are characterized by smaller cross sections, coherently with previous literature studies [2].

References

- [1] Sardone L., Greco R., Fiore A., Moccia C., De Tommasi D., Lagaros N.D., "A preliminary study on a variable section beam through Algorithm-Aided Design: a way to connect architectural shape and structural optimization", *Procedia Manufacturing*, Vol. 44, pp. 497-504, 2020
- [2] Fiore A., Marano G.C., Greco R., Mastromarino E., "Structural optimization of hollow-section steel trusses by differential evolution algorithm", *International Journal of Steel Structures*, Vol. 16(2), pp 411–423, 2016.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Signal processing techniques for bridge damage identification using vehicle monitoring

Author(s): Giulia Sansone^{*1}, Jean-Luc Dion², Stefania Lo Feudo³, Paolo Lonetti⁴, Arturo Pascuzzo⁵.

¹ Department of Civil Engineering, University of Calabria, Rende, Cosenza, Italy, giulia.sansone@unical.it

² QUARTZ (EA7393), VAST-FM, ISAE SUPMECA, Saint-Ouen, France, jean-luc.dion@isae-supmeca.fr

³ QUARTZ (EA7393), VAST-FM, ISAE SUPMECA, Saint-Ouen, France, stefania.lo-feudo@isae-supmeca.fr

⁴ Department of Civil Engineering, University of Calabria, Rende, Cosenza, Italy, paolo.lonetti@unical.it

⁵ Department of Civil Engineering, University of Calabria, Rende, Cosenza, Italy, arturo.pascuzzo@unical.it

Keyword(s): Drive-by inspection, bridge damage detection, vehicle-bridge interaction, moving mesh technique, indirect measurements

Abstract

The field of structural health monitoring (SHM) appears to have an increasing interest in recent decades. In particular, bridge health monitoring requires an optimal strategy to reduce the disastrous consequences related to any collapse, as they represent strategic structures for socio-economic development. Therefore, damage identification is a key aspect of the health status analysis of bridge structures.

Among the methods proposed in the literature, indirect methods rely on monitoring and assessing the dynamic response of the moving vehicle crossing the bridge [1]. These methods allow bridge SHM by employing fewer and low cost sensors, such as smartphones.

Therefore, a fundamental aspect to be achieved, is an accurate description of the dynamic interaction phenomena between the structure and the vehicle. For this purpose, an advanced finite element (FE) model is implemented to analyze the structural behavior of the bridge. In addition, the contact forces generated at the contact points between the vehicle and the structure are handled by a VBI finite element model based on the moving mesh methodology. This technique is based on the "Arbitrary Lagrangian-Eulerian" (ALE) [2–4] formulation that uses two coordinate systems that are a Referential system, which identifies the initial position of the mesh nodes of the vehicle inside the trajectory domain, and a Moving coordinate system that describes the positions occupied by the contact points during the vehicle's movement. The ALE formulation allows for reducing the computational effort for two orders of reasons. The first is due to the possibility of having a dense mesh only around the contact points domain and coarse in the rest of the domain. The second concerns reducing the number of remesh events due to the mesh regularization method consistent with a Laplace approach. The work presents a comparison between different damage identification methods based on "drive-by" inspection using acceleration responses of a moving vehicle. In particular, the feasibility of methods such as the Wavelet transform and the Kalman filter is addressed. The purpose is to identify the presence of damage and its location, achieving the second level of identification [5]. The damage identification procedures are validated through comparison with case studies from the literature.

References

- [1] Matarazzo, T.J., et al. "Crowdsourcing bridge dynamic monitoring with smartphone vehicle trips", *Commun Eng* 1, 29 (2022).
- [2] Greco F, Lonetti P., "Numerical formulation based on moving mesh method for vehicle–bridge interaction", *Advances in Engineering Software*, 121, 75-83, (2018).
- [3] Greco F, Lonetti P, Pascuzzo A., "A moving mesh FE methodology for vehicle–bridge interaction modeling", *Mechanics of Advanced Materials and Structures*, 27, 1256-68, (2020).

- [4] Donéa J, Huerta A., "Finite element methods for flow problems", Wiley, Chichester ; Hoboken, NJ, (2003).
- [5] Worden K., "Structural Health Monitoring using Pattern Recognition", Springer Vienna, Vienna, (2010).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: On-site application of radar interferometry to the estimation of axial force in tie rods for historical masonry constructions

Authors: Domenico Camassa¹, Anna Castellano², Antonio Curri^{*3}, Aguinardo Fraddosio⁴, Mario Daniele Piccioni⁵

¹ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, domenico.camassa@poliba.it

² Department of Mechanics, Mathematics and Management, Polytechnic University of Bari, Bari, Italy, anna.castellano@poliba.it

³ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, antonio.curri@poliba.it

⁴ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, aguinaldo.fraddosio@poliba.it

⁵ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, mariodaniele.piccioni@poliba.it

Keywords: tie rods, axial force estimation, dynamic identification methods, radar interferometry

Abstract

Tie rods are usually applied in historical masonry constructions to improve structural stability and, in particular, to absorb the horizontal thrusts of arches and vaults and to enhance the connection between orthogonal walls. Their performance is strictly related to the value of the axial force, which, however, may vary during time due to several causes, such as differential foundation settlements, damage, material corrosion, steel relaxation, etc. Hence, monitoring axial force in tie rods is of utmost importance to guarantee their functionality. Dynamic methods make it possible to estimate tensile force in tie rods without causing any type of damage to the structure [1-2]. These methods are based on the modal properties of tie rods, which can be estimated experimentally by measuring their structural vibrations. In general, contact sensors are used to measure vibrations. Installation and wiring of contact sensors, however, are time consuming and usually require the employment of cumbersome scaffoldings. In this work, we investigate the on-site application of the radar interferometry technique to the estimation of axial force in tie rods in masonry constructions [3-4]. Radar interferometry is an innovative measurement technique that makes it possible to measure structural vibrations at a great distance with high accuracy, thereby avoiding the main issues related to contact sensors. Despite of the great potentialities of radar interferometry, the on-site application presents some issues. We have found that one of the most critical issues concerns the presence of static clutters, which may generate spurious frequencies and lead to a wrong estimation of the axial force. Here we show that, in order to overcome this issue, the choice of the clutter removal technique is one of the main issues to be addressed.

References

- [1] Camassa D., Castellano A., Fraddosio A., Miglionico G., Piccioni M.D., "Dynamic Identification of Tensile Force in Tie-Rods by Interferometric Radar Measurements", *Applied Sciences (Switzerland)*, 11, 8, (2021)
- [2] Makoond N., Pelà L., Climent M., "Robust estimation of axial loads sustained by tie-rods in historical structures using Artificial Neural Networks", *Structural Health Monitoring*, (2022)
- [3] Pieraccini M., "Monitoring of Civil Infrastructures by Interferometric Radar: A Review", *The Scientific World Journal*, 2013, 786961 (2013)
- [4] Camassa D., Vaiana N., Castellano A., "Modal testing of masonry constructions by ground-based radar interferometry for structural health monitoring: A mini review", *Frontiers in Built Environment*, 8, 1062912 (2023)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Measurements of vibrations induced by vehicles according to ISO 2631-1 and ISO 5349-1

Author(s): Giovanni Artale¹, Valentina Cosentino², Dario Fiandaca³, Francesco Oddo^{*4}, Antonina Pirrotta⁵

¹ Department of engineering, University of Palermo, Palermo, Italy, giovanni.artale@unipa.it

² Department of engineering, University of Palermo, Palermo, Italy, valentina.cosentino@unipa.it

³ Department of engineering, University of Palermo, Palermo, Italy, dario.fiandaca@unipa.it

⁴ Department of engineering, University of Palermo, Palermo, Italy, francesco.oddo@community.unipa.it

⁵ Department of engineering, University of Palermo, Palermo, Italy, antonina.pirrotta@unipa.it

Keyword(s): whole body vibration, hand arm vibration, vibration analysis, measurement uncertainty

Abstract

The evaluation of human body exposure to vibrations represents a topic of growing interest. In fact, the human body can be considered as a lumped parameter structure [1], with its own resonance frequencies, and it is possible to observe the correlation between vibrations and certain pathologies [2]. In this framework, this work presents a study based on the measurement of accelerations induced by driving means of transport, according to the actual standards [3]-[5]. A proper data acquisition system has been built, by using commercial triaxial MEMS accelerometers ADXL335 and two C-DAQs: NI USB-9239 and NI USB 9252. A virtual instrument has been developed to evaluate the exposure level of the driver for each mean of transport [6], and to analyse the factors that can influence the measurement itself (such as driver position) [7] and the uncertainties due to static and dynamic characteristics of employed measurement equipment [8]. The analysis has been supported by several experimental tests, as specified in [9], which have been carried out by employing a driving simulator and two different vehicles crossing various driving paths. The study allowed to compare the C-DAQ-based acquisition system performances with those of more sophisticated hardware, i.e. the NI PXIe-1082, and to evaluate the main sources of uncertainty in measuring the parameters of interest, showing the feasibility of the developed measurement setup.

References

- [1] Arslan, Yunus Ziya, "Experimental assessment of lumped-parameter human body models exposed to whole body vibration", *Journal of Mechanics in Medicine and Biology*, 15, (2015).
- [2] Katu, R G U S Desavale, "Effect Of Vehicle Vibration On Human Body – RIT Experience.", (2003).
- [3] UNI EN ISO 2631-1
- [4] UNI EN ISO 5349-1
- [5] UNI EN ISO 8041-1:2017
- [6] A. Kowalska-Koczwara and K. Stypuła, "Influence of crest factor on evaluation of human perception of traffic vibration," *Journal of Measurements in Engineering*, vol. 6, no. 4, pp. 250–255, (2018).
- [7] F. Orsini, A. Scorza, A. Rossi, F. Botta, S. A. Sciuto and R. di Giminiani, "A preliminary uncertainty analysis of acceleration and displacement measurements on a novel WBV platform for biologic response studies," 2016 IEEE International Symposium on Medical Measurements and Applications (MeMeA), Benevento, Italy, (2016).
- [8] JCGM 100:2008, "Evaluation of measurement data — Guide to the expression of uncertainty in measurement", (2008).
- [9] INAIL, *La valutazione del rischio vibrazioni*, (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Modal identification of concrete bridge decks with dapped-end girders

Author(s): Matteo Mazzeo^{*1}, Dario De Domenico¹, Davide Messina¹, Antonino Recupero¹, Roberta Santoro¹

¹ *Department of Engineering, University of Messina, Messina, Italy, {matteo.mazzeo, dario.dedomenico, davide.messina, antonino.recupero, roberta.santoro}@unime.it*

Keyword(s): Free vibrations, Modal parameters identification, Dapped-end girders, Variational Mode Decomposition

Abstract

One of the most common applications in the field of structural health monitoring is the dynamic identification: the knowledge of modal parameters may be exploited for damage localization as well as to validate or update numerical finite element models of the structure.

The execution of free vibration tests, especially on big structures like bridges, represents an attractive solution for monitoring purposes due to less stringent constraints: a limited number of sensors is required on the structure for a short time span to retrieve essential modal information, thus limiting both the required time and the economic impact of the test.

This contribution presents the results of an extensive dynamic identification campaign based on free vibration tests performed on a series of 50-years-old road overpasses in the Messina province (Italy) with a variable number of dapped-end girders (Gerber scheme). Two different series of free vibration tests are performed on these structures, one before and another one after the application of the maximum serviceability load as per current Italian bridge standards.

The dynamic identification is carried out as formulated in [1] exploiting a tuned version of the Variational Mode Decomposition [2] for both the extraction of modal components and their related modal frequencies, the application of an area-based approach for the damping ratio estimation and the use of a time-domain method based on the phase shift of free vibration response peaks for mode shapes estimation.

The results in terms of frequency and mode shapes are critically compared to those obtained by a numerical finite element model of the analysed structures.

References

- [1] Mazzeo M., De Domenico D., Quaranta G., Santoro R., "Automatic modal identification of bridges based on free vibration response and variational mode decomposition technique", *Engineering Structures*, 280, 115665, (2023).
- [2] Dragomiretskiy K., Zosso D., "Variational mode decomposition", *IEEE Transactions on Signal Processing*, 62(3), 531–44, (2013).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A Comparative Analysis of Nonlinear Hysteretic Models in Oscillating Systems

Author(s): Raffaele Capuano^{*1}, Davide Pellecchia², Tommaso Coppola³, Nicolò Vaiana⁴

¹ Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy, raffaele.capuano@unina.it

² Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy, davide.pellecchia@unina.it

³ Department of Industrial Engineering, University of Naples Federico II, Napoli, Italy, tommasso.coppola@unina.it

⁴ Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy, nicolo.vainana@unina.it

Keyword(s): Hysteresis; Path-dependent work; Vibration control.

Abstract

Starting from the nonlinear equilibrium equation of a general class of Single Degree of Freedom (SDoF) hysteretic mechanical systems including both conservative and non-conservative forces, we first derive the expression of the Modified Work-Energy (MWE) theorem [1]. Then, we use the MWE theorem to evaluate the time evolution of the generalized work and energy components of the system and how the generalized work of the non-conservative forces is related to the generalized internal energy of the system. Furthermore, we provide (closed-form) expression(s) to compute the path-dependent work performed by generalized rate-dependent (rate-independent) hysteretic forces, simulated by using the Seleemah and Constantinou [2] (Vaiana-Rosati [3]) model. For the latter, we also provide a closed-form expression for the variation of internal energy associated with the generalized rate-independent work when a complete cycle of generalized displacement is applied. Finally, we use the previously developed concepts to describe the behavior of different types of systems under loadings of arbitrary nature.

References

- [1] Vaiana, Nicolò, Raffaele Capuano, and Luciano Rosati. "Evaluation of path-dependent work and internal energy change for hysteretic mechanical systems." *Mechanical Systems and Signal Processing* 186 (2023): 109862.
- [2] Seleemah, A. A., and Michalakis C. Constantinou. *Investigation of seismic response of buildings with linear and nonlinear fluid viscous dampers*. Buffalo: National Center for Earthquake Engineering Research, 1997.
- [3] Vaiana, Nicolò, and Luciano Rosati. "Classification and unified phenomenological modeling of complex uniaxial rate-independent hysteretic responses." *Mechanical Systems and Signal Processing* 182 (2023): 109539.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Detection of Water Content Profile of Concrete Using Ground Penetrating Radar of the Abstract

Author(s): Zihan Xia^{*1}, Liyu Xie¹, Zheng Lu¹, XiaoLi Fu², Chao Shen²

¹ Department of Disaster Mitigation for Structures, Tongji University, Shanghai, China

² Department of Hydraulic Engineering, Tongji University, Shanghai, China

^{*} Author Email: Zihan Xia: xzhooo@tongji.edu.cn; Liyu Xie: liyuxie@tongji.edu.cn;

Zheng Lu: luzheng111@tongji.edu.cn; XiaoLi Fu: xlfu@tongji.edu.cn; Chao Shen: shenc@tongji.edu.cn

Keyword(s): Water content, GPR, Non-contact monitoring, Full waveform inversion

Abstract

Water content is a crucial parameter that has a significant impact on the durability and integrity of concrete structures. Ground penetrating radar (GPR) has been extensively employed as a non-destructive evaluation technique for concrete. This paper aims to explore the potential of GPR in detecting the distribution of water content in concrete. By utilizing the approximate linear relationship between the dielectric constant and the water content of concrete, this study investigates the feasibility of using GPR for detecting the water content distribution of concrete through GPR simulation monitoring of a concrete with different water content layers. The water content distribution of the concrete profile is obtained by inversion of the obtained radar echo data using full waveform inversion. The simulation results reveal that GPR can effectively detect changes in the water content distribution of concrete, providing valuable information on the moisture status of the material.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A microtransit pilot study in Palermo, Italy

Authors: Martina Citrano*¹, Marco Migliore²

¹ Department of Engineering, University of Palermo, Viale delle Scienze, Building 8, Palermo 90128, Italy, martina.citrano@unipa.it

² Department of Engineering, University of Palermo, Viale delle Scienze, Building 8, Palermo 90128, Italy, marco.migliore@unipa.it

Keyword(s): Microtransit, Public Transportation, Suburbs.

Abstract

A widespread problem with suburban transport is the lack of mobility options to access basic services and amenities located in other parts of the city. Indeed, suburban areas are often provided with poor-quality public transport services [1]. Introducing microtransit services is a promising way to improve public transport in suburban areas, ensuring greater social inclusion for the most disadvantaged population groups (low-income people, ethnic minorities, elderly people, people with disabilities, young students, etc.) [2]. Microtransit can expand access to high-frequency public transport services, connecting isolated suburban areas with the main public transportation hubs. Moreover, microtransit services could potentially reduce pollutant emissions and road congestion, limit the use of private cars, and bring great benefits to both populations and public institutions through its economic advantages [3]. The paper aims to present a microtransit pilot implemented in a suburban area in the northern part of Palermo, Italy. The study area covers about 10.5 km². Two fixed routes named A and B, and 8 detours have been designed to satisfy the travel demand in the study area, mainly considering non-commuting trips. These fixed routes were designed to be a connection to Tommaso Natale railway station, expanding at the same time the travel options to reach the points of interest in the study area. Some pick-up and drop-off (PUDO) stops have been located along the microtransit routes. The pilot study was conducted between November and December 2022, using a fleet composed of four cars. The microtransit routes were tested, using the MVMANT app developed by the start-up Edisonweb S.R.L. Involving some students of the University of Palermo in the pilot study, 94 users' requests were made to test the efficiency of the service, analysing the waiting times at pick-up stops and the in-vehicle times experienced by each user. Two smartphone applications were tested: one for the drivers and one for the users. The user application showed users different microtransit options with specific waiting and in-vehicle times to go from a point a to a point b in the study area. The differences between the times estimated by the application and the observed ones were assessed (5 minutes for waiting time considering an average waiting time of 10 minutes and 5 minutes for in-vehicle time considering an average in-vehicle time of 11 minutes).

References

- [1] Velaga N.R., Nelson J.D., Wright S.D., Farrington J.H., "The Potential Role of Flexible Transport Services in Enhancing Rural Public Transport Provision," *Journal of Public Transportation*, 15, 111-131, (2012).
- [2] König A., Grippenkov J., "The actual demand behind demand-responsive transport: Assessing behavioral intention to use DRT systems in two rural areas in Germany," *Case Studies on Transport Policy*, 8, 954–962, (2020)
- [3] Dytckov S., Persson J.A., Lorig F., Davidsson P., "Potential Benefits of Demand Responsive Transport in Rural Areas: A Simulation Study in Lolland, Denmark," *Sustainability*, 14 (6), (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Measuring Walkability and Cyclability in Urban Areas around Railway Stations: A GIS-Based Approach in Palermo, Italy

Author(s): Muhammad Yasir^{*1}, Marco Migliore ²

¹ *Department of Engineering, University of Palermo, Palermo, Italy, muhammad.yasir02@unipa.it*

² *Department of Engineering, University of Palermo, Palermo, Italy, marco.migliore@unipa.it*

Keyword(s): Walkability, Cyclability, GIS, Transit Oriented Development

Abstract

Walking is generally the primary mode to access a railway station [1] and bikes and scooters can extend its catchment area [2]. Poor-quality pedestrian paths and discontinuous and unsafe cycle networks can be real obstacles to accessing the public transport system and the points of interest from the public transport hubs, limiting citizens' use of public transit and multimodal behavior. The Transit-Oriented Development (TOD) urban model underlines the need to pay attention to the design of urban space, making the areas around rail stations walkable and cyclable [3] [4]. However, the research on walkability and cyclability around stations still has some gaps to fill [1]. Improving the walkability and cyclability of the urban areas around the railway stations is therefore crucial for promoting multimodality and the active modes of transport as first- and last-mile solutions, reducing car dependency and greenhouse gas emissions. This research develops a method for assessing the walkability and cyclability of urban areas around railway stations, presenting a case study conducted in Palermo, Italy. The study analyzes the quality of walking/cycling infrastructure around some stations of the Palermo metropolitan railway service, like Notarbartolo and Lolli stations, using different walkability/cyclability measures. Walkable areas typically have high residential density, greater street connectivity, and mixed land uses [2]. Thus, the approach considers these features and micro-scale walkability indicators describing how much pedestrian routes are safe, without obstacles, and pleasant to walk. The pedestrian and cycle networks are created using GIS software, and all the indicators are assessed and mapped considering the walkable area with a radius of 500m around the stations. The method can be used as a decision support tool to assess the potential of the station areas to become TOD neighborhoods and their criticalities; it can help local authorities in drawing policies by identifying which station areas need more attention and, for each station, which features should be improved.

References

- [1] Otsuka N., Wittowsky D., Damerau M., Gerten C., "Walkability assessment for urban areas around railway stations along the Rhine-Alpine Corridor", *Journal of Transport Geography*, 93, 103081, 2021.
- [2] Moinse D., Goudeau M., L'Hostis A., Leysens T., "Intermodal use of (e-)scooters with train in the Provence-Alpes-Côte d'Azur region: towards extended train stations areas?", *Environmental Economics and Policy Studies*, <https://doi.org/10.1007/s10018-022-00349-7>, 2022.
- [3] Singh Y.J., Lukman A., Flacke J., Zuidgeest M., Van Maarseveen M.F.A.M., "Measuring TOD around transit nodes - Towards TOD policy", *Transport Policy*, 56, 96-111, 2017.
- [4] Jeffrey D., Boulangé C., Giles-Corti B., Washington S., Gunn L., "Using walkability measures to identify train stations with the potential to become transit oriented developments located in walkable neighbourhoods", *Journal of Transport Geography*, 76, 221-231, 2019.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Walkability assessment for improving the attractiveness of the public transport system in the suburban areas.

Author(s): Leonardo Minaudo^{*1}, Marco Migliore²

1 Department of Engineering, University of Palermo, Palermo, Italy, leonardo.minaudo@unipa.it

2 Department of Engineering, University of Palermo, Palermo, Italy, marco.migliore@unipa.it

Keyword(s): Walkability, Sustainability

Abstract

The push towards a sustainable lifestyle also requires us to rethink how we move around. Currently, people tend to fulfill their mobility needs using private vehicles, contributing to the deterioration of air quality, especially in urban areas, and exacerbates congestion phenomena, leading to an overall decline in the quality of the urban environment. The challenge is to encourage users to use more sustainable modes of transportation, such as public transportation and active mobility, which involves forms of transportation that do not require external engines, such as walking and cycling. The active mobility is the most sustainable form of mobility, emitting zero emissions, and it also has significant positive effects on human health, reducing the risk of cardiovascular diseases and preventing obesity (Van Cauwenberg J. et Al., 2015). It is also a necessary step for those who use public transportation to get to and from the bus stop, as walking and cycling are often used as first and last-mile options. Proper attention to pedestrian routes, especially around public transportation stops, could therefore encourage users to choose more sustainable modes of transportation, while simultaneously increasing the attractiveness of public transportation (Wu J., et al., 2018). Therefore, an evaluation of the walkability of the northern suburbs of Palermo was carried out, particularly in the neighborhoods of Partanna Mondello, Mondello, Tommaso Natale, and Addaura, to determine the best location for the stops of a microtransit service operating in the area, in order to maximize accessibility to the stops, ensure safe and convenient pedestrian routes for users, and increase the overall attractiveness of the service. The walkability assessment was performed in a GIS environment, considering relevant indicators derived from scientific literature and analyzing both the neighborhood level (macro scale) and the individual pedestrian paths (micro scale). After the evaluation, maps were created showing the walkability of the study area and the ideal locations for the placement of the stops.

References

- [1] Van Cauwenberg J., Van Holle V., De Bourdeaudhuij I., Van Dyck D., Deforche B., “Neighborhood walkability and health outcomes among older adults: The mediating role of physical activity”, *Health & Place*, Volume 37, Pages 16-25, (2015).
- [2] Wu J., Yang M., Sun S., Zhao J. “Modeling travel mode choices in connection to metro stations by mixed logit models: a case study in Nanjing, China”, *Promet – Traffic & Transportation*, Vol. 30, No. 5, 549-561 (2018)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The potential of Demand Responsive Transport (DRT) to enhance accessibility in suburban areas: the case of Palermo (Italy)

Author(s): Pierfrancesco Leonardi^{*1 a)}, Vincenza Torrisi², and Matteo Ignaccolo¹

¹*University of Catania, Department of Civil Engineering and Architecture, Via S. Sofia 64, 95125 Catania, Italy*

²*University of Catania, Department of Electric, Electronic and Computer Engineering, Via S. Sofia 64, 95125 Catania, Italy*

^{a)}Corresponding author: pierfrancesco.leonardi@phd.unict.it

Keywords: Accessibility; active mobility; isochrones; VISUM; Public Transport; DRT.

Abstract

To foster sustainable mobility, one of the key actions is the reorganization of local public transport (LPT) supply in order to increase accessibility through intermodal use of all LPT services. In weak demand areas, public transport companies tend to allocate few resources, often offering a service characterized by low frequency, poor accessibility and high waiting times at stops. In recent years, the use of Demand Responsive Transport (DRT) services has been growing, these services guarantee better performance in terms of reliability and waiting times in weak demand areas [1]. Based on this premise, this work proposes a multi-step methodology for evaluating the potential increase in accessibility due to the implementation of DRT services with flexible routes and timetables. The methodological approach has been applied to the case study coinciding with the neighbourhood of Tommaso Natale and Partanna Mondello in Palermo (Italy), which is a residential area characterized by poor-quality of LPT services and a discontinuous urban fabric. The procedure starts out with the reconstruction of a macro-simulation model to identify activated routes and stops during the operational service of DRT. Then, the accessibility evaluation is performed through the calculation of isochrones [2,3], by implementing a macro-simulation model of the entire transport network [4]. The starting nodes of isochrones coincide with the stop points activated the most during the service, considering two-time intervals (i.e. 5-10 minutes) and the transport mode walking. The results allow for assessing and quantifying the convenience of using innovative modal transport alternatives to private vehicles. Furthermore, this work aims to provide support to administrations in the decision-making process for the implementation of DRT services in weak-demand areas.

References

- [1] Gorev, A., Popova, O., & Solodkij, A. (2020). Demand-responsive transit systems in areas with low transport demand of “smart city”. *Transportation Research Procedia*, 50, 160-166.
- [2] Baltyzhakova, T. I., & Bryzhataya, E. S. (2019, October). Analysis of urban territory in terms of accessibility to social objects. In *Journal of Physics: Conference Series* (Vol. 1333, No. 3, p. 032005). IOP Publishing.
- [3] Zhang, Y., Li, W., Deng, H., & Li, Y. (2020). Evaluation of public transport-based accessibility to health facilities considering spatial heterogeneity. *Journal of Advanced Transportation*, 2020, 1-10.
- [4] Torrisi, V., Ignaccolo, M., & Inturri, G. (2022, November). The microsimulation modeling as a tool for transport policies assessment: An application to a real case study. In *AIP Conference Proceedings* (Vol. 2611, No. 1, p. 060006). AIP Publishing LLC

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Reduction of Hand-Arm Vibrations (HAV) when driving electric scooters

Authors: Salvatore Russotto^{1,4}, Salvatore Orlando^{*1,4}, Andrea Evola⁵, Antonina Pirrotta^{1,4}, Alessandro Albano^{2,4}, Antonella Plaia^{2,4}, Antonio Galvano^{3,4}, Valerio Gristina³, Antonio Russo^{3,4}

¹ Department of Engineering, University of Palermo, Palermo, Italy, salvatore.russotto01@unipa.it

² Department of Economics, Business and Statistics, University of Palermo, University of Palermo, Palermo, Italy

³ Department of Surgical, Oncological and Oral Sciences, University of Palermo, Palermo, Italy

⁴ Sustainable Mobility Center (Centro Nazionale per la Mobilità Sostenibile—CNMS)

⁵ Skorpion Engineering Divisione Additive Manufacturing, Moncalieri, Italy

Keywords: Hand-Arm Vibrations; Vibrations control; Sustainable mobility.

Abstract

With a view to sustainable mobility, it has been noted in recent years that an ever-increasing number of users are using electric scooters as a means of transport to travel short distances [1-2]. The use of such means exposes users to mechanical vibrations, both transmitted to the whole body (WBVs) [3] and to the hand-arm group (HAVs) [4-5]. Exposure to vibrations while riding electric scooters is usually not a problem for human health as the exposure times are very short. However, these vehicles are also used by workers to make home deliveries. In the latter case, the times of exposure to mechanical vibrations can become relevant for human health.

In this paper, the daily exposure to HAVs during electric scooter use was estimated by performing in-situ experimental test. In particular, first, the HAVs were acquired using low-cost instrumentation, and then they were analyzed both in the time domain, taking into account the requirements contained in the UNI EN ISO 5349 standard [4-5], and in the frequency domain, considering the amplitude of the Power Spectral Density (PSD) in the most significant frequency range for the hand-arm group. Furthermore, the same tests were performed by replacing the stock handle with a 3D printed handle (Italian Patent No. 102021000004691 filed on 16.03.2023, International Patent Application No. PCT/IB2022/051673 filed on 25/02/2022). The results show that using the 3D printed handle allows for a reduction in daily exposure to HAVs such as increasing the maximum exposure time by 20%.

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References

- [1] Sanders R.L., Branion-Calles M., Nelson T.A., "To scoot or not to scoot: Findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders", *Transp. Res. Part A Policy Pract.*, 139, 217–227, (2020).
- [2] Sandt L., Harmon K., "Dockless Electric Kick Scooter Systems: What we know and don't know.", In: Presentation at the Transportation Research Board Annual Meeting, January 14, 2019.
- [3] UNI ISO 2631-1: 2014. Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-Body Vibration – Part 1: General Requirements.
- [4] UNI EN ISO 5349-1: 2004. Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements.
- [5] UNI EN ISO 5349-2: 2015. Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 2: Practical guidance for measurement at the workplace.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Non linear invariant beam formulations: The Kirchhoff-Love rod case

Authors: Leopoldo Greco¹, Domenico Castello^{*1}, Simone Scalisi¹, Massimo Cuomo¹.

¹ Department of Civil Engineering and Architecture, University of Catania, Catania, Italy, leopoldo.greco@unict.it, domenicocastello.950@gmail.com, simone.scalisi@phd.unict.it, mcuomo@dica.unict.it

Keywords: Invariant formulation, Geodesic interpolation, mixed formulation, conforming finite element, Kirchhoff-Love rod

Abstract

In this contribute a new non linear invariant formulation for beam Finite Element (FE) based on the Kirchhoff-Love rod model is presented. Following the idea of Crisfield [1] a re-formulation of the smallest rotation map suitable to account at the element formulation the orthogonality and inextensibility constraints analogously to [2,3]. On this way, a new geodetic interpolation suitable for the Kirchhoff-Love rod model is obtained then a new family of conforming FE's is designed.

Since the configuration space of the beam model is given by the cartesian product $R^3 \times S^2 \times S^1$ the FE formulation designed is prone to locking (membrane and flexural locking), then a mixed approach is preferred in order to improve the efficiency of the numerical methodology.

The Hessian of the FE is symmetric since the second variation is performed accounting the Levi-Civita connection of the manifold.

Furthermore, these beam FE's can be coupled easily with the shell and plate FE's proposed in [4,5].

In conclusion the proposed FE's presents high accuracy end robustness as shown by the several numerical investigation proposed.

References

- [1] Crisfield M.A., Gordan J., "Objectivity of strain measures in the geometrically exact three-dimensional beam theory and its fininite-element implementation," *Proceeding of Royale Society of London A*, 455(1983), page 1125-1147, (1999).
- [2] Greco L., Scrofani A., Cuomo M., "A non-linear symmetric G1-conforming Bézier finite element formulation for the analysis of Kirchhoff beam assemblies," *Computer Method in Applied Mechanics and Engineering*, 387, page 114176, (2021).
- [3] Greco L., Cuomo M., Castello D., Scrofani A., "An updated Lagrangian Bézier finite element formulation for the analysis of slender beams," *Mathematics and Mechanics of Solids*, 27(10), page 2110-2138, (2022).
- [4] Greco L., Cuomo M., "An implicit G1-conforming bi-cubic interpolation for the analysis of smooth and folded Kirchhoff-Love shell assemblies", *Computer Method in Applied Mechanics and Engineering*, 373, page 113476, (2021).
- [5] Greco L. Cuomo M., Contrafatto L., "Two new triangular G1-conforming finite elements with cubic edge rotation for the analysis of Kirchhoff plates", *Computer Method in Applied Mechanics and Engineering*, 356, page 354-386, (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Closed-form solutions for mass moments of domains having inhomogeneous density distribution and arbitrary shape

Authors: Davide Pellecchia^{*1}, Nicolò Vaiana¹, Agnese Spedicato¹, Anna Castellano²

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy, davide.pellecchia@unina.it*

² *Department of Mechanics, Mathematics & Management, Politecnico di Bari, Bari, Italy*

Keywords: Mass moments; Inhomogeneous fields; Analytical solutions

Abstract

Mass moments play a critical role in various fields of engineering and physics. The analysis of mechanical systems and the design of engineering components rely on knowledge of properties such as mass, static moment and inertia tensor, also known as moments of order 0, 1 and 2, respectively. The evaluation of the centre of gravity, for example, is of great significance for statics and dynamics in both two and three dimensions. Despite their crucial nature, the evaluation of mass moments of a two-dimensional domain, except for a few regular shapes such as rectangles, circles, and triangles, typically requires a complex double integration [1]. Conversely, the much more effective approach based on the transformation of the original domain integral into a boundary integral is rarely presented in books, a remarkable exception being [2], and is usually confined to papers [3] where algebraic formulas related to polygonal domains can be found. As an alternative, the Monte Carlo method is sometimes favoured, although this approach increases the computational time. In two recent papers [4-5], Ochiai has presented a procedure for computing the mass moments of inhomogeneous domains based on the boundary element method. Specifically, Ochiai rephrased the original domain integrals in terms of boundary integral equations discretised by constant or linear elements, thus obtaining a linear system of equations for the interpolation parameters.

A general methodology for evaluating mass moments of axisymmetric domains with inhomogeneous density distributions is presented in this paper. The methodology involves two steps: (1) converting the original domain integrals to integrals extended to the relevant boundary using Gauss theorem, and (2) transforming the boundary integrals by algebraic expressions specialised for polygonal and circular sector domains, or a combination of both. The presented methodology is authenticated by comparing the computational outcomes resulting from utilizing the proposed equations with the analytical assessment of the domain integrals, which were obtained by the authors.

References

- [1] Arfken G., Weber H., Harris F., *Mathematical Methods for Physicists: A Comprehensive Guide*, Elsevier Science, (2013).
- [2] Romano G., *Scienza delle Costruzioni vol. 2* (in Italian), Hevelius, Naples (2003).
- [3] Yeih W., Chang J., Chen J., A boundary formulation for calculating moments of an arbitrary closed planar region, *Eng. An. Bound. Elem.* 23 (7) 611–617 (1999).
- [4] Ochiai Y., Numerical integration to obtain moment of inertia of nonhomogeneous material, *Eng. An. Bound. Elem.* 101 149–155 (2019).
- [5] Ochiai Y., Numerical integration to obtain second moment of inertia of axisymmetric heterogeneous body, *Eng. An. Bound. Elem.* 133 398–406 (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Uncertainty in the model of out-of-plane mechanisms for masonry structures

Author(s): Matteo Mazzeo^{*1}, Rossella Laudani¹, Roberta Santoro¹

¹ *Department of Engineering, University of Messina, Messina, Italy, {matteo.mazzeo, rossella.laudani, roberta.santoro}@unime.it*

Keyword(s): masonry, out-of-plane collapse mechanisms, uncertainty quantification

Abstract

In the last decade, the seismic analysis of historic masonry structures has attracted considerable attention: most of the present studies are devoted to the prediction of their structural behavior and capacity in order to preserve structural integrity and ensure the safety. The catastrophic seismic events occurred in recent years have shown once again the vulnerability of existing masonry buildings to the so-called collapse local mechanisms.

Specifically, the local mechanisms consist in out-of-plane responses of the walls, typically depending on both the poor connections among the orthogonal walls and structural elements as well as their quality and slenderness, thus inhibiting a box-type global response of the structure.

The analysis is therefore conducted on kinematic chains of masonry portions, regarded as rigid macroblock assemblages, interacting through interface elements.

One of the most common approach to assess the masonry structure capacity is based on the theorems of limit analysis [1] which, using the principle of virtual work, allow the estimation of the load multiplier parameter responsible of the local failure mechanism.

Multiple (theoretically infinite) failure mechanisms need to be considered to estimate the minimum of the kinematically compatible load multipliers. The load multiplier evaluation certainly depends on the macroblocks' geometry (related i.e. to the positions of the hinges in the mechanisms models) that strongly influences the assessment of their structural integrity.

The present study aims to investigate the effect of the uncertainty in the kinematic model on the capacity definition. To address this problem, this study considers two perspectives: in a probabilistic framework, the uncertain parameters affecting the geometry of the macroblocks are described by random variables with assigned probability density functions (PDFs), whereas in a non-probabilistic context, the same parameters are defined as uncertain-but-bounded variables in terms of lower and upper bounds.

The stochastic analysis is conducted by applying the Probability Transform Method [2] while the non-probabilistic scenario is dealt with a proper application of the interval analysis [3].

The results in terms of dispersion in spectral acceleration capacity as well as in displacement capacity can guide the decision-making in design solutions depending in turn on seismic capacity predictions.

References

- [1] Heyman, J. The stone skeleton. *Int. J. Solids Struct.* 2, 249–279, (1966).
- [2] Laudani, R., Falsone, G. Use of the probability transformation method in some random mechanic problems. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, 7(1), 04020054. (2021).
- [3] Moore R.-E., *Interval Analysis*, Englewood Cliffs, Prentice-Hall (1966).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: An inerter-based isolation system for the vibration control of a continuous girder bridge under longitudinal seismic action

Author(s): Silvia Sciutteri*¹, Dario De Domenico¹, Giuseppe Ricciardi¹,

¹ *Dipartimento di Ingegneria, Università di Messina, Messina, Italy*

E-mail: silvia.sciutteri@unime.it, dario.dedomenico@unime.it, giuseppe.ricciardi@unime.it,

Keyword(s): isolation, inerter, bridge, longitudinal seismic action.

Abstract

The use of the inerter in vibration control has received much attention over the last 20 years, for a wide variety of structural problems. In particular, it has been shown that the use of the inerter for the improvement of the protection systems of civil structures based on seismic isolation allows to obtain considerable advantages on the structural response [1-3]. In fact, in addition to reducing the ductility demand of the seismic isolation system, while maintaining the effectiveness of the decoupling of the motion of the structure from that of the ground, the undesirable effects due to the increase in absolute accelerations on the superstructures are also reduced when one wishes to limit the displacements increasing the damping of the seismic isolators.

In this work, the behavior of continuous girder bridges subjected to a longitudinal seismic action is studied and a solution based on an innovative seismic isolation system which foresees the use of the inerter is proposed. This innovative seismic isolation system makes it possible to limit the longitudinal displacements, which are very dangerous to guarantee the protection of the end expansion joints and, at the same time, to produce a beneficial effect on the structural response of the piers.

References

- [1] De Domenico, D., Ricciardi, G., "An enhanced base isolation system equipped with optimal tuned mass damper inerter (TMDI)", *Earthquake Engineering and Structural Dynamics*, 2018;47:1169–92
- [2] De Domenico D, Ricciardi G., "Improving the dynamic performance of base-isolated structures via tuned mass damper and inerter devices: A comparative study", *Struct Control Health Monitor*. 2018;25:e2234.
- [3] De Domenico, D., Ricciardi, G., "Optimal design and seismic performance of tuned mass damper inerter (TMDI) for structures with nonlinear base isolation systems", *Earthquake Engineering and Structural Dynamics*, 47(12), 2018;47:2359–560.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Cloaking surface defects from Rayleigh waves using anisotropic symmetric yet feasible materials

Author(s): Z. Chatzopoulos^{1*}, A. Palermo¹, A. Diatta², S. Guenneau^{3,4}, A. Marzani¹

¹ *University of Bologna, Department of Civil, Chemical, Environmental and Materials Engineering - DICAM, 40136 Bologna, Italy*

² *Aix-Marseille Université, CNRS, Centrale Marseille, Institut Fresnel, Avenue Escadrille Normandie-Niemen, 13013, Marseille, France*

³ *Imperial College London, UMI 2004 Abraham de Moivre-CNRS, London, SW7 2AZ, UK*

⁴ *The Blackett Laboratory, Physics Department, Imperial College, London SW7 2AZ, United Kingdom*

Keyword(s): Rayleigh waves, cloaking, transformation elastodynamics, symmetrization

Abstract

Wave cloaking is the ability to reroute waves around an object/region without any scattering effects or loss of energy. Compared with other areas, e.g., acoustics or electromagnetism, cloaking of mechanical waves is a greater challenge, since the Navier elastodynamic equation does not retain its form upon an arbitrary geometric transformation required for cloaking [1]. Still, the idea of cloaking elastic waves has been of major interest due to its numerous applications in engineering and physics. In particular, the ability to cloak incident Rayleigh waves would represent a significant scientific advancement toward seismic and vibrations isolation of structures. Nonetheless, despite numerous available contributions on elastic waves, cloaking strategies for Rayleigh waves are scarce, with the most relevant studies exploiting the use of micropolar (Cosserat) materials [2]. Indeed, these materials can be complex to manufacture and can suffer from soft mechanism behaviours, and thus alternative approaches based on the use of standard (symmetric) materials are desirable.

In this study, we develop a strategy to cloak surface defects from incident Rayleigh waves by means of symmetrized anisotropic elastic tensors. To this purpose, we use transformation elastodynamics and exploit the invariance of the Navier elastodynamic equation [1] by assuming a Cosserat gauge between the displacement fields in the virtual (reference) and the transformed (cloaked) domain [3]. The obtained transformed cloaked region is thus characterized by a non-symmetric elastic tensor. For this reason, we adopt a symmetrization technique exploiting the arithmetic mean to approximate the non-symmetric Cosserat material with an anisotropic composite material with symmetric elastic tensors. We investigate the efficacy of the proposed design by performing time-harmonic numerical simulations and dispersion analyses, analyzing cloaks with triangular and semi-circular shapes. For the semi-circular shaped cloaks, we consider different coordinate transformations, linear and non-linear (quadratic and cubic) ones. Through our analysis, we conclude that a symmetrized semi-circular cloak with effective properties obtained from quadratic transformation presents the best cloaking performance among the investigated designs.

References

- [1] Milton, G.W., Briane, M., Willis, J.R., "On cloaking for elasticity and physical equations with a transformation invariant form", *New J. Phys.* 8 (10) (2006) 248. vol. 75, p. 195111, 2007.
- [2] H. Nassar, Y. Chen, G. Huang, "Isotropic polar solids for conformal transformation elasticity and cloaking", *Journal of the Mechanics and Physics of Solids* 129 (2019) 229–243
- [3] Brun, M., Guenneau S., Movchan A.B., "Achieving control of in-plane elastic waves", *Appl. Phys. Lett.* 94 (6) (2009) 061903.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Wave-based vibration analysis of jointed metamaterial rods

Author(s): Bartłomiej Piwowarczyk¹, Michael J. Leamy² and Paweł Packo¹

¹ Department of Mechanical Engineering and Robotics, AGH University of Science and Technology, Cracow, Poland, bartlomiej.piwowarczyk@agh.edu.pl, pawel.packo@agh.edu.pl

² George Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA, michael.leamy@me.gatech.edu

Keyword(s): wave-based vibration, elastic waves, elastic rods, periodic media, metamaterials

Abstract

Elastic metamaterials consist of internal structure which is typically periodic through shape and/or material distribution, or less frequently, periodic external supports (e.g., periodic rigid or elastic supports). Elastic metamaterials exhibit advantageous dynamic properties such as frequency bandgaps which reject wave propagation [1], fluid-like pentamode properties [2], and boundary effects with topological features [1]. Various methods can be employed for the investigation of dynamic properties of continuous metamaterials, such as the plane wave expansion [3] or the transfer matrix method [4]. In the presented paper, we propose a wave-based vibration [5,6] approach for analyzing elastic metamaterials, with particular attention focused on topological states. Additionally, we consider a class of continuous elastic metamaterials (periodic rods with internal and external attachments) incorporating periodic interfaces (i.e., joints), thereby increasing the design space to include additional joint damping, stiffness, and nonlinearity. We use the proposed wave-based approach with the considered elastic metamaterials to study complex topological phenomena arising from the introduced interfaces, such as topologically-protected states. Different interface conditions are studied and their impact on the presence or absence of topological states is discussed.

References

- [1] Muhammad, Lim, C., "Analytical modeling and computational analysis on topological properties of 1-D phononic crystals in elastic media", *Journal of Mechanics of Materials and Structures*, 15, 15-35, 2020.
- [2] Cai, C., Wang, X., et al., "Design and optimization of three-dimensional composite multilayer cylindrical pentamode metamaterials for controlling low frequency acoustic waves", *Scientific Reports*, 12, 2022.
- [3] Wu L-Y., Wu M-L. et al., "The narrow pass band filter of tunable 1D phononic crystal with a dielectric elastomer layer", *Smart Materials and Structures*, 18, 2008.
- [4] Tsai, Y.-W., Wang, Y.-T. et al., "Topological Phase Transition in a One-Dimensional Elastic String System", *Crystals*, 9, 313, 2019.
- [5] Mei C., Mace B., "Wave Reflection and Transmission in Timoshenko Beams and Wave Analysis of Timoshenko Beam Structures", *Journal of Vibration and Acoustics*, 127, 2005.
- [6] Balaji N. N., Brake M., Leamy M., "Wave-based analysis of jointed elastic bars: nonlinear periodic response", *Nonlinear Dynamics*, 110, 2022

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Stability of a periodic grid with rigid finite-sized joints

Author(s): Nicola Marasciuolo^{*1}, Francesco Trentadue¹, Domenico De Tommasi¹

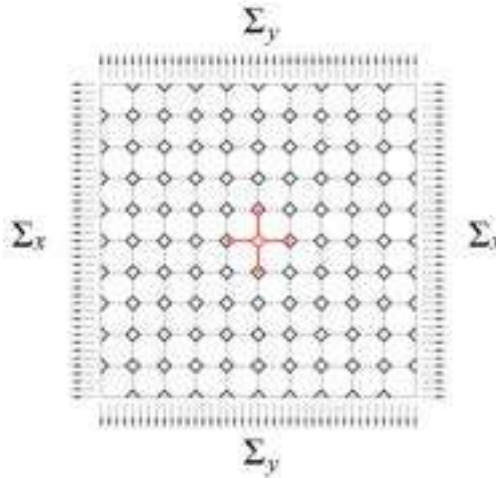
¹ DICATECh, Politecnico di Bari, 70125 Bari, Italy, n.marasciuolo@phd.poliba.it (N. Marasciuolo), francesco.trentadue@poliba.it (F. Trentadue), domenico.detommasi@poliba.it (D. De Tommasi)

Keyword(s): Metamaterials, Elastic stability, Bloch wave analysis

Abstract

Elastic stability is an important issue in the analysis of metamaterials, especially if the mechanical response of these engineered materials can be modulated in order to obtain unusual properties. In this work, we study a periodic bidimensional lattice composed by a square mesh of beams with rigid finite-sized nodes and determine a closed form solution of the stability domain of the lattice subjected to a plane macro-stress. The geometry and the analysis of the metamaterial here considered is inspired by other works. In particular, the uniaxial stress state case is discussed in [1], whereas the stability problem for a grid of beams has been considered in [2] by assigning the wavelengths of the critical modes and in [3] using the Floquet-Bloch theorem.

By choosing an adequate Representative Volume Element (RVE, drawn in red in the figure below) and assuming the inextensibility of the rods, in this work the wavelengths of the buckling modes have been derived in the general framework of the Floquet-Bloch analysis. Subsequently, the stability domain has been obtained by considering the influence of the nodes size. Finally, the analytical results achieved with this analytical approach have been compared with numerical analyses, e.g., Finite Element Method (FEM) analyses.



References

- [1] Cutolo A., Palumbo S., Carotenuto A. R., Sacco E., Fraldi M., "A class of periodic lattices for tuning elastic instabilities", *Extreme Mechanics Letters*, 55, 101839, (2022).
- [2] Haghpanah B., Papadopoulos J., Mousanezhad D., Nayeb-Hashemi H., Vaziri A., "Buckling of regular, chiral and hierarchical honeycombs under a general macroscopic stress state", *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 470(2167), 20130856, (2014).
- [3] Trentadue F., De Tommasi D., Marasciuolo N., "Stability domain and design of a plane metamaterial made up of a periodic mesh of rods with cross-bracing cables", *Applications in Engineering Science*, 5, 100036, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Experimentally validated stochastic generation of numerical samples of hydrated cement paste

Author(s): Felix Mett^{*1}, Matteo Broggi¹, Michael Beer^{1,2,3}

¹ Institute for Risk and Reliability, Leibniz University Hannover, Hannover, Germany, mett@irz.uni-hannover.de

² Institute for Risk and Uncertainty, University of Liverpool, Liverpool, United Kingdom, beer@irz.uni-hannover.de

³ International Joint Research Center for Resilient Infrastructure & International Joint Research Center for Engineering Reliability and Stochastic Mechanics, Tongji University, Shanghai, China, beer@irz.uni-hannover.de

Keyword(s): Stochastic microstructure generation, Model parameter calibration, Numerical homogenization

Abstract

Modeling of cementitious materials is a challenging task. The complex heterogeneous microstructure leads to an experimentally observable high variability in local and effective material properties. This work proposes an approach for the stochastic generation of hydrated cement paste (hcp) volume elements that can model the inherent uncertainty of local and effective mechanical properties.

Based on the approach used in [1], available micro-computed tomography (micro-CT) scans and nanoindentation data of hcp are used to establish a deterministic mapping between local x-ray attenuation and mechanical properties. Subvolumes of micro-CT scans are then extracted and utilized to construct spatially varying fields of material properties. Effective material properties of subvolumes are obtained by a fast Fourier transformation-based (FFT-based) homogenization method. FFT-based homogenization, originally proposed in [2], can directly be applied to the previously constructed fields of material properties. Recently, several discretization schemes and solution methods have been developed and lead to improvements of the original approach [3]. Resulting effective material properties are compared to microindentation data for validation and calibration of uncertain material parameters. The stochastic generation of numerical microstructure samples is based on a generative adversarial network [4] (GAN) that is trained on micro-CT scans of hcp. GANs have been successfully applied for the generation of 3D microstructures. E.g., Hsu et. al. used the approach to generate realistic microstructures of solid oxide fuel cell electrodes [5]. The quality of generated samples is examined by employing the previously established homogenization procedure and comparing the resulting collection of averaged-out properties to microindentation data.

References

- [1] Zhang H., Šavija B., Luković M. et. al., Experimentally informed micromechanical modelling of cement paste: An approach coupling X-ray computed tomography and statistical nanoindentation, *Composites Part B: Engineering*, 157, 109–122, (2019).
- [2] Moulinec H., Suquet P. A fast numerical method for computing the linear and nonlinear properties of composites, *Comptes rendus de l'Académie des sciences II*, 318, 1417–1423, (1994).
- [3] Schneider M., A review of nonlinear FFT-based computational homogenization methods, *Acta Mechanica*, 232, 2051–2100, (2021).
- [4] Goodfellow I., Pouget-Abadie J., Mirza M. et. al., Generative adversarial nets, *Advances in neural information processing systems*, 27, 2672–2680, (2014).
- [5] Hsu T., Epting W.K., Kim H. et al. Microstructure Generation via Generative Adversarial Network for Heterogeneous, Topologically Complex 3D Materials. *JOM: The journal of the Minerals, Metals & Materials Society*, 73, 90–102, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A flextegrity structure inspired by Leonardo da Vinci's triangular segmental construction

Authors: Claudio Boni^{*1}, Gianni Royer-Carfagnì²

¹ Department of Engineering and Architecture, University of Parma, Parma, Italy, claudio.boni@unipr.it

² Department of Engineering and Architecture, University of Parma, Parma, Italy, gianni.royer@unipr.it

Keywords: flextegrity; segmental structure; Leonardo da Vinci; beam; bending; shear.

Abstract

Leonardo da Vinci's genius manifested itself in many fields of art and science. His brilliant intuitions, although not supported by the scientific knowledge of his time, can be revisited today in interesting and innovative structural applications. Reference is now made to the *Tabula 91 verso* of the Codex Atlanticus [1], where an ingenious segmental structure is sketched. In Leonardo's drawings, the segments are composed by two flipped triangular portions, solidly joined together, and they face one another in unilateral contact, in order to obtain a lintel or jack arch with interlocked blocks; the segments shall be pressed together by the thrust provided by the end constraints. By adding a tensile member bridging the segments, this kind of structural system can represent an innovative example of flextegrity (flexural tensegrity) system [2].

Flextegrity is a broad concept that can be declined in many forms. In the fundamental setting, flextegrities are segmental structures consisting of chains of segments in unilateral contact, held together by prestressed tendons. The main characteristic is that the contact surfaces are shaped according to properly-designed pitch profiles, so that the relative rotation between any two consecutive segments, guided by the geometry of the contact surfaces, dictates the elongation of the tendons, thus affecting the variation of the strain energy of the system.

In most flextegrity systems the relative motion between the segments is designed to achieve a pure rolling motion along curved pitch profiles, which can be practically obtained with conjugate profiles, e.g., toothed profiles as in gears. In this case, the pitch point (instantaneous center of rotation) is univocally determined by the geometry of the joint once the rotation is assigned. On the contrary, in Leonardo's structure, the contact surface is planar in the initial unstrained state and the center of rotation under bending is localized at the vertices of the triangles. Since the reciprocal sliding due to shear is not ruled out by the shape of the contact joints, the center of rotation depends upon the loading condition and the friction coefficient between the contact surfaces, thus introducing additional variables in the bending problem.

The flextegrity system inspired by Leonardo's conceptual drawings is here theoretically analyzed, considering the competition between shear- and bending-deformation mechanisms in the resulting segmental beam. Tests on 3D-printed prototypes shall confirm the theory with experiments.

References

- [1] da Vinci L., "Codex Atlanticus", manuscript, (1478-1518). Original manuscript at the Veneranda Biblioteca Ambrosiana (Milan), digitalized version available online at <https://www.codex-atlanticus.it>
- [2] Boni C., Silvestri M., Royer-Carfagnì G., "Flexural tensegrity of segmental beams", *Proceedings of the Royal Society A*, 476(2237), 20200062, (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Some insights for a new constitutive model of snow

Author(s): Gianmarco Vallero^{*1}, Monica Barbero¹, Fabrizio Barpi¹, Mauro Borri-Brunetto¹, Valerio De Biagi¹

¹ DISEG, Politecnico di Torino, Torino, Italy, gianmarco.vallero@polito.it

Keyword(s): constitutive models, snow mechanics, computational mechanics, solids, natural materials

Abstract

In the last decades particular interest has been given to the modelling of the mechanical behaviour of snow not only for snow avalanche applications but also for other different purposes, such as: safety and transportation engineering, building engineering, design and optimization of new materials for sport and leisure activities, ice and snow physics, etc.

To deal with such a large number of different applications, a reliable and as more general as possible constitutive model is needed [1]. In this work an improved visco-plastic and nonlinear constitutive model for snow is proposed, which takes into account the sintering/degradation process of snow as well as the rate-dependent behaviour of this particular natural material. The model bases on the existing one proposed by [2] and introduces a smooth and simply convex function to describe both the yield surface and the visco-plastic potential. These curves can change their shapes in the meridian section to follow some experimental findings and improve the reliability of the numerical implementation of the model itself.

The model, consisting of a system of ten nonlinear differential constitutive equations, was integrated over time via a fully implicit backward Euler's method which was implemented into a UMAT format (written in Fortran 77) for the FE code Abaqus/Standard. The local problem (i.e., finding the solutions of the system of equations) was iteratively solved with a dedicated algorithm based on the multi-dimension Powell's hybrid method.

Here, we refer on some results obtained using our model with reference to some literature laboratory experiments (triaxial and volumetric compression, relaxation, creep, etc.). Moreover, some further improvements (new hardening law, large deformation theory, etc.) aiming at generalizing the applicability of the model are briefly described, together with some insights on possible future developments.

References

- [1] Vallero G., Barbero M., Barpi F., Borri-Brunetto M., De Biagi V. "Some Computational Issues in the Elasto-Plastic Modelling of Snow" in Proceedings of the 16th International Conference on Computational Plasticity (COMPLAS 2021), Barcelona (virtual), 7-9 September 2021, (2022).
- [2] Cresseri S., Jommi C. "Snow as an elastic viscoplastic bonded continuum: a modelling approach", Italian Geotechnical Journal, 4, 43-58 (2005).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Creep due to the humidity variations in a polymeric bidimensional homogeneous beam

Author(s): Angelo Scrofani^{*1}, Emilio Barchiesi², Anil Misra³, Luca Placidi⁴

¹ Dipartimento di Ingegneria e Scienze dell'Informazione e Matematica, Università degli Studi dell'Aquila, L'Aquila, Italy, angelo.scrofani@graduate.univaq.it

² Dipartimento di Architettura, Design e Urbanistica, Università degli Studi di Sassari, Alghero, Italy, ebarchiesi@uniss.it

³ Civil, Environmental & Architectural Engineering, University of Kansas, Lawrence (KS), USA, amisra@ku.edu

⁴ Engineering Faculty, Università Telematica Internazionale UNINETTUNO, Roma, Italy, luca.placidi@uninettunouniversity.net

Keyword(s): hemivariational method, diffusion, damage, creep

Abstract

Creep due to the humidity variations within a polymeric body is presented [1]. The creep effects are caused by the combined effects of the moisture extent in the body and the external static load.

A hemi variational approach is considered for describing this phenomenon [2]. We model a bidimensional homogeneous beam under a tensile and bending condition. The diffusion of the fluid is linked to the damage by means a suitable coupling term in the energy formulation.

Cycles of absorption and desorption are considered in order to show the behavior of the bidimensional beam.

Parametric analyses are carried out in terms of diffusivity and concentration-damage coupling term for clarifying the meanings of those parameters.

Parametric analyzes can allow the design of new materials (metamaterials) to be used in various fields including that of bioengineering. New materials which, having a longer life, would allow, for example, the design of more durable orthopedic prostheses.

References

[1] Solasi R., Huang X., Reifsnider K. "Creep and stress-rupture of Nafion® membranes under controlled environment" in Mechanics of Materials, page 678-685, (2010).

[2] Placidi L., Misra A., Barchiesi E. "Two-dimensional strain gradient damage modelling: a variational approach" in Zeitschrift für Angewandte Mathematik und Physik, (Apr. 2018).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Multifield nonlocal identification of periodic thermoelastic materials with two relaxation times

Author(s): Rosaria Del Toro^{*1}, Maria Laura De Bellis¹, Andrea Bacigalupo²

¹ *INGEO, University of Chieti-Pescara, Pescara, Italy*

² *DICCA, University of Genova, Genova, Italy*

e-mail: rosaria.deltoro@unich.it, marialaura.debellis@unich.it, andrea.bacigalupo@unige.it

Keyword(s): thermoelastic periodic material, non-local continua, asymptotic homogenization

Abstract

A non-local asymptotic homogenization scheme is outlined to analyze thermoelastic heterogeneous materials endowed with periodic microstructure [1]. Specifically, the asymptotic expansion of the micro-fields in terms of the characteristic size of the microstructure is performed. Leveraging on the expression of the microscale field equations and the asymptotic expansions, a chain of recursive differential problems defined over the periodic unit cell are solved. Then, the cell problems are extrapolated and written in terms of the perturbation functions, which rely on the geometrical and physical-mechanical properties of the material as well as the microstructural heterogeneities. The down-scaling relation is retrieved in a consistent form, which links the microscopic to the macroscopic fields and its gradients via the perturbation functions. Finally, the average field equations of infinite order are established by replacing the down-scaling relation into the microscale field equations. The average field equations of infinite order are formally solved by carrying out an asymptotic expansion of the macro-fields in power of the microstructural size, leading to a sequence of macroscopic recursive problems [2]. The problem of wave propagation through the thermoelastic homogenized continuum is investigated. Finally, the dispersion curves achieved from the non-local homogenized scheme are compared with the curves provided by the Floquet-Bloch theory to assess the reliability of the proposed model [3].

References

- [1] Ignaczak J., Ostoja-Starzewski M., Thermoelasticity with finite wave speeds, OUP Oxford, (2009).
- [2] Smyshlyaev V.P., Cherednichenko K.D., "On rigorous derivation of strain gradient effects in the overall behaviour of periodic heterogeneous media," *Journal of the Mechanics and Physics of Solids*, 48, 1325-1357 (2000).
- [3] Bacigalupo A., De Bellis M.L., Gnecco G., "Complex frequency band structure of periodic thermo-diffusive materials by Floquet-Bloch theory," *Acta Mechanica*, 230, 3339-3363, (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A poromechanical approach for subcutaneous drug delivery

Author: Simona Lo Franco^{*1},

¹ *Department of Engineering, University of Palermo, Palermo, Italy, Viale delle Scienze ed. 8*

Keywords: Poromechanics, Mechanics of biological tissues, Analytical approach, Nonlinear elasticity

Abstract

Subcutaneous injections have emerged as a prominent route for drug administration, including the delivery of monoclonal antibodies (mAbs) [1]. Improper administration of the injection can result in adverse outcomes including pain, tissue injury, compromised drug absorption, inconsistent administration rate and potential systemic complications. Understanding the mechanical behaviour of subcutaneous tissues during injection is therefore crucial for optimizing drug delivery efficiency and minimizing potential complications [2].

A growing number of studies in the recent literature have proposed the poromechanical framework for modelling fluid diffusion in biological media [3], simulating the mechanical response of tissues, with numerical methods emerging as the primary approach [4].

Despite of the well-established versatility and reliability of numerical methods, analytical solutions of benchmark problems are essential to serve as crucial points of comparison for evaluating the performance of numerical simulations, highlighting its importance and providing a reference point for further research and analysis.

To the best of our knowledge, no analytical solution for this particular case study has been investigated by previous study in literature. For this reason, this study seeks to present a novel framework for a comprehensive examination of the steady-state behaviour of a poroelastic tissue under radially outward fluid injection, utilizing a Eulerian approach.

The results obtained made it possible to clarify the fundamental elements that determine the response of the systems under examination, highlighting several original aspects for mechanical behaviour under large deformations, which were not previously known in the literature.

References

- [1] Danielle N. McLennan, Christopher J. H. Porter, and Susan A. Charman. Subcutaneous drug delivery and the role of the lymphatics. *Drug Discovery Today. Technologies*, 2(1):89–96, 2005.
- [2] Zijlstra E, Jahnke J, Fischer A, Kapitza C, Forst T. Impact of Injection Speed, Volume, and Site on Pain Sensation. *J Diabetes Sci Technol*. 2018 Jan;12(1):163-168. doi: 10.1177/1932296817735121. Epub 2017 Oct 8. PMID: 28990437; PMCID: PMC5761988.
- [3] Lucy C. Auton and Christopher W. MacMinn. From arteries to boreholes: Steady-state response of a poroelastic cylinder to fluid injection. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 473(2201):20160753, May 2017.
- [4] Yu Leng, Mario de Lucio, and Hector Gomez. Using poro-elasticity to model the large deformation of tissue during subcutaneous injection. *Computer Methods in Applied Mechanics and Engineering*, 384:113919, October 2021.

*Correspondence: simona.lofranco@unipa.it

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: New perspectives into the non-smooth contact dynamics of rigid masonry blocks

Authors: Mario Argenziano^{1,2,*}, Enrico Babilio², Yoshiki Ikeda³, Massimiliano Fraldi²

¹ Department of Engineering, University of Palermo, Palermo, Italy

² Department of Structures for Engineering and Architecture, University of Napoli "Federico II", Napoli, Italy

³ Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan

Keywords: masonry structures, non-smooth dry friction, nonlinear dynamics, rigid blocks.

Abstract

Masonry buildings represent the major part of the historical architectural heritage of cities in Italy and Europe, most of them being characterized by high seismicity rate. However, as well-known, they are sensibly vulnerable to seismic loads and often exhibit larger cracks -even for low-moderate earthquakes- if compared with steel and reinforced concrete structures. In the last decades, several numerical methods [1] have been proposed in the inherent literature in order to faithfully grasp the actual behaviour of these structures, and, more importantly, to define *ad hoc* seismic retrofit interventions. Despite the numerous different approaches suggested, the debate within the scientific community is still alive and does not converge to a unique modelling strategy. With the aim of providing a novel standpoint for understanding the complex mechanics of masonry structures, we enhance some discrete element methods widely employed [2,3], also taking into consideration non-smooth dynamics of rigid masonry blocks separated by mortar joints. In detail, more refined models are uploaded to account for some dissipative mechanisms, for instance, the contact friction between rigid blocks, *ad hoc* implementing several parametric analyses to provide a comprehensive view on the competition of the above-mentioned effects on the strong nonlinear dynamics of masonry panels. Starting from the outcomes, we finally exploit the possibility of replacing the mortar joints at specific parts of the structure glimpsing engineered interfaces that can allow dissipation of energy for non-invasive seismic retrofit applications.

References

- [1] D'Altri, A. M., Sarhosis, V., Milani, G., Rots, J., Cattari, S., Lagomarsino, S., ... & De Miranda, S. (2019). A review of numerical models for masonry structures. *Numerical modeling of masonry and historical structures*, 3-53.
- [2] Moreau, J. J. (2002). Numerical dynamics of granular materials. In *Contact Mechanics* (pp. 1-16). Springer, Dordrecht.
- [3] Rafiee, A., Vinches, M., & Bohatier, C. (2008). Application of the NSCD method to analyse the dynamic behaviour of stone arched structures. *International Journal of Solids and Structures*, 45(25-26), 6269-6283.

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* speaker: mario.argenziano@unipa.it

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Digital Twin for Cultural Heritage Monitoring

Author(s): Cosimo Pellecchia^{*1}, Marianna Crognale², Melissa De Iuliis², Cecilia Rinaldi², Gian Paolo Cimellaro¹, Vincenzo Gattulli²

¹ *Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy e-mail: {cosimo.pellecchia, gianpaolo.cimellaro}@polito.it*

² *Department of Structural and Geotechnical Engineering, Sapienza Università di Roma, Via Eudossiana 18, 00184, Rome, Italy e-mail: {melissa.deiuliis, marianna.crognale, cecilia.rinaldi, vincenzo.gattulli}@uniroma1.it*

Keyword(s): Digital Twin, Structural Health Monitoring, Model Updating, Cultural Heritage, Operational Modal Analysis

Abstract

Digital Twin (DT) has gained much attention in the past few years, as it is considered an effective tool to realize the fusion between physical and virtual spaces. Internet of Things (IoT) technology for Cultural Heritage represents a revolutionary approach integrating sensors, services, intelligent objects, and applications within cultural locations such as exhibitions, monuments, and museums. This study proposes a DT approach for structural monitoring of Cultural Heritage through vibration signal processing and model updating. DT techniques require sufficient prior knowledge – such as modeling information (including geometry and material properties) and operating conditions for health state estimation. Data-driven methods (e.g., Stochastic Subspace Identification SSI) and physics-based methods (e.g., the finite element method) are implemented in the methodology to enrich the DT description. A short-term monitoring system consisting of six triaxial accelerometers is installed in the Esedra Hall at the Capitoline Museum of Rome. Results in terms of time–frequency domain features are extracted from the recorded data using IoT systems and used to update the Finite Element Model (FEM) to refine the mechanical twin model. To optimize the DT implementation, different methods for parameterization and FEM models' automatic updating have been described, and the development of an artificial intelligence system for predictive analysis of the analyzed structure has been illustrated. Future research will focus on integrating the abovementioned techniques within the proposed methodology.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: BIM/FEM interoperability for modeling and management of the Moulay Abdellah arch dam

Author(s): C. Mastroiacovo¹, C. Rinaldi¹, A. Bendarma², R. Zoggia¹, V. Gattulli¹

¹ *Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy, c.mastroiacovo2211@gmail.com, cecilia.rinaldi@uniroma1.it, riccardo.zoggia@alice.it, vincenzo.gattulli@uniroma1.it*

² *Department of Mechanical Engineering, Universiapolis-International University of Agadir, Agadir, Morocco, amine.bendarma@gmail.com*

Keyword(s): BIM, interoperability, dam monitoring, digital twin.

Abstract

Over the past few years, the use of Building Information Modeling (BIM) has been made mandatory for an increasing number of projects, requiring construction and civil engineering professionals to change their workflow. In the market there are several tools for structural analysis based on the Finite Element Method (FEM) that allow direct integration with BIM through the IFC open format for geometries and model information transferring. Also, BIM approaches are starting to renovate the structural monitoring field aiming to create digital twins of structures which allow a bi-directional correlation between the physical world and the 3D model and a better understanding of their structural safety in a more direct and prompt way.

The aim of this contribution is to investigate the methods of exchange and integration between BIM and FEM models where there is still no excellent implementation of software related to the discipline of civil engineering for hydraulic infrastructures, like arch dams. The study was conducted by examining the Moulay Abdellah double-curved arch dam located in Agadir, Morocco. It was not possible to generate the analytical model of a complex geometry such as that of the case study, therefore, in this thesis, an investigation was conducted to allow the transition from BIM to FEM also using other instruments. Finally, a BIM-based management of the monitoring system of the dam is described and procedures for data collecting and processing aiming to update the dam digital twin are illustrated.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Dynamic identification of slender structures by means of stochastic subspace identification method.

Author(s): Massimo Cuomo¹, Leopoldo Greco¹, Simone Scalisi¹, Domenico Castello¹

¹*Department of Civil Engineering and Architecture, University of Catania, Catania, Italia, mcuomo@dica.unict.it, leopoldo.greco@unict.it, simone.scalisi@phd.unict.it, domenicocastello.950@gmail.com,*

Keyword(s): stochastic subspace identification, modal identification, masonry buildings, tower bell

Abstract

Structural monitoring primarily requires the identification of the dynamic properties of the structure (frequencies, modes, damping). Vibration tests using ambient excitations are becoming more and more popular since they are reasonably inexpensive and easy to perform [1]. The main problems related to this kind of tests is to distinguish between true modes and artificial, mathematical, modes, that derive from noise and other imprecisions in the data treatment. Several methods have been proposed, and in this work investigates on the performance of the so called, stochastic subspace identification methods [2]. Although becoming very popular, its success depends on the setting used for the implementation, and on criteria adopted for evaluating the confidence of the results [3]. The purpose of the investigation is to analyse the different parameters and criteria involved on the procedure, with the aim to develop a procedure for assigning confidence levels to the results obtained from the method. Some case studies will be described, related to laboratory tests, and to two slender masonry bell towers located in Eastern Sicily.

References

- [1] Ranieri C., Fabbrocino G., Operational modal analysis of civil engineering structures, Springer, New York (2014).
- [2] Peeters, B., System Identification and Damage Detection in Civil Engineering, in Faculteit Toegepaste Wetenschappen Arenbergkasteel. 2000, Katholieke Universiteit Leuven: Heverlee (Belgium).
- [3] M. Scionti, J. Lanslots, I. Goethals, A. Vecchio, H. Van der Auweraer, B. Peeters, and B. De Moor, "Tools to Improve Detection of Structural Changes from In-Flight Flutter Data," the VIII Int. Conf. on Recent Advances in Structural Dynamics, 2003.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Scan-to-BIM procedures for the management of built environment

Author(s): F. Di Benedetto^{*1}, L. Pinnetti¹, M. Crognale¹, M. De Iuliis¹, C. Rinaldi¹, V. Gattulli¹

¹ *Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy, dibenedetto.1701545@uniroma1.it, pinnetti.1991097@studenti.uniroma1.it, marianna.crognale@uniroma1.it, melissa.deiuliis@uniroma1.it, cecilia.rinaldi@uniroma1.it, vincenzo.gattulli@uniroma1.it*

Keyword(s): point cloud, reverse engineering, digital twins.

Abstract

Digital technologies are more and more needed to allow an efficient and smart management of built environment aimed to a sustainable maintenance and preservation. The Digital Twin (DT) concept, including Building Information Model (BIM) approaches, data acquisition systems based on Internet of Things (IoT) and cloud-based management platforms, answers properly to the “data-centric” evolution, to the growing need to optimize the efficiency in the existing facilities management, to deal with a common language, to share procedures and basic documents, to use interoperable and sharable information. This paper highlights the efficiency of different approaches for the development of DT models based on geometry reconstruction from 3D point cloud acquired through terrestrial laser scanner, as well as integrating this information into a BIM via semantic enrichment of an as-built Industry Foundation Classes (IFC) model. Discussion on the effectiveness and the potentiality of such reverse engineering approaches is also presented by focusing on their impact on culture heritage monitoring and maintenance.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Seismic isolation of art objects via inverted pendulum devices: from theory to practise

Author(s): Giuseppe Tommaso Di Venti, Francesco Cannizzaro, Salvatore Caddemi, Ivo Calì

Department of Civil Engineering and Architecture, University of Catania, Italy, diventi@dica.unict.it.

Department of Civil Engineering and Architecture, University of Catania, Italy, francesco.cannizzaro@unict.it.

Department of Civil Engineering and Architecture, University of Catania, Italy, salvatore.caddemi@unict.it.

Department of Civil Engineering and Architecture, University of Catania, Italy, ivo.calio@unict.it.

Keyword(s): Art objects, museum contents, rigid block, passive control, nonlinear dynamic, seismic isolation, ball system device, friction pendulum, inverted pendulum, seismic protection of cultural heritage.

Abstract

In the literature related to the prevention of seismic damage, undeservedly little attention has been paid to the protection of art objects and museum contents which, although they are not proper structures, represent a common heritage to be safeguarded. The present paper deals with the passive control of the vibrations of art objects subjected to earthquake excitations whose vulnerability is related to the rocking behaviour. The object is modelled as a rigid block simply supported on a seismic isolated support endowed with ball systems pendulum devices. When subjected to earthquake excitation, the art object may remain in contact with the base or tilt over the movable supporting mass and eventually overturn. The system is therefore characterised by different phases of motion. When the object is in full contact with the movable base the overall system possesses a single degree of freedom and behaves as a nonlinear inverted pendulum. When the object tilts over the base the system possesses two degrees of freedom related to the rocking of the art object on the movable base. In the paper, the large displacements behaviour of typical art objects are investigated by integrating the exact nonlinear equations of motions and experimentally on simple prototypes subjected to shaking table tests. The numerical versus experimental results allow to obtain useful data for better understand the performance of this passive control strategy and to identify the main characteristic parameters of the isolation device that can provide a significant seismic isolation effect on object of arts.

References

[1] Calì I, Marletta M. Passive control of the seismic rocking response of art objects. *Engineering Structures*, 2003; 25: 1009–1018.

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Palermo, Italy, August 27 - 30, 2023

Title: A workflow for crystallinity prediction of 3D printed poly-ether-ether-ketone

Author(s): Francesca Rotini^{*1}, Gianluca Alaimo¹, Stefania Marconi^{1,2}

¹ Department of Civil Engineering and Architecture, University of Pavia, Pavia, Italy, francesca.rotini01@universitadipavia.it, gianluca.alaimo@unipv.it

² IRCCS Policlinico San Matteo Hospital Italy, Pavia, Italy, stefania.marconi@unipv.it

Keyword(s): PEEK, additive manufacturing ,FDM, process simulation, Avrami's law

Introduction

Poly-Ether-Ether-Ketone (PEEK) is a high-performance thermoplastic polymer used in a wide range of applications and it can be processed using additive manufacturing techniques, like Fused Deposition Modelling (FDM). By controlling process temperatures, it is possible to optimize the degree of crystallinity that affects the final properties of the material [1]. In the present work, we propose a numerical workflow to predict the degree of crystallinity of PEEK printed components.

Methods

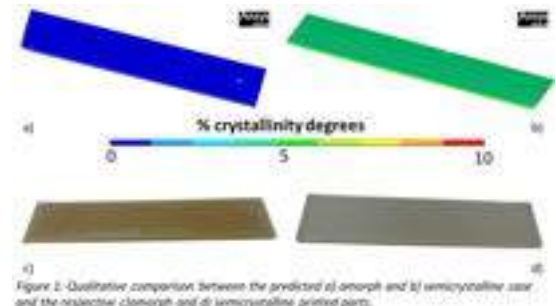
Starting from the G-Code file, we retrieve the 3D printed geometry and create a volumetric mesh, in which groups of elements are defined and sequentially activated in the thermal simulation run through the Ansys® DED Process module. At each thermal step, the elements' temperatures are used to predict the crystallinity degree according to Avrami's Law [2]:

$$X_{vc} = X_{vc\infty}(w_1 F_{vc1} + w_2 F_{vc2}) \text{ with } F_{vc,i} = 1 - \exp \left[-C_{i1} \int_0^t \exp \left\{ \frac{-C_{i2}}{T - T_g + T_{add,i}} - \frac{C_{i3}}{T(T_{m,i} - T)^2} \right\} n_i t^{n_i-1} dt \right]$$

Where X_{vc} is the evaluated volume fraction crystallinity, $X_{vc\infty}$ the equilibrium volume crystallinity fraction, w_1 and w_2 the weight factors (with $w_1 + w_2 = 1$), n_i the Avrami's coefficient, T the current temperature, T_g the glass transition temperature, T_m the melting temperature, $T_{add,i}$ an additional model temperature defined by the Avrami's law and C_{i1}, C_{i2}, C_{i3} the physical properties of PEEK.

Results and discussions

We have conducted two simulations respectively on a) amorph and b) semicrystalline cases. Predictions are qualitatively comparable to the respective 3D printed parts (Fig.1). The framework requires further improvement with a deeper analysis of process temperatures, using a thermal imaging camera, and must be validated through Differential Scanning Calorimetry to assess the actual degree of crystallinity of 3D printed components.



References

- [1] Yang C, Tian X., et al., "Influence of thermal processing conditions in 3D printing on the crystallinity and mechanical properties of PEEK material", Journal of Materials Processing Tech., 248,1-7,2017
- [2] Avrami M., "Kinetics of Phase Change. I general Theory", The Journal of Chemical Physics, 7, 1103, 1939

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Influencing parameters of additive manufacturing on the viscous encapsulation phenomena of PLA-PCL blending

Author(s): F. Amiri^{*1,2}, P. Fucile², G. Nuzzo¹, M. Zingales^{1,3}, L. Moroni²

*1*Università degli studi di Palermo, Dipartimento di Ingegneria, Viale delle Scienze, Palermo, Italy

2 MERLN Institute for Technology Inspired Regenerative Medicine, Complex Tissue Regeneration department, Maastricht University, Maastricht, the Netherlands

3 Bio/NanoMechanics for Medical Sciences Laboratory (BNM 2 -Lab), Advanced Technology Network (ATeN)-Center, CHAB Pole, Viale delle Scienze, Ed.18, 90128, Palermo, Italy

Keyword(s): viscous encapsulation, 3D printer, PLA, PCL, core-shell structure

Abstract

In the field of additive manufacturing (AM), coextrusion technique involves the simultaneous deposition of two or more materials with a common longitudinal axis, producing a core-shell or multi-core-shell multi-material structure with unique properties and performance ^[1,2]. However, it usually need more effort, work, materials, facilities and handling ^[3]. Anyway, it is also possible make it exploiting the so-called “Viscous Encapsulation phenomena”, a rheological phenomenon in which the fluid with higher viscosity usually encapsulates the less viscous one ^[4,5]. Nevertheless, only few works have been published about this topic, since in polymer science it is often a phenomenon that is to be avoided.

In this work, we studied the viscous encapsulation that occurs into polymeric blends of Poly(lactide- ϵ -caprolactone) (PLC) and Poly(L-lactide)(PLA) in different ratios, using a 3D printing techniques. In detail, we assessed their rheological properties through DSC analysis, while the inter-phases of PLA and PCL were further investigated through SEM analysis on both normal and transverse direction of the scaffolds, in addition to the TEM and XRD analysis on the cross section of the single fibers. To further validate the structure, we also performed a dissolution test in Acetic Acid to dissolve only PCL within the scaffolds. Moreover, we have investigated the influence on the phase-separation phenomenon of many process parameters, such as pressure, nozzle length/diameter ratio, and screw and extrusion speed. Consequently, knowing the influence of these factors, we were able to create an interesting bi-phasic circular structure, using only one blend into the cartridge of the 3D-printer. In fact, the resulting core-shell structure can be used to combined biochemical and biomechanical properties in a simple way, representing a new strategy for fabricating functional human tissues and organs, especially for prosthetic implants, scaffolds for regenerative medicine, anti-adhesive surfaces, and controlled release devices. Anyway, we investigated PLA-PCL blends, which are widely used in biomedical and biomaterials engineering, but this phenomenon could also be extended to blends of different immiscible polymers.

References

- [1] Lamnawar, K., Huagui Zhang & Maazouz, A. Coextrusion of Multilayer Structures ,. *Encycl. Polym. Sci. Technol.* (2013).
- [2] Takase, M., Kihara, S. I. & Funatsu, K. Three-dimensional viscoelastic numerical analysis of the encapsulation phenomena in coextrusion. *Rheol. Acta* 37, 624–634 (1998).
- [3] Rafiee, M., Granier, F. & Therriault, D. Advances in Coaxial Additive Manufacturing and Applications. *Adv. Mater. Technol.* 6, 1–25 (2021).
- [4] Chen, W., Chu, J., Wu, G., Zhang, Y. & Yang, M. Rheology control of HDPE/PP binary system forming a multilayer structure: Effects of MWD and shear rate. *Polym. Test.* 73, 60–71 (2019).
- [5] Yue, P., Zhou, C., Dooley, J. & Feng, J. J. Elastic encapsulation in bicomponent stratified flow of viscoelastic fluids. *J. Rheol. (N. Y. N. Y.)* 52, 1027–1042 (2008).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Phase transformation in the presence of anomalous heat transfer: a fractional order theory

Author(s): Gianmarco Nuzzo^{*1}, Fabiana Amiri¹, Emanuela Bologna¹, Massimiliano Zingales¹

¹ *Department of Engineering, University of Palermo, Palermo, Italy, Viale delle Scienze ed. 8*

Keyword(s): Fractional calculus, anomalous heat transfer, Stefan Problem

Abstract

Phase transition in materials due to heat transfer is known as Stefan problem, that is, mathematically, a system of partial differential equations concerning a material subject to a phase transition, usually the melting from solid to liquid. The set of equations requires to be completed the well-known Stefan condition, which ties the two phases involved to the rate of advancement of the liquid frontier.

The system solution includes the temperature distributions in the liquid and solid phases and the position of the frontier [1].

In recent years some authors [2] have tried to find a time-fractional solution to this problem by introducing an order of derivation α ($0 < \alpha < 1$), whereby α approaching to 1 the solution converges to the known one, but without providing any explanation for the introduction of this parameter.

In this perspective, our purpose has been the introduction of a fractional order Fourier law, rigorously derived in [3] and search for the solution of such fractional Stefan problem describing this anomalous diffusion, called sub-diffusion.

In this study the authors developed the Stefan problem with fractional Fourier equation by introducing the fractional derivative of Caputo on temperature [3], differently from what was presented in other study. This approach implies a different solution to the Stefan problem. Differently from the solutions proposed so far, the fractional integral of the flow appears in the result. The authors propose a numerical solution of a disc, which showed the fusion of the latter one considering the isotropic heat propagation. It is worth remarking that, in this case, the solution found coincides with the classical solution when the order of derivation tends to 0.

References

- [1] Gupta, S. C. (2018). The Stefan Problem and Its Classical Formulation. In The Classical Stefan Problem.
- [2] Roscani, S. D., & Tarzia, D. A. (2018). Explicit solution for a two-phase fractional Stefan problem with a heat flux condition at the fixed face. *Computational and Applied Mathematics*, 37(4), 4757–4771.
- [3] Alaimo, G., Piccolo, V., Chiappini, A., Ferrari, M., Zonta, D., Deseri, L., & Zingales, M. (2018). Fractional-Order Theory of Thermoelasticity. I: Generalization of the Fourier Equation. *Journal of Engineering Mechanics*, 144(2), 04017164.

*Correspondence: gianmarco.nuzzo@unipa.it

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The free energy function for advanced manufactured materials

Author(s): Emanuela Bologna^{1,2}, Gaia Prezioso^{*1}, Massimiliano Zingales^{1,2}

¹ *Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali, Viale delle Scienze, ed. 8, I-90100, Palermo, Italy, emanuela.bologna@unipa.it, gaia.prezioso@community.unipa.it*

² *Bio/NanoMechanics for Medical Sciences Laboratory (BNM²-Lab) Advanced Technology Network (ATeN)-Center, CHAB Pole, Viale delle Scienze, ed. 8, I-90128, Palermo, Italy, massimiliano.zingales@unipa.it*

Keyword(s): hereditariness; fractional calculus; free energy; dissipation; additive manufacturing

Abstract

Material hereditariness has been a widely studied topic. Indeed, several materials, such as rubber or foams, do not show a clear separation between the solid phase and the liquid one, and this has led to the formulation of a mono-axial fractional-hereditary model. This model is based on the relaxation function $G(t)$ and the creep one $J(t)$ that are formulated in terms of power laws. Furthermore, material hereditariness of fibrous human tissues has recently become an interesting subject especially because of their non-linear behaviour [1].

However, the mono-axial model is not appropriate for the biological materials. This is the reason why, starting from the mono-axial fractional-hereditary model, a three-dimensional constitutive relation describing material hereditariness was formulated [2]. This constitutive relation is based on creep and relaxation functions, which are expressed in terms of power laws, but, in order to obtain an exhaustive mathematical description to capture the real behaviour of these tissues, the functions are represented in matrix form, moreover the two matrices are mathematically linked.

In this study, the extension of the free energy function, that has already been formulated for the mono-axial model, will be proposed for the three-axial fractional-hereditary isotropic model. Indeed, for the mono-axial case, in recent years a model for the free energy function was proposed in order to obtain a unique formulation, and it was done also in order not to create ambiguity in deriving the maximum recoverable work and the dissipation [3,4,5].

However, the extension of this formulation to the three-axial fractional model is not such immediate.

That is why, in this study, a generalization is proposed together with some numerical considerations that show the flexibility of the model.

Indeed, thanks to this mathematical representation, the authors will apply this model to the realisation of additive manufacturing materials.

References

- [1] Bologna E., Di Paola M., Dayal K., Deseri L., Zingales M., "Fractional-order nonlinear hereditariness of tendons and ligaments of the human knee", *Phil. Trans. R. Soc. A*, 378(2172), (2020).
- [2] Bologna E., Graziano F., Deseri L., Zingales M., "Power-Laws hereditariness of biomimetic ceramics for cranioplasty neurosurgery", *International Journal of Non-Linear Mechanics*, 115, 61-67, (2019).
- [3] Staverman A., Schwarzl T., "Thermodynamics of viscoelastic behavior", *Ver. Akad. Can. Wet. Amsterdam*, B55, 474-485, (1952).
- [4] Deseri L., Di Paola M., Zingales M., "Free energy and states of fractional-order hereditariness", *International Journal of Solids and Structures*, 51, 3156-3167, (2014).
- [5] Colinas-Armijo N., Di Paola M., Pinnola F., "Fractional characteristic times and dissipated energy in fractional linear viscoelasticity", *Commun Nonlinear Sci Numer Simulat*, 37, 14-30, (2016).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Comparison of three design of customized stent-graft for AAA realized in additive manufacturing.

Author(s): Sara Ragusa^{*1}, Katia Siciliano², Emanuela Bologna³, Massimiliano Zingales⁴, Felice Pecoraro⁵

¹ AMED srl. , 90128 Palermo, Italy, ragusa@amedsrl.com

² AMED srl. , 90128 Palermo, Italy, siciliano@amedsrl.com

³ Department of Engineering, University of Palermo, 90128 Palermo, Italy, emanuela.bologna@unipa.it

⁴ Department of Engineering, University of Palermo, 90128 Palermo, Italy, massimiliano.zingales@unipa.it

⁵ Department of Surgical, Oncological and Oral Sciences, University of Palermo, 90133 Palermo, Italy, felice.pecoraro@unipa.it

Keyword(s): EVAR, stent-graft, FSI, additive manufacturing

Abstract

Abdominal Aortic Aneurysm (AAA) is a permanent dilation of the aorta in the infrarenal region. Appropriate surgical treatment varies from patient to patient and is necessary in order to prevent the aneurysm's rupture. Endovascular aneurysm repair (EVAR) is an innovative and minimally invasive procedure, which involves the release of a stent-graft introduced via catheter in the aneurysm site. It reduces perioperative mortality and recovery time associated with open surgical repair techniques, but still has some limitations related to the patient's anatomical morphology (neck angulation, neck diameter or iliac diameter) [1]. Commercial stent-graft used in clinical practice are related with different complications, such as graft migration, endoleak or leakage. The main cause is the mismatch between patient's vascular anatomy and device graft, which is uniform in size and structure [2]. In this context, customized stent grafts are considered the device of next generation. They can accommodate the true patient's vascular anatomy, avoiding adverse events. In our previous works, we proposed a 3D printing patient-specific stent-graft for the EVAR treatment of a patient, demonstrating its benefits through Computational Fluid Dynamics (CFD) [3, 4].

In this work, we have studied the stent-graft's metallic frame, by designing three possible configuration. We also have performed a Fluid-Structure Interaction (FSI) analysis to evaluate the interaction between rings and graft, in term of Von Mises Stress. The authors propose to identify the optimal desing by in silico testing. This preliminary study is aimed at realizing a prototype in additive manufacturing in collaboration with the innovative start-up AMED srl.

References

- [1] S. Jaunoo. "Endovascular aneurysm repair (EVAR)". In: International journal of surgery (London, England), page 266–269, (2008)
- [2] Zhang L., Chen X., Liu M., "Research of customized aortic stent graft manufacture" In IOP Conference Series: Materials Science and Engineering; IOP Publishing: Hong Kong, 2016; Vol. 187, page 012027. (2016)
- [3] Ragusa, S., Katia Siciliano, K., Di Simone, F., Russotto, S., Bologna, E., Zingales, M., "Fluid-structure interaction (FSI) analysis of 3D printing personalized stent-graft for aortic endovascular aneurysm repair (EVAR)", Materials Research Proceedings, Vol. 26, pp 299-304, (2023)
- [4] Bologna E., Dinoto E., Di Simone F., Pecoraro F., Ragusa S., Siciliano K., Zingales M., "Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEM) of a Customized Stent-Graft for Endovascular (EVAR) Treatment of Abdominal Aortic Aneurism (AAA)". Appl. Sci. 1, (2023), (pre-print)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Polysaccharide-based bio-ink for 3D printing of scaffolds for cartilage reconstruction

Author(s): E. Muscolino^{1*}, S. Galvano¹, A.B. Di Stefano², F. Toia², M.A. Sabatino¹, M. Trapani², F. Moschella², A. Cordova², D. Giacomazza³, C. Dispenza^{1,3}

¹ *Dipartimento di Ingegneria, Università degli Studi di Palermo, Viale delle Scienze 6, 90128 Palermo, Italy;*

² *BIOPLAST - Laboratory of BIOlogy and Regenerative Medicine-PLASTic Surgery, Dipartimento di Discipline Chirurgiche, Oncologiche e Stomatologiche, Università degli Studi di Palermo, via del Vespro 129, 90127, Palermo, Italy;*

³ *Istituto di BioFisica, Consiglio Nazionale delle Ricerche, Via U. La Malfa 153, 90146 Palermo, Italy.*

Keyword(s): 3D printing, hydrogels, polysaccharides, cartilage regeneration, tissue engineering

Abstract

Hydrogels are widely used as bio-inks in 3D printing methods aimed at reconstructing the extracellular matrix of relatively soft tissues. The ability to control the printing process based on computer-aided design (CAD) of a patient's injured or missing body part promises to create patient-specific structures. [1] The physicochemical and biological properties of the formed hydrogel should be paralleled by a proper viscoelastic behavior of the formulation during and after extrusion from the printing nozzle. Physically crosslinked hydrogels are often preferred over chemically crosslinked systems because they do not require initiators or catalysts that induce cytotoxicity and require rigorous purification.

Due to their structural composition and self-assembly behavior in aqueous media, some polysaccharides have an inherent ability to form strong networks under mild conditions. k-carrageenan (kC) is one of the most prominent examples [2]. kC is a sulfated polygalactan from red algae with a sulfate content of 25–30% and an average molecular weight well above 100 kDa that has a similar structure to glycosaminoglycans (GAGs), which are central components of connective tissue. For this reason, kC can be considered as a suitable scaffold material for tissue engineering. kC is water soluble at temperatures above 60 °C and hardens into a stable hydrogel when cooled. The kC network is characterized by a strong, fragile, multilayer morphology. kC blends with other tougher polymers such as polyvinyl alcohol (PVA) can improve mechanical properties and create porosity [3].

In our study, we investigate the suitability of an aqueous kC/PVA systems with three different weight ratios between the two polymers for the 3D printing of scaffolds for cartilage reconstruction. Their rheological behavior was investigated for effects on processing and product properties. In addition, we investigated the morphological features and mechanical properties, through quasi-static compression tests and dynamic mechanical analysis (DMA). The actual printability of the formulation was also tested with and without adipose-derived stem cell (SASC) spheroids. The cells were cultured for 21 days in the presence of two different media, resulting in an increased cell viability for all formulations when cells were cultured in chondrocytic differentiation conditions.

References

[1] Y. Zhang, L. Ye, M. Cui, B. Yang, J. Li, H. Sun, F. Yao, RSC Adv., 2015, 5(95), 78180-78191.

[2] J.T. Oliveira, R.L. Reis, J. Tissue Eng. Regen. Med. 2011, 5, 421-36.

[3] J. Necas, L. Bartosikova, Veterinarni Medicina, 2013, 58, 187–205.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Bio-Inspired Parametric Design of Graded Cell Size Primitive based in B-Spline Interpolation

Massimo Cuomo¹, Golshan Farzi²

¹ *Department of Civil Engineering and Architecture, University of Catania, Italy, mcuomo@dica.unict.it*

² *Department of Civil Engineering and Architecture, University of Catania, Italy, golshan.farzi@phd.unict.it*

Keywords: Bio-inspired Design, Graded Cell Size, TPMS, Parametric Modeling

Abstract

In nature, many biological structures exhibit graded cell size arrangements, where the size and distribution of cells or structural elements change gradually across the material. Bio-inspired parametric design offers a unique approach to enhancing the mechanical properties of structures through the integration of graded cell size primitives. Graded cell size involve the systematic variation of cell sizes within a design, taking inspiration from hierarchical structures found in nature.

Architected materials presenting continuous microstructures can be realized by means of Triply Periodic Minimal Surfaces. Scaling in this case is possible without modifying the morphology of the microstructure nor losing continuity. This result is particularly important in biomedical devices, where accessible porosity is essential in order to guarantee transport of cellular material.

The study presents a novel approach to design porosity graded elements using B-Spline interpolation for the density function. In this way it is possible to obtain generic types of grading just changing the values of the control variables. The approach appears particularly interesting since it allows to use a unique environment for the design, the optimization procedure and the mechanical simulation using Iso Geometrical Analysis.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Innovative passive structural control systems including a nonlinear fluid inerter: an experimental-numerical study

Authors: Miriam Chillemi^{*1}, Thomas Furtmüller², Christoph Adam³, Antonina Pirrotta⁴

¹ Unit of Applied Mechanics, Universität Innsbruck, Innsbruck, Austria, miriam.chillemi@uibk.ac.at

² Unit of Applied Mechanics, Universität Innsbruck, Innsbruck, Austria, thomas.furtmueller@uibk.ac.at

³ Unit of Applied Mechanics, Universität Innsbruck, Innsbruck, Austria, christoph.adam@uibk.ac.at

⁴ Department of Engineering, University of Palermo, Palermo, Italy, antonina.pirrotta@unipa.it

Keywords: Structural control, fluid inerter, small-scale experiment, inertance

Abstract

The need to take into account architectural features when solving structural issues leads to the so-called structural vibration control, i.e. the prevention and mitigation of vibrations. Among the devices for structural control, passive vibration control systems are commonly used in construction due to their robustness. Thanks to their efficiency, passive devices such as Tuned Mass Dampers (TMDs) or Tuned Liquid Column Dampers (TLCDs) have received much attention and recognition in the context of vibration control. However, it should be noted that the performance of such mass-dependent devices strongly relies upon their design. With this mind, the development of innovative vibration systems capable of overcoming the limits of already widely used passive control devices has gained considerable attention in the literature. Inerters were first introduced by Smith [1], in 2002 and have since been employed in the automotive sector. Nowadays, however, the interest in their properties has spread also around the civil engineering sector. The inerter fictitiously increases the mass of the system to which it is attached, allowing for a mass amplification effect. It can be treated as a two-terminal device in which the internal force is proportional to the relative acceleration between the two terminals. The constant of proportionality is called inertance and corresponds to the generated apparent mass. It may be very large and can be used in combination with springs and dashpot dampers (referred to as Tuned Inerter Dampers, TIDs) or to improve the performance of TMDs and TLCDs (referred to as Tuned Mass Damper Inerters and Tuned Liquid Column Damper Inerters). While mechanically built and prototyped inerters have been widely tested, experimental verification of fluid inerters is not as widespread in the literature. The latter are easier to design and develop and exhibit less pronounced parasitic effects than the mechanical alternatives [2]. Nevertheless, according to their nature, they can be affected by nonlinearities, i.e., fluid viscous shear friction, pressure drop, and other tribological effects [3]. For these reasons, an experimental-numerical study has been carried out to characterize the dynamic properties of a fluid inerter. The prototype consists of a hydraulic cylinder in which the inerter effect is achieved by the flow of the working fluid through an external channel. Once an accurate mechanical model of the device has been determined, its efficiency is demonstrated by comparative studies. The good agreement between analytical and experimental outcomes proves that it is possible to generate a fictitious mass that is orders of magnitude larger than the mass of the flowing fluid. This highlights the large potential of fluid inerters when applied to vibration control in civil structures. Moreover, a mechanical model that accounts for the aforementioned nonlinear effects enables the development of more realistic numerical simulations of devices implemented for structural controlling.

References

[1] Smith M., "Synthesis of mechanical networks: the inerter," IEEE Transactions on Automatic Control, 47, 1648–1662, (2002).

- [2] Sarkar S., Fitzgerald B., "Fluid inerter for optimal vibration control of floating offshore wind turbine towers," *Engineering Structures*, 266, 114558, (2022).
- [3] Chillemi M., Furtmüller T., Adam C., Pirrotta A., "Nonlinear mechanical model of a fluid inerter," *Mechanical Systems and Signal Processing*, 188, 109986, (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Numerical Modelling and Experimental Analysis on a Scaled Unreinforced Masonry Building

Author(s): Mariagrazia Elena Alberti^{*1}, Francesco Lo Iacono¹, Giuseppe Mugnos¹, Giacomo Navarra¹

¹ *Facoltà di Ingegneria e Architettura, Università degli Studi di Enna Kore, Enna, Italy*

Emails: mariagraziaelena.alberti@unikorestudent.it, francesco.loiacono@unikore.it,

giuseppe.mugnos@unikorestudent.it, giacomo.navarra@unikore.it

Keywords: masonry building, dynamic identification, finite element modelling, shaking table tests

Abstract

Masonry structures represent a significant part of the European building heritage and include historic constructions with architectural and cultural value. However, recent earthquakes in the Mediterranean area have dramatically demonstrated that the seismic behaviour of unreinforced masonry buildings is typically characterized by premature brittle collapse mechanisms. Therefore, the issue related to seismic assessment and retrofit of existing masonry buildings is currently attracting considerable attention due to the progressive relative reduction of new construction activity with respect to interventions on existing structures. This highlights the necessity to improve the knowledge about the dynamic behaviour of masonry structures excited by strong ground motions, to develop useful design solutions to mitigate the seismic vulnerability of the historical constructions and of masonry buildings in general. In this regard, numerical simulation is still a very complex task due to the different construction characteristics, properties and heterogeneity of materials. Finite element modelling (FEM) can be used to predict and numerically analyse the structural behaviour of masonry buildings under seismic loading [1] but needs to be calibrated by experimental tests among which shaking table tests can provide important information because the seismic scenario can be rendered realistically. The main purpose of this study is the evaluation of the seismic performance of a 2:3 scale model of a two-storey masonry building, built with the typical materials and construction techniques used for old masonry buildings in central Sicily. The dynamic characterization of the unreinforced masonry model was estimated from the acceleration time histories recorded during Ambient Vibration (AVT) and Impact Hammer (HT) tests. Using a macro-modelling approach, the estimation of the dynamic modal characteristics of the system has allowed the calibration of finite element (FE) numerical models, useful for simulating the dynamic response of the masonry model through the execution of seismic analyses in all the three directions and with increasing intensity [2]. The numerical results obtained will support the design and execution of shaking table tests which will be performed at the LEDA Research Institute (Enna, Italy [3]), before and after seismic reinforcement works with innovative techniques.

References

- [1] Ravichandran N., Losanno D., Parisi F., "Comparative assessment of finite element macro-modelling approaches for seismic analysis of non-engineered masonry constructions", *Bull Earthquake Eng*, 19, pp. 5565–5607, (2021).
- [2] Pepi C., Cavalagli N., Gusella V., Giofrè M., "Damage detection via modal analysis of masonry structures using shaking table tests," *Earthquake Engineering Structural Dynamics*, 50(8), pp. 2077-2097, (2021).
- [3] Lo Iacono, F., Navarra, G., Oliva, M., Cascone, D., "Experimental Investigation of the Dynamic Performances of the LEDA Shaking Tables System" in *Proceedings of the 23rd Conference of the Italian Association of Theoretical and Applied Mechanics, AIMETA 2017, Salerno, 4-7 September 2017*, 5, pages. 897–915 (2017).

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Title: Sensitivity Analysis on a Novel Continuous Particle Swarm Optimization Algorithm for EMA Model Updating

Author(s): Giuseppe Mugnos^{*1}, Francesco Lo Iacono¹, Giacomo Navarra¹, Angela Ricciardello¹.

¹ Faculty of Engineering and Architecture, University of Enna Kore, Enna, Italy,

Emails: giuseppe.mugnos@unikorestudent.it, francesco.loiacono@unikore.it, giacomo.navarra@unikore.it, angela.ricciardello@unikore.it.

Keyword(s): Continuous Particle Swarm Optimization; Experimental Modal Analysis; Model Updating

Abstract

The effectiveness of design, construction, and validation processes in the production of human artifacts are crucial to ensure success in the development of an industrial product and to guarantee its structural robustness during lifetime. More often, these three processes are not related one to each other and the discrepancy between the design of an artifact and its actual construction can generate uncertainty on the mechanical behaviour of the structures. To fill up the gap between design and actual built structural models, several model updating methods [1] have been proposed by the scientific literature in the past decades.

In a previous work proposed by the same authors [2], a structural model updating procedure based on a recent variant of the Particle Swarm Optimization algorithm, called Continuous Particle Swarm Optimization (CPSO), has been developed showing good performance in terms of accuracy and computational time reduction in comparison with other heuristic search algorithms.

In the present paper, the results of a numerical campaign aiming to assess the robustness of the proposed algorithms CPSO is reported. An extensive sensitivity analysis has been conducted by varying the CPSO parameters and the target objective functions by focusing on several structural parameters.

The proposed model updating method has been stressed and validated by using the experimental data recorded on a real-scale large electrical device whose dynamical properties have been characterized by using Experimental Modal Analysis (EMA) approach. Both random noise and seismic experimental responses of the structure under investigation have been acquired by taking advantage of the shaking table system of the L.E.D.A. (Laboratory of Earthquake engineering and Dynamic Analysis) Research Institute at the “Kore” University of Enna, Italy [3].

References

- [1] Friswell, M., & Mottershead, J. E., Finite element model updating in structural dynamics. Springer Science & Business Media (1995).
- [2] Lo Iacono, F., Navarra, G., Orlando, C. and Ricciardello, A., "Continuous particle swarm optimization for model updating of structures from experimental modal analysis" in Proceedings of the 24rd Conference of the Italian Association of Theoretical and Applied Mechanics, AIMETA 2022, Palermo, 4-8 September 2022, pp. 467-472 (2023).
- [3] Lo Iacono, F., Navarra, G., Oliva, M., Cascone, D., “Experimental Investigation of the Dynamic Performances of the LEDA Shaking Tables System” in Proceedings of the 23rd Conference of the Italian Association of Theoretical and Applied Mechanics, AIMETA 2017, Salerno, 4-7 September 2017, 5, pp. 897–915 (2017).

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Title: Structural vibration control through Sliding Tuned Liquid Column Damper: an experimental study

Authors: Chiara Masnata¹, Salvatore Di Trapani^{*1}, Antonina Pirrotta¹

¹ *Department of Engineering, University of Palermo, viale delle Scienze, 90128, Palermo, Italy*

Keywords: Small-Scale Model, Sliding Tuned Liquid Column Damper, STLCD, Vibration Control, Shake Table Test

Abstract

In the context of structural control, Tuned Liquid Column Dampers (TLCDs) are among the most popular passive control devices for vibration mitigation of structures subjected to dynamic excitations such as wind and earthquakes [1,2]. However, being long-period systems, their applicability is often limited to flexible structures. Hence, in order to extend their use to short-period structures, previous studies considered a translational spring-connected model of TLCD [3]. This device is herein referred as Sliding TLCD (STLCD) since it is essentially composed of a traditional TLCD, which is a U-tube container, with liquid inside, able to slide on a linear guide rail and connected to the structure by a spring-dashpot system. This kind of flexible mounting allows tuning the proposed STLCD to a wider range of structural systems. Nevertheless, this configuration was explored in literature only from a theoretical point of view. Therefore, in this study, the dynamic behavior and the great potential of this device are experimentally investigated using shake table testing and considering a scale STLCD-controlled structure with a focus on the reduction of the top story accelerations. The validity of the mathematical model is verified both in time and frequency domains through experimental tests conducted in the Laboratory of Experimental Dynamics at the University of Palermo, Italy. Finally, for comparison purposes, the effectiveness of the proposed control strategy for the vibration suppression of stiff structures is evaluated by analyzing its structural responses in contrast to the corresponding uncontrolled structure under harmonic excitations.

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References

- [1] Hochrainer M.J., Ziegler, F., "Control of tall building vibrations by sealed tuned liquid column damper", *Structural Control and Health Monitoring* 13 (6), 980–1002, (2006).
- [2] Di Matteo, A., Lo Iacono, F., Navarra, G., Pirrotta, A., "Direct evaluation of the equivalent linear damping for TLCD systems in random vibration for pre-design purposes", *International Journal of Non-Linear Mechanics* 63, 19–30 (2014).
- [3] A. Ghosh, B. Basu, "Seismic vibration control of short period structures using the liquid column damper", *Engineering Structures*, 26(13):1905-13, (2004).

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Title: Operational Modal Analysis of quasi-periodic multi-span bridges: a model-based approach for Hierarchical Clustering

Author(s): Elisa Tomassini^{*1}, Enrique García-Macías², Edwin Reynders³ and Filippo Ubertini⁴

¹ Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 - 06125 Perugia, Italy, elisa.tomassini1@studenti.unipg.it

² Department of Structural Mechanics and Hydraulic Engineering, University of Granada, Av. Fuentenueva sn, 18002 Granada, Spain, enriquegm@ugr.es

³ Department of Engineering, University of Leuven (KU Leuven), Kasteelpark Arenberg 40, B-3001 Leuven, Belgium, edwin.reynders@kuleuven.be

⁴ Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 - 06125 Perugia, Italy, filippo.ubertini@unipg.it

Keyword(s): Structural Health Monitoring, Operational Modal Analysis, Periodic structures, Multi-span bridges, Hierarchical clustering

Abstract

In recent decades, increasing efforts have been devoted to develop innovative techniques to evaluate the health state of transportation network components. In this field, vibration-based Structural Health Monitoring (SHM) strategies play a key role in relation to their low intrusiveness and non-destructive characteristics [1]. Particularly, Operational Modal Analysis (OMA) is a vibration-based SHM technique that allows the extraction of the modal features of the structures starting from the accelerations recorded under operating conditions [2]. Many highway bridges can be classified as quasi-periodic structures, in relation to their geometrical and mechanical recursive properties. The distinctive characteristic of periodic structures is that the frequencies appear as dense clusters and mode-shapes present similar wavelengths [3-4]. Therefore, the global assessment of these structures is particularly challenging for OMA purposes. To overcome such an issue, span-wise modal identification is frequently applied, which is justified by the fact that the static pattern is that of simply supported spans. Nonetheless, a partial continuity between the spans often exists due to partial closure of expansion joints and weak deck/asphalt connections at the intermediate supports. Therefore, a global modal identification of the structure may be more effective to properly characterize the bridge behaviour. One of the most used time-based OMA methods is the covariance-based Stochastic Subspace Identification, in relation to its capability to identify closely-spaced frequencies [5-7]. The stable poles are evaluated by mean of a stabilization diagram [8], and the resulting physical frequencies can be automatically identified by means of clustering techniques. To this end, Hierarchical Clustering machine learning algorithms are widely adopted [9-10]. These approaches are based on the calculation of a distance between the poles considering the similarity between frequencies and mode-shapes and the composition of a Π -shape clustering diagram (dendrogram). Particularly, the identified modes depend on the cut-off distance defined on the dendrogram. In this light, a novel methodology to compute the optimal cut-off distance threshold for the specific case of quasi-periodic multi-span bridges is proposed in this work. The formulation is based on the analytical modal solution to the free vibration problem of multi-span Euler-Bernoulli beams with weak rotational coupling between adjacent spans. The developed methodology is validated on a real seven-span concrete girder bridge.

References

- [1] An Y., Chatzi E., Sim S., Laflamme S., Blachowski B., Ou J., Recent progress and future trends on damage identification methods for bridge structures, *Structural Control Health Monitoring* 26, e2416, (2019).
- [2] Magalhães F., Cunha Á., Explaining operational modal analysis with data from an arch bridge, *Mechanical systems and signal processing* 25 (5), 1431–1450, (2011).
- [3] Zhang J., Reynders E., De Roeck G., Lombaert G., Model updating of periodic structures based on free wave characteristics, *Journal of Sound and Vibration*, 442, 281–307, (2019).
- [4] Zhang J., Maes K., De Roeck G., Lombaert G., Model updating for a large multi-span quasi-periodic viaduct based on free wave characteristics, *Journal of Sound and Vibration*, 506, 116161, (2021).
- [5] Peeters B., De Roeck G., Reference-based stochastic subspace identification for output-only modal analysis, *Mechanical Systems and Signal Processing*, 13 (6), 855–878, (1999).
- [6] Rainieri C., Fabbrocino G., Cosenza E., Automated Operational Modal Analysis as Structural Health Monitoring tool: theoretical and applicative 574 aspects, *Key Engineering Materials*, Vol. 347, Trans Tech Publications, 479–484, (2007).
- [7] García-Macías E., Ubertini F., MOVA/MOSS: Two integrated software solutions for comprehensive Structural Health Monitoring of structures, *Mechanical Systems and Signal Processing* 143, 106830, (2020).
- [8] Reynders E., Houbrechts J., De Roeck G., Automated interpretation of stabilization diagrams, *Modal Analysis Topics*, 3, 189–201, (2011).
- [9] Ubertini F., Gentile C., Materazzi A. L., Automated modal identification in operational conditions and its application to bridges, *Engineering Structures*, 46, 264–278 (2013).
- [10] Zini G., Betti M., Bartoli G., A quality-based automated procedure for operational modal analysis, *Mechanical Systems and Signal Processing*, 164, 108173, (2022).

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Title: Development of a low-cost Vehicle-Bridge Interaction based approach for the structural modal identification of a bridge.

Author(s): Dario Fiandaca^{*1}, Antonina Pirrotta²

¹ Department of Engineering, University of Palermo, Palermo, Italy dario.fiandaca@unipa.it

² Department of Engineering, University of Palermo, Palermo, Italy antonina.pirrotta@unipa.it

Keyword(s): VBI, monitoring, SHM, bridge, frequency, mode shape.

Abstract

Structural health monitoring (SHM) is critical for ensuring the safety and longevity of bridge infrastructure networks [1]. Bridges are exposed to various environmental and operational loads that can cause damage, deterioration, and potential failure. Regular monitoring and maintenance are necessary to identify and address structural issues before they become a safety concern.

Operational Modal Analysis (OMA) methods are commonly used for SHM due to their reliability in monitoring structural parameters such as natural frequencies, mode shapes, and damping ratios. However, OMA methods can be expensive and time-consuming, which makes it difficult to implement them on a large scale.

To overcome these challenges, a low-cost Vehicle-Bridge Interaction (VBI) based approach for the identification of structural modal parameters has been developed [2-3]. In particular, the analysis is carried out, employing an appropriate identification procedure, in the frequency domain to extract the main frequencies and mode shapes from the dynamic response, in terms of vertical acceleration, of the platform positioned over the bridge. This approach therefore provides a reliable estimate of the structural parameters of the bridge by taking advantage of the interaction between the bridge and the mobile platform.

The proposed VBI approach was experimentally tested on a pedestrian bridge in Palermo, Italy using a scaled-up electric mobile platform equipped with both piezoelectric and micro-electromechanical systems (MEMS) accelerometers. It should be notice that the VBI-based approach is particularly suited also for bridges that are open to traffic, making it possible to assess their condition during regular use without disrupting traffic.

In addition, the study includes a conventional OMA-based technique used as a benchmark for comparison with the results obtained from the innovative approach proposed. Finally, the feasibility of using MEMS accelerometers of ordinary smartphones to record vehicle accelerations is also explored to investigate the potential of employing a crowd-sensing technique for bridge monitoring purposes [4].

References

- [1] Cottone G., Pirrotta A., Salamone S., "Incipient damage identification through characteristics of the analytical signal response", *Structural Control and Health Monitoring*, 15, (2008).
- [2] Yang Y.-B., Lin C., Yau J., "Extracting bridge frequencies from the dynamic response of a passing vehicle" *Journal of Sound and Vibration*, 272, 471-493, (2004).
- [3] Malekjafarian A., McGetrick P., O'Brien E., "A Review of Indirect Bridge Monitoring Using Passing Vehicles", *Shock and Vibration*, 4, (2015).
- [4] Di Matteo A., Fiandaca D., Pirrotta A., "Smartphone-based bridge monitoring through vehicle-bridge interaction: analysis and experimental assessment", *Proceedings of the international conference on structural health monitoring of intelligent infrastructure*, Porto, Portugal, 30 June - 2 July 2021, 259-266, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Bridge model updating by parametric design and SHM

Authors: Rebecca Asso^{1,2}, Pietro Palumbo², Luis Bohorquez², Valentina Boretti², Luigi Liberti², Davide Masera²

¹ Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino

² Masera Engineering Group, Corso Re Umberto 8, Torino)

Keyword(s): Model Updating, parametric design, bridge engineering, Structural Health Monitoring

Abstract

Parametric design has emerged as a powerful tool in the field of structural engineering, offering numerous benefits in various applications. This abstract explores the use of parametric design in the model updating of existing bridges, where real bridge data obtained from sensors is compared with the data from a numerical model, typically a Finite Element Method (FEM) model.

Parametric design provides the ability to quickly create and modify models by adjusting parameters, allowing for dynamic modifications throughout the model updating process. In the context of bridge monitoring, sensors are installed on the bridge to collect data related to its behavior, such as vibrations, deflections, and strains. This real-time data is then compared with the data obtained from a numerical (FEM) model of the same bridge.

The use of parametric design principles enables engineers to efficiently update the numerical model based on the sensor data. First, the characteristic features that need to be modified are identified. Then, by adjusting the parameters of the numerical model, the design can be automatically modified to match the behavior observed in the real bridge. This iterative process facilitates the identification of discrepancies between the numerical model and the actual behavior of the bridge, allowing for more accurate predictions and assessments. It can also include optimization algorithms for the most efficient model updating.

Additionally, the use of parametric design in model updating of existing bridges offers several advantages. Firstly, it streamlines the updating process by automating routine design tasks, enabling engineers to focus on analyzing and interpreting the sensor data. Secondly, parametric design allows for the exploration of different design scenarios and optimization of the numerical model to match the observed behavior. This iterative approach leads to more accurate and reliable predictions.

In conclusion, parametric design is a valuable tool in the model updating of existing bridges. By combining real bridge data from sensors with a numerical model, engineers can effectively update the model to match the observed behavior. The use of parametric design principles enables efficient modifications and optimization of the numerical model, leading to enhanced accuracy in predicting the structural performance of the bridge. This abstract serves as an overview of the advantages and methods of utilizing parametric design in the model updating of existing bridges, specifically focusing on the comparison of sensor data with a FEM model, and give an example of application of such methodology in a real case.

References

- [1] Holzer D, Hough R, Burry M. Parametric Design and Structural Optimisation for Early Design Exploration. *International Journal of Architectural Computing*. 2007;5(4):625-643. doi:10.1260/147807707783600780
- [2] Rasmus Rempling, Alexandre Mathern, David Tarazona Ramos, Santiago Luis Fernández, Automatic structural design by a set-based parametric design method, *Automation in Construction*, Volume 108, 2019, 102936, ISSN 0926-5805,
- [3] Boretti, V., Sardone, L., Bohórquez Graterón, L. A., Masera, D., Marano, G. C., & Domaneschi, M. (2023). Algorithm-Aided Design for Composite Bridges. *Buildings*, 13(4), 865.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Junior MS09 - Generative Design strategies and applications in the Architecture, Engineering, and Construction Industry

Title: Parametric optimization of steel truss structures using cutting Stock Problem (CSP)

Authors: Raffaele Cucuzza*¹, Marco Domaneschi¹, Marco Martino Rosso¹, Luca Martinelli², Giuseppe Carlo Marano¹

¹ Department of Structural, Building and Geotechnical Engineering, Politecnico di Torino, Torino, Italy

² Politecnico di Milano, Milano, Italy

Keyword(s): Structural optimization, bin package problem (BPP), cutting stock problem (CSP), steel structure.

Abstract

Over the past decade, the scientific community has been focused on minimizing the cost of structures by exploring ways to manipulate material, fabrication, and maintenance expenses. Structural optimization has received significant attention, particularly in reducing material costs, with the aim of achieving a slender structure while utilizing resources optimally. The researchers and practitioners in this field primarily adopted the conventional approach of optimizing the design cost of structures while adhering to safety regulations provided by standard protocols. This paper highlights an essential aspect that has been overlooked in cost optimization, i.e., the waste of material from the cutting process. Simply minimizing the amount of material involved in the construction process without careful cutting design leads to inefficient cost optimization, resulting in additional expenses. Along with the economic impact, this also leads to a higher environmental impact, which can be evaluated in terms of CO₂ emissions recorded at the production stage.

In this paper, we focus on the material waste aspect of cost optimization and propose an innovative approach that considers material waste during the design optimization stage. Our approach minimizes the material waste during the cutting stage and provides a cost-effective and environmentally friendly solution while ensuring the safety and stability of the structure.

Construction and demolition wastes were expected to account for around 23% of the overall solid waste stream. This waste ratio equates to more than 100 million tonnes every year. Over the world, several surveys corroborate the estimates from the United States. A percentage of the waste created by stock reduction is preventable, which means it is generated as a result of improper material utilisation. The quantity of superfluous acquired materials, needless workmanship, wastes and trucking and tipping fees required to discharge the garbage would be reduced if the supplies were used more efficiently [1].

Indeed, efficient resource use is not just in the interests of the industrialist, but also of the world at large. The disposal of trash from a stock-cutting operation may cause pollution, and excessive wasting may deplete our planet's precious supplies [2]. Cutting losses is possibly the most major source of steel waste. Cutting losses arise when normal steel lengths are shortened to fit the project's required lengths. A significant amount of the created steel waste according to Adham et al. [3] is related to cutting losses, which are mostly caused by dividing an order into separate, smaller orders typically results in more waste due to fewer cutting alternatives. Moreover using inefficient cutting patterns in the cutting schedule results in the generation of avoidable waste that could be avoided through better stock-cutting planning. Finally using the optimum cutting patterns may result in unavoidable waste which is the minimum waste generated if the optimum cutting patterns are used. In order to minimize waste, the cutting stock problem (CSP) represents a significant source of one-dimensional stock waste in the construction industry.

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Title: Parametric design for an accurate and cost-effective Civil Engineering

Authors: Pietro Palumbo², Rebecca Asso^{1,2}, Luis Bohorquez², Valentina Boretti², Luigi Liberti², Davide Masera²

¹ Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino

² Masera Engineering Group, Corso Re Umberto 8, Torino)

Keywords: Bridge design, Structural design, Set-based design, Parametric design

Abstract

The power of parametric modeling in bridge design has revolutionized the field of structural engineering by offering enhanced productivity, accuracy, and safety throughout the design and construction stages. Parametric design involves the use of parameters and algorithms to generate design alternatives and explore various configurations efficiently. This abstract explores the advantages and methods of parametric design applied to the class of composite steel-concrete slab bridges, specifically focusing on the implementation of the Algor4Bridge procedure. This approach enables designers to quickly create and modify models by adjusting parameters, facilitating dynamic modifications throughout the design and construction phases. The automation of design tasks allows for faster iteration and optimization, empowering designers to explore a broader design space and select the most suitable design solution. Furthermore, the integration of parametric design methods with finite element analysis (FEA) enhances the accuracy of the design process. By utilizing FEA, engineers can perform comprehensive structural analyses on the generated design alternatives. This analysis includes evaluating factors such as load-bearing capacity, stress distribution, and deflection, leading to a more accurate and reliable design process. Safety is a critical aspect of bridge construction, and parametric design techniques contribute to improved safety measures. By automating the design process, engineers can efficiently explore various design scenarios and assess their compliance with safety standards and regulations. To specifically address the methodological approach for defining the advantages and methods of parametric design applied to composite steel-concrete slab bridges, the Algor4Bridge procedure is utilized. Algor4Bridge is a specific procedure developed to improve the timing and quality of projects in this domain. In conclusion, the application of parametric design in the field of composite steel-concrete slab bridges offers numerous advantages, including improved productivity, accuracy, and safety. By incorporating parametric design principles and utilizing tools like Algor4Bridge, engineers can optimize the design process, automate routine tasks, perform comprehensive structural analyses, and ensure compliance with safety standards. The methodology is outlined as a comprehensive approach to define the advantages and methods of parametric design applied to composite steel-concrete slab bridges, aiming to enhance the timing and quality of projects.

References

- [1] Holzer D, Hough R, Burry M. Parametric Design and Structural Optimisation for Early Design Exploration. *International Journal of Architectural Computing*. 2007;5(4):625-643. doi:10.1260/147807707783600780
- [2] Rasmus Rempling, Alexandre Mathern, David Tarazona Ramos, Santiago Luis Fernández, Automatic structural design by a set-based parametric design method, *Automation in Construction*, Volume 108, 2019, 102936, ISSN 0926-5805,

[3] Boretti, V., Sardone, L., Bohórquez Graterón, L. A., Masera, D., Marano, G. C., & Domaneschi, M. (2023). Algorithm-Aided Design for Composite Bridges. *Buildings*, 13(4), 865.

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Palermo, Italy, August 27 - 30, 2023

Title: Efficient Stochastic Response Determination of Nonlinear Systems By Leveraging the Unique Extrapolation Capabilities of the Wiener Path Integral Technique

Author(s): Ilias G. Mavromatis^{*1}, Ioannis A. Kougoumtzoglou¹

¹ Department of Civil Engineering & Engineering Mechanics, Columbia University, USA, im2580@columbia.edu

² Department of Civil Engineering & Engineering Mechanics, Columbia University, USA, iak2115@columbia.edu

Keyword(s): Stochastic dynamics, nonlinear system, Wiener path integral, efficient extrapolation

Abstract

The recently developed Wiener path integral (WPI) technique for determining the stochastic response of diverse nonlinear dynamical systems relies on the concept of representing the system response joint transition probability density function (PDF) as a functional integral over the space of all possible paths satisfying the initial and final conditions in time (e.g., [1]). Further, employing a functional integral series expansion, the contribution only of the first term is ordinarily considered, pertaining to the path with the maximum probability of occurrence. This is referred to in the literature as the most probable path and corresponds to an extremum of the functional integrand. In this regard, the most probable path, which is used for determining approximately the system response joint transition PDF, is computed by solving a functional minimization problem that takes the form of a deterministic boundary value problem (BVP) (e.g., [2]). This BVP corresponds to a specific grid point of the response PDF effective domain. Note, however, that for a specific nonlinear system under consideration, the equations of the BVP are independent of the grid point. In fact, only the boundary conditions change with different grid points, whereas the equations of the BVP remain unaltered. Remarkably, the BVPs corresponding to two neighboring grid points not only share the same equations but, also the boundary conditions differ only slightly. Thus, it is expected that the BVP solutions, i.e., the most probable paths, referring to the two grid points, are highly correlated.

In this paper, the above unique aspect of the technique is explored further, and it is shown that solution of a BVP and estimation of the response PDF value at a specific grid point can be used for extrapolating and estimating efficiently the PDF values at neighboring points without the need for solving additional BVPs. Notably, the developed approach significantly enhances the computational efficiency of the WPI technique while exhibiting a satisfactory accuracy degree. Various nonlinear systems are considered in the numerical examples for demonstrating the reliability of the technique. Comparisons with pertinent Monte Carlo simulation data are included as well.

References

- [1] Petromichelakis I., Kougoumtzoglou I. A. (2020) Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries. *Proc. of the Royal Society A: Mathematical, Physical and Engineering Sciences* **476**: 20200385.
- [2] Petromichelakis I., Bosse R. M., Kougoumtzoglou I. A., Beck A. T. (2021) Wiener path integral most probable path determination: A computational algebraic geometry solution treatment, *Mechanical Systems and Signal Processing*, vol. 153, 107534: 1-24.

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Title: A Wiener Path Integral Formalism for Treating Nonlinear Systems with Non-Markovian Response Processes

Author(s): Ilias G. Mavromatis¹, Apostolos F. Psaros², Ioannis A. Kougioumtzoglou^{*1}

¹ *Department of Civil Engineering & Engineering Mechanics, Columbia University, USA*

² *Division of Applied Mathematics, Brown University, USA*

Keyword(s): Stochastic dynamics; Nonlinear system, non-Markovian process, hysteresis, fractional derivative, Wiener path integral

Abstract

The Wiener path integral (WPI) technique, pioneered by Kougioumtzoglou and Spanos [1], for determining the stochastic response of diverse dynamical systems exhibits, remarkably, both high accuracy [2] and low computational cost [3]. However, the formulation of the WPI technique has been developed to-date in conjunction with the Markovian assumption for the system response process. Herein, a novel WPI formalism is developed to account, in a direct manner, also for systems with non-Markovian response processes. In this regard, nonlinear systems with a history-dependent state, such as hysteretic structures or oscillators endowed with fractional derivative elements, can be treated in a straightforward manner. That is, without resorting to any ad hoc modifications of the WPI technique pertaining, typically, to employing additional auxiliary filter equations and state variables. Indicative numerical examples include a Biot hysteretic oscillator and a tuned mass-damper-inerter nonlinear system with a fractional derivative element. Comparisons with relevant Monte Carlo simulation data demonstrate the reliability of the technique.

References

- [1] Kougioumtzoglou I. A., Spanos P. D. (2012) An analytical Wiener path integral technique for non-stationary response determination of nonlinear oscillators. *Probabilistic Engineering Mechanics* **28**: 125–131.
- [2] Psaros A. F., Kougioumtzoglou I. A. (2020) Functional series expansions and quadratic approximations for enhancing the accuracy of the Wiener path integral technique. *Journal of Engineering Mechanics*, **146**(7): 04020065
- [3] Petromichelakis I., Kougioumtzoglou I. A. (2020) Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries. *Proc. of the Royal Society A: Mathematical, Physical and Engineering Sciences* **476**:2243.

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Title: Estimation of Evolutionary Power Spectra of Univariate Stochastic Processes by Energy-Based Reckoning

Author(s): Hanshu Zhang¹, Qingxia Yue², Alberto Di Matteo³, Pol D. Spanos^{*4}

Abstract

a novel procedure is developed for evolutionary power spectra (EPS) estimation of univariate nonstationary stochastic processes. Specifically, the EPS is determined by estimating the statistical moments of the energy of a lightly damped linear filter excited by the nonstationary stochastic process [1]. In this context, a smoothing procedure is incorporated by using the Savitzky-Golay (S-G) moving average filter to obtain reliable EPS based on a limited number of available records. Further, a refinement of the approach is implemented relying on a polynomial model of the energy function of the filter output. Several numerical applications, involving both simulated nonstationary processes with known spectra, and historical accelerograms are used to assess the reliability and accuracy of the proposed procedure. Comparisons with the EPS estimated by a wavelets-based procedure are also provided [2, 3, 4].

References

- [1] Spanos, P-T. D., Roesset, J., and Donley, M. Evolutionary power spectrum estimation of September 19, 1985 Mexico earthquake accelerograms. *Stochastic Approaches in Earthquake Engineering*. Springer, Berlin, Heidelberg, (1987). 322-333.
- [2] Spanos, P-T. D., and Failla, G. Evolutionary spectra estimation using wavelets. *Journal of Engineering Mechanics* 130.8 (2004): 952-960.
- [3] Daubechies, I. C. *Ten lectures on wavelets*. Society for industrial and applied mathematics (1992).
- [4] Newland, D. E. "Wavelet analysis of vibration: part I—Theory." *Journal of Vibrations and Acoustics* (1994): 409-416.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: An efficient performance-based design optimization approach for nonlinear systems subject to non-stationary excitation via arbitrary polynomial chaos expansion

Author(s): Ketson R. M. dos Santos^{*1}, André T. Beck², Rafael H. Lopez³.

¹*Department of Civil, Environmental, and Geo- Engineering, University of Minnesota, Minneapolis, USA, dossantk@umn.edu*

²*Department of Structural Engineering, University of São Paulo, São Paulo, Brazil, atbeck@sc.usp.edu*

³*Department of Civil Engineering, University of Santa Catarina, Florianopolis, Brazil, rafaelholdorf@gmail.com*

Keyword(s): performance-based optimization, statistical linearization, polynomial chaos, simulated annealing.

Abstract

The performance-based design optimization (PBDO), which was originally developed in [1], is a framework for determining the optimal design of engineering systems modeled as nonlinear oscillators subject to random excitation considering its life-cycle performance. This framework takes into account the hazard uncertainty, the structural response, and the cost of damage for distinct structural demands. In this paper, the PBDO framework is extended to take into account the occurrence of both stationary and non-stationary excitation modeling for instance wind gusts and earthquakes, respectively. Moreover, the computational performance of the technique is improved by adopting an arbitrary polynomial chaos expansion (aPCE) [2] for estimating the expected cost of failure as a function of the design parameters. An optimization problem is then constructed for finding the optimal combination of design parameters capable of minimizing the total expected cost, which is given by the initial costs (e.g., construction, manufacturing) plus the expected cost of failure, accounting for the monetary losses over the system's life-cycle. However, estimating the total expected costs for multi-degree-of-freedom (MDOF) systems subject to non-stationary excitation and under degrading conditions requires the determination of the time-variant system stochastic response; moreover, there is no guarantee that this function has a global minimum. Therefore, a sequential meta-heuristic method based on the simulated annealing [3], referred to as sequential simulated annealing (SSA), is developed for efficiently finding the best possible solution. Two illustrative examples are considered for assessing the computational performance of both aPCE and the SSA algorithm within the PBDO framework.

References

- [1] Beck A. T., Kougiumtzoglou I. A., dos Santos K. R. M., "Optimal performance-based design of non-linear stochastic dynamical RC structures subject to stationary wind excitation," *Engineering Structures*, 78, 145-153, (2014).
- [2] Oladyshkin S., Nowak W., "Data-driven uncertainty quantification using the arbitrary polynomial chaos expansion," *Reliability Engineering and System Safety*, 106, 179-190, (2012).
- [3] van Laarhoven P. J. M., Aarts E. H. L., *Simulated Annealing: Theory and Applications*, Springer, Dordrecht, Netherlands (2010).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Transverse and axial vibrations of masonry beams: nonlinear interactions

Author(s): Maria Girardi*¹

¹*Institute of Information Science and Technologies "A. Faedo", CNR-ISTI, Via Moruzzi, 1 Pisa, Italy, maria.girardi@isti.cnr.it*

Keyword(s): masonry beams, nonlinear dynamics, seismic loads

Abstract

Masonry structures' dynamic response is heavily influenced by constitutive nonlinearity. When the axial force is applied outside the central nucleus of inertia of a masonry beam, there is a reduction of the section's stiffness, and the behaviour of the beam becomes nonlinear. The problem is studied here by resorting to the constitutive equation of masonry-like beams. Under the Euler-Bernoulli hypothesis, the bending moment and normal force acting over a beam's section are functions of both curvature and elongation of the beam's axis [2]. As a result, the equations of the motion that describe the transverse and axial displacements of masonry beams are coupled.

This work presents a study on the effects of such coupling on the stress and displacement field of masonry beams subjected to dynamic loads. The nonlinear dynamic problem is solved numerically, and some examples are presented and discussed. The issue has great relevance for seismic loads and this work gives a contribution to understanding the role played by the ground motion's vertical component on the damage and collapse of masonry structures.

References

- [1] Del Piero G. Constitutive equation and compatibility of the external loads for linear elastic masonry-like materials. *Meccanica*; 24:150-621 (1989)
- [2] Lucchesi M, Pintucchi B. "A numerical model for non-linear dynamic analysis of slender masonry structures", *European Journal of Mechanics-A/Solids*; 26(1):88-105, (2007).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Behaviour of complex systems under random damage

Author(s): Lorenza Abbracciavento^{*1}, Valerio De Biagi²

¹ Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Torino, Italy.
Email: lorenza.abbracciavento@polito.it

² Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Torino, Italy.
Email: valerio.debiagi@polito.it

Keyword(s): robustness, damage propagation analysis, structural response, series-parallel system.

Abstract

Damage tolerance has been shown to be a fundamental prerequisite for the safety and the robustness of large complex systems [1]. Modern requirements for construction design consider mandatory to provide structures with alternative load paths able to maintain structural integrity, in order to deal with progressive degradation and reduce the probability of failure. Although it has been shown that systems in parallel exhibit robust characteristics if structurally complex [2], no specific studies devoted to the critical analysis of the mutual effects of complexity and robustness on mixed systems have been proposed. In this study, the structural response of a simple system made of rods in series and parallel configurations is analysed. To highlight the redistribution capabilities, damage on the system is considered. Strain energy is regarded as the functional that better describes the effects of damage on the system [3]. The paper aims both to highlight the behaviour of rods working in the coupled mechanism and to define a possible strategy to sustain damage acting at random on one element. The behaviour of the complex system result statically indeterminate due to the presence of multiple load paths able to redistribute and absorb the effects of damage. The outcome of the analysis highlight that, even each component of the system (mechanical characteristics of materials, acting loads, etc.) behaves linearly, the structural response of the system under progressive damage is not linear. In addition, as much the complexity increases the possibility to handle with the consequences of the random damages improved.

References

- [1] Starossek U., Haberland M., "Approaches to measures of structural robustness," Structure and Infrastructure Engineering, Vol. 7-8, page 625-631 (2011).
- [2] De Biagi, V., Chiaia, B.: Damage tolerance in parallel systems. Int. J. Damage Mech. 25(7), 1040–1059 (2016)
- [3] De Biagi, V.: Structural behavior of a metallic truss under progressive damage. Int. J. Solids Struct. 82, 56–64 (2016).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The effect of different turbulence model on the hydroacoustic of a pump.

Author(s): Renato Montillo^{*1}, Armando Carravetta², Oreste Fecarotta³

¹*Dipartimento di Ingegneria Civile, Edile e Ambientale, Università degli Studi di Napoli Federico II, Napoli, Italy, renato.montillo@unina.it*

²*Dipartimento di Ingegneria Civile, Edile e Ambientale, Università degli Studi di Napoli Federico II, Napoli, Italy, arcarrav@unina.it*

³*Dipartimento di Ingegneria Civile, Edile e Ambientale, Università degli Studi di Napoli Federico II, Napoli, Italy, oreste.fecarotta@unina.it*

Keyword(s): hydroacoustic, large eddy simulation, unsteady Reynolds average Navier-Stokes, Lighthill, Ffowcs-Williams and Hawking, OpenFOAM

Abstract

In recent years the study of noise generation is becoming crucial in a large variety of problems. The noise footprint generated by a pump or a turbine can give different important information on the proper operation of the device. The noise volume generated by a device can also be a decisive factor for the success of a product, e.g. when it is sold as a domestic device. For those reasons, the present work aims to compare different techniques for the simulation of hydroacoustic noise generation for a pump.

Recently an acoustic model based on the Lighthill equation was developed allowing the noise propagation across different media tested on a plain channel flow. Here the model was expanded to consider the complete source term of the Ffowcs-Williams and Hawking equation and applied to a simplified pump geometry. The aim of this work is to test the influence of different CFD models on the hydroacoustic source in a close and confined geometry. To carry out the fluid dynamic simulation the open-source software OpenFOAM has been used, then by applying the acoustic analogy the hydroacoustic source has been evaluated.

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Palermo, Italy, August 27 - 30, 2023

Effects of compressibility and cavitation on flow reattachment in orifice plates

Author(s): Luca Nicola Quaroni^{*1}, Stefano Malavasi²

¹ Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy, lucanicola.quaroni@polimi.it

² Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy, lucanicola.quaroni@polimi.it

Keyword(s): orifice plates, cavitation, compressibility, flow reattachment, flow instability

Abstract

Orifice plates are devices widely used for flow control/measurement purposes [1]. Due to their ability to display complex fluid-dynamic phenomena for a relatively simple geometry, they're also employed in academic research [2]. Amongst such phenomena, instabilities linked to intermittent flow reattachment within the orifice's bore have been observed [3]. In this mini-symposium, the results of an experimental campaign on sharp-edged orifice plates involving the use of an incompressible fluid subject to cavitation (water) and of a compressible one (dry air) are discussed. Plates with different relative thicknesses $t^* = t/d_h$ (with t the plates' thickness and d_h the hole's diameter) were analysed to have a condition promoting reattachment instabilities ($t^* = 0.4$) and another preventing it ($t^* = 1$), based on available literature [4]. The use of water and dry air permitted to evaluate the effect of cavitation and of compressible flow, respectively, on the onset of reattachment. In water, it was found that the condition of incipient cavitation causes a drop in the pressure losses for the case of the plates with $t^* = 0.4$. This has been linked to the mechanism of the 're-entrant' jet, previously observed in hydrofoils [5]. This could cause an earlier reattachment of the flow to the inner walls of the orifice, reducing the exit velocity (and the relative pressure losses). In subsonic air flows, experimental evidence suggests that as compressibility effects gain importance, the expansion and retreat of the *vena contracta* causes the flow to reattach within the perforation for the plate with $t^* = 0.4$. Cavitation and compressibility could then be linked to flow reattachment and to a reduced pressure loss. Strong whistling is also detected for the tested geometries in air, with the frequency of the tone influenced by the reattachment instability.

References

- [1] Reader-Harris, Michael. Orifice Plates and Venturi Tubes. Cham: Springer International Publishing (2015).
- [2] Malavasi, S., Messa G., Fratino U. and Pagano A. "On the Pressure Losses through Perforated Plates". Flow Measurement and Instrumentation, Vol. 28:57–66 (2012).
- [3] Binder, C., Kinell M., Utriainen E., Eriksson D., Bahador M., Kneer J. and Bauer H. "Experimental Study on Pressure Losses in Circular Orifices for the Application in Internal Cooling Systems". Journal of Turbomachinery 137:3 (2015).
- [4] Flow of Liquids: Pressure Losses across Orifice Plates, Perforated Plates and Thick Orifice Plates in Ducts. London: ESDU International (2007).
- [5] Stanley, C., T. Barber, e G. Rosengarten. «Re-Entrant Jet Mechanism for Periodic Cavitation Shedding in a Cylindrical Orifice». International Journal of Heat and Fluid Flow. Vol. 50:169–76 (2014).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Vehicle-bridge dynamics during braking

Author(s): Angelo Aloisio^{*1}, Alessandro Contento², Giuseppe Quaranta²

¹ *Department of Civil Construction-Architecture and Environmental Engineering, University of L'Aquila, Italy, angelo.aloisio1@univaq.it*

² *College of Civil Engineering, Fuzhou University, Fuzhou, China, alessandro@fzu.edu.cn*

³ *Department of Civil and Geotechnical Engineering, Sapienza University, Rome, Italy, giuseppe.quaranta@uniroma1.it*

Keyword(s): Vehicle-Bridge dynamics; Braking

Abstract

The effect of vehicle braking can significantly amplify a bridge deflection compared to that induced by a vehicle moving at a constant speed. However, the magnitude of this amplification depends on vehicle bridge interaction (VBI) phenomena activated by the road roughness. The road roughness triggers the vehicle dynamics, thus magnifying the interaction between the vehicle and the bridge. This paper proposes a probabilistic model for the amplification factor. The amplification factor is associated with the vehicle's hard braking by the mid-span of the bridge under different road roughness classes. The amplification factor, defined as the ratio between the maximum deflections corresponding to a vehicle braking and moving at a constant speed, is estimated as a function of the mass, velocity, natural frequency and damping of the vehicle. The VBI model is obtained by discretizing the coupled governing equations using the finite difference method. The vehicle is modelled as a two-degrees of freedom system corresponding to the bouncing and pitching motions. The computational efficiency of this model supported an expensive set of analyses, where the parameter values were selected using the Latin Hypercube sampling scheme. The model outputs have been validated against a middle-span bridge's measured experimental displacement response under different scenarios.

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Palermo, Italy, August 27 - 30, 2023

Title: Formulation of a fiber beam element based on plastic damage models for prestressed concrete bridges

Author(s): Luca Parente^{*1}, Daniela Addessi², Enrico Spacone³

¹ Department of Engineering and Geology, G. D'Annunzio University of Chieti-Pescara. Viale Pindaro 42, 65127, Pescara, Italy. luca.parente1@unich.it

² Department of Structural and Geotechnical Engineering, Sapienza University of Rome. Via Eudossiana 18, 00184, Rome, Italy. daniela.addessi@uniroma1.it

³ Department of Engineering and Geology, G. D'Annunzio University of Chieti-Pescara. Viale Pindaro 42, 65127, Pescara, Italy. enrico.spacone@unich.it

Keyword(s): beam finite element, fiber section, damage, plasticity, regularization, prestressed concrete, cyclic analysis, nonlinear analysis.

Abstract

Damage modeling in prestressed concrete beams is a relevant issue in the assessment of existing structures and infrastructures, especially bridges. This work focuses on the formulation of a high-performance fiber beam element to model the nonlinear behavior of prestressed concrete beams and their degrading mechanisms.

Beam elements can be used in a large number of structural cases and represent the best compromise between computational burden and efficiency. This work presents a new 3D prestressed concrete Timoshenko beam element, based on existing force-based formulations for reinforced concrete elements [1], that takes into account the interaction of multi-axial stress components, and includes the most relevant effects of prestressing, mainly time-dependent phenomena in steel and concrete.

A single element can be used to represent most cases, where the prestressing cables are treated as additional, fully bonded fibers in each section. This way, complex geometry tendon layouts are modeled with a small number of elements [2].

Full bond between prestressing cables and concrete is assumed between the cables and the concrete.

A fiber discretization of the cross section is used to model concrete, steel reinforcements and prestressing cables through three-dimensional constitutive laws based on damage and plasticity for concrete, and plasticity for steel [3]. The presence in the concrete constitutive law of strain-softening requires appropriate regularization procedures [4].

One or more tendons are added to the fiber section as fibers where the applied prestressing is equivalent to an initial fiber strain. No additional discretization is required. Time-dependent phenomena such as the concrete creep and shrinkage and the cable relaxation are taken into account at the fiber level.

The 3D finite beam element proposed in this work is implemented in the open-source computational platform OpenSees [5]. New classes are created for the new 3D damage-plastic constitutive law for concrete, the condensation algorithm, the regularization technique and a new load command which applies prestress and time-dependent properties to elements. The 3D fiber section and the force-based beam element were modified to accommodate the new properties.

The element is tested with specific correlation studies and shows good agreement with experimental and analytical results. Future possible extensions of the model include: application to the study of prestressed concrete infrastructures in long term and nonlinear seismic analysis; extension to unbonded tendon with bond-slip; extension to prestressed steel-concrete composite beams.

References

- [1] Spacone E, Filippou FC, Taucer FF. Fibre beam–column model for non-linear analysis of R/C frames: Part I. Formulation. *Earthq Eng Struct Dyn* 1996;25:711–25.
- [2] Doty HA. A Module for Finite Element Analysis of Prestressed Concrete Bridges. M. S. Thesis. University of Colorado, 2001.
- [3] Di Re P, Addessi D, Filippou FC. Mixed 3D beam element with damage plasticity for the analysis of RC members under warping torsion. *Journal of Structural Engineering* 2018;144.
- [4] Addessi D, Ciampi V. A regularized force-based beam element with a damage–plastic section constitutive law. *Int J Numer Methods Eng* 2007;70:610–29.
- [5] McKenna F, Fenves GL, Scott MH. Open System for Earthquake Engineering Simulation 2000.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Bridge-Vehicle Interaction for Dislocating of Electrical Conduits

Author(s): Fangyin Zhang^{*1}, Zhi Zhang¹, Liling Cao¹.

¹ Forensics, Thornton Tomasetti Inc., New York City, USA, fzhang@thorntontomasetti.com

Keyword(s): Steel Truss Bridge, Electrical Conduit, Dislocation, Bridge-Vehicle Interaction

Abstract

In many cases, bridges not only carry traffic vehicles, but critical pipelines such as electrical conduits, water pipelines, oil pipelines, etc. This study investigates the root cause of the dislocation of electrical conduits mounted at the underside of the lower roadway of a steel truss bridge. The electrical conduits were found dislocated from their supporting roller seats in longitudinal and transverse directions since 2010. Dynamic bridge-Vehicle Interaction (BVI) analysis is performed to investigate the impact of the vehicle-induced vibration on the movement of the electrical conduits.

The bridge consists of five spans and two levels of roadway. Both upper- and lower-roadways have four lanes for two-direction vehicles. Lower-roadway has bike/pedestrian sidewalk on each side. Underside the lower-roadway, the electrical conduits are supported by roller seats that provide vertical restraints only. It is estimated that 180,000 vehicles and 1,000 bikers/pedestrians passing the bridge per day.

The bridge structure and conduits are modelled in ANSYS. The trusses are modelled by beam elements and the decks by shell elements. The electrical conduits are modelled by beam elements. The supports of the electrical conduits are modelled by short massless beam elements with adequate restraint releases.

Per AASHTO^[1] and design requirement, HS20 truck is the design vehicle and has the highest daily frequency passing the bridge. The HS20 truck has three axles and each axle has two contact points with the bridge deck through the tires, which result in total six contact points to the deck surface. At each contact point, two sets of dashpots were created in series to model the stiffness and damping of the suspension system of the truck and the tires. The truck bodies are modelled by rigid beam elements passing through their mass centers. The mass and mass moment of inertia of the truck bodies are simulated by nodal mass elements. The interaction between the truck tires and the deck is modelled by point-to-surface contact. The deck roughness of roadway is determined following the International Road Index (IRI). The roughness values at each node of the lower-roadway deck is calculated by Gaussian distribution and added into the existing node coordinates^[2, 3]. Two scenarios for generating the worst torsional movement are analysed: (1) One HS20 truck moves on one lane of the bridge; (2) two HS20 trucks move side by side on two lanes. The reactions at the conduit supports are extracted and investigated. The results show that the vehicle-induced vibrations cause the movement and dislocation of the electrical conduits. To eliminate the vibration-induced dislocations of the conduits, a new type of roller support made of high-damping rubber material is recommended to replace the existing roller supports.

References

- [1] AASHTO, 2014, LRFD Bridge design specifications.
- [2] Thompson M. K. Methods for generating rough surfaces in ANSYS.
- [3] Souza R.O., Neto S.D., Farias M.M., 2006, Statistical analysis between roughness indices and roughness prediction model using neural networks.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Filter equations for simulation of ground motion of multi-layered soil model

Author(s): Rossella Laudani*¹

¹ *Department of Engineering, University of Messina, Messina, Italy*

E-mail: rlaudani@unime.it

Keyword(s): Stochastic ground motion simulation; point-source model; filtered seismic excitation; multi-layered soil

Abstract

The earthquake ground motion modeling is one of the initial assessments for the design of structures in seismic areas. In the literature, many models for the proper definition of seismic action have been established. Among these, the modeling of the power spectral density function (PSDF) of the ground motion is considered to be the characteristic of the seismic action to design earthquake-resistant structures [1]. With the developments in the civil engineering field, the design of complex earthquake-resistant structures is becoming increasingly frequent. For these structures, the dynamic analysis of the response is highly recommended instead of an analysis in terms of response spectrum functions. In general, a dynamic analysis of a structure requires a very high number of artificial accelerograms. Thus, several researchers agree on the advantage of the use of filter equations giving a compatible excitation as response and which allow performing a time-domain stochastic analysis. In this framework, recently, the author proposed a new stochastic procedure for the random characterization of artificial accelerograms. Based on the seismological point-source model [2], the stochastic procedure provides the resolution of a set of filter equations, that, subject to a white noise input give the earthquake excitation, compatible with the point-source model, as response [3]. In this work, the author proposes to improve the stochastic generation of accelerograms, taking into account a multi-layered soil velocity model, the incident and the azimuthal angles, to simulate the radial, tangential, and vertical seismic components.

References

- [1] Barone, G., Iacono, F. L., Navarra, G., & Palmeri, A. Closed-form stochastic response of linear building structures to spectrum-consistent seismic excitations. *Soil Dynamics and Earthquake Engineering*, 125, 105724, (2019).
- [2] Boore, D. M. Simulation of ground motion using the stochastic method. *Pure and applied geophysics*, 160, 635-676, (2003).
- [3] Laudani, R., & Falsone, G. Filter Equations Compatible with the Point-Source Model for Seismic Acceleration. *Journal of Earthquake Engineering*, 1-19, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Effect of vertical acceleration component on the seismic performance of an earth dam

Author(s): Andrea Nardo¹, Giovanni Biondi¹, Ernesto Cascone¹

¹ *University of Messina, Contrada di Dio, Messina, Italy*

Keyword(s): Earth dams, seismic performance, predictive correlation, vertical motion.

Abstract

Large earth dams are strategic infrastructure as they supply local communities with large water resources, promoting livelihood. In high seismicity areas, the stability conditions during earthquakes and the potential sudden flooding represent a major concern for the safety and sustainability of the areas downstream the dam. Also, seismic-induced displacements and distortions, as well soil mass movements and cracks, may significantly affect the post-seismic serviceability of earth dams and of the overall plant. Thus, for both new and existing dams, design or retrofitting procedures should aim to improve the seismic resilience in terms of ability to recover and adapt to the severe ground motions. The seismic performance of earth dams is usually examined under only horizontal input motions [e.g. 1-2], however, analyses carried out considering the effect of the vertical component of the ground motion [e.g. 3-5] revealed the need of further investigation and motivated the analyses presented herein.

In this vein, through 2D numerical analyses, the paper investigates the role of the vertical component of the ground motion on the seismic performance of an earth dam. In the analyses the behaviour of the dam and foundation soils has been described using an isotropic hardening elasto-plastic hysteretic model. The results of the analyses are described in terms of main features of the seismic-induced plastic mechanisms and magnitude of the corresponding crest settlements showing that in some cases the effect of the vertical acceleration component is not negligible. Finally, an empirical correlation between some seismic parameters and the permanent crest settlements of the dam has been proposed.

References

- [1] Aliberti, D., Cascone, E., Biondi, G. Seismic performance of the San Pietro dam. *Procedia Engineering*, 158, 362-367. (2016).
- [2] Casablanca, O., Nardo, A., Biondi, G., Di Filippo, G., Cascone, E. Seismic performance of a zoned earth dam. *Proc. 4th Int. Conf. on Performance Based Design in Earthquake Geotechnical Engineering* (pp. 1929-1936). Cham: Springer International Publishing. (2022).
- [3] Masini, L., S. Rampello, and R. Donatelli. Seismic performance of two classes of earth dams. *Earthquake Engineering and Structural Dynamics*. 50:692–711. doi: 10.1002/eqe.3352. (2021).
- [4] Masini, L. and S. Rampello. Influence of input assumptions on the evaluation of the seismic performance of earth dams. *Journal of Earthquake Engineering*, 26:9, 4471-4495. doi: 10.1080/13632469.2020.1835747. (2020).
- [5] Cascone, E., Biondi, G., Aliberti, D., Rampello, S. Effect of vertical input motion and excess pore pressures on the seismic performance of a zoned dam. *Soil Dynamics and Earthquake Engineering*, 142, 106566. (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Accounting for earthquake- and environmentally-induced damage accumulation in single-building loss assessment

Author(s): Kenneth Otárola^{*1}, Leandro Iannacone², Roberto Gentile³, Carmine Galasso²

¹ *Department of Science, Technology and Society, Scuola Universitaria Superiore (IUSS) Pavia, Pavia, Italy, kenneth.otarola@iusspavia.it*

² *Department of Civil, Environmental, and Geomatic Engineering, University College London, London, United Kingdom, l.iannacone@ucl.ac.uk*

³ *Institute for Risk and Disaster Reduction, University College London, London, United Kingdom, r.gentile@ucl.ac.uk*

⁴ *Department of Civil, Environmental, and Geomatic Engineering, University College London, London, United Kingdom, c.galasso@ucl.ac.uk*

Keyword(s): chloride-induced corrosion; damage accumulation; ground-motion sequence; time- and state-dependent fragility; vulnerability relationship; loss assessment.

Abstract

Current frameworks for single-building loss assessment entail numerous nonlinear dynamic analyses, each considering individual earthquake-induced ground motions. However, buildings in actively seismic regions are exposed to multiple ground-motion sequences during their service life. Consequently, such structures may be affected by damage from prior ground motions when subject to subsequent seismic excitations, leading to significant direct/indirect losses. Furthermore, the impact of ground-motion sequences may be further exacerbated by the effect of gradual deterioration mechanisms caused by environmental exposure, resulting in additional damage accumulation and, thus, higher losses. This study proposes a simulation-based framework to perform a single-building loss assessment accounting for damage accumulation from environmental deterioration and multiple ground-motion sequences. To this aim, a multidimensional probabilistic seismic demand model and a collapse generalised logistic model are developed to estimate the probability of exceeding a damage state and the probability of failure following an earthquake. Then, using a plain Monte Carlo approach, an appropriate chloride-penetration model is combined with the seismic vulnerability models to obtain the time-varying evolution of the parameters of the seismic vulnerability relationships. Expected loss ratios are simulated using the derived time-varying seismic vulnerability models and ground-shaking intensities from an illustrative event-based seismic probabilistic seismic hazard analysis. The proposed methodology is demonstrated using a case-study reinforced concrete building. The results indicate that accounting for damage accumulation across a series of events and environmental deterioration can significantly increase expected loss ratios compared to a conventional mainshock-only loss assessment. This study can help analysts develop and apply time- and state-dependent vulnerability models to quantify damage accumulation's potential impact on loss estimates, and can easily be extended to building-portfolio loss assessment at the regional level.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Vibration problems in the coupled theory of triple porosity thermoelastic materials

Author(s): Merab Svanadze

Institute of Fundamental and Interdisciplinary Mathematic Research, Ilia State University, Tbilisi, Georgia, svanadze@gmail.com

Keyword(s): Thermoelasticity, triple porosity materials, potential method, existence and uniqueness theorems

Abstract

In this work, the linear mathematical model for triple porosity thermoelastic solids is presented in which the coupled phenomenon of Darcy's law and the concept of the volume fraction of pore network is developed. Then, the basic boundary value problems (BVPs) of steady vibrations of this model are investigated. In particular, the fundamental solution of the system of steady vibration equations is constructed. The uniqueness theorems for the classical solutions of the BVPs are proved. The basic properties of the surface and volume potentials are established. The BVPs are reduced to the always solvable singular integral equations for which Noether's theorems are valid. Finally, the existence theorems for classical solutions of the internal and external BVPs are proved by means of the potential method (boundary integral equation method) and the theory of singular integral equations. A review of the basic results on the potential method may be found in the book [1].

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References

- [1] Svanadze, M., Potential Method in Mathematical Theories of Multi-Porosity Media, Interdisciplinary Applied Mathematics, vol. 51, Springer Nature Switzerland AG (2019).

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Title: Closed form solution of the elastoplastic constitutive problem in three-dimensional continua

Author(s): Fabio De Angelis^{*1}, Robert L. Taylor²

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples 80125, Italy, fabio.deangelis@unina.it*

² *Department of Civil and Environmental Engineering, University of California, Berkeley, Usa, rlt@ce.berkeley.edu*

Keyword(s): elastoplasticity, constitutive problem, closed form solution.

Abstract

In this analysis three-dimensional elastoplasticity boundary value problems are discussed and an exact closed form solution is illustrated for the local constitutive elastoplasticity problem, see De Angelis and Taylor [1][2]. In the present analysis small strain elastoplasticity problems are considered and nonlinear kinematic hardening rules are adopted for modelling the behavior of ductile materials. In the literature a notable proposal for an exact closed form solution of elastoplasticity problems has been presented e.g. by Simo and Govindjee [3]. However, such analysis is related to plane stress problems and elastoplasticity problems with linear kinematic hardening. Conversely, the present approach has the remarkable ability to be suitably applied to three-dimensional inelastic problems [4]. Furthermore, the analysis is herein presented for elastoplasticity problems characterized by nonlinear kinematic hardening rules. Consequently, the present approach is valid and can be suitably applied to model the behavior of solids and structures subject to phenomena of cyclic plasticity. The present procedure reduces the local constitutive equation to the solution of a single variable algebraic equation. It is shown that the analytical solution of the algebraic equation can be found in exact closed form. A remarkable feature of the present approach is that no iterative solution method is needed to solve the local constitutive equations of three-dimensional problems in elastoplasticity. The consistent tangent operator is derived by ensuring a quadratic rate of asymptotic convergence for the global solution procedure of the structural problem, see e.g. [5][6][7]. Numerical applications and computational results are finally reported for different types of complex and cyclic loading conditions.

References

- [1] De Angelis, F., and Taylor, R.L., An efficient return mapping algorithm for elastoplasticity with exact closed form solution of the local constitutive problem, *Engineering Computations*, Vol. 32, Issue 8, 2259 - 2291 (2015).
- [2] De Angelis, F., Taylor, R.L., A nonlinear finite element plasticity formulation without matrix inversions, *Finite Elements in Analysis And Design*, Vol. 112, 11-25 (2016).
- [3] Simo, J.C., and Govindjee, S., Exact closed form solution of the return mapping algorithm for plane stress elasto-viscoplasticity, *Engineering Computations*, Vol. 3, 254 - 258 (1988).
- [4] De Angelis, F., A multifield variational formulation of viscoplasticity suitable to deal with singularities and non-smooth functions, *Int. Journal of Engineering Science*, Vol. 172, Art. 103616, pp. 1-16, (2022).
- [5] Zienkiewicz, O.C., Taylor R.L., and Fox, D., *The Finite Element Method for Solid and Structural Mechanics*, 7th ed., Elsevier, Oxford, (2013).
- [6] Simo, J.C., and Hughes T.J.R., *Computational Inelasticity*, Springer-Verlag, Berlin, (1998).
- [7] De Angelis, F., Cancellara, D., Multifield variational principles and computational aspects in rate plasticity, *Computers and Structures*, Vol. 180, pp. 27-39, (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Clustered cable-actuation strategies of a family of V-Expander tensegrity cells

Authors: Muhao Chen¹, Aguinardo Fraddosio², Andrea Micheletti³, Gaetano Pavone^{*2}, Mario Daniele Piccioni², Robert E. Skelton¹

¹ Department of Aerospace Engineering, Texas A&M University, College Station, USA, muhaochen@tamu.edu

² Department of Civil Engineering and Architecture Sciences (ARCOD), Polytechnic University of Bari, Italy, aguinardo.fraddosio@poliba.it, gaetano.pavone@poliba.it, mariodaniele.piccioni@poliba.it

³ Department of Civil Engineering and Computer Engineering (DICII), University of Rome, Tor Vergata, 00133, Rome, Italy, micheletti@ing.uniroma2.it

Keyword(s): tensegrity structure, spider fiber, tensile structure, lightweight structure, structural stiffness

Abstract

This research introduces a method for designing cable-driven V-Expander tensegrity elementary cells based on the nonlinear tensegrity statics [1]. Through clustered actuation, we capitalize on the cable elements present in tensegrity structures, allowing these cables to run over frictionless joints. Initially, the paper outlines the nonlinear static equations for clustered tensegrity systems. Following that, we delve into the topology of V-Expander tensegrity cells, highlighting variations in their complexity (p) and aspect ratio. To facilitate cable actuation, particular cables are selected from the broader set and designated as the active elements of the V-Expander cells. As these selected cables contract during actuation, we evaluate the efficiency of each actuation method to determine the most effective strategy. This innovative technique offers a foundation for examining and creating diverse cable-powered tensegrity configurations suitable for shape-shifting structures and soft robotics applications. This paper's findings also offer valuable insights and practical applications for structures inspired by natural designs [2].

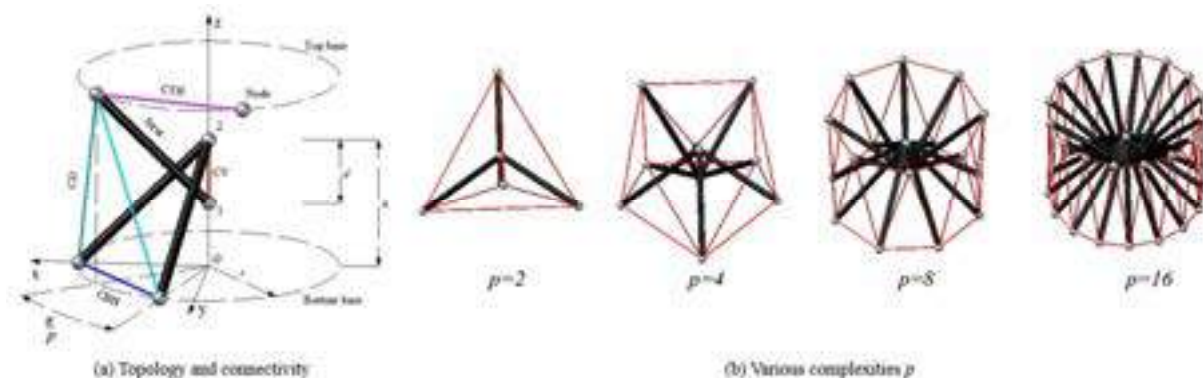


Figure 1 V-Expander tensegrity cell: (a) Topology and connectivity, (b) different values of cell complexity $p = 2, 4, 8$, and 16 . The thin red cylinders are cables, and the thick black cylinders are struts.

References

- [1] Skelton, R.E. and De Oliveira, M.C., "Tensegrity systems," New York: Springer, Vol. 1, 2009.
- [2] Fraternali, F., Stehling, N., Amendola, A., Tiban Anrango, B.A., Holland, C. and Rodenburg, C., "Tensegrity modeling and the high toughness of spider dragline silk," Nanomaterials, 10(8), p.1510, 2020.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A CFD-based analysis on the effects of bundle porosity in regularly packed hollow fiber membrane contactors

Author(s): Nunzio Cancilla^{*1}, Luigi Gurreri², Michele Ciofalo¹, Andrea Cipollina¹, Alessandro Tamburini¹, Giorgio Micale¹

¹ *Dipartimento di Ingegneria, Università degli Studi di Palermo, Viale delle Scienze Ed. 6, 90128 Palermo, Italy, nunzio.cancilla@unipa.it, michele.ciofalo@unipa.it, andrea.cipollina@unipa.it, alessandro.tamburini@unipa.it, giorgio.micale@unipa.it*

² *Dipartimento di Ingegneria Elettrica, Elettronica e Informatica, Università di Catania, Viale Andrea Doria 6 Ed. 3, 95125 Catania, Italy, luigi.gurreri@unict.it*

Keyword(s): Computational Fluid Dynamics, hollow fiber membrane contactor, Darcy permeability, mass transfer coefficient

Abstract

Hollow Fiber Membrane (HFM) contactors are very common today in many applications of membrane separation processes, e.g. in the biomedical field, in gas separation treatments, in water treatment and desalination processes but also in gas-liquid or liquid-liquid extraction [1]. HFM contactors are cylindrically shaped devices with two separate compartments (lumen and shell), which guarantee the fluids segregation. While the analysis of the lumen side flow is fairly simple and it is usually modelled by the Hagen Poiseuille law and by semi-empirical correlations providing information on the mass transport, the analysis on the shell side is very complex since it depends on many parameters and involves complex flow fields formation.

This work aims to investigate by means of CFD the influence of the porosity ε on fluid flow around bundles of straight fibers, arranged in regular square and hexagonal lattices. In the range of low Reynolds number (Re) studied, the fluid flows across the bundle following the Darcy's law. Purely axial ($Re_z=10$, $Re_t=0$), purely transverse ($Re_z=0$, $10^{-3}<Re_t<30$) and mixed ($Re_z=100$, $10^{-3}<Re_t<30$) flows are investigated in steady laminar and fully developed conditions [2]. Simulations use the unit cell approach [3], in which the periodic computational domain includes a single fiber with the associated fluid.

Both in purely axial and in purely transverse flow, the axial and the transverse permeabilities K_z and K_t increase strongly with ε , especially for $\varepsilon>0.8$. In mixed flow, K_z is not affected by Re_z (as expected for a Darcy medium), but for $Re_z>1$ K_z decreases significantly with Re_t . For both lattices, K_t is not affected by Re_z . For $Re_z<10$, K_t is not affected either by Re_t (Darcian medium) or by the angle θ between the applied pressure gradient and the x axis (isotropic medium).

In purely axial flow, the mass transfer coefficient vs ε curve exhibits a bell-shaped behaviour. In purely transverse flow, Sherwood number (Sh) strongly depends on θ even at $Re_t<0.01$, denoting a strong anisotropy. For both lattices, the mass transfer coefficient exhibits minima at θ corresponding to directions of symmetry, while it is much larger at intermediate angles. In mixed flow, the axial flow causes Sh to increase in a complex dependence on geometry (square vs hexagonal), ε and Re_t .

References

- [1] Gabelman A., Hwang S., "Hollow fiber membrane contactors", J. Membr. Sci., 159, 61-106, (1999).
- [2] Cancilla N., Gurreri L., La Rosa M., Ciofalo M., Cipollina A., Tamburini A., Micale G., "Influence of bundle porosity on shell-side hydrodynamics and mass transfer in regular fiber arrays: A computational study", Int. J. Heat Mass Tran, 203, 123841, (2023).
- [3] Cancilla N., Gurreri L., Marotta G., Ciofalo M., Cipollina A., Tamburini A., Micale G., "CFD prediction of shell-side flow and mass transfer in regular fiber arrays", Int. J. Heat Mass Tran, 168, 120855, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Drag reduction on porous coated cylinders invested by a fluid

Author(s): Daniele Puleo, Calogero Picone, Costanza Aricò*

Department of Engineering, University of Palermo, Palermo, Italy, daniele.puleo02@unipa.it, calogero.picone@unipa.it, costanza.arico@unipa.it

Keyword(s): passive flow control, porous coating, numerical method, mesoscale approach, macroscale approach

Abstract

Unsteady stresses experienced by cylindrical bodies are mainly caused by vortex separation which could lead to vortex induced vibrations and consequently to the failure of components such the ones used in offshore industry, as submarine pipelines and risers [1]. For these reasons dampening the amplitude of oscillating forces plays a crucial role in structural design. Recent research in this field have focused on modifying the dynamics of flow separation through passive control techniques, based on covering, by means of a porous layer, cylindrical structures invested by a fluid in order to mitigate vortex shedding and so to decrease lift and coefficients. Passive control efficiency is strongly affected by permeability and porosity of the porous coating, and the interface region between the bulk free fluid region and the bulk porous medium region, plays a fundamental role [2].

The study of the fluid–porous interface transfer can be performed at different scales. To overcome the main drawbacks of the pore-scale approaches (e.g., high computational effort due to the spatial discretization and the lack of the exact knowledge of the porous geometry), the descriptions at the mesoscopic and macroscopic scales are introduced.

In the continuum one-domain approach (ODA), a fictitious medium replaces the fluid and solid phases, and one set of governing equations is used to model the transfer processes. At the mesoscopic scale, the transition from the bulk fluid to the bulk porous region is obtained by a continuous variation of the porosity and permeability within a transition zone (or transition layer), located in between the two bulk regions. In the macroscopic ODA, the so-called penalized-Navier-Stokes equations has been widely applied. An extra penalizing Darcy term in the momentum equation accounts for the drag force of the solid particles of the porous medium over the fluid [2]. The Darcy term is a function of the porosity and inverse of the permeability, and it is active only within the porous region. Porosity and permeability undergo discontinuous change between the values in the bulk porous region and those in the clear fluid region.

In the present work we first derive from pore-scale simulations the porosity and permeable profiles in the TL. Then we compare the results obtained applying a mesoscale and a macroscale ODA numerical approach [3] to simulate the the flow around a cylinder invested by a flow in a ocean offshore application.

References

- [1] M. Zhao, L. Cheng, “Finite element analysis of flow control using porous media”, *Ocean Engineering*, vol 37, 1357—1366 (2010)
- [2] C.-H. Bruneau, I. Mortazavi, “Numerical modelling and passive flow control using porous media”, *Computers & Fluids*, vol. 37, 488.498 (2008)
- [3] C. Aricò, M. Schneider, D. Puleo, R. Helmig, “A new numerical *mesoscopic scale* one-domain approach solver for free fluid/porous medium interaction” in preparation

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A study on permeability in Portland pastes with high water-cement ratio.

Authors: Roberto Serpieri¹, Michela Monaco²

¹DADI – Department of Architecture and Industrial Design, University of Campania “Luigi Vanvitelli”, Aversa, Italia, roberto.serpieri@unicampania.it

²DING - Department of Engineering, University of Sannio, Benevento, Italy, monaco@unisannio.it

Keyword(s): permeability, capillary flow, Kozeny-Carman estimates, percolation

Abstract

The sustainability objectives of Agenda 2030 include the fine-tuning of updated policies for the management of the heritage of concrete buildings and infrastructures, aiming at the suitable mitigation of the harm to environment and at the reduction of societal costs. Investigation of possible optimal policies must necessarily proceed from the identification of reliable methodologies to estimate the service-life and maintenance periodicity time for a given class of concrete structures. Concrete watertightness has been soon recognized as a basic property for assessing durability of the built heritage to weathering exposure and to be mainly dependent on permeability of the cement paste embedding the aggregates which typically have much lower permeability in an ordinary concrete. Fundamental research of the past century has shown that a reliable experimental determination of intrinsic permeability in stone materials can be achieved by uniaxial water-permeation open-flow tests by use of Darcy law [1].

For mature Portland cement pastes, the predictiveness of Kozeny-Carman [2,3] relation in providing intrinsic permeability of cement gel has been early positively assessed by Powers and Brownyard [4], although only up to water-cement ratio of about 0.5. Above such threshold permeation through the capillary space formed due to excess water becomes predominant over gel-space permeation. In this contribution, upon reviewing Powers and Brownyard's permeability model, an enhancement of such model is proposed by addressing simultaneous flow at the gel and capillary scales, combined with a model describing the onset of capillary percolation as the cement-water ratio is increased [5,6]. The predictivity of this novel model is finally assessed against experiments and discussed.

References

- [1] Darcy, H. (1856). Les fontaines publiques de la ville de Dijon: Exposition et application des principes à suivre et des formules à employer dans les questions de distribution d'eau: Ouvrage terminé par un appendice relatif aux fournitures d'eau de plusieurs villes, au filtrage des eaux et à la fabrication des tuyaux de fonte, de plomb, de tôle et de bitume (Vol. 2). Victor Dalmont.
- [2] Kozeny, J. (1927). Über kapillare leitung des Wassers im Boden (Aufstieg, Versickerung und Anwendung auf die Bewässerung). Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften in Wien, Mathematisch - Naturwissenschaftliche Classe, 136 (Abt. IIa) 271-306.
- [3] Carman, P.C. (1939). Permeability of saturated sands, soils, and clays. Journal Of Agricultural Science 29, 262-273.
- [4] Powers, T.C., Brownyard, T.L. (1947). Studies on the physical properties of hardened cement pastes. Part 7. Permeability and absorptivity. Journal of the American Concrete Institute. 43, 865-880.
- [5] Monaco, M., Serpieri, R., Guadagnuolo, M., Frunzio, G. (2023). A discussion on the determination of permeability and absorption in concrete, in: Testing and experimentation in Civil Engineering, Eds. Carlos Chastre et al, RILEM Bookseries, Vol. 41, ISBN: 978-3-031-29190-6.
- [6] Serpieri, R., Monaco, M. (2023). A percolation-threshold model for evaluating permeability in Portland pastes with high water-cement ratio. Journal of Building Engineering, 70, 106328.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Anomalous diffusion of membrane receptors in endocytosis process

Author(s): Gianmarco Nuzzo^{*1}, Mario Argenziano¹, Emanuela Bologna¹, Massimiliano Zingales¹

¹ *Department of Engineering, University of Palermo, Palermo, Italy, Viale delle Scienze ed. 8*

Keyword(s): Endocytosis, Biomechanics, Fractional calculus

Abstract

Endocytosis is one of the main processes by which the cells of the human body receive substances and nutrients from the extracellular matrix, but it is also the route whereby viruses enter host cells to reproduce [1,2].

The first step in this process involves contact between virus ligands and membrane receptors, which diffuse to the membrane region where endocytosis will be performed [3].

In the past decade many models have been made to describe how these receptors diffuse across the membrane and bind to the virus [4,5,6]. But these works have only dealt with the free diffusion of the receptors on the membrane, neglecting important phenomena such as the attractive influence exerted by the virus on the receptor's movement.

Recently the fractional calculus tool has provided excellent results to describe tissue biomechanics [7,8], proving its usefulness in describing tissue behaviour.

Therefore, in this study we have reported a model of receptor diffusion exploiting Stefan's fractional problem, in which we have considered a flow of receptors that diffuses under the virus, with a certain frontier evolving over time. To take in account the attractive potential of the virus and the chemical potential of membrane, instead of using the classical Fick's law, we used modified version of this, obtaining, after substitution in the continuity equation, the Smoluchowski equation in its fractional shape.

References

- [1] Joseph JG, Liu AP. 2020. Mechanical Regulation of Endocytosis: New Insights and Recent Advances. *Adv Biosyst.* 4(5):1–15.
- [2] Shang J, Wan Y, Luo C, Ye G, Geng Q, Auerbach A, Li F. 2020. Cell entry mechanisms of SARS-CoV-2. *Proc Natl Acad Sci USA.* 117(21).
- [3] Zhang S, Gao H, Bao G. 2015. Physical Principles of Nanoparticle Cellular Endocytosis. *ACS Nano.* 9(9):8655–8671.
- [4] Gao H, Shi W, Freund LB. 2005. Mechanics of receptor-mediated endocytosis. *102(27):3–8.*
- [5] Nguyen H, Dayan P, Goodhill GJ. 2014. How receptor diffusion influences gradient sensing. *J R Soc Interface.* 12(102).
- [6] Napoli G, Goriely A. 2020. Elastocytosis. *J Mech Phys Solids.* 145.
- [7] Deseri L, Pollaci P, Zingales M, Dayal K. 2016. Fractional hereditariness of lipid membranes: Instabilities and linearized evolution. *J Mech Behav Biomed Mater.* 58:11–27.
- [8] Bologna E, Di Paola M, Dayal K, Deseri L, Zingales M. 2020. Fractional-order nonlinear hereditariness of tendons and ligaments of the human knee: FOH for fibrous tissues. *Philos Trans R Soc A Math Phys Eng Sci.* 378(2172).

*Correspondence: gianmarco.nuzzo@unipa.it

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Title: Mechanical validation of meniscal tissue contrast enhancement micro-CT protocols

Author(s): Gregorio Marchiori^{1,2}, Melania Maglio¹, Gianluca Giavaresi¹, Giorgio Cassiolas¹, Gaia Prezioso³, Massimiliano Zingales³

¹ *Surgical Sciences and Technologies, IRCCS Rizzoli Orthopaedic Institute, Bologna, Italy, gregorio.marchiori@ior.it*

² *Information Engineering, University of Brescia, Brescia, Italy, g.marchiori002@unibs.it*

³ *Ingegneria, University of Palermo, Palermo, Italy, massimiliano.zingales@unipa.it*

Keyword(s): meniscus; micro-CT contrast protocol; mechanical test; fractional constitutive model

Abstract

Meniscus plays a key role in the stabilization of the knee joint; in fact, it contributes to the fair distribution of the loads to which the joint is subject, and it contributes to cushion shocks. However, several factors can contribute to the meniscus degeneration; in most cases, meniscus does not repair and it is necessary to surgically remove it. Therefore, an *ex vivo* analysis of the meniscal tissue represents a good starting point to characterize it in terms of both microstructure and functionality. One of the principal *ex vivo* imaging techniques is the micro-CT but differently from hard tissues that are “naturally contrasted”, soft tissues, including meniscus, require contrast enhancing agents to permit imaging [1]. However, these contrast agents can lead to changes of the tissue itself that could make imaging unreliable and be permanent. This study aimed at validating the contrast protocols and evaluating meniscus changes. Mechanical tests are useful in this contest, standing that mechanics is function. Cubic samples of human meniscal tissue underwent an unconfined compression test in strain control, with a sequence of five incremental ramp-step relaxations, loading along the sample vertical direction. In order to evaluate each phase of the contrast protocol, every sample was mechanically tested in four different conditions, respectively: 1) just extracted; 2) fixed in formalin; 3) contrasted with PTA in water or PTA in Ethanol (the contrast solutions); and 4) rehydrated (this last step was necessary to establish if the contrast step was reversible or not). To assess possible alterations of the tissue, it was proposed to fit the data with a standard poroelastic fibro-reinforced model [2]. Indeed, in this model the tissue was constituted by a fibro-reinforced solid phase and a fluid phase, being able to consider tension-compression nonlinearity and time-dependent phenomena. However, fitting error resulted high, especially for the contrasted samples, making unreliable the extracted constitutive parameters and consequently the mechanical validation. This can be since while the tissue's time-dependent mechanics should consider both poroelastic (flow-dependent) and viscoelastic (flow-independent) effects, the standard model considers only the first. Therefore, it was proposed the use of a fractional model to fit the data; this model allows to describe the tissue viscosity considering both the relaxation due to fluid leakage from channels (quick relaxation) and relaxation caused by the collagen fibres (slow relaxation). A torsion test on meniscal samples was added to the previously described unconfined compression to obtain a closed solution for the fractional model.

References

- [1] Bushara F., Maglio M., Marchiori G., Giavaresi G., Signoroni A., Guerrini F., Lopomo N., “Contrast-enhanced microtomography for volumetric analysis of microstructure in ligaments and tendons”, *Journal of Mechanics in Medicine and Biology*, doi: 10.1142/S0219519423400286, (2023).
- [2] Berni M., Marchiori G., Cassiolas G., Grassi A., Zaffagnini S., Fini M., Lopomo N., Maglio M., “Anisotropy and inhomogeneity of permeability and fibrous network response in the pars intermedia of the human lateral meniscus”, *Acta Biomaterialia*, 135, 393-402, (2021)

Title: Proof-of-concept of a new tonometer based on solitary waves.

Author(s): Madison Hodgson¹, Piervincenzo Rizzo*¹, Samuel Dickerson¹

¹ *Department of Electrical and Computer Engineering, University of Pittsburgh, 3700 O'Hara Street, 1124 Benedum Hall, Pittsburgh, PA 15261. Laboratory for Nondestructive Evaluation and Structural Health Monitoring*

² *Studies, Department of Civil and Environmental Engineering, University of Pittsburgh, 3700 O'Hara Street, 729 Benedum Hall, Pittsburgh, PA 15261.*

Keyword(s): highly nonlinear solitary waves, tonometer, glaucoma.

Abstract

A technique based on highly nonlinear solitary waves (HNSWs) has recently emerged to characterize engineering materials. It is based on the actuation and detection of solitary waves propagating along an array of spheres, the last of which is in dry point contact with the material to be evaluated. The method makes use of the so-called HNSW transducer, which consists of the array, an electromagnet, and a sensor. In the study presented in this paper, a portable, small wireless transducer was designed, assembled, and tested to test small or soft samples without any wired connection to electronic test equipment. The reliability of the new device was proven by completing a comparative test in which the conventional wired and the novel wireless configuration were used to probe three samples made of different materials. The experiments successfully proved that the instrument can accurately operate without the support of electronic equipment.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Modeling the effects of orthostatic stress on a global multiscale cardiovascular model

Author(s): Chiara Colombo^{*1}, Lucas O. Müller², and Annunziato Siviglia¹

¹ *Department of Civil, Environmental and Mechanical Engineering, University of Trento, Trento, Italy, chiara.colombo-1@unitn.it, annunziato.siviglia@unitn.it*

² *Department of Mathematics, University of Trento, Trento, Italy, lucas.muller@unitn.it*

Keyword(s): orthostatic stress, gravity, multiscale 1D-0D cardiovascular model, blood flow equations

Abstract

One-dimensional (1D) cardiovascular models have become increasingly important as a means of accurately simulating the behavior of the human cardiovascular system (CVS) under both healthy and pathological conditions. Nowadays, some 1D models comprise detailed descriptions of arterial and venous networks. Furthermore, these models incorporate geometrical multiscale physiological processes by utilizing lumped-parameter (0D) models that provide a comprehensive description of complex aspects of the CVS, including but not limited to cardiac function, microcirculation connecting arteries to veins, valve dynamics, and the closing of the CVS loop. Despite the usefulness of these models, it is worth noting that most of them do not consider the effects of orthostatic stress (gravity) on the CVS. This is because most of these models are designed for the supine position, which is not representative of a number of real-life scenarios in which gravity significantly affects cardiovascular function. Therefore, more sophisticated models that incorporate the effects of gravity and other external factors on the CVS need to be developed to more accurately represent cardiovascular dynamics in different postures and during different physical activities.

Gravity plays a crucial role on all the different compartments of the CVS. For example, when an upright position is assumed, blood is shifted from the upper body to the veins of the lower body, resulting in a decrease of the central venous pressure that alters the cardiac function. To restore dynamic equilibrium, compensatory mechanisms such as the arterial baroreflex and the cardiopulmonary reflex are triggered. However, when these control mechanisms fail to restore equilibrium, pathological conditions can develop. Therefore, understanding the effects of orthostatic stress on the CVS is critical for developing effective measures to prevent and treat some cardiovascular diseases.

In this study, we extend the global multiscale 1D-0D cardiovascular model proposed by Müller et al. [1] to incorporate the effects of gravity. Our goal is to develop a cardiovascular model that can accurately reproduce the most important physiological processes, both healthy and pathological, in response to postural changes. We have utilized the proposed model to investigate pathological conditions such as hypertension and orthostatic intolerance. Here, we present our preliminary results, which include a comparison of the solutions obtained with our model to some relevant physiological parameters, with a particular focus on the venous side. This model will serve as a valuable tool to expand our understanding of the CVS and the impact of gravity on its function.

References

[1] Müller L.O., Watanabe S.M., Toro E.F., Feijóo R.A., and Blanco P.J., "An anatomically detailed arterial-venous network model. Cerebral and coronary circulation", submitted for publication in Front., (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Analysis of the thromboembolic risk in the left atrial appendage under atrial fibrillation through a fluid-structure interaction numerical approach

Author(s): Giulio Musotto^{*1}, Alessandra Montelone¹, Danila Vella¹, Ruggero Cannova², Bernardo Zuccarello², Andrew Cook³, Giorgia M. Bosi⁴ & Gaetano Burriesci^{1,4}

¹ Bioengineering Unit, Ri. MED Foundation, Palermo, Italy, gburriesci@fondazionerimed.com;

² Dipartimento D'Ingegneria, Università degli Studi di Palermo, Palermo, Italy;

³ UCL Institute of Cardiovascular Science & Great Ormond Street Hospital for Children, London, United Kingdom;

⁴ UCL Mechanical Engineering, University College London, London, United Kingdom;

Keyword(s): Atrial Fibrillation; Left Atrial Appendage; Fluid Structure Interaction; Biofluid Mechanics

Abstract

Atrial fibrillation (AF) is a heart rhythm disorder with a high incidence and significant neurological consequences such as stroke and vascular dementia [1], [2]. The left atrial appendage (LAA) is an anatomical structure adjacent to the left atrium, which is closely related with the AF thromboembolic risk. This study aims to develop a numerical model to investigate the patient specific mechanisms associated with this complication. In particular, twelve patient-specific LAA models, classified according to their usual morphological families (chicken wing, windsock, cactus, and cauliflower), are compared under sinus rhythm and AF conditions. Both, structure deformation and haemodynamics are described through a fluid-structure interaction analysis. The mechanical properties of the appendage wall were defined on the basis of experimental uniaxial tests on porcine LAAs. Fluid pressure boundary conditions were extracted from available clinical data in healthy and the pathological cases [3]. In order to consider the healthy condition, the active muscular contraction of the LAA was replicated by setting appropriate thermal expansion coefficients and a virtual thermal load on the structure [4]; instead, no active contraction was imposed in AF. Haemodynamic parameters, such as the shear strain rate (SSR), were used to identify regions experiencing blood stasis for the whole cardiac cycle, which promote thrombus formation [5]. Risk maps were thus determined and compared for each patient-specific model. K-means clustering was applied to evaluate risk groups based on the main morphological and fluid dynamic parameters (volume, area, velocity, SSR). The relevance of these parameters to discriminate among the currently used morphological families was evaluated by means of Relief algorithm [6].

The analysed parameters appeared to be more directly related to the thromboembolic risk than the current morphological classification, suggesting that approaches based on basic shape and haemodynamic measurements easy to perform in the clinical setting may contribute to enhance risk stratification.

References

- [1] Nattel S., "New ideas about atrial fibrillation 50 years on", *Nature*, 415(6868), 219–226, 2002.
- [2] Yaghi S., *et al.*, "Left atrial appendage function and stroke risk", *Stroke* 46.12, 3554-3559, 2015.
- [3] Lane D. A., *et al.*, "Atrial fibrillation (chronic)", *BMJ Clinical Evidence*, 2015.
- [4] Musotto G., *et al.* "The role of patient specific morphological features of the left atrial appendage on the thromboembolic risk under atrial fibrillation", *Frontiers in Cardiovascular Medicine*, 1830, 2022.
- [5] Mackman N. New insights into the mechanisms of venous thrombosis. *J Clin Invest.* (2012) 122:2331–6
- [6] Robnik-Sikonja M. and Kononenko I., "Theoretical and empirical analysis of ReliefF and RReliefF." *Machine Learning*, 53, 23–69, 2003.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title 1: A monophasic fluid-structure interaction approach for cardiovascular applications

Author(s): Alessandra Monteleone^{*1}, Sofia Di Leonardo¹, Alessia Viola^{1,2}, Enrico Napoli², Gaetano Burriesci^{1,3}

¹ *Bioengineering Unit, Fondazione Ri.MED, Palermo, Italy, amonteleone@fondazionerimed.com*

² *Dipartimento di Ingegneria, Università degli Studi di Palermo, Palermo, Italy, enrico.napoli@unipa.it*

³ *UCL Mechanical Engineering, University College London, London, United Kingdom, g.burriesci@ucl.ac.uk*

Keyword(s): Aortic valve dynamics, Haemodynamics, Smoothed particle hydrodynamics (SPH); Fluid–structure interaction (FSI); Particle–spring systems

Abstract

Modelling the interaction between fluid and deformable structure is crucial in cardiovascular biomechanics. Due to the complexity of the problem, conventional numerical approaches are commonly used to obtain separate descriptions of structure deformation and hemodynamic aspects. Fluid-structure interaction (FSI) strategies lead to more realistic analysis since they capture structure deformation under the mechanical actions exerted by the blood, and consider the influence of the structure movement on the haemodynamics. However, regions where the fluid is affected by the deformation of immersed structures in pulsatile blood flows, such as heart valves, are very arduous to simulate both in terms of large mesh deformation and computational effort. In order to overcome these issues, alternative FSI grid-based strategies were proposed [1].

This work presents a novel FSI meshless approach based on the Lagrangian smoothed particle hydrodynamics (SPH) method [2], where no interface between solid and fluid domains is required. Fluid and solid computational domains are both represented in the SPH formulation using a set of particles having own mass, density, volume and other physical properties. To model the structure behaviour, internal elastic forces defined as mass springs are introduced in the fluid governing equations between the particles identified as solid. Springs that are compressed or stretched from the initial reference configuration react with forces attempting to restore their equilibrium. This allows to employ a unique solver to handle both the fluid and solid domains. Thanks to the absence of the time-consuming mesh generation procedure and interface handling, the method is suitable to model high deformable immersed structures. The proposed intrinsic FSI approach is first validated using a challenging verification problem [3], which consists of a two-dimensional channel flow past a thin elastic cantilever beam attached to a rigid cylinder. The validated model is then applied to simulate a complex cardiovascular mechanism, such as the aortic valve dynamics, whose understanding is essential to interpret common pathologies and devise optimal treatments.

References

- [1] Peskin C. S. “Flow patterns around heart valves: A numerical method”, *Journal of Computational Physics*, 10(2), 252–271, 1972.
- [2] Monaghan J. J., “Smoothed particle hydrodynamics”, *Annu. Rev. Astron. Astrophys.*, Vol. 30, no. 1, pp. 543–574, 1992.
- [3] Turek S., Hron J. “Proposal for numerical benchmarking of fluid-structure interaction between an elastic object and laminar incompressible flow”, *Fluid-structure interaction*. Springer, pp. 371-385, 2006.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A fast adaptive PD-FEM coupling model for predicting cohesive crack growth

Author(s): Reza Alebrahim^{*1}, Sonia Marfia¹

¹ *Department of Engineering, University of RomaTre, Rome, Italy*

Keyword(s): Peridynamic theory; Finite-element analysis; Adaptive coupling; Cohesive crack growth`

Abstract

Crack simulation study is a complicated phenomenon. The nonlocal theory of peridynamic (PD) has made significant advancements in crack growth simulation through offering integral-based equation of motion. However, although PD is a powerful method in the crack growth prediction, it is computationally expensive. The aim of this study is to simulate cohesive crack growth in quasi-brittle materials coupling the nonlocal theory of PD with finite element (FEM) in order to reduce the computational cost. To implement quasi-static loading conditions, the adaptive dynamic relaxation method is utilized. By taking into account the advantages of the peridynamic method in modeling crack propagation and the computational efficiency of finite elements, a novel method is proposed. In this method, the entire problem domain is initially solved by the FEM solver using coarse mesh grids. Coupling is then introduced to regions with critical conditions based on damage criteria. The following novelties are investigated in this study: 1) A complete adaptive coupling procedure for PD-FEM is presented, which allows for the dominant FEM solver to be replaced by the PD solver without prior knowledge of crack location, both before and during crack nucleation and propagation. 2) A combination of bond stretch and dilatational bond potential-based damage criteria [1,2] is applied to enhance the predictive ability of the state-based cohesive crack growth damage model for mixed-mode fracture in quasi-brittle materials. 3) The computational efficiency of the adaptive model in contrast to conventional PD-FEM coupling methods [3] is improved. In the FEM domain, a strategy for adaptive coupling crack growth is implemented by performing various operations such as interpolation, refinement, remeshing, and switching. To determine the direction of the crack path in each step of the solution, a virtual domain is utilized where a PD solver is employed. The proposed coupling method effectively models cohesive crack growth in quasi-brittle materials, and is shown to have improved computational efficiency compared to other conventional PD-FEM coupling methods. Experimental results are used to confirm the validity of the proposed method.

References

- [1] Y. Tong, W.-Q. Shen, J.-F. Shao, "An adaptive coupling method of state-based peridynamics theory and finite element method for modeling progressive failure process in cohesive materials", *Computer Methods in Applied Mechanics and Engineering* 370 (2020) 113248.
- [2] D. Yang, X. He, J. Zhu, Z. Bie, "A novel damage model in the peridynamics-based cohesive zone method (pd-czm) for mixed mode fracture with its implicit implementation", *Computer Methods in Applied Mechanics and Engineering* 377 (2021) 113721.
- [3] U. Galvanetto, T. Mudric, A. Shojaei, M. Zaccariotto, "An effective way to couple fem meshes and peridynamics grids for the solution of static equilibrium problems", *Mechanics Research Communications* 76 (2016) 41–47.

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Implementation of higher order kinematics using isogeometric analysis for curvilinear fibre composites

Trilok Madhukar Shende¹ and Devesh Punera^{*2}

¹ School of Infrastructure, IIT Bhubaneswar, Bhubaneswar, India, Email: tms10@iitbbs.ac.in

² School of Infrastructure, IIT Bhubaneswar, Bhubaneswar, India, Email: devesh@iitbbs.ac.in

Keyword(s): Variable stiffness composites; Isogeometric Analysis; NURBS; Higher order shear deformation.

Abstract

The composite structural systems utilize the functional advantages of tailored stiffness, frequently encountered in nature. The inception and advancements in multi-axis tow placement, multi-material additive manufacturing, and automated composite manufacturing have facilitated the creation of structures that exhibit this natural phenomenon in the form of sophisticated curvilinear fibre trajectory. These composites are known as variable angle tow (VATs) composites and belong to a family of materials known as variable stiffness composites (VSCs). These variable stiffness composites effectively improve structures' stress distribution and buckling load capacity while providing increased design space flexibility compared to constant stiffness designs. Traditional finite element requires finer meshing for modelling of curvilinear fibre profiles and it often assumes constant stiffness for individual elements. Such assumptions lead to the discontinuity of fibres at the element boundaries, suboptimal time utilization and the acquisition of less precise outcomes.

The present research delves into a novel framework for isogeometric analysis (IGA) utilizing nonuniform rational B-splines (NURBS) to simulate curvilinear fiber composites, ensuring the continuity of fiber angle across the entire panel for static analysis of plates using higher order kinematic models. We adopt a third order shear deformation model with nine displacement parameters and another twelve parameter shear and normal deformation model. It has been well established in literature that such higher order kinematics are more suitable for variable stiffness advanced composites [1, 2]. We establish the accuracy of present kinematic models and suitability of IGA for variable stiffness composites through a number of test problems. The results are also presented for functionally graded materials and a comparison with the traditional finite element is made. We also discuss the refinement at the order of basis functions and number of Gauss integration points for accurate analysis.

References

- [1] Punera, D., and Kant, T. "Elastostatics of laminated and functionally graded sandwich cylindrical shells with two refined higher order models." *Composite Structures* 182, 505-523, (2017).
- [2] Punera, D., and Mukherjee, P. "Recent developments in manufacturing, mechanics and design optimization of variable stiffness composites," *Journal of Reinforced Plastics and Composites*, 41, 917-945, (2022).

EMI 2023 International Conference

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Title: Parallel, high-performance Uneyama-Doi model for analyzing diblock copolymer and solvent mixtures using semi-implicit Fourier spectral method

Author(s): Farshid Mossaiby^{*1}, Arman Shojaei¹, Gregor Ibbeken², Christian Cyron¹, Marcus Müller²

¹ *Institute of Material Systems Modeling, Helmholtz-Zentrum Hereon, Geesthacht, Germany, {farshid.mossaiby, arman.shojaei, christian.cyron}@hereon.de*

² *Institut für Theoretische Physik, Georg-August Universität Göttingen, Göttingen, Germany, {gregor.ibbeken, marcus.mueller}@uni-goettingen.de*

Keyword(s): diblock copolymers, Fourier spectral method, semi-implicit, HPC, MPI

Abstract

In this work, we present a novel implementation of a parallel, high-performance Uneyama-Doi model [1-3] for analyzing diblock copolymer and solvent mixtures. Our C++ implementation is based on a semi-implicit Fourier spectral method, which enables the use of larger time steps compared to explicit methods, without requiring the solution of a system of differential/algebraic equations. The only inter-node communication is done via the FFTW library based on MPI, which simplifies the code. To ensure maximum performance, we utilize the parallel HDF5 library for I/O operations. The Uneyama-Doi model employed allows for accurate prediction of the behavior of diblock copolymers, which have numerous applications in various fields. We provide various performance results demonstrating the effectiveness of our approach. Our work has the potential to significantly advance the understanding of diblock copolymers and enable the development of new materials and technologies.

References

- [1] Uneyama, T. and Doi, M., "Density functional theory for block copolymer melts and blends" *Macromolecules*, Vol. 38, No. 1, pp.196-205 (2005).
- [2] Uneyama, T., "Density functional simulation of spontaneous formation of vesicle in block copolymer solutions", *The Journal of chemical physics*, Vol. 126, No. 11, p. 114902 (2007).
- [3] Dreyer, O., Ibbeken, G., Schneider, L., Blagojevic, N., Radjabian, M., Abetz, V. and Müller, M., "Simulation of Solvent Evaporation from a Diblock Copolymer Film: Orientation of the Cylindrical Mesophase", *Macromolecules*, Vol. 55, No. 17, pp. 7564-7582 (2022).

EMI 2023 International Conference

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Title: A perspective on conditional spectrum-based determination of response statistics of nonlinear systems: stationary and non-stationary cases

Authors: Pol D. Spanos¹, Beatrice Pomaro^{*2,3}

¹ L. B. Ryon Chair in Engineering, Rice University, 6100 Main Street, Houston, TX 77005-1827, USA, spanos@rice.edu

² Department of Civil, Environmental and Architectural Engineering, University of Padova, Via F. Marzolo 9, 35131 Padova, Italy, beatrice.pomaro@unipd.it

³ Department of Civil and Environmental Engineering, Rice University, 6100 Main Street, Houston, TX 77005-1827, USA

Keywords: Statistical Linearization; Stochastic Averaging; Conditional spectrum; Monte Carlo simulations; Stationary/Non-Stationary responses

Abstract

Despite their versatility and attractiveness, it can be argued that the Statistical Linearization [1-3] and the Stochastic Averaging [4] techniques may have limited success in determining the response power spectral density of nonlinear systems. The study is conducted by defining the resonance properties of the system in the frequency domain, in terms of the stationary power spectral density of the system displacement and velocity. This is pursued by revisiting the conditional power spectrum concept [5-7], with the assumption that the response process is ergodic and pseudo-harmonic, characterized by an amplitude and a phase. A theoretical elucidation of an existing formula for the conditional spectrum is attempted. In particular, this principle is interpreted in relation to the time averaging approximation made in the definition of the stationary probability density function of a characteristic amplitude quantity, associated with the original nonlinear system. It is shown that a proper definition of the stationary probability density of the response amplitude, along with a reasonable treatment of the distribution over the frequency domain of the amplitude contribution, lead to an improved approximation of the response stationary power spectral density function. This is confirmed by a large suite of *à propos* Monte Carlo simulations, both in terms of the shape and the range of the involved resonance frequencies, even at a strong degree of nonlinearity. Further, the acquired insight regarding the stationary spectral density of the nonlinear system is used to formulate a Lyapunov equation-based determination [4] of the non-stationary response statistics even in the presence of hysteretic and fractional derivative elements.

References

- [1] Booton R.C., "The analysis of nonlinear control systems with random inputs", IEEE Transactions on Circuit Theory, CT-1(1), 9-18, 1954.
- [2] Kazakov, I.E., "An approximate method for the statistical investigation of nonlinear systems" in Collected Scientific Papers of TVVIAI (N.E. Zhukovskogo), 399, 1-52 (1954).
- [3] Caughey T.K., "Equivalent linearization techniques", Journal of Acoustic Society of America, 35, 1706-1711, 1963.
- [4] Roberts J.B, Spanos P.D., "Stochastic averaging: an approximate method of solving random vibration problems", International Journal of Non-Linear Mechanics, 21, 111-134, 1986.
- [5] Miles R.N., "Spectral response of a bilinear oscillator", Journal of Sound and Vibration, 163(2), 319-326, 1993.
- [6] Bouc R., "The power spectral density of response for a strongly non-linear random oscillator", Journal of Sound and Vibration, 175(3), 317-331, 1994.
- [7] Spanos P.D., Kougiumtzoglou I.A., Soize C., "On the determination of the power spectrum of randomly excited oscillators via stochastic averaging: an alternative perspective", Probabilistic Engineering Mechanics, 26(1), 10-15, 2011.

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Title: Prediction via Gaussian Process of moment quantities of an offshore wind turbine using operational SCADA data

Author(s): Bridget Moynihan¹, Eleonora M. Tronci^{*1}, Babak Moaveni¹, Finn Rüdinger², Ross McAdam², Eric Hines

¹ *Tufts University, Medford, Massachusetts, USA, etronc01@tufts.edu*

² *Ørsted A/S, Nesa Allé 1, 2820 Gentofte, Denmark*

Keyword(s): Offshore Wind Turbines, Structural Health Monitoring, Moments Estimation, Gaussian processes, SCADA

Abstract

Governments worldwide have shown a strong commitment to renewable energy, leading to an increased interest in effectively monitoring offshore wind turbines (OWTs) in the short and long term. Typically, wind turbines are equipped with two types of monitoring systems. The first is the Supervisory Control and Data Acquisition (SCADA) system, which tracks operational data such as wind speed and power generation. This data is critical in understanding the turbine's performance and analyzing environmental factors that may affect its behavior. The second type of monitoring system uses common sensors like accelerometers and strain sensors to monitor structural dynamics over time. Strain information is especially important in detecting damage and faults and ensuring the structure's performance over time. However, there may be situations where strain sensors are missing or malfunctioning, or strain information is unavailable for an extended period. In such cases, it is crucial to develop strategies to predict and input the missing strain information.

This paper uses Gaussian process regression (GPR) to accurately predict the bending moment time-histories of a 6 MW offshore wind turbine. The model takes into account various SCADA data parameters such as wind speed, generated power, and nacelle acceleration as input. Thanks to the probabilistic nature of GPR, it is possible to quantify the levels of uncertainty in predicted bending moments. This information is crucial in determining fatigue estimators through a cycle-counting process. Our successful model can be extended to other turbines in the same wind farm to determine the remaining useful life of each OWT without the need for widespread installation of strain gauges.

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Title: Mesoscale random behavior of concrete-earth material: from CT to numerical modelling

Author(s): Francesco Faralli^{*1}, Federico Cluni¹, Vittorio Gusella¹

¹ *Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, francesco.faralli@studenti.unipg.it federico.cluni@unipg.it, vittorio.gusella@unipg.it*

Keyword(s): Concrete-earth material, Mesoscale behavior, Computed Tomography, Homogenization, Monte Carlo simulation.

Abstract

Computed Tomography (CT) analysis of concrete-like materials is often used to generate high fidelity geometrical reproductions, a mandatory task to study the features of these heterogeneous materials [2, 3]. However, the complexity of the reconstructed shapes does not allow an agile parameterization of their geometry, useful in order to generate numerical simulations concerning the stochastic distribution of their aggregates.

In the present paper, the results of an ongoing research, based CT experimental tests and numerical reconstruction of concrete-earth samples [3] are reported. Size and shape characteristics (e.g. volume, inertia tensor) of the inclusions experimentally detected have been analyzed thorough statistical methods.

Consequently, a parametric random two-phase (matrix and ellipsoidal inclusions) samples generator, based on the aforementioned distributions, has been proposed. The stochastic based geometry generation allows to automate the definition of a series of finite element models, which can be used to perform Monte Carlo analyses [4].

Particularly, a finite element homogenization process has been implemented which shows the possible correlations between elastic characteristics and geometrical properties for such innovative eco-friendly material and potentially, in general, for traditional concretes.

References

- [1] A. D. Rarasati F. D. E. Latief, I. H. Mohammad. Digital 3d microstructure analysis of concrete using x-ray micro computed tomography skyscan 1173: A preliminary study. IOP Conference Series: Materials Science and Engineering, 267(1):012020, nov 2017.
- [2] Gianluca Mazzucco, Beatrice Pomaro, Giovanna Xotta, Valentina Salomoni, and Carmelo Majorana. An efficient geometric reconstruction of mesoscale concrete structures accounting for confinement scenarios. International Journal for Multiscale Computational Engineering, 18, 01 2019.
- [3] A. Curto, L. Lanzoni, A.M. Tarantino, M. Viviani. Shot-earth for sustainable constructions. Construction and Building Materials, 2019, <https://doi.org/10.1016/j.conbuildmat.2019.117775>
- [4] David Tal Jacob Fish. Stochastic multiscale modeling and simulation framework for concrete. Cement and Concrete Composites, 90:61–81, 2018.

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Title: Acoustic response of a vibrating elongated cylinder in a hydrodynamic turbulent flow

Author(s): Giacomo rismondo¹ , Marta Cianferra² and Vincenzo Armenio³

¹ *Dipartimento di ingegneria e architettura, Università degli studi di Trieste, Trieste, Italy, rismondogiacomo@gmail.com*

² *Dipartimento di ingegneria e architettura, Università degli studi di Trieste, Trieste, Italy, marta.cianferra@dia.units.it*

³ *Dipartimento di ingegneria e architettura, Università degli studi di Trieste, Trieste, Italy, vincenzo.armenio@dia.units.it*

Keyword(s): Large Eddy Simulation (LES), Fluid Structure Interaction (FSI), Ffowcs Williams and Hawkings (FW-H), noise generation and propagation.

Introduction

The analysis and prediction of the sound generated by a turbulent flow are of fundamental importance in many engineering applications. An important field of application is acoustic pollution and its effects on the environment, which has led to considerable interest and to the development of different analytical and numerical techniques to perform reliable noise predictions [1, 2]. More recently, the generation and propagation of sound in incompressible flow conditions have been the focus of a large number of research projects. In the literature, the so-called acoustic analogy has been developed and is commonly in use, enabling one to decouple the acoustic problem from the fluid dynamic one. The acoustic analogy theory was developed by Lighthill [3]. This numerical methodology has been used by a number of authors (see [4]) and improved over the years. The research group in hydraulics of the University of Trieste has recently contributed in the field (see [5, 6, 7]). In [6], the authors proposed a novel computational method for the analysis of the noise contribution coming from the wake of the body (i.e., a slender square cylinder), whereas in [7], the authors analyzed the noise generated by a ship propeller. The goal of the present study is to take a step forward to evaluate the noise generated by a nonrigid slender body to detect differences between the ideal rigid-body case and the more realistic case of an elastic body. This is, indeed, the case in a number of applications both in the field of hydroacoustics and in aeroacoustics. Here, we consider a case where a simple body (a square cylinder, such as that of [6]) placed over a rigid wall and made of a linear elastic material is immersed in a flow and interacts elastically with it, hence working in the hydroelastic regime. The study is carried out numerically, using an LES for the evaluation of the hydrodynamic field and the computational hydroacoustics (CHA) for the evaluation of the noise. The direction along which the study is carried out is the identification of the differences between the two cases (rigid versus flexible body) evaluated in terms of the acoustic pressure and characteristics of the turbulent flow.

Materials and Methods

In this context, we used the incompressible Navier-Stokes equations to resolve the fluid dynamic fields (pressure and velocity), the momentum conservation law for a linear elastic solid to resolve the displacement of the solid and the direct integral formulation of FW-H equation to resolve the acoustic pressure. So the fluid and the acoustic fields are decoupled because we are not going to solve the compressible equations of Navier Stokes but we use the formulation of FW-H based on the Lighthill analogy. On the other hand the fluid and solid are coupled, through an iterative FSI (fluid structure interaction) algorithm, for the reason that the motion of the solid influenced the fluid dynamic fields and vice-versa.

Numerical setup

We considered a simple geometry, namely, a square cylinder mounted over a plane wall in an incompressible turbulent flow. The frame of reference had the x-axis along the fluid motion, the y-axis in the cross stream direction parallel to the wall and the z-axis parallel to the axis of the cylinder. The inlet flow was uniform with velocity $U = 10$ m/s along the x-direction. The square cylinder had a side $d = 0,4$ m and a length $h = 30d$. The value of kinematic viscosity was chosen in such a way as to obtain a value of the Reynolds number of $Re = 4000$, based on the side d . The domain was $125d \times 75d \times 50d$ long in the x- y- z-direction, respectively, for the frame of reference. The center of the cylinder was placed at $25d$ from the inflow plane of the domain. As boundary conditions, we set the wall-layer model at the surface of the cylinder and at the bottom wall and the symmetry condition at the lateral and top boundaries of the domain; we imposed a velocity ($u = U$) and zero gradient for the pressure at the inflow boundary and a zero gradient for the velocity, and we imposed arbitrary pressure $p = 0$ at the outflow boundary. We adopted quite a coarse mesh (1 193 000 number of cells) to reduce the computational efforts, which was allowed by the use of the wall-layer model approach. The grid resolution was $\Delta x^+ = \Delta y^+ \approx 30$ at the walls of the cylinder and $\Delta z^+ = 250$. The density of the fluid was $\rho = 1000$ kg/m³ and the kinematic viscosity $\nu = 0.001$ m²/s. The solid was modeled with a density of $\rho_s = 1.85e5$ kg/m³ and a stiffness module (Young's module) $E = 1e13$ N/m². These values were chosen so that the frequency of the first mode of vibration of the cylinder was as close as possible to the frequency of the detachment of the vortices from the cylinder.

Results

In this section, we report the numerical results of the acoustic pressure obtained from the direct FW-H equation. Of particular interest is the evaluation of the differences in the acoustic field in case that the solid immersed in the fluid is rigid or linear elastic. In order to evaluate the acoustic field, we analyzed the acoustic pressure in term of root mean square (rms) in polar coordinates. Finally, we compare the results obtained from the rigid case and the deformable one. We individuate the directivity plot of the acoustic pressure at different points placed in concentric circles around the body, namely at $5d$, $10d$, $100d$, $200d$, $300d$ and $600d$. We use and compare the linear and the non linear part of the FW-H equation. It is clearly shown from the Fig.1 that the linear part of the FW-H in the FSI case is more intense compared to the rigid one, near the source. This means that the presence of the deformable body, induces a more intense noise near the body. The velocity of the displacement of the body produces a positive value of the thickness term of the FW-H equation and a more intense acoustic pressure.



Figure 1: Directivity plot of the prms [Pa] determined by the linear solution of the FW-H equation on points placed on concentric circles at a) $r = 5d$, b) $r = 10d$, c) $r = 100d$ the solid line is the rigid case and the dash line is the FSI case

From the Fig.1 it is possible to figure out that with increasing distance from the body the difference between the rigid case and the deformable one becomes less and less intense, from the point of view of the linear terms of the FW-H equation. However, regarding the non linear terms, in the Fig.2 it is possible to observe that there are significant differences between the rigid and the FSI case, especially with increasing the distance from the source. Near the body ($5d$) there is not a substantial difference from the point of view of the preferred directions of propagation of the acoustic pressure, only the intensity is larger in the deformable case. Increasing the distance from the source the preferred directions of propagation of the sound pressure change significantly. This means that the behavior of the turbulent wake is substantially different in the two cases examined.



Figure 2: Directivity plot of the prms [Pa] determined by the non linear solution of the FW-H equation on points placed on concentric circles at a) $r = 5d$, b) $r = 10d$, c) $r = 100d$ the solid line is the rigid case and the dash line is the FSI case

Another important characteristic that is shown in Fig.1 and Fig.2 is that the non linear terms of the FW-H equation dominant near the acoustic source (the square cylinder) while increasing the distance from the source the linear terms dominates the acoustic pressure. Beyond the distance of $100d$ we do not observe significant differences between the rigid case and the deformable one, with regards to the linear terms of FW-H, as shown in Fig.3. With regard to the non linear terms, increasing the distance from the body the preferred directions of propagation of the sound pressure tends to coincide between rigid and deformable case, until the formation of an almost perfect quadrupole at a distance of $600d$, as shown in Fig.4. Interesting to note that in the near-body region the intensity of the pressure

fluctuations is larger in the FSI case, conversely in the far-field region the opposite behavior is found. This behavior reflects the fact that the elasticity of the body reduces the formation of large scale turbulent structures in the wake and increases the number of small-scale turbulent eddies.



Figure 3: Directivity plot of the $prms$ [Pa] determined by the linear solution of the FW-H equation on points placed on concentric circles at a) $r = 200d$, b) $r = 300d$, c) $r = 600d$ the solid line is the rigid case and the dash line is the FSI case



Figure 4: Directivity plot of the $prms$ [Pa] determined by the non linear solution of the FW-H equation on points placed on concentric circles at a) $r = 200d$, b) $r = 300d$, c) $r = 600d$ the solid line is the rigid case and the dash line is the FSI case

Conclusions

In the present study, we compare the acoustic pressure in term of directivity plot, between the rigid case and the deformable one. The assessed differences in sound pressure between the rigid case and the FSI case show that the interaction between the fluid and the elastic solid significantly changes the turbulent wake and consequently the noise. Finally, this result encourages a more detailed study, both as regards the fluid dynamic numerical simulation (for example, using a wall resolved LES) and, mostly, regarding the sensitivity of the FW-H equation due to the displacement of the solid.

References

- [1] E. Murphy and E. A. King, Environmental noise pollution: Noise mapping, public health, and policy. Newnes, 2014.
- [2] J. Carlton and D. Vlastic, "Ship vibration and noise: Some topical aspects," in 1st International Ship Noise and Vibration Conference. Citeseer, 2005, pp. 1–11.
- [3] M. J. Lighthill, "On sound generated aerodynamically i. general theory," Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences, vol. 211, no. 1107, pp. 564–587, 1952.
- [4] M. Wang, J. B. Freund, and S. K. Lele, "Computational prediction of flow-generated sound," Annu. Rev. Fluid Mech., vol. 38, pp. 483–512, 2006.
- [5] M. Cianferra, "Acoustic analogies and large-eddy simulations of incompressible and cavitating flows around bluff bodies," 2018.
- [6] M. Cianferra, V. Armenio, and A. Petronio, "Numerical prediction of the far field noise generated by a ship propeller," in INTER-NOISE and NOISE-CON Congress and Conference Proceedings, vol. 259, no. 5. Institute of Noise Control Engineering, 2019, pp. 4146–4157.
- [7] M. Cianferra, A. Petronio, and V. Armenio, "Non-linear noise from a ship propeller in open sea condition," Ocean Engineering, vol. 191, p. 106474, 2019.
- [8] D. P. Lockard, "An efficient, two-dimensional implementation of the fflowcs williams and hawkins equation," Journal of Sound and Vibration, vol. 229, no. 4, pp. 897–911, 2000.
- [9] J. F. Williams and D. L. Hawking, "Sound generation by turbulence and surfaces in arbitrary motion," Philosophical Transactions for the Royal Society of London. Series A, Mathematical and Physical Sciences, pp. 321–342, 1969.

EMI 2023 International Conference

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Title: Analytical model of an OWC embedded in a large floating circular platform.

Author(s): Antonino Simone Spanò^{*1,2}, Giovanni Malara³, Felice Arena⁴

¹ University School for Advanced Studies IUSS Pavia, Italy, antonino.spano@iusspavia.it

² Natural Ocean Engineering Laboratory (NOEL), Mediterranean University of Reggio Calabria, Reggio Calabria, Italy, antoninosimone.spano@unirc.it

³ Natural Ocean Engineering Laboratory (NOEL), Mediterranean University of Reggio Calabria, Reggio Calabria, Italy, giovanni.malara@unirc.it

⁴ Natural Ocean Engineering Laboratory (NOEL), Mediterranean University of Reggio Calabria, Reggio Calabria, Italy, arena@unirc.it

Keyword(s): wave energy, floating structure, Oscillating Water Column

Abstract

This article deals with the modelling of an Oscillating Water Column (OWC) wave energy converter embedded into a large floating cylindrical infrastructure. Its working principle is based on the wave induced movement of a vertical water column into a semi submerged structure open at the bottom [1]. These oscillations lead to a varying air pressure inside a closed air chamber located on top of the water column and an air flow through a self-rectifying air turbine generating electricity. These systems are quite developed in the wave energy sector, as they are robust, ensure high converted power, and are easily installed within multi-purpose infrastructures [2].

By relying on the linear potential flow theory, through the method of matched eigenfunctions expansion [3], an analytical solution to the scattering and radiation problem is sought under the assumption that the structure is in finite depths. The energy production is quantified by considering a linear power take off model [4]. Parametric analyses are performed to identify the optimal OWC geometry from an energy wise perspective.

Compared to state-of-the-art analytical models, the proposed solution has the advantage of modelling the configuration of an OWC spanning a limited portion of the floating platform boundary. Thus, making it applicable to realistic design implementations.

References

- [1] Falcão A. F. O., Henriques J. C. C., "Oscillating-water-column wave energy converters and air turbines: A review," *Renew Energy*, vol. 85, pp. 1391–1424, (2016)
- [2] Abhinav K. A. et al., "Offshore multi-purpose platforms for a Blue Growth: A technological, environmental and socio-economic review," *Science of The Total Environment*, vol. 734, p. 138256, (2020)
- [3] Linton C. M. and McIver P., *Handbook of mathematical techniques for wave/structure interactions*. (2001)
- [4] Falcão A. F. O., Henriques J. C. C., Gato L. M. C., "Self-rectifying air turbines for wave energy conversion: A comparative analysis," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 1231–1241, (2018)

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Title: Predicting the burst strength of composite pressure vessels through machine learning

Author(s): Rafael Santos^{*1,2}, Dirk Vandepitte¹, David Moens¹

¹ *Department of Mechanical Engineering Division LMSD, KU Leuven, Sint-Katelijne-Waver, Antwerp 2860, Belgium, rafael.santos@kuleuven.be*

² *SIM vzw Technologiepark 935, BE-9052, Zwijnaarde, Belgium*

Keyword(s): machine learning, kriging, gaussian processes, uncertainty quantification, pressure vessels, black-box modelling

Abstract

In Hydrogen Fuel Cell Electric Vehicles, hydrogen is stored as compressed gas in tanks made from carbon fibre composite. These are designed at 2.25 times the nominal working pressure [1]. If a low variability in the strength of the tank can be demonstrated, this margin of safety could be reduced. This can be achieved through prediction of the vessel's strength and its uncertainty. In this work, several composite pressure vessels (CPV) were manufactured through fiber winding, and the parameters that control the winding and curing were recorded as time signals. Some of these parameters include fiber tension, winding speed, liner pressure, fiber volume fraction, and curing pressure. The vessels were then tested for their burst pressure. Several configurations were defined, where each manufacturing parameter was changed. The recorded manufacturing data was fed to machine learning (ML) algorithms to train them to predict the respective vessels' burst pressure. These ML algorithms included neural networks, Gaussian process regression (Kriging), and reduction-regression algorithms (PCA, kPCA followed by Lasso, Ridge, and Elastic Net regression). Using kPCA – Lasso regression we were able to predict the strength with a coefficient of determination of 0.96, better than the best naïve prediction, using the average value of the burst strength for each configuration.

References

[1] 2021, BPVC Section X-Fiber-Reinforced Plastic Pressure Vessels - ASME, ASME.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Application of unsupervised machine learning algorithms on determining the rate of random impulses forcing an oscillator.

Author(s): Przemysław Frankiewicz¹, Natalia Frankowska², Marek Sulewski³, Agnieszka Ozga⁴.

*AGH University of Science and Technology, Department of Mechanic Engineering and Robotics,
Krakow, Poland,*

¹*email:*pfrankie@agh.edu.pl

²*email:*frankows@agh.edu.pl

³*email:*sulewski@agh.edu.pl

⁴*email:*aoszga@agh.edu.pl

Keyword(s): oscillator vibrations, stochastic impulses, unsupervised machine learning.

Abstract

The paper considers vibrations of a discrete, linear system, excited by stochastic impulses [1-4] with the following initial conditions $x(0)=0$ and $dx/dt=0$. A random series of impulses are generated using the following random variables: η_i is a sequence of independent identically random values of amplitude of i -th impulse with finite expectation, and it assumes a finite number of values $p_i=p(h_i)$. second random variable t_i are i -th time of excitation of the vibrations. The intervals between the impulses $t_{i-1} - t_i$ is a sequence of independent identically randomly distributed variables with exponential distribution with the impulse rate λ . The intervals between the impulses and amplitudes of the impulses are independent random variables.

This article compares various unsupervised machine learning algorithms to find methods that can classify time series generated for similar impulse intensities into the same classes.

Acknowledgments

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References

- [1] Jablonski, M., Ozga, A., "Distribution of Random Pulses Acting on a Vibrating System as a Function of Its Motion", Krakow: AGH-University of Science & Technology, 2013.
- [2] Rice S., "Mathematical analysis of random noise I", Bell. System Technical Journal, 23, 1944.
- [3] Roberts J.B., "On the Harmonic Analysis of Evolutionary Random Vibrations", J. Sound Vibr., 1965.
- [4] Roberts J.B., Spanos P.D., "Stochastic Averaging: an Approximate Method for Solving Random Vibration Problems", Int. J. Non-Linear Mech., 21, 1986.

EMI 2023 International Conference

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Title: Bootstrapping-based determination of power spectral density intervals from limited data

Author(s): Marco Behrendt^{*1}, Chao Dang¹, Michael Beer^{1,2,3}

¹ Institute for Risk and Reliability, Leibniz Universität Hannover, Germany, behrendt@irz.uni-hannover.de

² Institute for Risk and Uncertainty, University of Liverpool, United Kingdom

³ International Joint Research Center for Engineering Reliability and Stochastic Mechanics, Tongji University, Shanghai, China

Keyword(s): uncertainty quantification, power spectral density function, stochastic processes, structural reliability, bootstrapping.

Abstract

In engineering, and especially in stochastic dynamics, the modelling of environmental processes, for example wind or earthquake loads, is of paramount importance. Such load models are used in simulations to determine the reliability of existing buildings or are needed for the safe design of new structures. In this context, the power spectral density (PSD) function is an important tool as it can characterise stochastic processes in the frequency domain and thus determine the associated frequencies and amplitudes of the signal. However, determining a reliable PSD might be challenging due to the uncertainties inherent in the stochastic processes as well as the PSD estimation itself. To overcome this issue, these uncertainties must be taken into account to obtain a reliable representation of the PSD function. Many PSD functions, such as the Clough-Penzien model, are described by parameters with a physical background and can therefore reflect the real case up to a certain degree. The aim of this work is to expand these physical parameters in order to account for the uncertainties. For this purpose, bootstrapping is used to draw samples from a limited data set to obtain reliable maximum, minimum and standard deviation for each discretised frequency. These parameters are used in combination with a scaling parameter to derive reliable upper and lower bounds of the data set, which are subsequently used to determine interval parameters. This form of a PSD function is thus represented by intervals for its physical properties instead of relying on discrete values. The resulting interval-valued PSD function can be used to generate artificial stochastic processes. In combination with advanced interval propagation schemes the structural reliability will be efficiently determined by bounding the failure probability.

EMI 2023 International Conference

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Title: A New Correlation Structure for the Wavelet-Based Stochastic Generation of Fully Non-Stationary Artificial Accelerograms

Authors: Federica Genovese ^{*1}, Alessandro Palmeri ²

¹ *Department of Architecture and Territory (dArTe), Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy, Federica.Genovese@unirc.it*

² *School of Architecture, Building and Civil Engineering (SABCE), Loughborough University, Loughborough, U.K., A.Palmeri@Lboro.ac.uk*

Keywords: Artificial accelerograms, Circular wavelet transform, Fully non-stationary random processes.

Abstract

A rigorous definition of ground motions is essential to designing earthquake-resistant structural and geotechnical systems and evaluating their seismic vulnerability. Among all possible sources of uncertainty, the choice of the input motion tends to have the highest effect on the variability observed in time-history response analyses [1].

When geologic and tectonic conditions of a given location are similar to those of the sites where actual strong motions have previously been detected, recorded time histories can be directly used as input motions. Otherwise, the use of artificial accelerograms, having characteristics consistent with those expected in actual earthquake ground motions, could represent a valid alternative.

Signals typically encountered in earthquake engineering are non-stationary, as recorded accelerations change their amplitude and frequency content over time. Since the wavelets possess joint time-frequency localization capabilities, the wavelet analysis can be successfully exploited to generate artificial accelerograms with realistic features.

This study uses the circular harmonic wavelet transform to randomly generate an arbitrary number of seismic records with the same non-stationary characteristics of a parent signal [2]. Specifically, a recorded accelerogram is decomposed into the superposition of complex-valued harmonic wavelets, and an expedient extension of the well-known Shinozuka's formula randomizes their phases [3]. The present paper focuses on introducing and validating a new correlation structure for the random phases, which leads to the generation of "child" samples having different forms of variability with respect to the "parent" accelerogram.

The research shows the critical role played by the number and size of bands partitioning the frequency domain. For instance, assuming that the random phases are statistically independent and considering the two extreme cases, either with a single frequency band or several mono-frequency bands, leads to random processes in which information on the energy distribution is lost on the frequency or time domain, respectively. Instead, the assumption of a convenient time-frequency correlation structure for the random phases lets the designer preserve all the desired non-stationary characteristics of the parent signal and obtain an effective trade-off between time and frequency localization.

References

- [1] Dolsek, M., "Incremental dynamic analysis with consideration of modeling uncertainties", *Earthquake Engineering and Structural Dynamics*, Vol. 38, pages 805-825, (2009).
- [2] Genovese F., Muscolino G., Palmeri A. "Effects of stochastic generation on the elastic and inelastic spectra of fully non-stationary accelerograms". *Probabilistic Engineering Mechanics*, Vol. 71, article 103377, (2023).
- [3] Shinozuka M., Sato Y. "Simulation of nonstationary random process", *Journal of the Engineering Mechanics Division*, Vol. 93, pages 11-40, (1967).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Closed-form solutions for the spectral characteristics of the stochastic response of linear systems subjected to fully non-stationary excitations consistent with target seismic accelerograms

Authors: Federica Genovese¹, Giuseppe Muscolino^{* 2}

¹ *Department of Architecture and Territory (dArTe), University "Mediterranea" of Reggio Calabria, Reggio Calabria, Italy, Federica.Genovese@unirc.it*

² *Department of Engineering, University of Messina, Messina, Italy, giuseppe.muscolino@unime.it*

Keywords: Artificial accelerograms, Fully non-stationary random processes, Evolutionary frequency response function.

Abstract

Strong motion earthquakes represent critical actions for buildings located in seismically active regions. The analysis of recorded accelerograms after earthquakes evidences that different earthquakes produce ground motions with different characteristics in terms of intensity, strong motion duration, and frequency content. It follows that, in order to guarantee a good performance of structures in seismic areas, it needs to adequately characterize the ground motion acceleration [1]. Moreover, it has been recognized that recorded accelerograms possess both temporal and spectral non-stationarities. Temporal non-stationarity refers the variation in the intensity of the ground motion in time, whereas the spectral non-stationarity refers to the time variation of the frequency content [2]. It follows that they can be view as samples of fully non-stationary zero-mean Gaussian processes.

Recently, the authors proposed a new model of the evolutionary power spectral density (EPSD) function of the zero mean Gaussian processes to generate artificial accelerograms, in such a way that a given target accelerogram can be considered as one of its own samples [3,4]. The EPSP function can simply be evaluate once the frequency of peaks, the zero level up crossings and the total energy of a target accelerogram are determined.

In this study the procedure co-authored by the senior author [5] is extended to evaluate the closed-form solution of the evolutionary frequency response function of classically and non-classically damped linear structural systems subjected to fully non-stationary excitations consistent with target seismic accelerograms. Then the time dependent spectral characteristics of the response are evaluated by means of an innovative approach based on a pole-residue operation in the complex.

References

- [1] Villaverde R., Fundamental concepts of earthquake engineering, CRC press, (2009).
- [2] Rezaeian S., Der Kiureghian A., "A stochastic ground motion model with separable temporal and spectral nonstationarities", Earthquake Engineering & Structural Dynamics, 37(13), 1565-1584, (2008).
- [3] Muscolino G., Genovese F., Biondi G., Cascone E., "Generation of fully non-stationary random processes consistent with target seismic accelerograms", Soil Dynamics and Earthquake Engineering, 141, 106467, (2021).
- [4] Genovese F., Biondi G., Cascone E., Muscolino G., "Energy-compatible modulating functions for the stochastic generation of fully non-stationary artificial accelerograms and their effects on seismic site response analysis", Earthquake Engineering & Structural Dynamics, 1-26, (2023).
- [5] Muscolino G., Alderucci T., "Closed-form solutions for the evolutionary frequency response function of linear systems subjected to separable or non-separable non-stationary stochastic excitations", Probabilistic Engineering Mechanics, 40, 75-89, (2015).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Wavelet-Based Generation of Ensemble of Ground Motions Compatible with a Probabilistic Target Response Spectrum

Author(s): Suparno Mukhopadhyay^{*1}, Sandip Das², Vinay K. Gupta³

¹ Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, suparno@iitk.ac.in

² Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, India, sandip.das@iitg.ac.in

³ Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, vinaykg@iitk.ac.in

Keyword(s): ground motion simulation, response spectrum compatible ground motions, probabilistic target response spectrum, conditional spectrum

Abstract

The use of response spectrum compatible ground motions has been popular in the seismic design of structures and several algorithms have been proposed to generate such motions. One such algorithm works by modifying a recorded ground motion via frequency-band-dependent modification factors such that it becomes compatible with a target response spectrum, while the nonstationary features of the original motion are preserved in the component narrow-band wave levels of the modified motion [1]. It has also been shown that, in the context of ground motion selection based on matching a target spectrum, considering the variance of the target spectrum tends to increase the mean predicted response and the dispersion in response, with implications in code-based and performance-based designs [2]. This necessitates the development of methods to generate spectrum compatible ground motions which can also incorporate possible uncertainty in the definition of the target response spectrum. In this work, the algorithm proposed in [1] is extended into a probabilistic framework to address this issue. This extension results in the generation of an ensemble of ground motions, such that the response spectra of the motions in this ensemble statistically match a specified target probabilistic response spectrum model. The probabilistic model of the target spectrum is assumed to be represented by a mean vector and a fully populated covariance matrix, denoting uncertainty in each spectral value as well as possible correlation between the spectral values at different periods. It is shown that the generated ensemble is also statistically consistent in terms of peak ground motion parameters, when the target spectrum is defined using ground motion prediction equations. The applicability of the proposed method with conditional spectrum as target is also illustrated.

References

- [1] S. Mukhopadhyay, S. Das, V. K. Gupta, Wavelet-based generation of accelerogram-consistent, spectrum-compatible motions: New algorithms and short-period overestimation, *Soil Dynamics and Earthquake Engineering* 121, 327–340, 2019.
- [2] N. Jayaram, T. Lin, J. Baker, Computationally efficient ground-motion selection algorithm for matching a target response spectrum mean and variance, *Earthquake Spectra* 27, 797–815, 2011.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Perturbations for static problems of Timoshenko beams of local/non-local mixture

Author(s): Giuseppe Ruta^{*1}, Uğurcan Eroğlu²

¹*Department of Structural and Geotechnical Engineering, University of Roma "La Sapienza", Roma, Italy, giuseppe.ruta@uniroma1.it*

²*Faculty of Mechanical Engineering, Istanbul Technical University, Istanbul, Türkiye, ueroglu@itu.edu.tr*

Keyword(s): Nonlocal elasticity, Perturbation, Closed-form solutions, Timoshenko beam

Abstract

The classical theory of elasticity fails if the length that characterises the internal material interaction is comparable with the overall dimensions of the body. For these instances, quasi-continuum models are used: these maintain a continuum approach while taking into account some internal organisation of the material [1]. Among others, Eringen's "strong" integral model [2,3] found many applications, mainly assuming an infinite domain and turning the constitutive equations from integral to differential [4,5]. However, several applications of Eringen's constitutive equation in such a differential form to finite domains led to paradoxical results [6,7]. In addition, questions about existence and uniqueness of the solutions arose, particularly relating to the so-called "constitutive boundary conditions" that must be satisfied [8]. Indeed, these additional conditions seem to be spurious and not to have any physical basis, thus Eringen's model in differential form is somehow criticised.

As an answer, one can assume the material to consist of a mixture of local and non-local fractions. In [9] it was proved that when this two-phase model is perturbed with respect to the 'small' nonlocal fraction of the material response, the constitutive boundary conditions are no longer needed. In [10] we applied the same perturbation approach to free vibration problems, and satisfactory results were presented again, without requiring any additional non-physical conditions. In this contribution we use the perturbation approach presented in [9] to the analysis of static problems of Timoshenko beams. We provide the first-order expressions for some benchmark problems in closed-form and compare them with the results of the literature for which the constitutive boundary conditions are used.

References

- [1] Kunin I.A., Elastic media with microstructure I: one-dimensional models. Springer-Verlag, Berlin (1982)
- [2] Eringen A.C., Edelen D., On nonlocal elasticity, *Int. J. Eng. Sci.* 10:233–248 (1972)
- [3] Eringen A.C., Linear theory of nonlocal elasticity and dispersion of plane waves, *Int. J. Eng. Sci.* 10:425–435 (1972)
- [4] Eringen A.C., Screw dislocation in non-local elasticity, *J. Phys. D Appl. Phys.* 10(5):671–678 (1977)
- [5] Eringen A.C., Nonlocal continuum field theories (1st edn.). Springer-Verlag, New York (2002)
- [6] Challamel N., Wang C.M., The small length scale effect for a non-local cantilever beam: a paradox solved, *Nanotechnology* 19(34):345703 (2008)
- [7] Fernández-Sáez J., Zaera R., Loya J.A., Reddy J.N., Bending of Euler-Bernoulli beams using Eringen's integral formulation: a paradox resolved, *Int. J. Eng. Sci.* 99:107–116 (2016)
- [8] Romano G., Barretta R., Diaco M., Marotti de Sciarra F. Constitutive boundary conditions and paradoxes in nonlocal elastic nano-beams, *Int. J. Mech. Sci.* 121:151–156 (2017)
- [9] Eroğlu U. Perturbation approach to Eringen's local/non-local constitutive equation with applications to 1-D structures, *Meccanica* 55:1119–1134 (2020)
- [10] Eroğlu U., Ruta G. Approximate closed-form solutions for vibration of nano-beams of local/non-local mixture, *Meccanica* 57, 3033–3049 (2022)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Local-nonlocal stress-driven model for multi-cracked shear deformable nanobeams

Author(s): Andrea Caporale^{*1}, Raimondo Luciano²

¹ *Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino, Italy, a.caporale@unicas.it*

² *Dipartimento di Ingegneria, Università degli Studi di Napoli "Parthenope", Naples, Italy, raimondo.luciano@uniparthenope.it*

Keyword(s): Nanobeam, Nonlocal theory, Crack, Dirac delta

Abstract

This work provides closed-form solutions for multi-cracked shear deformable nanobeams. Small-scale structures, such as microcantilevers [1], can contain defects (cracks, voids, etcetera), which reduce the stiffness and the natural frequencies of these structures and can lead to their failure. Therefore, evaluating crack effects on small-scale structures' behavior becomes essential. In the existing literature on nanobeams, the cracks are modeled by separating the nanobeams into segments connected by hinges with rotational springs at the cracked sections [2]. This work adopts a different crack model: the cracked nanobeam is a continuous segment with variable bending flexibility, containing Dirac delta functions located at the cracked sections. Specifically, the crack model with Dirac delta is used for the first time in the local-nonlocal stress-driven model, i.e. a convex combination (mixture) of local and nonlocal phases, with the nonlocal phase given by the integral convolution of the bending moment over the nanobeam length [3]. In local problems, the bending flexibility with a Dirac delta produces a singularity of the bending curvature and a consequent slope discontinuity of the deflection line at the cracked sections [4]. The same happens in a nanobeam modeled as separate segments connected by springs at the cracked sections. On the other hand, in this work, it is shown that the bending flexibility with Dirac delta functions produces no singularity in the bending curvature and no rotation jump in the deflection line of the pure nonlocal stress-driven model (where the local fraction of the mixture is absent), in accordance with nonlocal theories; see, e.g., the absence of stress singularity at crack tips of nonlocal structures [5], in contrast to the local elasticity theory. The typical stiffness increase, due to the increase in the nonlocal fraction of the mixture or the increase in the length-scale parameter, also appears in multi-cracked nanobeams. This stiffening nonlocal effect is more pronounced in more constrained nanobeams.

References

- [1] Liu, X., Wang, L., Zhao, J., Zhu, Y., Yang, J., Yang, F., "Enhanced binding efficiency of microcantilever biosensor for the detection of yersinia", *Sensors (Switzerland)*, 19 (15), (2019).
- [2] Loya, J., López-Puente, J., Zaera, R., Fernández-Sáez, J., "Free transverse vibrations of cracked nanobeams using a nonlocal elasticity model", *J. Appl. Phys.*, 105 (4), (2009).
- [3] Romano, G., Barretta, R., "Nonlocal elasticity in nanobeams: the stress-driven integral model", *Internat. J. Engrg. Sci.*, 115, 14–27, (2017).
- [4] Palmeri, A., Ciciello, A., "Physically-based Dirac's delta functions in the static analysis of multi-cracked Euler-Bernoulli and Timoshenko beams", *Int. J. Solids Struct.*, 48 (14–15), 2184–2195, (2011).
- [5] Zhou, Z.G., Han, J.C., Du, S.Y., "Investigation of a Griffith crack subject to antiplane shear by using the non-local theory", *Int. J. Solids Struct.*, 36 (26), 3891–3901, (1999).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Nonlocal gradient bending of elastic nanobeams for piecewise regular fields

Author(s): Marzia Sara Vaccaro¹, Raffaele Barretta¹, Andrea Caporale², Raimondo Luciano³

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, via Claudio 21, Naples, 80125, Italy. E-mail: marziasara.vaccaro@unina.it, rabarret@unina.it*

² *Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, via G. Di Biasio 43, Cassino, 03043, Italy. E-mail: a.caporale@unicas.it*

³ *Department of Engineering, University of Naples Parthenope, via Amm. F. Acton 38, Naples, 80133, Italy. E-mail: raimondo.luciano@uniparthenope.it*

Keyword(s): Nonlocal gradient elasticity; Interface constitutive conditions; Nanobeams.

Abstract

Nonlocal continuum theories [1,2] are investigated in the case of non-smooth fields representing the most general condition in mechanics of nanobeams with several Nano-Engineering applications. The treatment starts from the general formulation of elasticity provided by the abstract form of nonlocal gradient theory for nanobeams. The equivalent differential problem is then derived to reverse the constitutive law. Such a formulation requires prescription of non-classical interface conditions at discontinuity abscissae [3,4] that play a fundamental role to close the relevant differential problem. In this research, the simplest constitutive interface conditions not involving spatial convolutions are established, thus providing an improvement of previous contributions in literature, such as [5]. The developed differential scheme is fundamental for theoretical and computational purposes and plays a key role for strain-driven based models for which inversion of the constitutive law is essential to explicitly get the unknown solution fields. Exemplar continuum problems are finally analysed and discussed to show merits and effectiveness of the proposed formulation in comparison with previous treatments in literature.

References

- [1] Eringen A.C., "On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves", *Journal of Applied Physics* 54, 4703–4710, (1983).
- [2] Lim C., Zhang G., Reddy J.N., "A higher-order nonlocal elasticity and strain gradient theory and its applications in wave propagation", *Journal of the Mechanics and Physics of Solids* 78, (2015).
- [3] Caporale A., Darban H., Luciano R., "Exact closed-form solutions for nonlocal beams with loading discontinuities", *Mechanics of Advanced Materials and Structures* 29, 1-11, (2020).
- [4] Vaccaro M.S., Marotti de Sciarra F., Barretta R., "On the regularity of curvature fields in stress-driven nonlocal elastic beams", *Acta Mechanica* 232, 2595–2603, (2021).
- [5] Caporale A., Darban H., Luciano R., "Nonlocal strain and stress gradient elasticity of Timoshenko nano-beams with loading discontinuities", *International Journal of Engineering Science* 173, 103620, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A fully implicit coupled pore-network/free-flow model for the pore-scale simulation of drying processes

Author(s): Anna Mareike Kosteletzky, Martin Schneider, Maziar Veyskarami, Hanchuan Wu, Rainer Helmig*

¹Hydromechanic and Modelling of Hydrosystems,, University of Stuttgart, Stuttgart, Germany, rainer.helmig@iws.uni-stuttgart.de

Keyword(s): keywords list (coupled systems, multi-phase flow, evaporation)

Abstract

Heat transfer processes and non-isothermal effects are found in many technical and environmental coupled porous-media free flow systems. Prominent examples including two-phase flow range from fuel-cell water management and food drying to soil evaporation and salinization. Modeling these types of systems is challenging due to the variety of length and time scales involved and the high physical complexity of the processes [1]. In this work, we introduce a fully coupled, locally energy- and mass-conservative dual network model [3] for the simulation of heat transfer in realistic natural porous media, allowing the consideration of pore-local thermal nonequilibrium and structural heterogeneity coupled with a free flow system [2]. Energy transfer in the dual network is modeled as a fully coupled processes using pore and grain-local heat transfer rules derived from the analysis of local idealized but spatially resolved problems and geometrical considerations. The solid space. Both porous media subdomains are simplified using the same model reduction technique commonly applied exclusively to the void space, where it is known as pore-network modelling. Using selected examples, we will show the conditions under which thermal non-equilibrium plays a role.

References

- [1] Weishaupt, K., R Helmig. A Dynamic and Fully Implicit Non-Isothermal, Two-Phase, Two-Component Pore-Network Model Coupled to Single-Phase Free Flow for the Pore-Scale Description of Evaporation Processes. *Water Resources Research* 57 (4) (2021),
- [2] Weishaupt K., T Koch, R Helmig. A fully implicit coupled pore-network/free-flow model for the pore-scale simulation of drying processes. *Drying Technology* (2022),
- [3] Koch, T.; Weishaupt, K.; Müller, J.; Weigand, B.; R Helmig. A (Dual) Network Model for Heat Transfer in Porous Media. *Transport in Porous Media*, 1–35 (2021)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Control-Volume Finite-Element Schemes for Coupling Free Flow with Porous-Medium Flow

Author(s): Martin Schneider^{*1}, Edward Coltman¹, Timo Koch², Rainer Helmig¹. (Arial font – 11 point size, mark the speaker with *)

¹ *Hydromechanics and Modelling of Hydrosystems,, University of Stuttgart, Stuttgart, Germany, martin.schneider@iws.uni-stuttgart.de*

² *Department of Mathematics, University of Oslo, Oslo, Norway*

Keyword(s): control-volume finite elements; numerical methods; free flow; porous-medium flow

Abstract

Exchange processes across a porous-medium free-flow interface occur in a wide range of environmental, technical and bio-mechanical systems.

In the course of these processes, flow dynamics in the porous domain and in the free-flow domain exhibit strong coupling, often controlled by mechanisms at the common interfaces.

In this work, we focus on the two-domain approach, which decomposes the problem into two disjoint subdomains. The free-flow region is described by the Navier-Stokes equations while Darcy's or Forchheimer's law is used in the porous-medium subdomain.

Appropriate coupling conditions are formulated at the common interface, which enforce the conservation of mass, momentum and energy.

In this work, we present a novel mass and momentum conservative control-volume finite-element (CVFE) scheme for the discretization of the free-flow subdomain.

Furthermore, a new approach to couple this CVFE scheme, which is used in the free-flow subdomain, with a vertex-centered finite-volume method (Box method), used for solving Darcy flow in the porous medium, is presented. This work is therefore an extension of the work presented in [1,2], where a staggered grid approach has been used to discretize the free-flow region. The advantages of the novel control-volume finite-element scheme and the new coupling approach are discussed in detail based on various test cases, ranging from convergence tests to real applications.

References

[1] Schneider, M., Weishaupt, K., Gläser, D., Boon, W. M., Helmig, R. Coupling staggered-grid and MPFA finite volume methods for free flow/porous-medium flow problems. In: Journal of Computational Physics, (2020).

[2] Schneider, M., Gläser, D., Weishaupt, K., Coltman, E., Flemisch, B., Helmig, R. Coupling staggered-grid and vertex-centered finite-volume methods, (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Gravel bed rivers: bed roughness structure and interface flow characterization

Author(s): Donatella Termini¹, Federica Lavignani^{*2}.

¹ *Department of Engineering, University of Palermo, Palermo, Italy, donatella.termini@unipa.it*

² *Department of Engineering, University of Palermo, Palermo, Italy, federica.lavignani@unipa.it*

Keyword(s): gravel beds, roughness, turbulence, simulation, CFX.

Abstract

Gravel bed rivers are characterized by a significant spatial variability of the grains in terms of size and shape. The point is that the heterogeneous distribution of the grains strongly affects the flow velocity field, especially in the near-bed region, determining the formation of coherent turbulence structures. Thus, the characterization of the gravel bed surface is extremely important to analyze fluvial processes such as the dispersion and mixing of substances and the sediment transport [1, 2].

Different approaches have been proposed in the literature to identify the gravel-bed surface to characterize the bed roughness [3] and to adequately simulate the near-bed flow characteristics by considering the spatial variability of the grains [4, 5]. But how to reasonably quantify gravel bed surface roughness is still an open question.

The present work reports on a study conducted to explore the flow structure in the near-bed region over a non-uniform gravel bed, with the aid of data collected in a laboratory flume. The flow velocity and turbulent fields are simulated by using the commercial ANSYS CFX code, assuming different computational grids of the mesh in the near-bed region [6]. The image-based technique is used to identify the gravel bed structure in the laboratory flume and the spatial distribution of the grains. Statistical analysis is then applied to evaluate the gravel surface and the variogram is determined to quantify the bed roughness proprieties. The results are used for the numerical simulations and the comparison between the numerical results and the experimental data is used to assess the goodness of the procedure. .

References

- [1] Termini D., Lavignani F., Benistati N., 'Investigation of turbulence characteristics and mixing layer thickness in gravel bed flows'. 11th International Conference on Fluvial Hydraulics - RiverFlow2022, Kingstone and Ottawa (Canada), November 8-10. (2022).
- [2] Navaratnam, C. U., Aberle, J., Qin, J., Henry, P. 'Influence of Gravel-Bed Porosity and Grain Orientation on Bulk Flow Resistance'. HENRY. Hydraulic Engineering Repository. Water 2018, 10, 561; (2018).
- [3] Aberle J., Nikora V. Statistical properties of armored gravel bed surfaces. Water Resour. Res. 42, W11414. . 2006
- [4] Alfonsi, G., Ferraro, D., Lauria, A., Gaudio R. 'Large-eddy simulation of turbulent natural-bed flow'. Physics of Fluids 31, 085105. (2019)
- [5] Hardy, R. J. and Lane, S. N. and Ferguson, R. I. and Parsons, D. R. 'Emergence of coherent flow structures over a gravel surface: a numerical experiment.', Water resources research., 43, W03422. (2007)
- [6] Lazzarin T., Constantinescu G., Di Micco L., Wu H., Lavignani F., Lo Brutto M., Termini D. Viero D. P., 'Influence of Bed Roughness on Flow and Turbulence Structure Around a Partially-Buried, Isolated Freshwater Mussel', Water Resources Research, 59. (2023). DOI: 10.1029/2022WR034151.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Predicting the growth of wood structures based on a micromechanics-informed beam model

Author(s): Antonia Wagner¹ and Stefan Scheiner*¹

¹ Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria, stefan.scheiner@tuwien.ac.at

Keyword(s): tension wood, trees, multiscale, homogenization, beam theory

Abstract

Growing trees respond to mechanical disturbances, resulting, e.g., from environmental forces or gravity, by forming so-called reaction wood [1]. The latter is called compression wood in gymnosperms and tension wood in angiosperms. It enables the tree to control its posture by reinforcing and reorienting the axes of stems and branches, which is a key prerequisite for reaching large heights. The movement is due to asymmetric cambial activity resulting in eccentric growth and varying growth strains. While the underlying biological mechanisms of growth strain generation are not yet fully understood, various hypotheses correlating the induced macroscopic movement with the difference in cell wall structure of reaction and non-reaction wood have been proposed. On that basis, a homogenization procedure was developed for upscaling and evaluating the macroscopic effect of growth strains implemented at the cell wall level [2]. In particular, we aim at unraveling the effect of the characteristic composition and microstructure of tension wood containing G-layers on the elastic properties and macroscopic growth strains by employing multiscale homogenization modeling techniques, based on the concept of continuum micromechanics. A three-step homogenization scheme is employed to estimate the elastic properties of the cell wall layers based on the volume fractions of elementary components. The structural organization at the cell wall level is represented by multilayered cylindrical inclusions exhibiting transversely isotropic material behavior taking into account the previously evaluated layer properties depending on the composition of their elementary constituents, such as cellulose, hemicellulose, lignin and water. We derive the stress and strain fields corresponding to four different loading conditions, which allows for constructing the complete stiffness tensor of tension wood and upscaling the growth strains induced within the G-layer. Coupling the micromechanics model with non-linear beam mechanics, applied to a growing branch inclined with respect to the vector of gravity, allows to simulate the reorientation process induced by growth strains at the cell wall level. In combination with experimental data of the branch shape evolution found in literature of specific species, growth-related parameters can be deduced, which may lead, in further consequence, to a better understanding and predictability of the growth process.

References

- [1] M. Fournier, T. Almeras, B. Gril, J. Gril, Biomechanical action and biological functions. In *The Biology of Reaction Wood*. Springer Series in Wood Science, Springer, pp. 139-169, 2014.
- [2] E. Hervé and A. Zaoui, Elastic behavior of multiply coated fiber-reinforced composites. *International Journal of Engineering Science* (1995), 33: 1419-1433.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Complex Biomechanics: from atoms to patients

Author(s): Christian Hellmich^{*1}, Johannes Kalliauer¹, Niketa Ukaj¹ Stefan Scheiner¹

¹ *Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria, christian.hellmich@tuwien.ac.at*

Keyword(s): biomechanics, molecular mechanics, homogenization, Boltzmann integro-differential equations, COVID-19

Abstract

Complex systems are characterized by an overall behavior which is different from that of the components making up the systems - hence, (nonlinear) interactions between the components play a very important role. Taking an interdisciplinary approach rooted in theoretical and applied mechanics and engineering mechanics, we report on two types of recently studied systems where individual system components (atoms and patients) interact in a way which unfolds very interesting emerging patterns that can be mathematically quantified through concepts arising from (bio-)mechanics: (i) the interaction of atoms within a short thread of DNA, which, as a compound, result in a family of a highly nonlinear beam structures with varying, but always coupled torsion-stretching modes [1]; (ii) the compliance of sets of patients to the lethal effect of SARS-COV-2 [2,3], which follows integro-differential equations reminiscent of those introduced by Boltzmann in the context of creep (or hereditary) mechanics [4]. We conclude that smart classical concepts of applied mechanics and physics continue to show an unparalleled potential for solving pressing global problems in the context of computational modelling of living systems.

References:

- [1] J. Kalliauer, G. Kahl, S. Scheiner, Ch. Hellmich, A new approach to the mechanics of DNA, J Mech Phys Sol 143, 104040, 2020.
- [2] S. Scheiner, N. Ukaj, Ch. Hellmich, Mathematical modeling of COVID-19 fatality trends: death kinetics law versus infection-to-death delay rule, Chaos, Solitons & Fractals 136, 109891, 2020.
- [3] N. Ukaj, S. Scheiner, Ch. Hellmich, Toward "hereditary epidemiology": a temporal Boltzmann approach to COVID-19 fatality trends, Applied Physics Reviews, 8, 041417, 2021.
- [4] H. Markovits, Boltzmann and the Beginnings of Linear Viscoelasticity, Transactions of the Society of Rheology 21, 381-398, 1977.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Some insights into caterpillar's locomotion for soft robots applications

Authors: Mario Argenziano^{1,2,*}, Massimiliano Fraldi², Massimiliano Zingales¹

¹ Department of Engineering, University of Palermo, Palermo, Italy

² Department of Structures for Engineering and Architecture, University of Napoli "Federico II", Napoli, Italy

Keywords: caterpillar's locomotion, bio-inspired soft robots; crawling gait.

Abstract

Soft robotics has emerged as a promising field that seeks to develop robots with compliant structures capable of performing versatile tasks in complex environments. Mimicking biological organisms has been a fundamental approach for designing soft robots with adaptable locomotion. Within this framework, this research investigates the mechanical principles of caterpillars' locomotion, with the aim of theoretically predicting their motion and artificially reproducing it.

Caterpillars exhibit sequential shortening and expansion of body segments, enabling efficient crawling movement, thanks to some key features such as coordinated muscular contractions and frictional anchors. By emulating these features and exploiting them for endoscope and drug delivery purposes, novel medical micro-robots can achieve caterpillar-like locomotion, facilitating navigation through confined spaces and adapting to diverse environments.

In this work, some insights into the mechanical models of such animals are provided, in order to faithfully grasp the complex mechanisms of their locomotion. To do this, the *in vivo* locomotion of samples of larvae belonging to the species *Pieris Brassicae* is observed on several substrates made by different materials, with the aim of elucidating the roles played by the anchoring of the terminal prolegs and the body contractions mainly involving the abdominal subunits. Starting from experimental observations and results by other scholars [1-3], a lumped mass multiple degrees-of-freedom model with springs arranged in series is adopted for representing the locomotion of each body segment of the animal. Additionally, further Pasternak-like constraints are uploaded to some specific subunits for modulating their interaction with the substrate and predicting the detachment of some prolegs of the caterpillar. By neglecting the inertial forces, a quasi-static approach has been implemented, the muscular contraction being utilized for triggering the crawling gait of the larva. Several parametric analyses are finally performed, with the aim of understanding the effects of the competition of anchoring and muscular contractions phenomena on the overall behaviour of the system.

References

- [1] Van Griethuijsen, L. I., & Trimmer, B. A. (2014). Locomotion in caterpillars. *Biological Reviews*, 89(3), 656-670.
- [2] Zhou, W., & Gravish, N. (2020). Rapid two-anchor crawling from a milliscale prismatic-push-pull (3P) robot. *Bioinspiration & Biomimetics*, 15(6), 065001.
- [3] Schuldt, D. W., Rife, J., & Trimmer, B. (2015). Template for robust soft-body crawling with reflex-triggered gripping. *Bioinspiration & biomimetics*, 10(1), 016018.

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* speaker: mario.argenziano@unipa.it

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Eulerian and Lagrangian analysis of stented coronary flow

Authors: Paolo Peruzzo^{*1}, Chiara Conforto¹, Francesca Maria Susin¹, Stefano Lanzoni¹

¹*Department of Civil, Environmental and Architectural Engineering, University of Padova, Padova, Italy, paolo.peruzzo@dicea.unipd.it*

Keywords: stent, coronorary flow, computational fluid dynamics, particles tracking.

Abstract

Stents are wire-mesh tubes routinely adopted to treat coronary stenosis and preserve the capability of irrigating the myocardium with blood. In the last decades, stent design has been improved to ensure a radial strength sufficient to recover the original lumen size of the coronary, an easy implantation via transcatheter technique, and, even though to a less extent, to reduce the effects on blood flow of the mesh protruding from the vessel wall [1].

In the several studies analyzing the hemodynamics in stented coronaries, most efforts have been devoted to estimate the alteration of the wall shear stress (WSS) and of the oscillatory shear index (OSI) associated with the risk of restenosis [2,3]. In contrast, the alteration induced on the bulk region of the flow remains almost unexplored.

In the present work, we employed a numerical approach to investigate the hemodynamics within an idealized stented coronary. The aim is to assess how the presence of the stent frame trigger flow disturbances, which may lead to potential blood damage. The analysis was performed using the CFD module of Comsol 5.5 (Comsol Inc., Stockholm), considering two different blood rheologies, namely the Newtonian and Carreau-Yasuda models. We first adopted the Eulerian approach to reconstruct the vessel hemodynamics focusing on the local flow patterns originating from the wire mesh. We then performed a Lagrangian analysis based on the release of idealized red blood cell particles upstream of the stent to record the shear stress experienced along several paths.

In accordance with other numerical studies, our results show that the stent causes secondary circulation zones with low shear stress (<0.5 Pa) both upstream and downstream of the wire, a condition that can promote vessel restenosis [4,5]. Moreover, the secondary circulations increase the residence time of the blood particles traveling close to the wall. Particles in this region are subjected to spatial-varying shear stress with peaks up to 2.0 times the mean shear stress in the same position within a non-stented coronary, thus increasing the risks of blood cell damage. On the other hand, the observed hemodynamic alterations are inversely proportional to the mesh gap, suggesting that a suitable stent design can mitigate the above drawbacks.

References

- [1] Quarteroni, Alfio. "Modeling the cardiovascular system—A mathematical adventure: Part I." SIAM News 34.5: 1-3. (2001).
- [2] Scott, Neal A. "Restenosis following implantation of bare metal coronary stents: pathophysiology and pathways involved in the vascular response to injury." Advanced drug delivery reviews 58.3:358-376, (2006).
- [3] Brown, Adam J., et al. "Role of biomechanical forces in the natural history of coronary atherosclerosis." Nature reviews cardiology 13.4: 210-220, (2016).
- [4] Benard, Nicolas, Robert Perrault, and Damien Coisne. "Computational approach to estimating the effects of blood properties on changes in intra-stent flow." Annals of biomedical engineering 34: 1259-1271, (2006).

[5] Mejia, Juan, Rosaire Mongrain, and Olivier F. Bertrand. "Accurate prediction of wall shear stress in a stented artery: Newtonian versus non-Newtonian models." *Journal of Biomechanical Engineering*, 133.7:074501, (2011).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Flow dynamics of silicone oil tamponade in steady and unsteady conditions

Author(s): P.G. Ledda^{*1}, F. Angius², M.G. Badas³, T. Rossi⁴, G. Querzoli⁵

¹DICAAR, Università degli Studi di Cagliari, Cagliari, Italy, piergiuseppe.ledda@unica.it

²DICAAR, Università degli Studi di Cagliari, Cagliari, Italy, federico.ngs@gmail.com

³DICAAR, Università degli Studi di Cagliari, Cagliari, Italy, mgbadas@unica.it

⁴IRCCS - Fondazione G.B. Bietti ONLUS, Roma, Italy, tommasso.rossi@usa.net

⁵DICAAR, Università degli Studi di Cagliari, Cagliari, Italy, querzoli@unica.it

Keyword(s): ocular fluid dynamics, silicone oil tamponade, wall shear stresses

Abstract

Pars plana vitrectomy is a surgical procedure performed following retinal detachment and consists in the replacement of the vitreous with a fluid substitute. Surface tension and buoyancy affect the equilibrium states and the dynamics due to the everyday movements, with consequences on the near-wall forces and mass transport. While gas tamponade is subject to intense sloshing [1], silicone oil tamponade is less prone to wide motions. However, the higher viscosity and the comparable density with the aqueous humour may affect the near-wall fluid dynamics, with important implications in transport and phlogistic processes. We numerically study the multiphase flow of silicone oil tamponade with aqueous humour at different filling ratios in a model of a human eye, both in steady and unsteady conditions. The two fluid phases are simulated through the VOF method embedded in OpenFoam. We employ a Local-Time-Stepping algorithm to obtain steady solutions for varying filling ratios. In opposition to the gas tamponade case [1], the interface shape is dominated by surface tension, and, because of the contact angle, large surface wetting of the silicone oil is obtained only with very large filling ratios. The unsteady equations are instead solved in the non-inertial reference frame by including the accelerations in the momentum equations. We study a transient saccadic movement, a sudden car braking, a head rotation, and a stand-up movement [1]. We firstly describe the large-scale flow features and secondly focus on the topology of the wall shear stresses. In the latter framework, we identify stable and unstable manifolds and critical points and discuss the link to the forces acting on the endothelium and the near-wall transport. The approach has been successfully applied to cardiovascular flows [2]. Larger filling ratios are associated with higher and more uniform stresses over the whole surface wetted by the silicone oil. For the saccadic motion, after the transient, persistent attracting manifolds appear at the surface wetted by aqueous humour below and aligned with the interface. Similar persistent patterns in the silicone oil phase (above the interface) are observed, in the posterior eye, for the rotating head and car braking movements. Movements such as a stand-up from a supine condition induce more intense velocities and intricate manifold patterns also in the silicone oil phase, although the interface and contact line barely move.

References

- [1] Rossi, T.; Badas, M.G.; Angius F.; Querzoli, G. "Do Daily Activities Impact Gas Tamponade-Retina Contact after Pars Plana Vitrectomy? A Computational Fluid Dynamics Study." *Retina*():10.1097/IAE.0000000000003750 (2023)
- [2] Mazzi, V., et al. "Wall shear stress topological skeleton analysis in cardiovascular flows: Methods and applications." *Mathematics* 9.7: 720 (2021)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: On the comparison between the airflow in pre- and post- surgery nasal anatomies via Computational Fluid Dynamics (CFD)

Authors: Eric Segalerba^{*1}, Jan Oscar Pralits², Maurizio Quadrio³

¹ Department of Civil, Chemical and Environmental Engineering, University of Genova, Genova, Italia, eric.segalerba@edu.unige.it

² Department of Civil, Chemical and Environmental Engineering, University of Genova, Genova, Italia, jan.pralits@unige.it

³ Department of Aerospace Sciences and Technologies, Politecnico di Milano, Campus Bovisa, Milano, Italia, Maurizio.quadrio@polimi.it

Keywords: nasal flow, CFD, LES, nasal resistance, constant power input

Abstract

Nasal breathing difficulties are widespread and difficult to diagnose; the large majority of the population [1] exhibits an anatomic deformity of the nose. Clinicians are frequently confronted with the issue of whether deformities observed during physical examination are the actual cause of patient's symptoms and, while some situations are self-evident, the interpretation of less pronounced deformities is often debatable. Surgeons have to rely on their own judgment and experience to take surgical decisions, and errors are unavoidable [2]. CFD enables diagnosis of these diseases and surgery planning [3]: currently, this comparison is carried out with more than one strategy, under the implicit assumption that results are unaffected. The present contribution addresses one such question, which has not been identified so far, let alone answered: How should a comparison between preop and postop anatomies be carried out? The question is apparently simple, yet the answer is non-trivial, and requires putting together concepts ranging from numerical analysis to physiology of the entire respiratory system. The pre-op anatomy considered in the present study is derived from a CT scan after segmentation. The post-op anatomy is obtained by virtual surgery of the same patient for endoscopic medial maxillectomy, executed under the close guidance of an ENT (Ear, Nose & Throat) surgeon. The pre- and post-op flow fields are computed with a relatively standard high-fidelity approach; since in physiological conditions, the nasal flow is typically transitional and it is often unsteady (even when the boundary conditions are steady) we adopt, for maximum accuracy, a time-resolved approach, i.e. a high-resolution Large-Eddy Simulation (LES). The numerical simulations compute the flow, under three types of global constraints, derived from the field of turbulent flow control. A constant pressure drop (CPG) between the external ambient and throat, a constant flow rate (CFR) through the airways, and a constant power input (CPI) from the lungs can be enforced. The pressure drop, the flowrate and the power input are measured and, while in the preop case the results are the same, a significant difference is observed in the postop both in global and local quantities. Among the three available forcings, we argue that CPG is the least adequate. Arguments favouring either CFR or CPI are presented.

References

- [1] Gray, L. Deviated Nasal Septum. Incidence and Etiology. Ann. Otol. Rhinol. Laryngol. 3 20 (1978).
- [2] Dinis, P. B. & Haider, H. Septoplasty: Long-term evaluation of results. American Journal of Otolaryngology 23 (2), 85-90 (2002).
- [3] Inthavong, P. Das, N. Singh, and J. Sznitman, "In silico approaches to respiratory nasal flows: A review," Journal of Biomechanics, vol. 97, p. 109434, Dec. 2019.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: On XFEM modelling of static crack propagation in brittle micropolar elastic plates based on linear elastic fracture mechanics (LEFM)

Author(s): Meral Tuna^{*1,2}, Patrizia Trovalusci¹, Marco Pingaro¹, Nicholas Fantuzzi²

¹*Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy, meral.tunaeroglu@uniroma1.it, patrizia.trovalusci@uniroma1.it, marco.pingaro@uniroma1.it*

²*Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Bologna, Italy, nicholas.fantuzzi@unibo.it*

Keyword(s): Cosserat, Micropolar, Non-local, XFEM, LEFM, Crack growth

Abstract

Understanding fracture mechanism is of vital importance for the reliable application of brittle composite materials where the interfaces between matrix and inclusion parts or the grain boundaries can be viewed as the source of defects, having an adverse effect on the strength of the structures [1]. In this contribution, the crack is modelled as a discontinuity in the domain, and the evaluation of crack propagation is traced via associating linear elastic fracture mechanics (LEFM) [2,3,4] with micropolar theory of elasticity (e.g. [5]) regarding its capability on describing the mechanical behaviour of complex materials accounting for the presence of particle rotations. For simulation purposes, the extended finite element method (XFEM) [6] is generalized considering the effect of both translational and micro-rotational fields on the enrichment functions. The in-house code is developed in Wolfram Mathematica© within the linearized kinematical framework under plane strain assumption. The resulting crack paths, obtained for various benchmark problems, are compared with the current literature, via which the accuracy and versatility of combined LEFM/XFEM approach on examining the crack propagation phenomenon in brittle, size-dependent micropolar structures is demonstrated.

References

- [1] Inglis C.E., "Stresses in a Plate Due to the Presence of Cracks and Sharp Corners," SPIE Milestone Series, 137, 3-17, (1913).
- [2] Griffith A.A., "The phenomena of rupture and flow in solids," Philosophical Transactions of the Royal Society of London Series A, 221, 163-198, (1921).
- [3] Irwin G.R., "Fracture Dynamics, Fracture of Metals," Americal Society for Metals, 147-166, (1948).
- [4] Nuismer R.J., "An energy release rate criterion for mixed mode fracture," International Journal of Fracture, 11, 245-250, (1975).
- [5] Nowacki W., "Theory of Asymmetric Elasticity," Pergamon Press, (1986).
- [6] Sukumar N., Prevost J.H., "Modeling quasi-static crack growth with the extended finite element methof Part I: Computer implementation," International journal of Solids and Structures, 40, 7513-7537, (2003).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Reinforced Concrete Slab Panels under Oblique Projectile Impact- Numerical Study

Author(s): Roouf Un Nabi Dar ^{*1}, Dr. P. Alagappan ²

^{*1} PhD Student, Structural Engineering Division, Department of Civil Engineering, Indian Institute of Technology Madras Chennai, Tamil Nadu - 600036, India roufunnabi16@gmail.com

² Assistant Professor, Structural Engineering Division, Department of Civil Engineering, Indian Institute of Technology Madras Chennai, Tamil Nadu - 600036, India alagappan@civil.iitm.ac.in

Keyword(s): Projectile, Incidence angle; Concrete; JH-2; Impact; Ricochet.

Abstract

Concrete is widely used as a structural material in military and civil infrastructure. The ballistic impact load is one of the critical loading conditions that the concrete structure may undergo during its service life. Consequently, a considerable number of studies were performed for concrete slab panels subjected to perpendicular projectile impact in the past. However, in a realistic situation, there is a possibility of a projectile impact on a structure or a structural element at different angles. Therefore, the penetration resistance of concrete slab panels under projectile impact at various incidence angles is studied in this paper. The ballistic performance of RC panels has been evaluated by considering four incidence angles (0°, 30°, 45° and 60°) of an ogive nosed projectile with respect to the normal to the slab face. The Johnson-Holmquist-2 (JH-2) constitutive model has been adopted to represent the dynamic behaviour of concrete, however, the impacting steel projectile is modelled as rigid. The behaviour is studied in terms of depth of penetration (DOP), damage area, residual velocity, and projectile ricochet. Results show that the projectile suffered ricochet at 60° and any subsequent increase in angle results in the rebound of the projectile from the concrete surface. Furthermore, the depth of penetration and residual velocity reduced with an increase in incidence angle. With an increase in incidence angle, the circular shape of both front and rear craters changed to an elliptical shape. Projectile when intercepted by the reinforcement has a significant influence on the studied parameters of interest. This study shows that a normal projectile impact (0° angle) results in highest DOP and residual velocity of the projectile compared to inclined projectile impact. Whereas, inclined projectile impact results in an increased crater diameter compared to normal projectile impact.

References

- [1] Mina, A.L.; Petrou, M.F.; Trezos, K.G.: Resistance of an Optimized Ultra-High Performance Fiber Reinforced Concrete to Projectile Impact. *Buildings* 11, 63. (2021) <https://doi.org/10.3390/buildings11020063>
- [2] Kim, S.H, Wang, H., J. and Kang, T., H., M.: Behavior of High-Strength and Ultrahigh-Performance Concrete Targets Subjected to Relatively Rigid Projectile Impact. *J. Struct. Eng.*, (2021), 147(10): 04021152.
- [3] Rajput, A. and Iqbal M.A.: Ballistic performance of plain, reinforced and pre-stressed concrete slabs under normal impact by an ogival-nosed projectile, *International Journal of Impact Engineering*, Volume 110, (2017), Pages 57-71, ISSN 0734-743X, <https://doi.org/10.1016/j.ijimpeng.2017.03.008>.

- [4] Iqbal, M.A., Rajput, A, Bhargava, and P. : Plain and Reinforced Concrete Targets Subjected to Projectile Impact, *Procedia Engineering*, Volume 173, 2017, Pages 138-144, ISSN 1877-7058, <https://doi.org/10.1016/j.proeng.2016.12.050>.
- [5] Almusallam, T., Salloum, Y., Alsayed, Saleh., Iqbal, R., and Abbas, H. Effect of CFRP strengthening on the response of RC slabs to hard projectile impact, *Nuclear Engineering and Design*, Volume 286, 2015, Pages 211-226, ISSN 0029-5493, <https://doi.org/10.1016/j.nucengdes.2015.02.017>.
- [6] Sovják, R., Vavříník T., Máca, Petr., Zatloukal, Jan., Konvalinka, Petr., and Song, Yupu.: Experimental Investigation of Ultra-high Performance Fiber Reinforced Concrete Slabs Subjected to Deformable Projectile Impact, *Procedia Engineering*, Volume 65, 2013, Pages 120-125, ISSN 1877-7058, <https://doi.org/10.1016/j.proeng.2013.09.021>.
- [7] Almusallam, T. H., Siddiqui, N. A., Iqbal, A. R., and Abbas, H.: Response of hybrid-fiber reinforced concrete slabs to hard projectile impact, *International Journal of Impact Engineering*, Volume 58, 2013, Pages 17-30, ISSN 0734-743X, <https://doi.org/10.1016/j.ijimpeng.2013.02.005>.
- [8] Sovják, R., Vavříník, T., Zatloukal, J., Máca, P., Mičunek, Frydřín, M.: Resistance of slim UHPFRC targets to projectile impact using in-service bullets, *International Journal of Impact Engineering*. Volume 76, 2015, Pages 166-177, ISSN 0734-743X <https://doi.org/10.1016/j.ijimpeng.2014.10.002>.
- [9] Dancygier, A. N., Yankelevsky, D. Z., and Jaegermann, C., Response of high performance concrete plates to impact of non-deforming projectiles, *International Journal of Impact Engineering*, Volume 34, Issue 11, 2007, Pages 1768-1779, ISSN 0734-743X, <https://doi.org/10.1016/j.ijimpeng.2006.09.094>.
- [10] Ong, K.C.G., Basheerkhan, M., and Paramasivam, P.: Resistance of fibre concrete slabs to low velocity projectile impact. *Cement and Concrete Composites*, Volume 21, Issues 5–6, 1999, Pages 391-401, ISSN 0958-9465, [https://doi.org/10.1016/S0958-9465\(99\)00024-4](https://doi.org/10.1016/S0958-9465(99)00024-4).
- [11] Kheml, P., Sovják, R., Kravanja, Sebastjan, J., Zatloukal.: Cratering damage of high-performance cementitious composites and conventional normal strength concrete caused by in-service projectile impact, *Materials Today: Proceedings*, 2022, ISSN 2214-7853, <https://doi.org/10.1016/j.matpr.2022.02.587>.
- [12] Rajeev, A., Mohotti, D., and Shelke, A.: Implications of impact experiments on honeycomb shielded exterior beam-column joint, *Engineering Structures*, Volume 212, 2020, 110470, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2020.110470>.
- [13] Shao, R., Wu, C., Su, Y., Liu, Z., Liu, J., Chen, G., and Xu, S. Experimental and numerical investigations of penetration resistance of ultra-high strength concrete protected with ceramic balls subjected to projectile impact, *Ceramics International*, Volume 45, Issue 6, 2019, Pages 7961-7975, ISSN 0272-8842, <https://doi.org/10.1016/j.ceramint.2019.01.110>.
- [14] Rajeev, A., Parsi, S. S., Raman, S. N., Ngo, T., and Shelke, A.: Experimental and numerical investigation of an exterior reinforced concrete beam-column joint subjected to shock loading, *International Journal of Impact Engineering*, Volume 137, 2020, 103473, ISSN 0734-743X

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Printable beam-based lattices: A novel geometry generation algorithm and thermo-mechanical characterization via Asymptotic Homogenization

Author(s): Francesco De Canio^{*1}, Patrizia Trovalusci², Marco Pingaro²

¹ *Ingegneria Strutturale e Geotecnica, La Sapienza, Rome, Italy, francesco.decanio@uniroma1.it*

² *Ingegneria Strutturale e Geotecnica, La Sapienza, Rome, Italy, patrizia.trovalusci@uniroma1.it*

³ *Ingegneria Strutturale e Geotecnica, La Sapienza, Rome, Italy, marco.pingaro@uniroma1.it*

Keyword(s): Homogenization, Periodic Lattices, Unit Cell Design, Multiscale Methods, Optimization

Abstract

Beam-based lattices have gained significant popularity in engineering applications due to their ease of production using additive manufacturing [1,2,3]. However, the design of the unit cell geometry is mostly based on intuition rather than on proper geometrical algorithms: this leads to confusion in the classification of the cell types, as authors propose different names for the same type of cell. In our work, a novel geometric algorithm is introduced for the generation of beam-based cubic unit cells of the O_h symmetry group. This algorithm enables the creation of complex unit cells that are self-connecting, providing structural integrity to the lattice, by the variation of two geometrical parameters. Typically, such unit cells are challenging to design, but our algorithm simplifies the process and proposes a new taxonomy based on the selected geometrical parameters. The variation of the geometrical variables determines the categorization, and four distinct classes of cells are suggested. Additionally, thermo-mechanical analysis of the static effective properties is performed for each class of unit cells using the Asymptotic Homogenization method [4,5], implemented in a Finite Element Method (FEM) framework. The results are presented as gridded data, available on a GitHub repository, and depend on the unit cell's volume fraction, Poisson's ratio (variable within the thermodynamically admissible range $0 < \nu < 0.5$), and the geometrical parameters of the unit cell class. The effective parameters are normalized with respect to the solid bulk properties, thus behaving as purely geometrical properties of the unit cell class. These parameters act as scaling functions on the bulk properties and can be readily utilized in optimization schemes for enhancing the static performance of lattices. Overall, these findings provide a valuable tool for real-world engineering applications.

References

- [1] L. Cheng, J. Liu, A. C. To, "Concurrent lattice infill with feature evolution optimization for additive manufactured heat conduction design", *Structural and Multidisciplinary Optimization*, Vol 58, page 511-535, (2018)
- [2] F. Ituarte, N. Kretschmar, "Implications of lattice structures on economics and productivity of metal powder bed fusion", *Additive Manufacturing*, Vol 31, (2019)
- [3] H. Cetin, C. Baykasoğlu, "Energy absorption of thin-walled tubes enhanced by lattice structures", *International Journal of Mechanical Sciences*, Vol 157-158, pages 471-484, (2019)
- [4] A. Bensoussan, J. Lions, G. Papanicolaou, "Asymptotic Analysis for Periodic Structures", North-Holland,

Amsterdam (1978)

[5] L. Tartar, "The General Theory of Homogenization", Springer Berlin Heidelberg, Berlin, Heidelberg (2010)

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Title: Analytical multi-shape composite mechanics: going beyond the limits of Mori-Tanaka homogenization

Author(s): Nabor Jimenez Segura^{1,2}, Bernhard Pichler¹, Christian Hellmich^{*1}

¹ *Institute for Mechanics of Materials and Structures, TU Wien - Vienna University of Technology, Vienna, Austria, christian.hellmich@tuwien.ac.at; nabor.segura@tuwien.ac.at, bernhard.pichler@tuwien.ac.at*

² *Department of Materials Science, Polytechnic University of Madrid (UPM), Madrid, Spain*

Keyword(s): micromechanics, Mori-Tanaka scheme, symmetrization, concentration tensors

Abstract

The Mori-Tanaka (MT) scheme, proposed in 1973 [1] and reformulated in 1987 by Benveniste [2], is one of the most efficient and popular micromechanical models for the elastic behavior of composite materials. At the same time, it has been criticized because the elasticity tensor it predicts is only symmetric if at least one of the following requirements are met [3]: (i) all phases and the overall composite are isotropic; (ii) all inclusion phases have the same stiffness, (iii) all inclusion phases have the same shape and the same orientation.

Instead of deploring this alleged drawback, Sevostianov and Kachanov [3] simply symmetrized the MT-predicted stiffness output, and this motivates us to present a new way [4] to obtain the corresponding concentration (or downscaling) tensors quantifying the macro-to-phase-strain link. We start with the traditional Mori-Tanaka scheme, symmetrize its homogenized stiffness estimate, and identify the inclusion phase strains with those arising in an Eshelby-Laws inhomogeneity which is embedded into an auxiliary infinite matrix. Then, we deviate from the Mori-Tanaka scheme by introducing a novel remote-to-RVE strain conversion tensor, which allows us to derive an alternative expression for the homogenized stiffness tensor. Identifying the latter with the symmetrized elasticity tensor provides access to concentration tensors which indeed overcome all the classical MT limitations.

We expect our highly efficient scale transition and homogenization scheme to accelerate the understanding and development of advanced composite materials, in particular so biogenic ones, exhibiting interesting morphological features such as differently oriented fibers in wood-plastic composites [5], or inelastic dislocations [6] in metal-spiked structural protein matrices [7].

References

[1] Mori T, Tanaka K, "Average stress in matrix and average elastic energy of materials with misfitting inclusions", *Acta Metallurgica*, Volume 21, Issue 5, Pages 571-574 (1973)

[2] Benveniste Y, "A new approach to the application of Mori-Tanaka's theory in composite materials", *Mechanics of Materials*, Volume 6, Issue 2, Pages 147-157 (1987)

[3] Sevostianov I, Kachanov M, "On some controversial issues in effective field approaches to the problem of the overall elastic properties", *Mechanics of Materials*, Volume 69, Issue 1, 2014, Pages 93-105 (2014)

[4] Jiménez Segura N, Pichler B, Hellmich Ch, "Concentration tensors preserving elastic symmetry of multiphase

composites". *Mechanics of Materials*, Volume 178, 104555 (2023)

[5] Bader T, Dastoorian F, Ebrahimi G, Unger G, Lahayne O, Hellmich Ch, Pichler B, "Combined ultrasonic-mechanical characterization of orthotropic elastic properties of an unrefined bagasse fiber-polypropylene composite", *Composites Part B: Engineering*, Volume 95, 2016, Pages 96-104 (2016)

[6] Shahidi M, Pichler B, Hellmich Ch, "Viscous interfaces as source for material creep: A continuum micromechanics approach", *European Journal of Mechanics - A/Solids*, Volume 45, Pages 41-58 (2014)

[7] Zelaya-Lainez L, Balduzzi G, Lahayne O, Ikeda K, Raible F, Herzig Ch, Nischkauer W, Limbeck A, Hellmich Ch, "Jaws of *Platynereis dumerilii*: Miniature Biogenic Structures with Hardness Properties Similar to Those of Crystalline Metals", *JOM*, Volume 73, Pages 2390–2402 (2021)

A dynamically reprogrammable surface with self-evolving shape morphing

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Yun Bai^{1,14}, Heling Wang^{2,3,4,5,6,14}✉, Yeguang Xue^{2,3,4}, Yuxin Pan¹, Jin-Tae Kim⁷, Xinchen Ni⁷, Tzu-Li Liu⁷, Yiyuan Yang³, Mengdi Han^{7,8}, Yonggang Huang^{2,3,4,7,9}✉, John A. Rogers^{2,3,4,7,9,10,11,12}✉ & Xiaoyue Ni^{1,7,13}✉

Dynamic shape-morphing soft materials systems are ubiquitous in living organisms; they are also of rapidly increasing relevance to emerging technologies in soft machines^{1–3}, flexible electronics^{4,5} and smart medicines⁶. Soft matter equipped with responsive components can switch between designed shapes or structures, but cannot support the types of dynamic morphing capabilities needed to reproduce natural, continuous processes of interest for many applications^{7–24}. Challenges lie in the development of schemes to reprogram target shapes after fabrication, especially when complexities associated with the operating physics and disturbances from the environment can stop the use of deterministic theoretical models to guide inverse design and control strategies^{25–30}. Here we present a mechanical metasurface constructed from a matrix of filamentary metal traces, driven by reprogrammable, distributed Lorentz forces that follow from the passage of electrical currents in the presence of a static magnetic field. The resulting system demonstrates complex, dynamic morphing capabilities with response times within 0.1 second. Implementing an in situ stereo-imaging feedback strategy with a digitally controlled actuation scheme guided by an optimization algorithm yields surfaces that can follow a self-evolving inverse design to morph into a wide range of three-dimensional target shapes with high precision, including an ability to morph against extrinsic or intrinsic perturbations. These concepts support a data-driven approach to the design of dynamic soft matter, with many unique characteristics.

Soft matter that can dynamically reconfigure its shape upon interactions with environment or perceptions of information is thriving³¹. Pioneering studies rely on an exploitation of responsive materials (for example, liquid crystal elastomers^{8,9}, dielectric elastomers¹⁰, responsive hydrogels^{11–13} and others¹⁴) and multimaterial structures^{7,15} to enable large deformation, but face challenges in implementing fast control to refined structures. The design of a shape-morphing process usually requires a prerequisite modelling effort to be programmed into the fabrication process, and this is therefore hard to reprogram on-the-fly (for example, 3D printing^{7,11,19,24,30}, magnetization^{19,32}, laser or wafer-jet cutting^{26,27,33}, and mechanical buckling²⁵). The desire to shift shapes among a number of configurations invites investigations of various architectures and programmable stimuli (for example, temperature⁸, light^{34,35}, magnetic field^{20,36}, electric field¹⁰ and Lorentz-force actuation^{22,23,37}). Traditional inverse design of the input–output relationships in the resulting non-linear and high-dimensional system can, however, lead to difficulties in establishing analytical solutions or problems of

high computational costs. Also, existing computer-aided methods usually leave the inclusion of imperfections, damages or coupling between the system and the unforeseen environment. Incorporating instant feedback is necessary for the morphing process to see the deployment scheme to precisely account for specific, multifunctional or time-varying requirements³⁸.

Programmable electromagnetic actuation

A materials architecture consisting of a mesh of optimized, planar conductive features operating in a magnetic field and with programmable control over distributions of electrical current, as introduced here, presents an intriguing set of opportunities. The metasurface takes the form of interconnected, serpentine-shaped beams that consist of a thin conductive layer of gold (Au, thickness $h_{\text{Au}} = 0.3 \mu\text{m}$, width $b_{\text{Au}} = 130 \mu\text{m}$) encapsulated by polyimide (PI, thickness $h_{\text{PI}} = 7.5 \mu\text{m}$, width $b_{\text{PI}} = 160 \mu\text{m}$) (see Methods section ‘Sample fabrication’, Supplementary Fig. 1 and

¹Department of Mechanical Engineering and Materials Science, Duke University, Durham, NC, USA. ²Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL, USA. ³Department of Mechanical Engineering, Northwestern University, Evanston, IL, USA. ⁴Department of Materials Science and Engineering, Northwestern University, Evanston, IL, USA.

⁵Laboratory of Flexible Electronics Technology, Tsinghua University, Beijing, China. ⁶Institute of Flexible Electronics Technology of THU Jiaxing, Zhejiang, China. ⁷Querrey Simpson Institute for Bioelectronics, Northwestern University, Evanston, IL, USA. ⁸Department of Biomedical Engineering, College of Future Technology, Peking University, Beijing, China. ⁹Department of Biomedical Engineering, Northwestern University, Evanston, IL, USA. ¹⁰Department of Neurological Surgery, Feinberg School of Medicine, Northwestern University, Chicago, IL, USA. ¹¹Department of Chemistry, Northwestern University, Evanston, IL, USA. ¹²Department of Electrical and Computer Engineering, Northwestern University, Evanston, IL, USA. ¹³Department of Biostatistics and Bioinformatics, Duke University, Durham, NC, USA. ¹⁴These authors contributed equally: Yun Bai, Heling Wang ✉e-mail: helingswang1@gmail.com; y-huang@northwestern.edu; jrogers@northwestern.edu; xiaoyue.ni@duke.edu

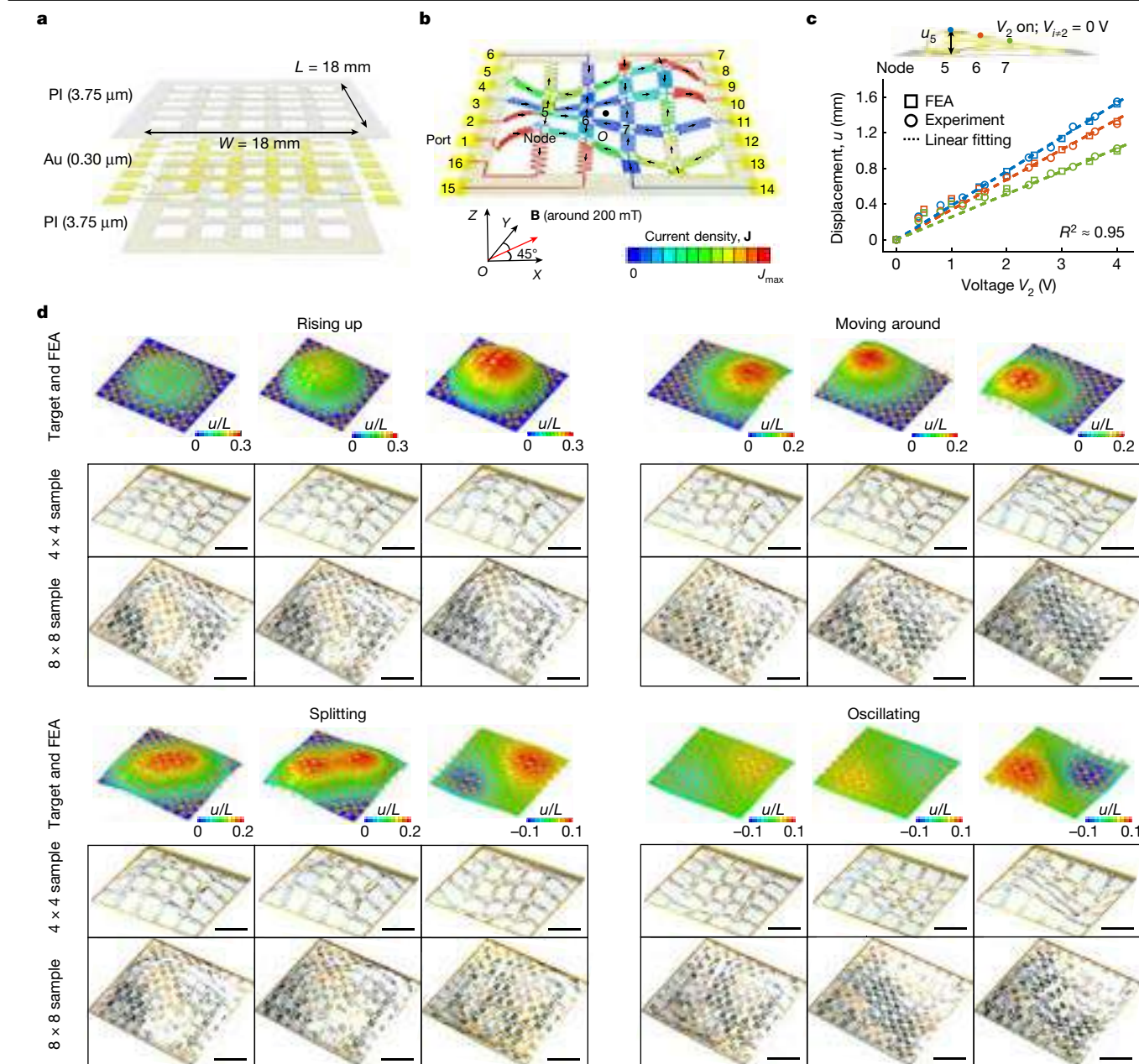


Fig. 1 | Mechanical metasurfaces driven by reprogrammable electromagnetic actuation. **a**, Schematic illustration (enlarged view) of a representative square mesh sample constructed from the serpentine beams consisting of thin PI and Au layers. **b**, Schematic illustration of a 4×4 sample placed in a magnetic field (in-plane with the sample in a diagonal direction). Portal voltages define the current density distribution (**J**) in the sample and hence control the local Lorentz-force actuation. **c**, FEA provides a linear-model

approximation of the nodal displacement in response to the portal voltage input for the 4×4 sample. Experimental characterization using a side camera agrees with the FEA prediction. **d**, FEA and experimental results of a 4×4 and 8×8 sample morphing into four target abstract shape-shifting processes with control of the instantaneous velocity and acceleration of the dynamics. Scale bars, 5 mm.

Supplementary Note 1 for details). The intersections of the beams form an $N \times M$ mesh as shown in Fig. 1a ($N = M = 4$, sample size $L = W = 18.0$ mm, column and row serpentine beam length $L_{N/M} = 3.60$ mm). A tailored design ensures sufficiently large, fast and reversible out-of-plane deformation ($u/L \approx 30\%$) (in-plane deformation less than $0.01L$; response time less than 0.07 s) of the serpentine beam, driven by a modest electric current ($I < 27.5$ mA) in an approximately uniform magnetic field $\mathbf{B}$ (magnitude $B = 224 \pm 16$ mT) (see Extended Data Fig. 1, Supplementary Figs. 2–6 and Supplementary Notes 2–5 for details). An analytical model validated by experiment can be used to guide design choices for a tunable electromagnetic response in a broad range of magnetic

field strengths (for example, B reduced to 25 mT; see Extended Data Fig. 2 and Supplementary Note 3.1). Figure 1b shows that independent voltages ($\mathbf{V} = \{V_j\}$) of size $2(N + M)$ applied to the peripheral ports define the distribution of current density ($\mathbf{J}$) in the conductive network (see Methods section ‘Digital control’ and Supplementary Fig. 7 for details) and therefore control the Lorentz force, $\mathbf{F}_{\text{EM}} = \mathbf{J} \times \mathbf{B}$. The spatially distributed actuation $\mathbf{F}_{\text{EM}}(\mathbf{J})$ determines the local, out-of-plane (Z direction) deformations ($\mathbf{u} = \{u_i\}$, where u_i is the displacement of the i th node) of the sample in a magnetic field $\mathbf{B}$ aligned with its diagonal, enabling a large set of accessible three-dimensional (3D) shapes from the same precursor structure.

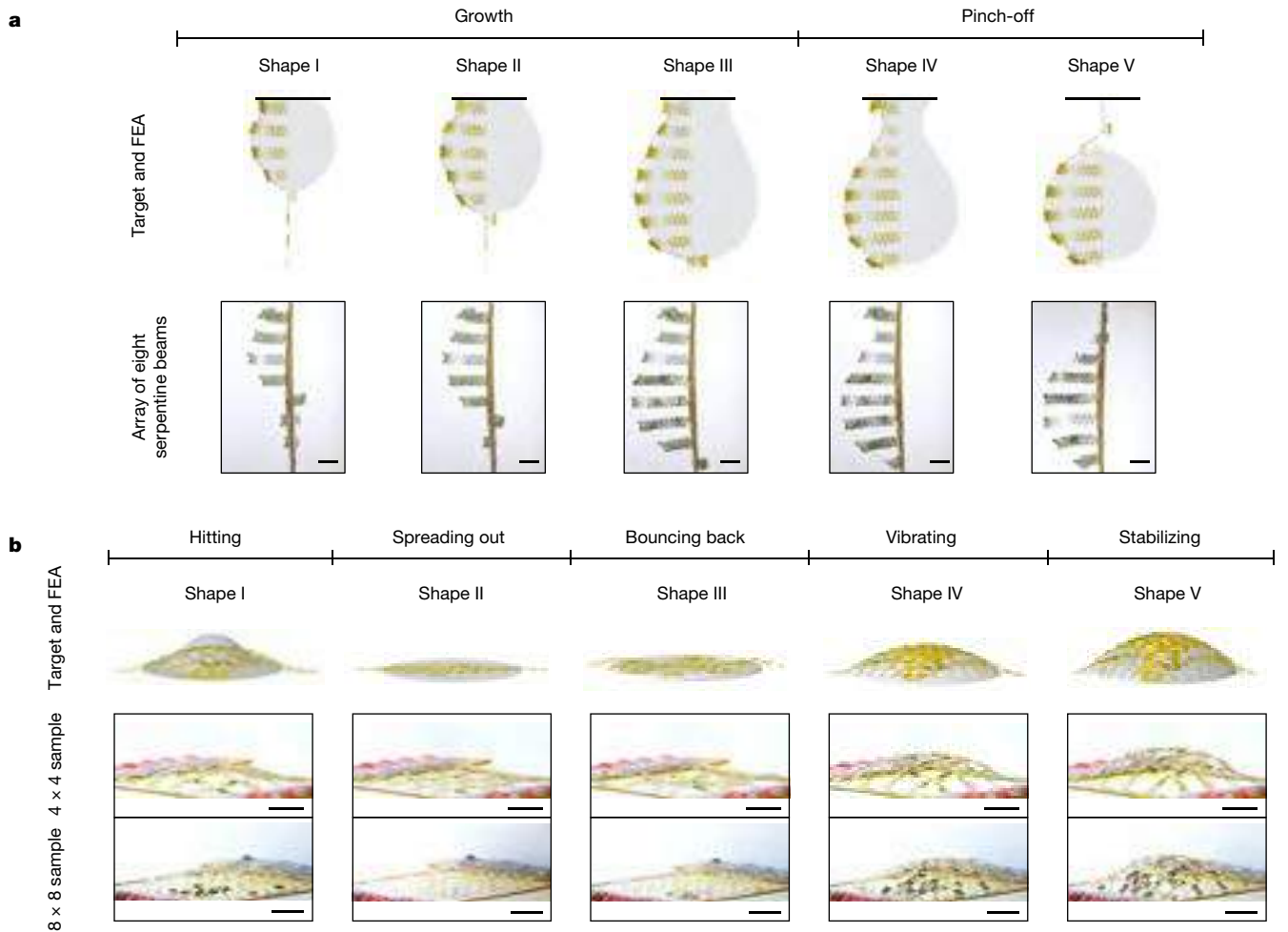


Fig. 2 | Model-driven inverse design of the metasurfaces for dynamic, complex shape morphing. a, FEA and experimental results of an array of eight serpentine beams morphing into the growth and pinch-off of a droplet dripping from a nozzle. Scale bars, 2.5 mm. **b**, FEA and experimental results of a 4 × 4 and an 8 × 8 sample morphing into the dynamic process of a droplet

hitting a solid surface, spreading out, bouncing back, vibrating and stabilizing. Scale bars, 5 mm. The target shapes in **a** were reconstructed with permission from the images in Fig. 3 in ref. ⁴¹ (The American Physical Society). The target shapes in **b** were reconstructed with permission from the frames in supplementary video 1 in ref. ⁴² (Elsevier).

Model-driven inverse design

The unusual structure and material design enables the system to adopt an approximate, linearized model, such that the nodal displacement response to the input voltages is as follows:

$$u_i = \sum_{j=1}^{2(N+M)} C_{ij} V_j, \text{ for } i=1, \dots, N \times M, \quad (1)$$

where the coupling matrix $\mathbf{C} = \{C_{ij}\}$ fully characterizes the electro-magneto-mechanical system. Figure 1c shows the finite-element analysis (FEA) and the experimental characterization of the coupling coefficients C_{ij} for representative nodes in the actuation range of 0–4 V for the 4 × 4 sample in the magnetic setup. Linear regression of the FEA results predicts $\mathbf{C}$. The analytical model and the FEA studies, together with experimental validation, provide a scaling law of the coefficients as $C_{ij} \propto (BLH^2 b_{Au} h_{Au}) / (E_{PI} b_{PI} h_{PI}^3 \rho_{Au})$ (where H is the serpentine beam width, E_{PI} is the PI Young's modulus and ρ_{Au} is the Au electrical conductivity; see Supplementary Figs. 8 and 9 and Supplementary Notes 3.2 and 3.3 for details). Following this linear approximation, a model-driven approach attempts to zero the errors, $e_i(\mathbf{V}) = (u_i(\mathbf{V}) - u_i^*) / L$ (the difference between the output deformation, $u_i(\mathbf{V})$, from the target, u_i^* , normalized by the system size L), to optimize the voltages for the precursor surfaces to deform to a target shape. Given a convex problem with

linear target functions and constraints, a gradient-descent-based algorithm iterates over $\mathbf{V}$ to minimize a loss function, $f(\mathbf{V}) = \sum_i e_i^2(\mathbf{V})$ with a maximum-current constraint (see Methods section 'Optimization algorithm' and Supplementary Note 6 for details). The linearized model-driven approach yields a prediction for $\mathbf{V}$ within 0.01 s. The same approach driven by numerical methods (for example, FEA) without linearization is not possible because of unaffordable computational costs (around 10 days using a workstation with 40-core, 2.4 GHz CPU and 64 GB memory). Figure 1d shows FEA and experimental results of an inverse-designed, continuous shape morphing of a 4 × 4 and an 8 × 8 sample ($L = W = 22.4$ mm, $L_{N/M} = 2.48$ mm, see Supplementary Note 7.1 for a detailed discussion of scalability). The process consists of four phases: rising up, moving around, splitting and oscillating, with a prescribed control of the instantaneous velocity and acceleration of the dynamics (Supplementary Video 1, Supplementary Figs. 10–13 and Supplementary Note 8).

In addition to the abstract shapes, the reprogrammable metasurface demonstrates an ability to reproduce dynamic processes in nature that involve a temporal series of complex shapes, provided with the inversely designed current distributions. Figure 2a shows an array of eight serpentine beams ($L = 10.4$ mm, $W = 20.6$ mm, $L_N = 5.2$ mm, $L_M = 2.52$ mm, Supplementary Fig. 14 and Supplementary Note 9) morphing into the two-dimensional profile of a droplet dripping from a nozzle (see Methods section 'Target shapes of the droplets' and Supplementary Fig. 15).

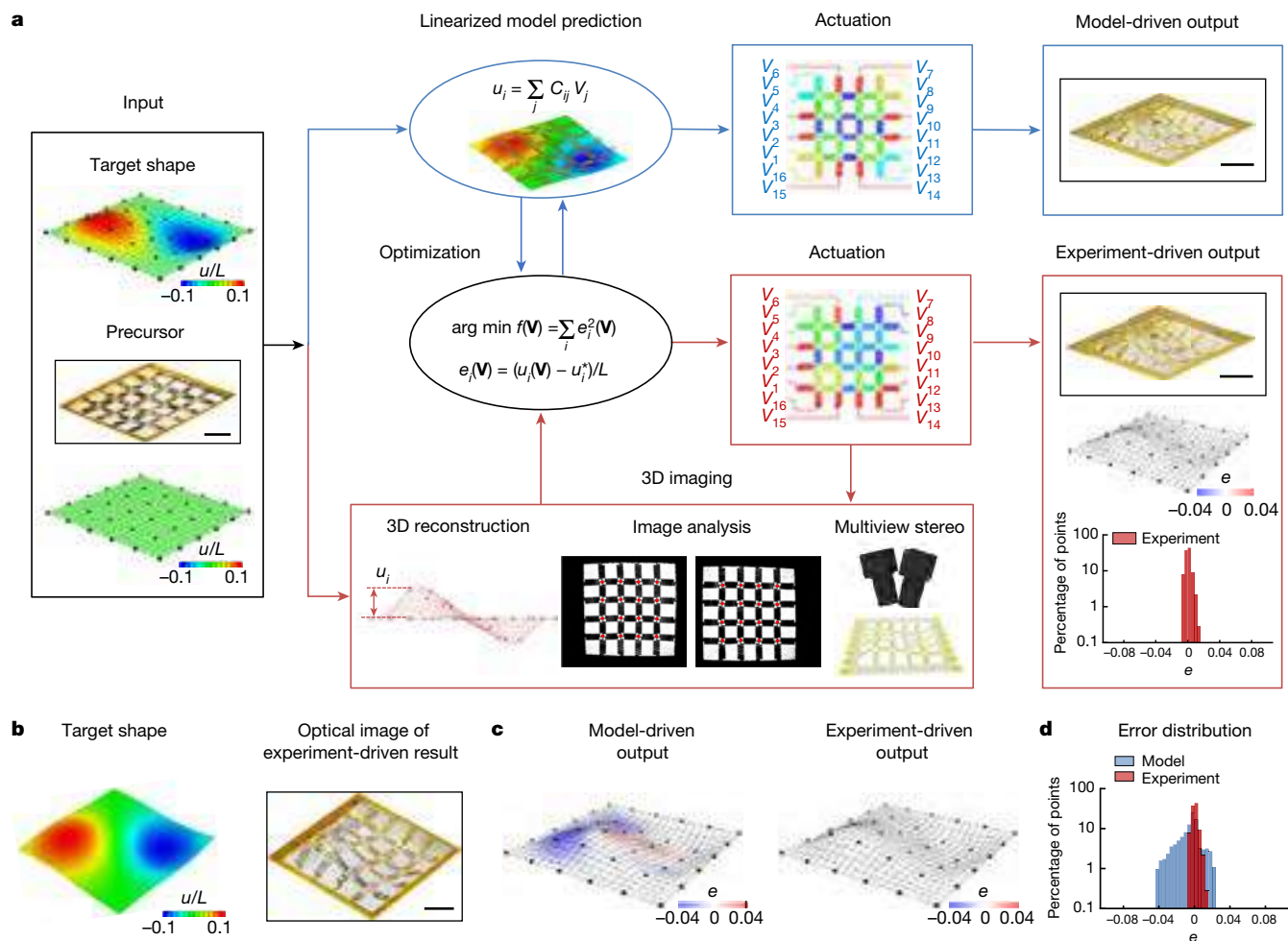


Fig. 3 | The experiment-driven self-evolving process in comparison with the model-driven approach. **a**, A flow diagram of the model-driven inverse design approach (top, blue) and an experiment-driven self-evolving process enabled by in situ 3D imaging feedback and a gradient-descent-based optimization algorithm (bottom, red). **b**, The target abstract shape and optical image of the

experiment-driven morphing result of the 4×4 sample. **c**, 3D reconstructed surfaces overlaid with contour plots of the minimized errors. **d**, Histogram plot of the minimized errors for model-driven and experiment-driven outputs. Scale bars, 5 mm.

Shapes I–III describe the growth of a pendant drop to its critical volume. Shapes IV–V capture the following pinch-off process. Figure 2b presents the 4×4 and 8×8 samples simulating the 3D surface of a droplet falling onto a rigid surface in five stages: hitting the surface, spreading out, bouncing back, vibrating and stabilizing (see Methods section ‘Target shapes of the droplets’, Supplementary Video 2 and Supplementary Figs. 16–19). Numerical analysis further illustrates that the mesh structure can morph into an extensive set of target shapes (Supplementary Figs. 20–27 and Supplementary Notes 8, 10 and 11). Increasing the number of control inputs and introducing a time-varying magnetic field or a field gradient enhance the range of target shapes that can be morphed with sufficient accuracy (Extended Data Fig. 3, Supplementary Figs. 28 and 29, and Supplementary Notes 7 and 12).

The linearized model-driven approach accomplishes an inverse design when a modest error from the non-linearity is tolerable. Extending the model-driven approach to include non-linearity is challenging owing to the large computational expense (Supplementary Note 13) or difficulties in establishing analytical solutions. The open-loop model-based inverse design has constraints on the design space and cannot account for non-ideal factors, such as environmental changes or defects in the sample. The existing limitations motivate the development of sensing feedback for a closed-loop self-evolving inverse design approach.

Experiment-driven self-evolving process

Figure 3a illustrates an experiment-driven process in comparison with the linearized model-driven process. Whereas the model-driven route relies on the presumption of a linear and stationary model, the experimental method takes the in situ measurement of the system output and feeds the difference between the current state and the target state for actuation regulation. In this work, a custom-built stereo-imaging setup using two webcams enables a 3D reconstruction of the nodal displacement at a rate of 30 frames per second, with a displacement resolution of around 0.006 mm and a measurement uncertainty of ± 0.055 mm (see details of 3D imaging in Methods, Supplementary Fig. 30 and Supplementary Note 14). After each update of the actuation ($\mathbf{V}$), the real-time imaging provides an in situ nodal displacement error analysis. An optimization algorithm (the same one as used in the model-driven approach but wrapping the 3D imaging process) performs the experimental iterations over $\mathbf{V}$ to minimize $f(\mathbf{V})$. For a 4×4 sample morphing into a representative target shape ($f(\mathbf{V} = \mathbf{0}) = 0.05$ – 0.35), the optimization process takes 5–15 iterations (Extended Data Fig. 4a–c). Each feedback control cycle in the current setup takes around 0.25 s due mainly to the time overhead from the image processing algorithm but this time is ultimately limited by the mechanical response time (which is less than 0.1 s) (Supplementary

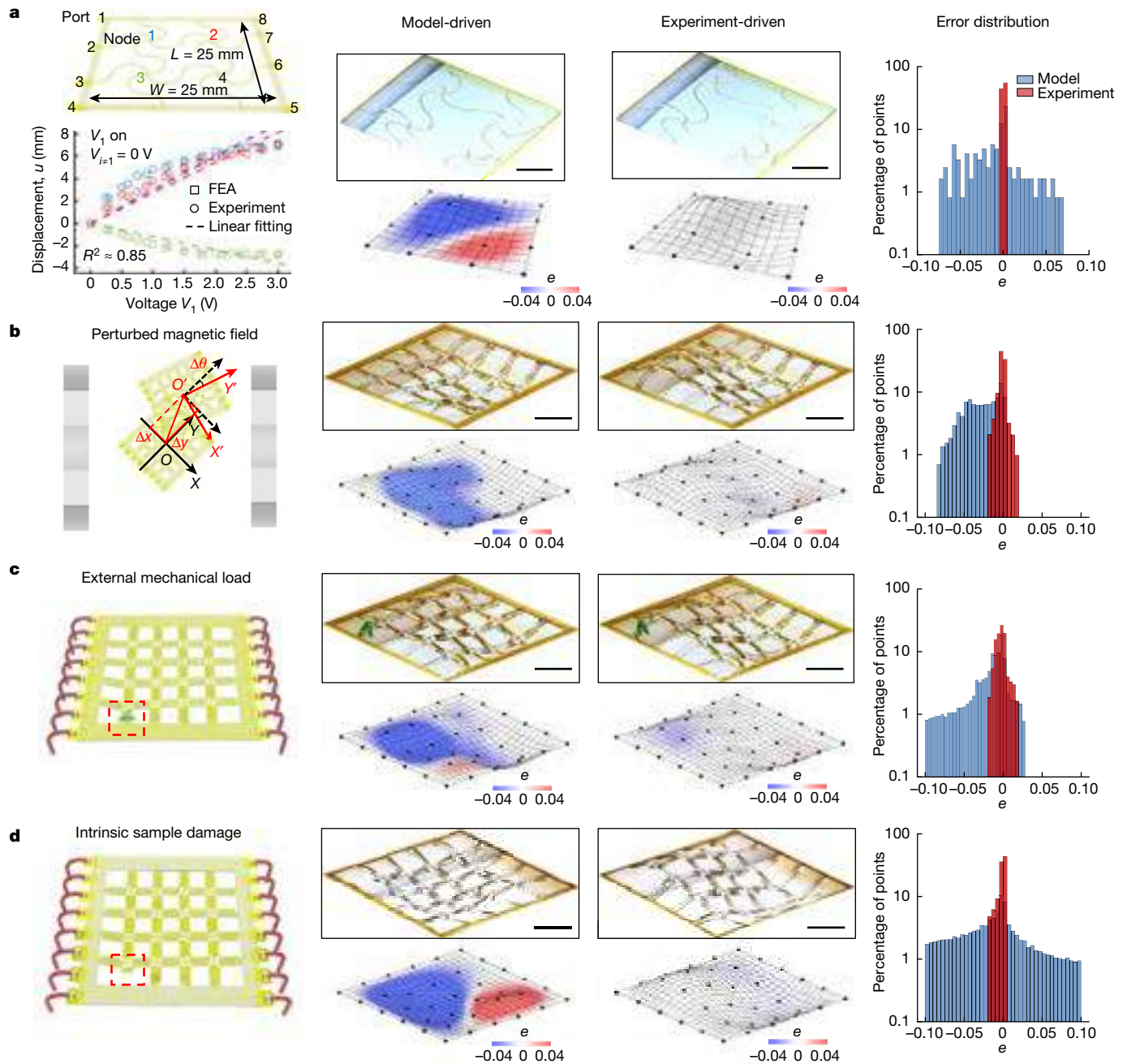


Fig. 4 | Self-evolving shape morphing against extrinsic or intrinsic perturbations. **a–d**, Experimental results of a 2×2 sample (**a**) and a 4×4 sample (**b–d**) morphing into the same target shape (Fig. 3b) via model-driven and experiment-driven processes. A modified serpentine design that amplifies the non-linearity of the voltage-driven deformation (**a**), and the introduction of an extrinsic magnetic perturbation by displacing the sample from the original, centred position ($\Delta x = 8$ mm, $\Delta y = 12$ mm, $\Delta \theta = 15^\circ$) (**b**), an extrinsic mechanical

perturbation by applying an external mechanical load (around 0.1 g) on a serpentine beam (**c**) and intrinsic damage by cutting one beam open, causing substantial changes in both mechanical and electrical conductivity of the sample (**d**). Left: schematic illustration of the experimental configuration. Middle: optical images and 3D reconstructed surfaces superimposed with an error map. Right: histogram plots of errors. Scale bars, 5 mm.

Table 1 and Supplementary Note 6). A hybrid method, taking a model-driven prediction as the initial input, reduces the number of iterations to around three. The experiment-driven process opens opportunities for the metasurface to self-evolve to target shapes without any previous knowledge of the system (Supplementary Video 3). Figure 3b–d and Extended Data Fig. 5 provide a quantitative comparison between the model-driven and experiment-driven morphing results from the same 4×4 precursor, targeting representative shapes (Supplementary Video 4, Supplementary Figs. 31–33 and Supplementary Note 8). The resulting errors from the model-driven approach

follow a wide (over $\pm 5\%$), mostly skewed distribution (Fig. 3d, considering 441 points from the interpolated 3D surface; Supplementary Note 14). The experiment-driven approach, accounting for the subtle non-linear deviation, yields a relatively narrow ($\pm 2\%$), symmetric error distribution. The dominant sources of errors are the discreteness in the input voltages and the uncertainties associated with the 3D imaging (Extended Data Fig. 6 and Supplementary Note 14). Experimental noise also adds complexity to the error function and, when pronounced, requires global optimization solvers (Extended Data Fig. 4d–f and Supplementary Note 6).

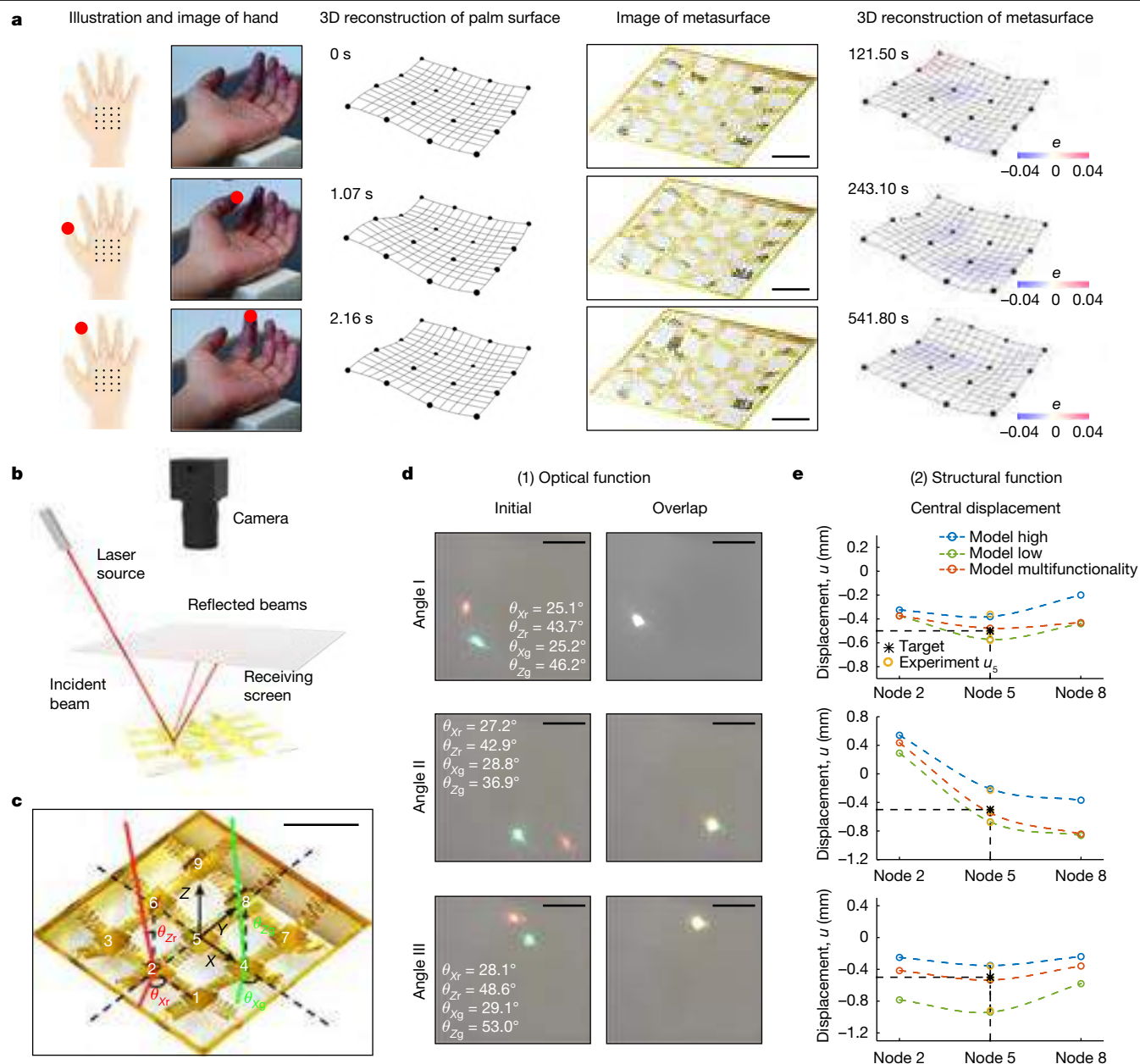


Fig. 5 | Self-evolving shape morphing towards semi-real-time shape learning and multifunctionality. **a**, Morphing results of representative frames from a recording of a hand making eight gestures with different fingers moving. **b**, Schematic illustration of a 3×3 sample with gold patches ($2 \text{ mm} \times 2 \text{ mm}$ in size, $0.3 \mu\text{m}$ in thickness) mounted on the nodes reflecting a laser beam from an incident angle. A top-positioned camera monitors the laser spot projected on a paper screen. **c**, An optical image of a 3×3 sample with nine reflective patches morphing via a hybrid experiment-driven and model-driven process to perform two functions: (1) reflecting and overlapping two laser

beams (red, green) with different incident angles ($[\theta_{Xr}, \theta_{Zr}], [\theta_{Xg}, \theta_{Zg}]$) and (2) achieving the target displacement (-0.5 mm) of the central node (u_s) of the sample. **d**, Imaging of the screen from the camera provides experimental feedback of the distance between the two laser spots. **e**, Model predictions of the displacement profile of the sample (cross-sectional view) when overlapping the laser spots with the highest-possible (blue), lowest-possible (green) and optimized (red) central positions. Ex situ stereo imaging provides 3D reconstructed measurement of the optimized deformation (orange) that validates the in situ model predictions. Scale bars, 5 mm .

The experiment-driven process works as a physical simulation to accommodate appreciable non-linearity without a substantial increase in the computational cost. Figure 4a introduces a 2×2 sample ($L = W = 25.0 \text{ mm}$, $L_{N/M} = 10.25 \text{ mm}$) morphing into the same target shape in Fig. 3b. Centred in the same magnetic setup, the sample shows an amplified non-linear mechanical behaviour in response to input voltages due to the reduced arc length of each serpentine beam (Extended Data Fig. 7 and Supplementary Note 15). The model-driven approach based on the assumption of a linear system results in an absolute maximum error of around 8%. The experiment-driven approach achieves a

more accurate morphing result in around 20 iterations with absolute errors below 1%.

Guided by the experiment-driven process, the metasurface can also self-adjust to morph against unknown perturbations. Figure 4b–d shows three representative cases in which a 4×4 sample morphs with perturbed magnetic field, external mechanical load and intrinsic damage, respectively. In all cases, the model-driven approach following the original inverse design results in absolute maximum errors of around 8–10%. In comparison, the experiment-driven approach adapts the shape to reach the target with absolute errors below around 3%, which is

comparable with that of an intact sample (around 2%) (Supplementary Video 5). The boosted accuracy level demonstrates the 'self-sustained' morphing ability enabled by the experiment-driven process.

Shape learning and multifunctionality

The adaptive, self-evolving metasurface platform delivers a semi-real-time morphing scheme to learn the continuously evolving surface of a real object. In this experiment, a duplicated stereo-imaging setup measures the displacement of a 4×4 array of markers (with inter-spacing $a_0 = 15$ mm) on the palm (Extended Data Fig. 8a). The optimization acts directly to minimize the displacement difference between the 16 markers and their corresponding nodes in the 4×4 sample. Given continuity, the gradient-descent process takes the last morphing result as the initial state for the next morphing task. This differential method (with the target descent $\Delta f(\mathbf{V}) \approx 0.0032$) requires only at most three iterations (approximately 20 s) to reach the optimum. Figure 5a shows the representative frames from a video recording a hand making eight gestures with different fingers moving (see Supplementary Video 6 and Extended Data Fig. 8b,c for complete results of all gestures). All morphing results agree with the target with absolute errors below 2%.

In addition to self-evolving to optimize shapes, the metasurface can self-evolve to optimize functions. Setting multiple target functions drives the optimization towards emergent multifunctionality, with the ability to decouple naturally coupled functions. Figure 5b,c illustrates a scheme in which a 3×3 sample ($L = W = 14.8$ mm, $L_{N/M} = 4.06$ mm) with nine reflective gold patches at the nodes attempts to perform an optical and a structural function: (1) reflecting and overlapping two laser beams (red, green) with different incident angles ($[\theta_{xr}, \theta_{zg}], [\theta_{xg}, \theta_{zg}]$) on a receiving screen (Extended Data Fig. 9a) and (2) achieving the target displacement of the central node of the sample. The optimization takes a hybrid strategy combining the model-driven and experiment-driven processes (Supplementary Note 16). While the voltages control the reflected beam paths, a top camera provides imaging feedback of the distances between the beam spots on the screen. The model-driven process predicts the difference between the central nodal displacement and the target. The total loss takes a linear combination of the two errors (Extended Data Fig. 9b and Supplementary Note 16). Figure 5d shows the self-evolving results of three optical configurations with distinctive incident beam angles. Figure 5e shows that the metasurface can morph to overlap the laser spots on the receiving screen with a range of possible shapes (Extended Data Fig. 10a). By enforcing both functions, the sample overlaps the spots and settles its central node to a target displacement. A post analysis through ex situ 3D imaging validates that the final experimental central nodal displacement reaches the target within an error of $\pm 2\%$ (Supplementary Video 7 and Extended Data Fig. 10b).

Discussion

The work presents a reprogrammable metasurface that can precisely and rapidly morph into a wide range of target shapes and dynamic shape processes. The Lorentz-force-driven serpentine mesh construction supports an approximately linear input–output response with easily accessible solutions to the inverse problem. The highly integrable digital–physical interfaces incorporating actuation, sensing and feedback enable an in-loop optimization process to attain model-free solutions when the system deviates from the linear, time-invariant response. The experiment-driven shape-shifting capability addresses theoretical and computational challenges in complex, non-linear systems, bringing new opportunities for physical simulations for a real-time, data-driven inverse design process. Such a scheme enables an autonomous materials platform to promptly change structures, actively explore the design space and responsively reconfigure functionalities. The platform is compatible with the typical materials,

structures and thin-film fabrication techniques used in existing flexible electronics frameworks. It supports optimized choices of materials, geometries, layouts, control systems and magnetic setups for design flexibility and potential scalability, which promises a wide, versatile application scenario in wearable techniques, soft robotics and advanced materials. Many possibilities exist to improve this system, such as incorporating a mechanical locking mechanism (for example, applying phase transition materials^{21,39} or a jamming configuration⁴⁰ could hold the morphed shapes without actuation). Exploring constructions with low in-plane stiffness will enable additional deformation modes of the metasurface (Supplementary Fig. 34). The demonstration of the current modular platform invites higher levels of integration to embed functional materials and components into the morphing matter, to support on-board power sources (supercapacitors), sensors (strain gauges), feedback control mechanisms (analogue devices), computational resources (microcontrollers) and wireless communication capabilities (radios). Using advanced data-driven techniques in the loop (for example, Bayesian optimization, deep learning and reinforcement learning) will enhance the capabilities of self-evolving designs for artificial matter in pursuit of functions or performance inspired by those in their natural counterparts, paving the way for new classes of intelligent materials that adopt spatiotemporally controlled shapes and structures for advanced on-demand functionalities.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at <https://doi.org/10.1038/s41586-022-05061-w>.

- Rafsanjani, A., Bertoldi, K. & Studart, A. R. Programming soft robots with flexible mechanical metamaterials. *Sci. Robot.* **4**, eaav7874 (2019).
- McEvoy, M. A. & Correll, N. Materials that couple sensing, actuation, computation, and communication. *Science* **347**, 1261689 (2015).
- Morin, S. A. et al. Camouflage and display for soft machines. *Science* **337**, 828–832 (2012).
- Wang, C., Wang, C., Huang, Z. & Xu, S. Materials and structures toward soft electronics. *Adv. Mater.* **30**, 1801368 (2018).
- Rogers, J. A., Someya, T. & Huang, Y. Materials and mechanics for stretchable electronics. *Science* **327**, 1603–1607 (2010).
- Cianchetti, M., Laschi, C., Mencias, A. & Dario, P. Biomedical applications of soft robotics. *Nat. Rev. Mater.* **3**, 143–153 (2018).
- Boley, J. W., Rees, W., Lissandrello, C., Horenstein, M. N. & Mahadevan, L. Shape-shifting structured lattices via multimaterial 4D printing. *Proc. Natl Acad. Sci. USA* **116**, 201908806 (2019).
- Liu, K., Hacker, F. & Daraio, C. Robotic surfaces with reversible, spatiotemporal control for shape morphing and object manipulation. *Sci. Robot.* **6**, eabf5116 (2021).
- Guo, Y., Zhang, J., Hu, W., Khan, M. T. A. & Sitti, M. Shape-programmable liquid crystal elastomer structures with arbitrary three-dimensional director fields and geometries. *Nat. Commun.* **12**, 5936 (2021).
- Hajiesmaili, E. & Clarke, D. R. Reconfigurable shape-morphing dielectric elastomers using spatially varying electric fields. *Nat. Commun.* **10**, 183 (2019).
- Gladman, A. S., Matsumoto, E. A., Nuzzo, R. G., Mahadevan, L. & Lewis, J. A. Biomimetic 4D printing. *Nat. Mater.* **15**, 413–418 (2016).
- Yu, C. et al. Electronically programmable, reversible shape change in two- and three-dimensional hydrogel structures. *Adv. Mater.* **25**, 1541–1546 (2013).
- Zhang, H., Guo, X., Wu, J., Fang, D. & Zhang, Y. Soft mechanical metamaterials with unusual swelling behavior and tunable stress-strain curves. *Sci. Adv.* **4**, eaar5535 (2018).
- Li, S. et al. Liquid-induced topological transformations of cellular microstructures. *Nature* **592**, 386–391 (2021).
- Pikul, J. et al. Stretchable surfaces with programmable 3D texture morphing for synthetic camouflaging skins. *Science* **358**, 210–214 (2017).
- Barnes, M. et al. Reactive 3D printing of shape-programmable liquid crystal elastomer actuators. *ACS Appl. Mater. Interfaces* **12**, 28692–28699 (2020).
- Ford, M. J. et al. A multifunctional shape-morphing elastomer with liquid metal inclusions. *Proc. Natl Acad. Sci. USA* **116**, 21438–21444 (2019).
- Alapan, Y., Karacakol, A. C., Guzelhan, S. N., Isik, I. & Sitti, M. Reprogrammable shape morphing of magnetic soft machines. *Sci. Adv.* **6**, eaab6414 (2020).
- Kim, Y., Yuk, H., Zhao, R., Chester, S. A. & Zhao, X. Printing ferromagnetic domains for untethered fast-transforming soft materials. *Nature* **558**, 274–279 (2018).
- Cui, J. et al. Nanomagnetic encoding of shape-morphing micromachines. *Nature* **575**, 164–168 (2019).

21. Ze, Q. et al. Magnetic shape memory polymers with integrated multifunctional shape manipulation. *Adv. Mater.* **32**, 1906657 (2020).
22. Mao, G. et al. Soft electromagnetic actuators. *Sci. Adv.* **6**, eabc0251 (2020).
23. Zhang, F. et al. Rapidly deployable and morphable 3D mesostructures with applications in multimodal biomedical devices. *Proc. Natl Acad. Sci. USA* **118**, e2026414118 (2021).
24. Xia, X. et al. Electrochemically reconfigurable architected materials. *Nature* **573**, 205–213 (2019).
25. Fan, Z. et al. Inverse design strategies for 3D surfaces formed by mechanically guided assembly. *Adv. Mater.* **32**, 1908424 (2020).
26. Choi, G. P., Dudte, L. H. & Mahadevan, L. Programming shape using kirigami tessellations. *Nat. Mater.* **18**, 999–1004 (2019).
27. Bossart, A., Dykstra, D. M., van der Laan, J. & Coullais, C. Oligomodal metamaterials with multifunctional mechanics. *Proc. Natl Acad. Sci. USA* **118**, e2018610118 (2021).
28. Baek, C., Martin, A. G., Poincloux, S., Chen, T. & Reis, P. M. Smooth triaxial weaving with naturally curved ribbons. *Phys. Rev. Lett.* **127**, 104301 (2021).
29. Coullais, C., Sabbadini, A., Vink, F. & van Hecke, M. Multi-step self-guided pathways for shape-changing metamaterials. *Nature* **561**, 512–515 (2018).
30. Guseinov, R., McMahan, C., Pérez, J., Daraio, C. & Bickel, B. Programming temporal morphing of self-actuated shells. *Nat. Commun.* **11**, 237 (2020).
31. Kaspar, C., Ravoo, B. J., van der Wiel, W. G., Wegner, S. V. & Pernice, W. H. P. The rise of intelligent matter. *Nature* **594**, 345–355 (2021).
32. Hu, W., Lum, G. Z., Mastrangeli, M. & Sitti, M. Small-scale soft-bodied robot with multimodal locomotion. *Nature* **554**, 81–85 (2018).
33. Overvelde, J. T., Weaver, J. C., Hoberman, C. & Bertoldi, K. Rational design of reconfigurable prismatic architected materials. *Nature* **541**, 347–352 (2017).
34. Waters, J. T. et al. Twist again: dynamically and reversibly controllable chirality in liquid crystalline elastomer microposts. *Sci. Adv.* **6**, eaay5349 (2020).
35. Wang, Y. et al. Repeatable and reprogrammable shape morphing from photoresponsive gold nanorod/liquid crystal elastomers. *Adv. Mater.* **32**, 2004270 (2020).
36. Xu, C., Yang, Z. & Lum, G. Z. Small-scale magnetic actuators with optimal six degrees-of-freedom programming temporal morphing of self-actuated shells. *Adv. Mater.* **33**, 2100170 (2021).
37. Phelan, M. F. III, Tiriyaki, M. E., Lazovic, J., Gilbert, H. & Sitti, M. Heat-mitigated design and lorentz force-based steering of an MRI-driven microcatheter toward minimally invasive surgery. *Adv. Sci.* **9**, 2105352 (2022).
38. Kotikian, A. et al. Innervated, self-sensing liquid crystal elastomer actuators with closed loop control. *Adv. Mater.* **33**, 2101814 (2021).
39. Wang, X. et al. Freestanding 3D mesostructures, functional devices, and shape-programmable systems based on mechanically induced assembly with shape memory polymers. *Adv. Mater.* **31**, 1805615 (2019).
40. Wang, Y., Li, L., Hofmann, D., Andrade, J. E. & Daraio, C. Structured fabrics with tunable mechanical properties. *Nature* **596**, 238–243 (2021).
41. Zhang, B. et al. Short-term oscillation and falling dynamics for a water drop dripping in quiescent air. *Phys. Rev. Fluids* **4**, 123604 (2019).
42. Tang, C. et al. Dynamics of droplet impact on solid surface with different roughness. *Int. J. Multiph. Flow* **96**, 56–69 (2017).

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Methods

Sample fabrication

The fabrication process (Supplementary Fig. 1) began with the spin coating of a thin layer of PI (HD Microsystems PI2545, 3.75 μm in thickness) on a silicon wafer with poly(methyl methacrylate) (Microresist 495 A5, 0.08 μm in thickness) as the sacrificial layer. Subsequent lift-off processes patterned the metal electrodes and serpentine connections (Ti/Au, 10 nm/300 nm in thickness). Spin coating another layer of PI (HD Microsystems PI2545, 3.75 μm in thickness) covered the metal pattern. Photolithography and oxygen plasma etching of PI defined the outline of the sample. Undercutting the bottom layer of poly(methyl methacrylate) allowed the transfer of the sample to a water-soluble polyvinyl alcohol tape (3M) from the silicon wafer.

Digital control

The digital control system used (1) pulse-width modulation (PWM) drivers (PCA9685, 16-channel, 12-bit), (2) voltage amplifier circuits (MOSFET, IRF510N, Infineon Tech) and (3) a single-board computer (Raspberry Pi 4) remotely connected to an external computer (Intel NUC, Intel Core i7-8559U CPU@2.70 GHz). The external computer ran the optimization algorithm and sent the updated values of the voltages wirelessly to the single-board computer through Python Socket network programming. The PWM driver received the actuation signals from the single-board computer. Each PWM channel, operated at a frequency of 1,000 Hz, generated an independent voltage in the range of 0–6 V with 12-bit (around 0.0015 V) resolution. The single stage MOSFET provided a reversely linear amplification to the PWM output with a gate voltage, $V_{\text{gs(th)}} = 4$ V, and an external power supply, $V_{\text{ex}} = 6$ V (Supplementary Fig. 7).

Optimization algorithm

Sequential least squares programming with a three-point method (SciPy-Python optimize.minimize function) computed the Jacobian matrix in the loop to minimize the loss function $f(\mathbf{V})$. The model-driven approach adopted the same optimization algorithm, with $f(\mathbf{V})$ evaluated by equation (1) and a maximum of around 10,000 iterations. For the experiment-driven approach, a maximum final loss value of 0.005 ($f(\mathbf{V} = \mathbf{0})$) and a maximum of 15 iterations set the stopping criteria for the optimization process. Each iteration required $4(N + M) + 2$ function evaluations for an $N \times M$ sample (Supplementary Note 6).

Target shapes of the droplets

The target shapes in Fig. 2a were reconstructed from the images in Fig. 3 in ref.⁴¹. The target shapes in Fig. 2b were reconstructed from frames of the supplementary video in ref.⁴². 3D models of the target shapes were built and rendered using Solidworks (Dassault Systèmes). The target shapes and slow-motion video in Supplementary Video 2 were reconstructed (00:00:15–00:04:23, 0.6 $\times$ playback) and reproduced from ref.⁴².

3D imaging

The multiview stereo-imaging platform consisted of two cameras (Webcams, ELP, MI5100, 3,840 $\times$ 2,160-pixel resolution, 30 frames per second) connected to the external computer taking top-view images of the sample from symmetric angles (Supplementary Fig. 30a). A calibration algorithm (OpenCV-Python calibrateCamera function) applied to a collection of images of a chequerboard (custom-made, 7 $\times$ 8 squares, 2 mm $\times$ 2 mm per square) returned the camera matrix, distortion coefficients, rotation and translation vectors to correct for the lens distortion of the images (OpenCV-Python undistort function). The nodes of the mesh samples provided a distinguishable geometry for image registration. A template matching algorithm (OpenCV-Python matchTemplate function) returned the locations of the nodes in the images from the two cameras. A perspective projection algorithm (OpenCV-Python reprojectImageTo3D function) transformed the disparity map into the nodal heights in units of pixels. An additional side camera provided ground-truth measurements of the displacement of the discernible nodes and provided a linear-model prediction of the 3D-reconstructed nodal displacement (Supplementary Fig. 30b,c and Supplementary Note 14).

Data availability

All data are contained within the manuscript. Raw data are available from the corresponding authors upon reasonable request.

Code availability

The codes that support the findings of this study are available from the corresponding authors upon reasonable request.

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Author contributions Y.B., H.W., Y.H., J.A.R. and Xiaoyue Ni conceived the idea and designed the research. Y.B. and Y.Y. fabricated the samples. Y.B., Y.X., Y.P., J.-T.K., Xinchen Ni, T.-L.L., M.H. and Xiaoyue Ni performed the experiments. H.W. and Y.H. performed the finite-element modelling and theoretical study. Y.B. and Xiaoyue Ni analysed the experimental data. Y.B., H.W., Y.H., J.A.R. and Xiaoyue Ni wrote the manuscript, with input from all co-authors.

Competing interests The authors declare no competing interests.

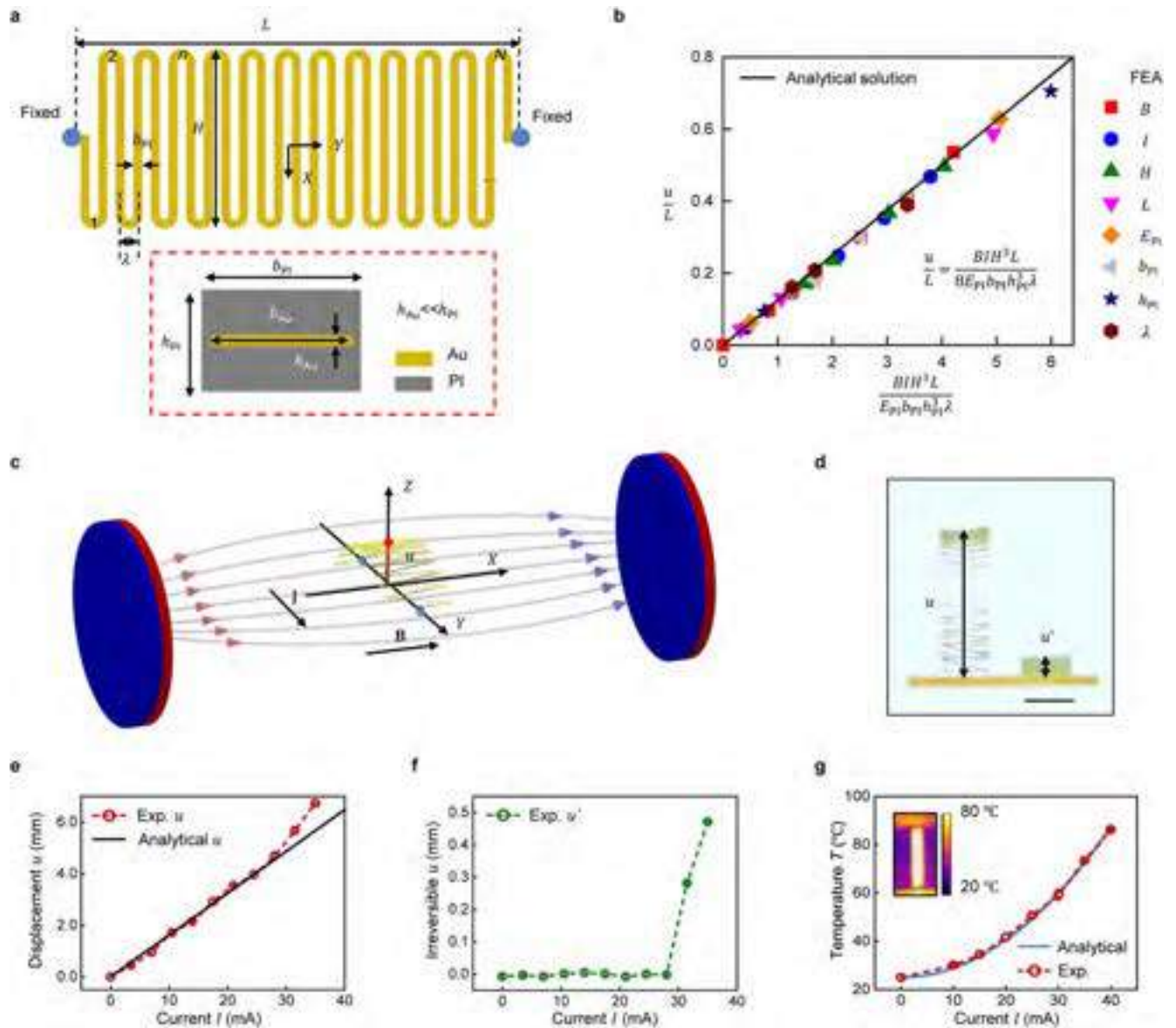
Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41586-022-05061-w>.

Correspondence and requests for materials should be addressed to Heling Wang, Yonggang Huang, John A. Rogers or Xiaoyue Ni.

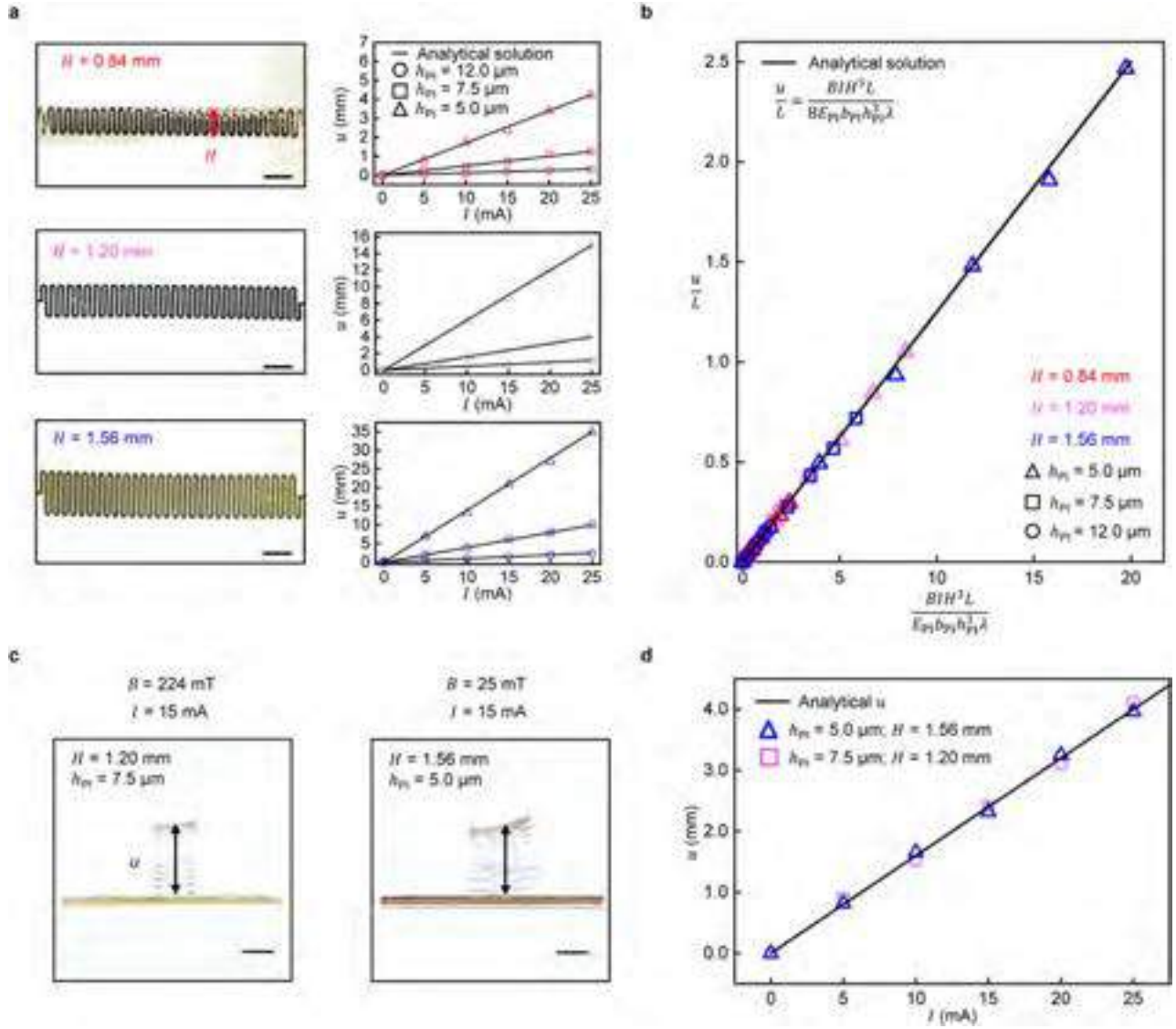
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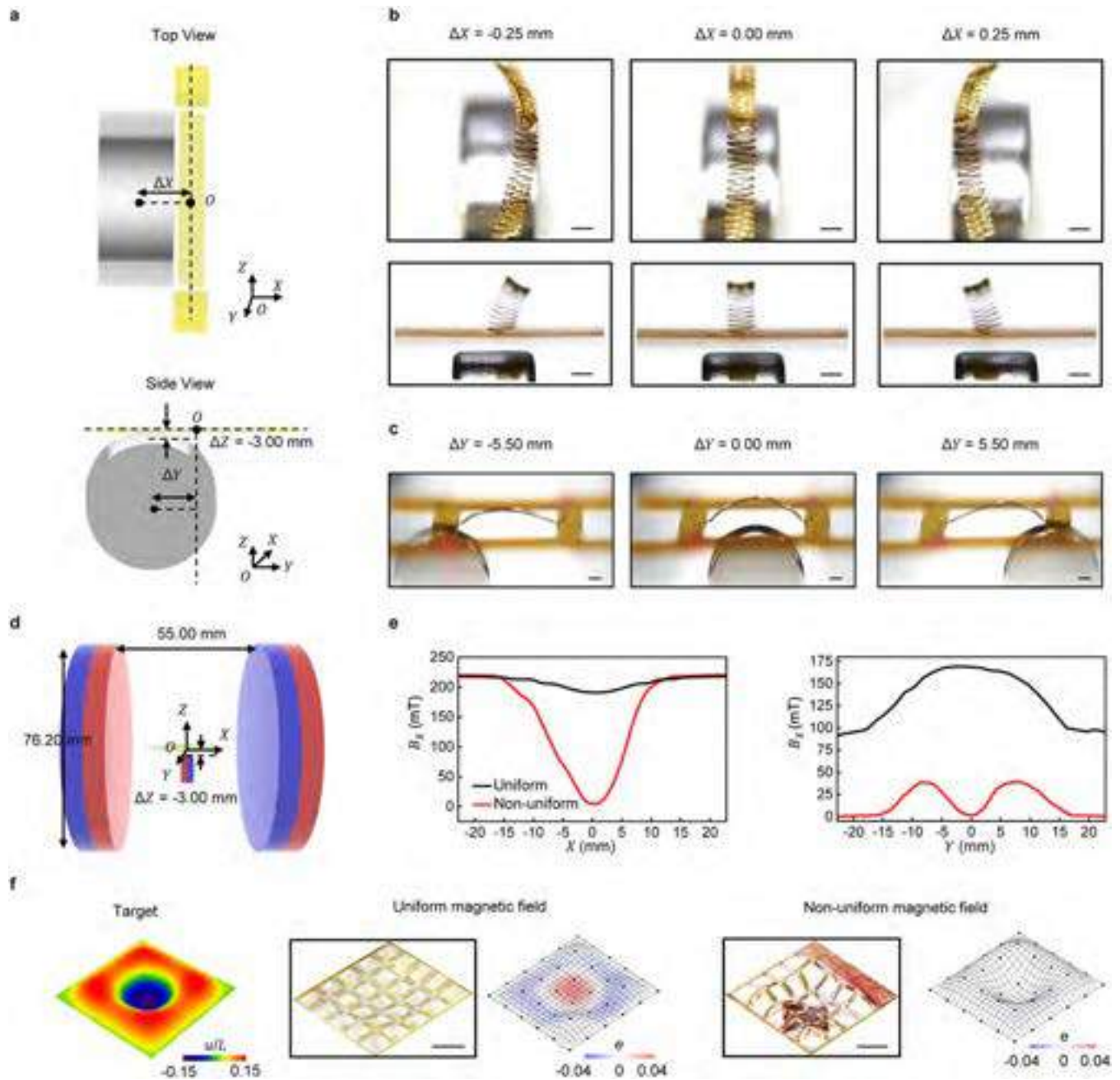
Extended Data Fig. 1 | The analytical model of the electromagnetic response of a serpentine beam corroborated by FEA study and experimental characterizations. **a**, Schematic illustration (top and cross-sectional views) of the initial state of a serpentine beam (beam width $H=1.20$ mm, serpentine period $\lambda=0.18$ mm). **b**, Analytical model and FEA prediction of the maximum out-of-plane displacement u dependent on the combination of electric current I , magnetic field B , and material and geometry parameters. **c**, Schematic illustration of a single beam, placed in a magnetic

field $\mathbf{B}$ and carrying a current density $\mathbf{J}$ with an out-of-plane displacement u , under an electromagnetic force $\mathbf{F}_{EM}=\mathbf{J} \times \mathbf{B}$. **d**, Optical images of a representative serpentine beam (side view) driven to the maximum displacement u . If exceeding the elastic limit, an irreversible deformation u' will remain after unloading. **e–g**, Experimental characterizations of mechanical (e, f) and thermal (g) behaviors of a single beam under current-controlled electromagnetic actuation ($B=224$ mT) in comparison with the theoretical predictions. Scale bar, 1 mm.



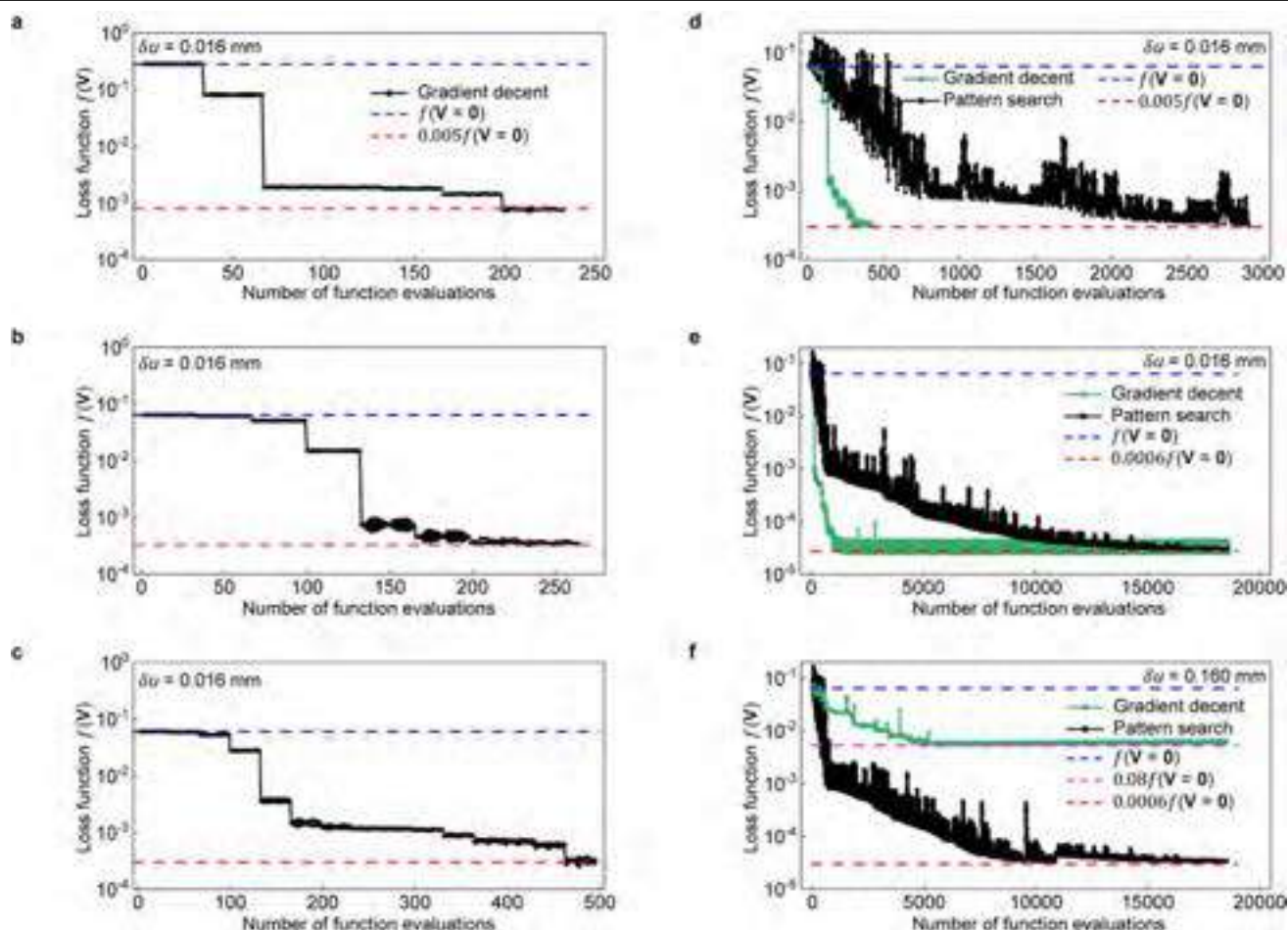
Extended Data Fig. 2 | Experimental validation of the scaling law using a single serpentine beam. **a**, Top-view optical images of serpentine beams with the same beam length ($L = 11 \text{ mm}$) but different beam widths ($H = 0.84 \text{ mm}$, 1.20 mm , 1.56 mm). In a magnetic field of 224 mT , current-controlled experiments show that the electromagnetic responses of the beams with various PI thicknesses ($h_{PI} = 5.0 \text{ } \mu\text{m}$, $7.5 \text{ } \mu\text{m}$, $12.0 \text{ } \mu\text{m}$) agree with the analytical solutions. **b**, Experimentally measured electromagnetic responses follow the scaling law

predicted by the analytical model. **c**, Side-view optical images of a serpentine beam of the design presented in the main text ($H = 1.20 \text{ mm}$, $h_{PI} = 7.5 \text{ } \mu\text{m}$) actuated in a magnetic field of 224 mT (left) and a tailored serpentine beam ($H = 1.56 \text{ mm}$, $h_{PI} = 5.0 \text{ } \mu\text{m}$) actuated in a reduced magnetic field of 25 mT (right). Applying the same current (15 mA) deforms the two beams to the same height (around 2.25 mm). **d**, The two beams in (c) exhibit approximately the same current-controlled mechanical behavior. Scale bars, 1 mm .



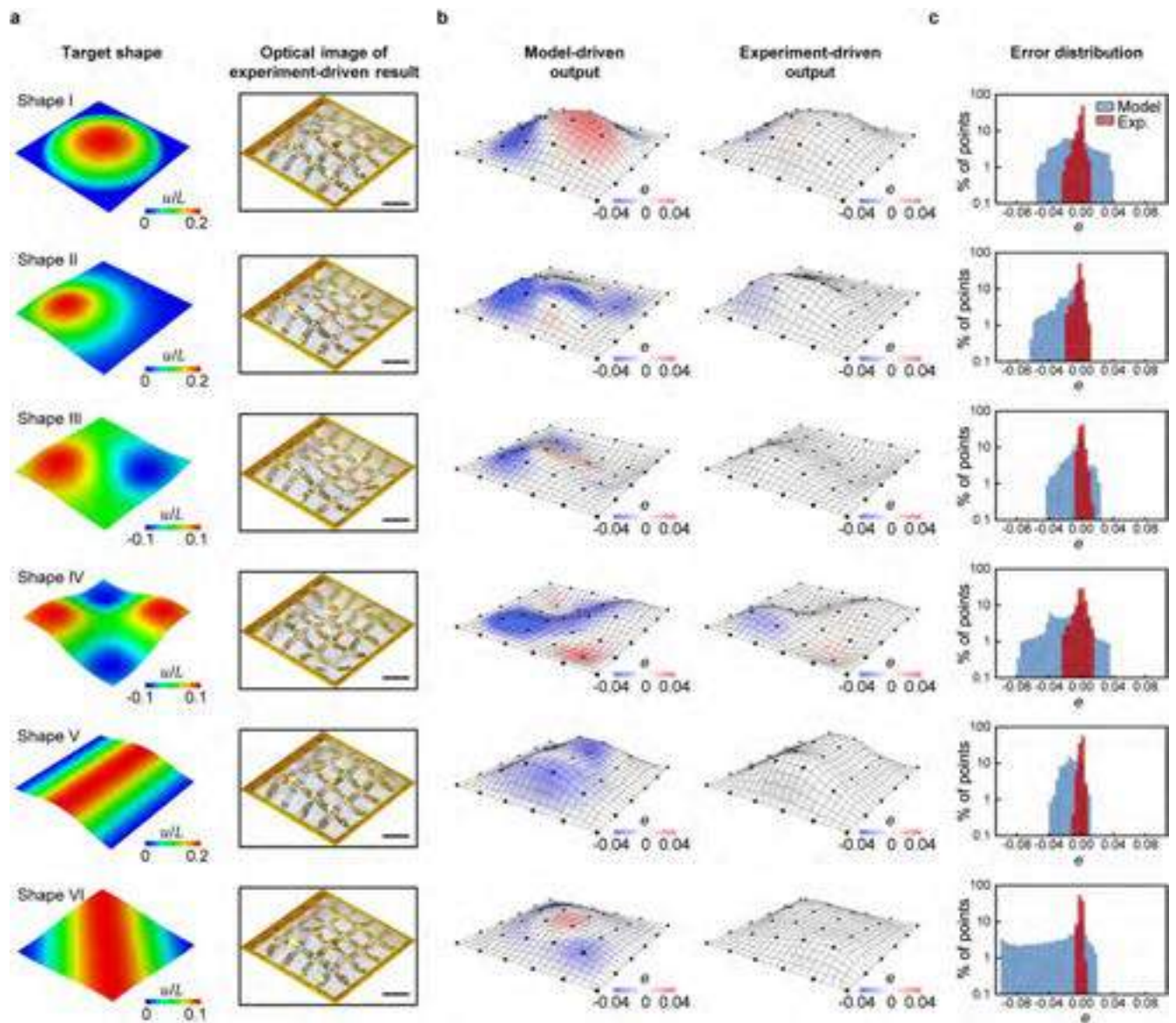
Extended Data Fig. 3 | Shape morphing in time-varying, non-uniform magnetic fields. **a**, Schematic illustration of a single serpentine beam in a non-uniform magnetic field generated by a small disk magnet (diameter $D = 11.0$ mm, thickness $h = 5.0$ mm, surface field $B = 481.6$ mT) moving 3-mm below the beam ($\Delta Z = -3$ mm). **b**, **c**, Optical images of the beam (applied current $I = 20$ mA) changing shapes as the position of the magnet changes along X -axis (**b**, $\Delta Y = 0$) and Y -axis (**c**, $\Delta X = 0$). Scale bars, 1 mm. **d**, Schematic illustration of a 4×4 sample in a non-uniform magnetic field generated by a pair of large magnets ($D = 76.2$ mm, $h = 12.7$ mm, surface field $B = 245.1$ mT) and a small

magnet ($D = 11.0$ mm, $h = 5.0$ mm, surface field $B = 481.6$ mT) in the middle, 3.0 mm below the center of the sample. **e**, Magnetic flux density in X -direction (B_x) of the approximately uniform/non-uniform field measured by a gaussmeter (GMHT201, Apex Magnets) with/without the presence of the small magnet across the center (O) along X -axis (left) and Y -axis (right). **f**, Experimental results (optical images and 3D reconstructed surfaces) of a 4×4 sample morphing into the same donut-like target shape via the experiment-driven self-evolving process in the uniform and the non-uniform magnetic field. Scale bars, 5 mm.



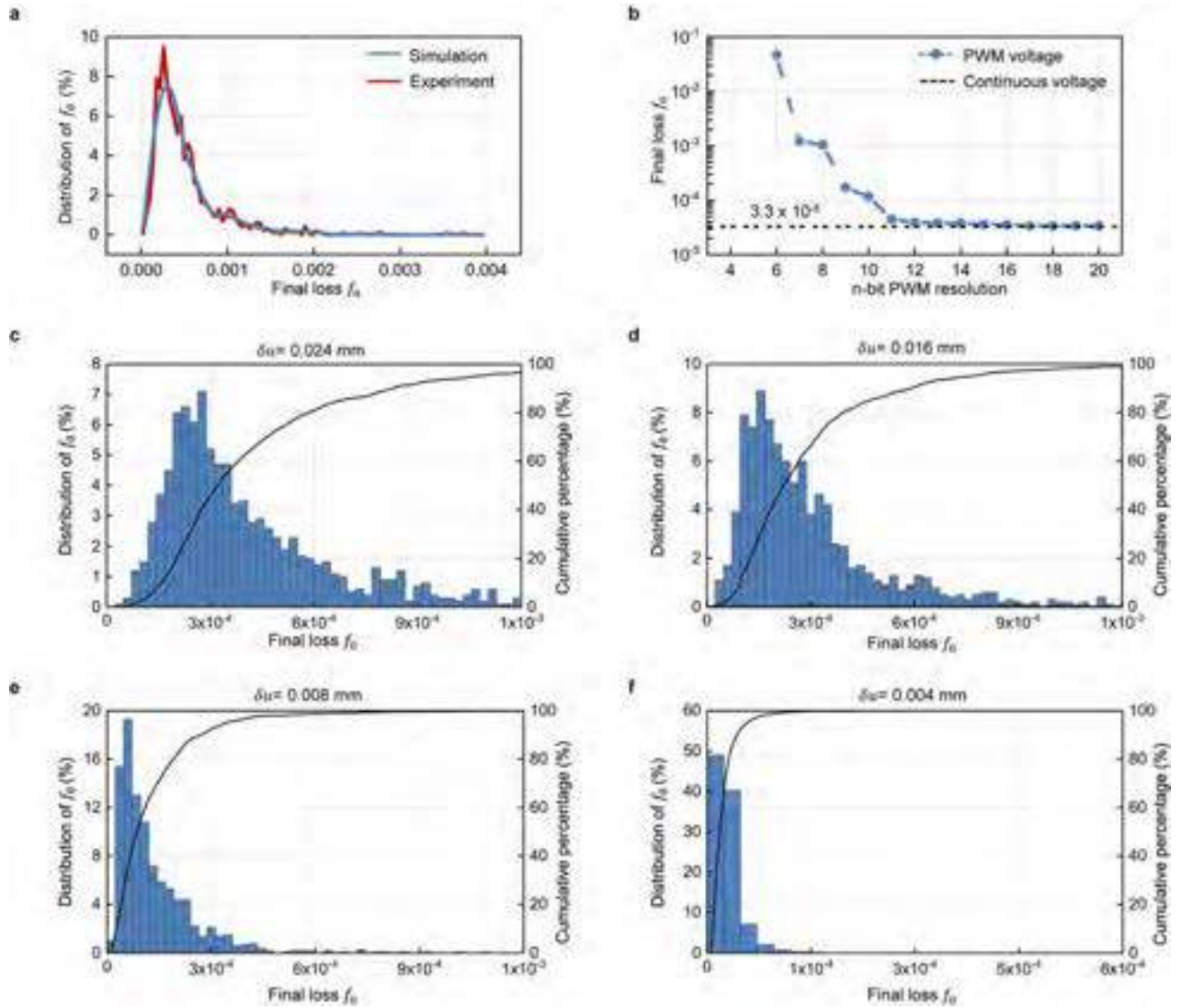
Extended Data Fig. 4 | Typical descent of loss function over function evaluations. **a–c,** For a 4×4 sample morphing into Shape I (a), III (b), IV (c) (Supplementary Note 8) through the experiment-driven approach using the gradient-based algorithm (see Methods section ‘Optimization algorithm’), the experimentally-measured loss function $f(V)$ (with an initial value $f(V=0)$ in the range of 0.05–0.35) descends by ~99.5% to a steady state in 170–510 function evaluations (5–15 iterations). The 3D imaging noise is $\delta u = 0.016$ mm (Supplementary Note 14). **d–f,** Comparison of a global solver (pattern search algorithm) with the gradient-based algorithm for a 4×4 sample morphing into

Shape IV using model-driven simulation. Subjecting the objective function to typical experimental noise ($\delta u = 0.016$ mm, Supplementary Note 14) and targeting a final loss of $0.005f(V=0)$, the gradient-based algorithm finds the solution faster than the global solver (d). Both algorithms settle to a minimum loss of $0.0006f(V=0)$ within 20,000 function evaluations (e). With pronounced noise ($\delta u = 0.16$ mm), the gradient descent method ends up with a local solution ($0.08f(V=0)$), while the pattern search method finds the same minimum ($0.0006f(V=0)$) as the case with low noise (f).



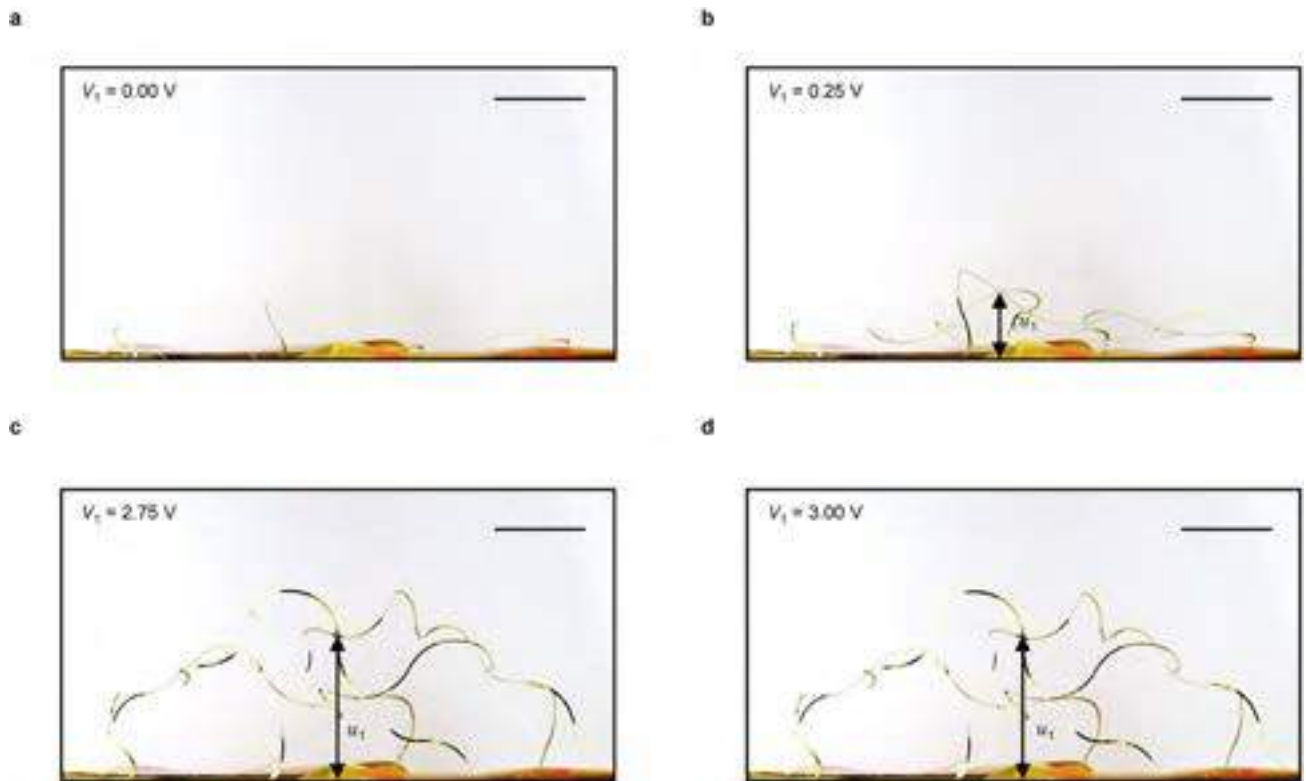
Extended Data Fig. 5 | Experiment-driven self-evolving process in comparison with the model-driven approach. a, Target explicit shapes and optical images of the experiment-driven morphing results of a 4×4 sample.

b, 3D reconstructed surfaces overlaid with contour plots of the minimized errors. **c,** Histogram plots of the minimized errors for model-driven and experiment-driven outputs. Scale bars, 5 mm.



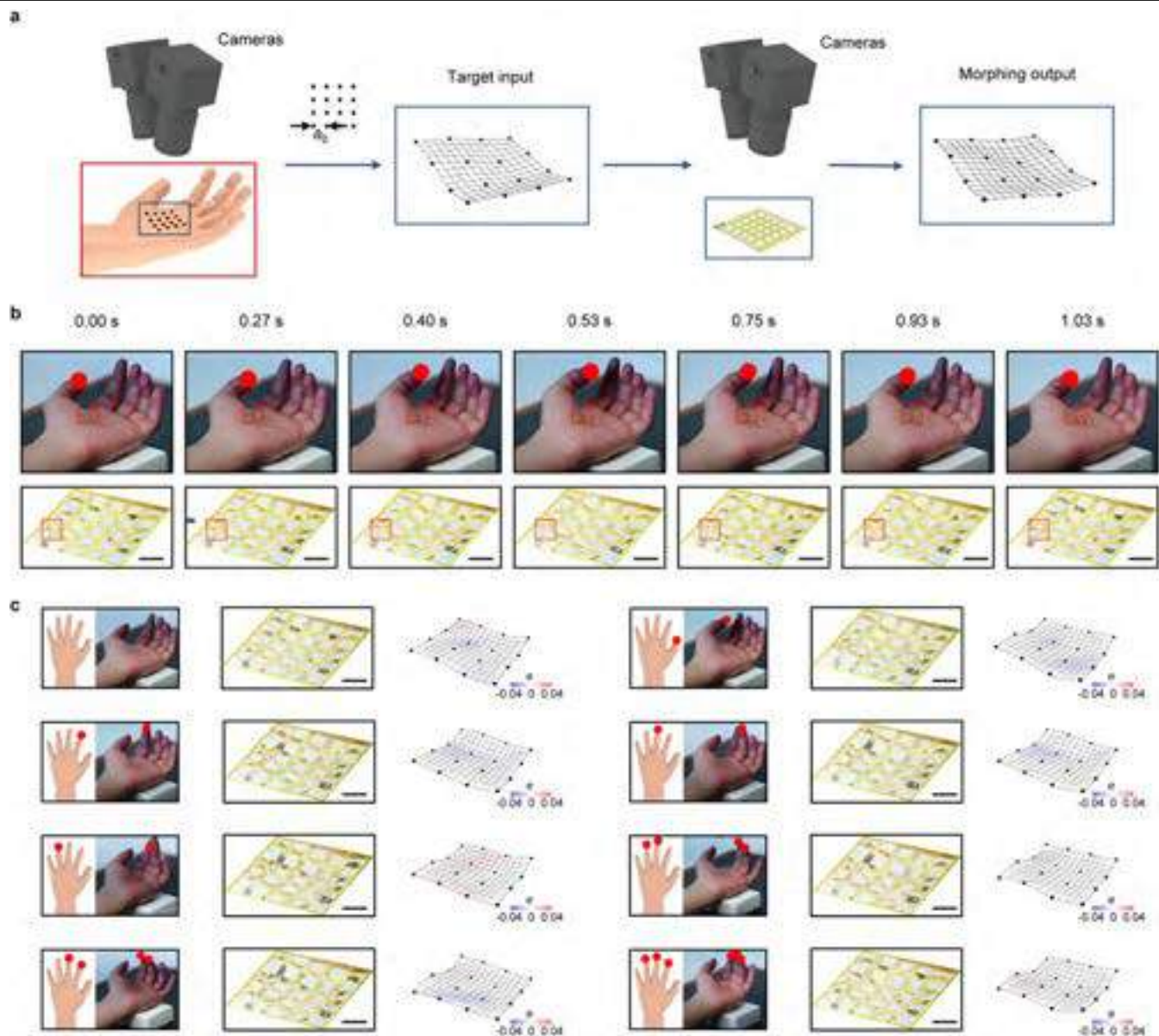
Extended Data Fig. 6 | Simulation of the impact of experimental noise on the optimization process. **a**, Comparison between the distribution of final loss f_0 after 15 iterations from model-driven simulations (1,000 trials, given 3D imaging noise $\delta u = 0.016$ mm, 12-bit PWM output, and maximum current $I_{\max} = 27$ mA) versus that from the experiments (97 trials), for a 4×4 sample morphing into the target shape in Fig. 3b. **b**, Simulation results of the final loss

f_0 (without imaging noise and iteration constraint) given n -bit PWM voltage control, compared with the case without actuation noise (continuous, analog voltage control). **c–f**, Histogram plots of the final loss f_0 (1,000 simulation trials) with a decreasing 3D imaging noise $\delta u = 0.024$ mm (c), 0.016 mm (d), 0.008 mm (e) and 0.004 mm (f).



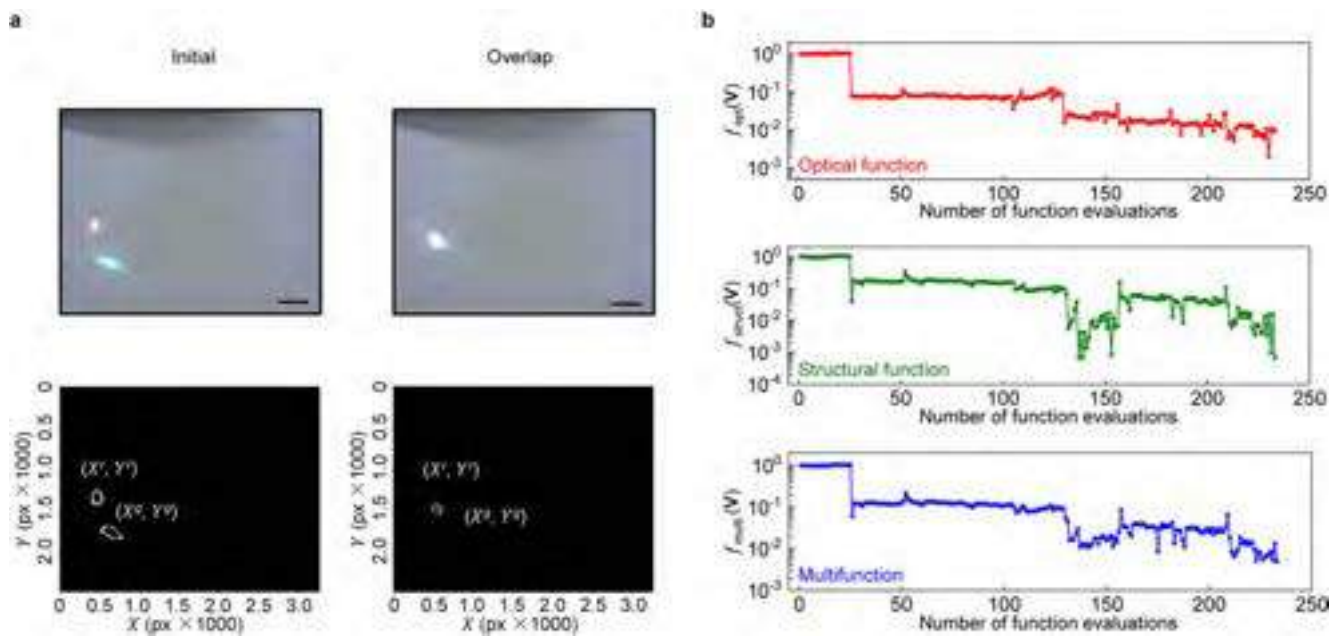
Extended Data Fig. 7 | The optical images of a 2×2 sample with modified serpentine design for amplified nonlinear mechanical behavior in response to a range of actuation voltages. a–d, Side-view images of the

sample deforming out-of-plane given an increasing voltage to port 1 (Fig. 4a) given $V_1 = 0$ V (a), 0.25 V (b), 2.75 V (c), and 3 V (d), respectively. The rate of change of u_1 decreases as the actuation voltage increases. Scale bar, 5 mm.



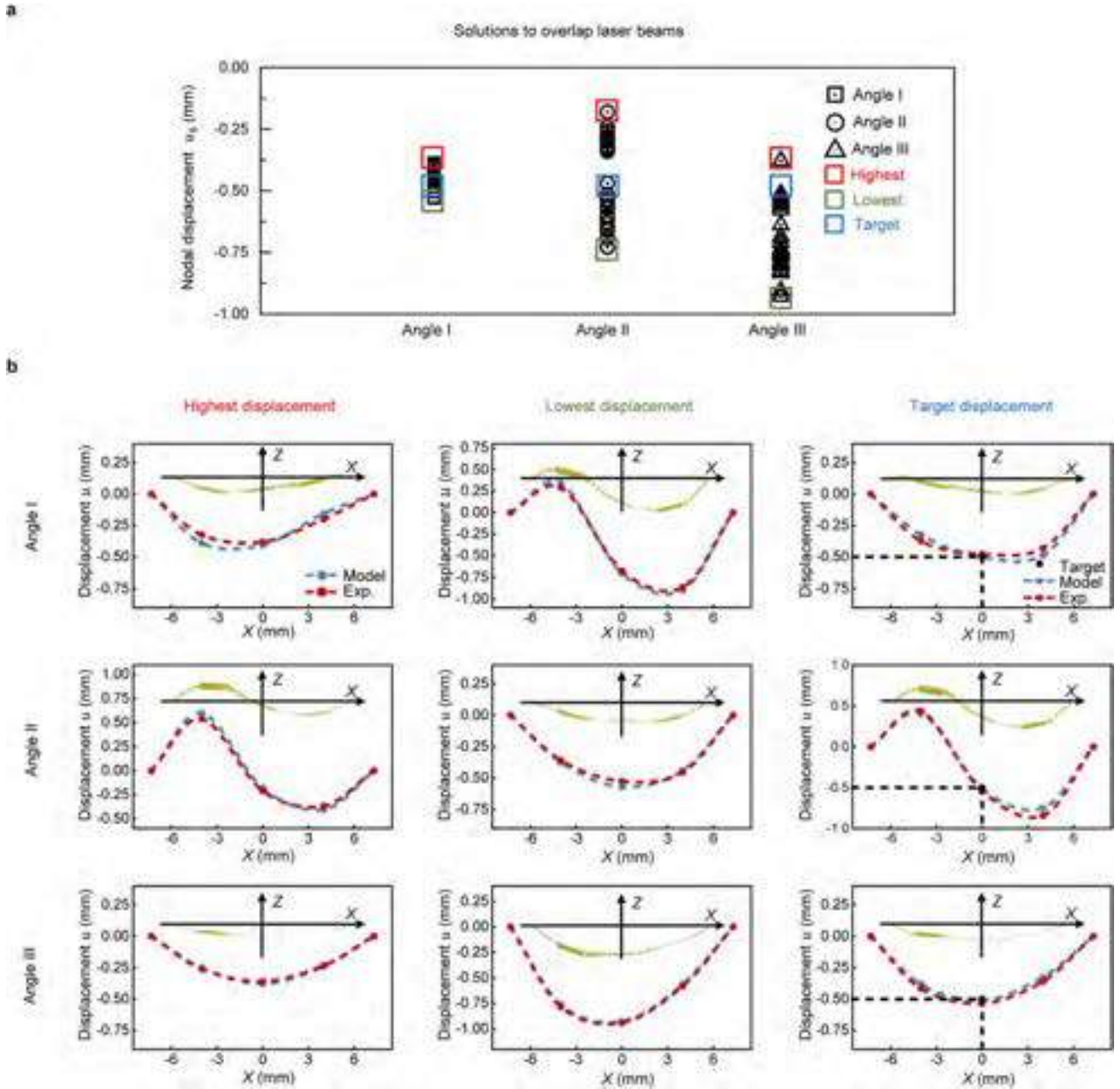
Extended Data Fig. 8 | Self-evolving shape morphing toward semi-real-time shape learning. **a**, Schematic illustration of a duplicated stereo-imaging setup enabling a semi-real-time control of a 4×4 sample simulating the dynamic shape-shifting of a palm surface with 4×4 markers (with inter-spacing

$a_0 = 15$ mm). **b**, Experimental results of the continuous semi-real-time shape learning of the palm surface with the thumb moving up. **c**, Morphing results of representative frames from a recording of hand making eight gestures. Scale bars, 5 mm.



Extended Data Fig. 9 | A 3×3 reflective sample self-evolving to achieve an optical and a structural function simultaneously. a, Representative optical images of the laser spots on the receiving screen. The target optical function is to overlap two laser spots on the receiving screen. A customized image analysis method detects the centroid coordinates of the red/green laser spots to monitor their current locations on the screen ($[x^{r/g}, y^{r/g}]$). **b,** The typical

evolution of loss functions (Supplementary Note 16) over number of functional evaluations. The optimized loss function ($f_{\text{multi}}(\mathbf{V})$) is a linear combination of two parts: I) an optical loss function $f_{\text{opt}}(\mathbf{V})$ that evaluates the distance between the center of the two laser spots; II) a structural loss function $f_{\text{struct}}(\mathbf{V})$ that evaluates the central nodal displacement error. Scale bar, 5 mm.



Extended Data Fig. 10 | Allowed shape (structural function) configurations of a 3×3 sample enforcing only the optical function (Fig. 5c, d). a, Allowed values of the central nodal displacement (u_z) when the sample overlaps the beams (when the distance between the centroids of the laser spots is less

than 0.1 mm) with three distinctive incident angles. **b,** Model predictions, and the ex-situ 3D imaging results of the sample (cross-sectional view) when overlapping the laser spots in the configurations with the highest, lowest, and target central displacement.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Modelling Uniaxial Compressive Fracture of Concrete with Nonlocal Macro-Meso-Scale Consistent Damage Model

Author(s): Yudong Ren^{*1}, Jianbing Chen², Guangda Lu³.

¹ College of Civil Engineering, Tongji University, Shanghai, P. R. China, rydmaize@tongji.edu.cn

² College of Civil Engineering, Tongji University, Shanghai, P. R. China, chenjb@tongji.edu.cn

³ College of Civil Engineering, Tongji University, Shanghai, P. R. China, guangdalu@tongji.edu.cn

Keyword(s): nonlocal macro-meso-scale consistent damage model, structured deformation, uniaxial compression, concrete

Abstract

Inspired by the peridynamics and phase field theory, the nonlocal macro-meso-scale consistent damage model (NMMD) was proposed and succeeded in modelling tension-dominated fractures in quasi-brittle materials under static and dynamic loading. To extend NMMD to the challenging compression dominated failure problems, the concept of structured deformation is adopted to define the structured elongation quantity of material point pairs, which is a decomposition of the deformation of point pairs. When the structured elongation quantity of a point pair surpasses the critical elongation quantity, two material points undergo irreversible separation, and mesoscopic damage starts to develop in this point pair. A mesoscopic damage function is introduced to quantify the damage state of point pairs. The topologic damage at one material point is defined as the weighted summation of the mesoscopic damage of point pairs connected to this point within the influence domain. Through the energetic degradation function which bridges the damage in geometric sense and energy dissipation, the topologic damage is incorporated into the framework of continuum damage mechanics, and thus this model can be solved numerically in the framework of numerical discretization of continuum, say, by the finite element method. Numerical example indicates that the NMMD can well capture the vertical crack in concrete under uniaxial compression loading. Samples of concrete specimens were generated by the random aggregate placement procedure and uniaxial compression simulations were conducted with the proposed model. Crack patterns similar to the experimental results can be obtained, and the strain-stress whole curves agree well with the experimental range. Problems to be further studied will also be discussed.

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Title: Virtual dynamic tests on soil-structure interaction data-driven assessment using HPC resources

Author(s): Tony Fierro^{*1}, Stefano Ercolessi¹, Giovanni Fabbrocino^{1,2}, Filippo Santucci de Magistris¹, Carlo Rainieri³

¹ Department of Biosciences and Territory, University of Molise, Campobasso, Italy,

² Secondary Branch of L'Aquila, Construction Technologies Institute, National Research Council of Italy, 67100 L'Aquila, Italy

³ Secondary Branch of Naples, Construction Technologies Institute, National Research Council of Italy, 80146 Naples, Italy

* tony.fierro@unimol.it

Keyword(s): Soil-structure interaction, Virtual dynamic tests, Data-driven, HPC

Abstract

The modelling of the interaction between the soil beneath a structure and the structure itself has always been considered a crucial aspect in Earthquake Engineering. In fact, it is well established that if a structure rests on a stiff soil, the base can be considered fixed, otherwise the effect due to soil-structure interaction (SSI) cannot be neglected (see Bielak [1]; Wolf [2]; Mylonakis and Gazetas [3]; Bapir et al. [4]). If in some cases the modelling of SSI is an essential feature to gain reliable results, in other cases it can dramatically increase the computational demand without a significant influence in the accuracy of the response.

In order to investigate the need of introducing the SSI in dynamic analyses, in this work, the case-study of an existing 30 m-high bridge pier resting on a 14 m-large caisson foundation located in Molise region is taken into account.

In particular, starting from the geotechnical and structural characterization of these foundation structures and the most adopted analysis techniques, the digital twin of the bridge pier has been developed using the OpenSees parallel modules. Virtual dynamic tests are conducted with a view to finding the natural frequencies of the coupled system made by soil and structure, and the latter are compared to those of the structure itself. In this manner, the necessity to consider the soil-structure interaction in the model is evaluated.

It is worth noting that tests are data-driven: in particular, they are performed by applying different input sources in an HPC environment with a view to increasing computational efficiency.

References

- [1] Bielak J. (1974). Dynamic behaviour of structures with embedded foundations. *Earthq. Eng. Struct. Dyn.* 3, 259–274. doi:10.1002/eqe.4290030305
- [2] Wolf J. P. (1989). Soil-structure-interaction analysis in time domain. *Nucl. Eng. Des.* 111, 381–393. doi:10.1016/0029-5493(89)90249-5
- [3] Mylonakis, G., and Gazetas, G. (2000). Seismic soil-structure interaction: Beneficial or detrimental? *J. Earthq. Eng.* 4, 277–301. doi:10.1080/13632460009350372
- [4] Bapir B., Abrahamczyk L., Wichtmann T., and Prada-Sarmiento L.F. (2023). Soil-structure interaction: A state-of-the-art review of modeling techniques and studies on seismic response of building structures. *Front. Built Environ.* 9:1120351. doi: 10.3389/fbuil.2023.1120351

EMI 2023 International Conference

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Title: Sensitivity of displacement measures in detecting damages induced by shaking table tests on masonry barrel vaults with hemp bio composite strengthening.

Author(s): Elena Alberti¹, Massimiliano Giofrè², Francesco Lo Iacono¹, Giacomo Navarra^{*1}, Maria Oliva¹, Chiara Pepi²

¹ Faculty of Engineering and Architecture, Kore University of Enna, Enna, Italy

Emails: mariagraziaelena.alberti@unikorestudent.it, francesco.loiacono@unikore.it, giacomo.navarra@unikore.it, maria.oliva@unikore.it.

² Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy

Emails: massimiliano.gioffre@unipg.it, chiara.pepi@unipg.it

Keyword(s): Bio composite materials; Damage detection; Hemp ropes; Structural strengthening; Masonry vault; Shaking table tests

Abstract

The Italian architectural heritage presents a high vulnerability to seismic actions. Among the various structural elements, masonry vaults are of widespread use and often require strengthening. In the last decade, a relevant research activity has been devoted to different reinforcement techniques, as Fiber Reinforced Polymers (FRP) or Fiber Reinforced Cementitious Matrix (FRCM) [1]. More recently, with the increasing sensitivity for environmental sustainability, the interest in using innovative composite materials based on vegetal fibers and organic matrices have received growing notice. In particular, extensive experimental investigation has been carried out to explore the mechanical properties and the strengthening effects of a new composite material consisting of continuous mono- or bi-directional hemp ropes bonded in a layer of *cocciopesto* matrix [2]. After first static tests performed on arches to characterize the proposed innovative reinforcement technique, full-scale masonry vaults were built and dynamically tested in the 6-DOF shaking table system of the L.E.D.A. (Laboratory of Earthquake engineering and Dynamic Analysis) Research Institute at the “Kore” University of Enna, Italy [3]. Specifically, two identical vault specimens were built, one of which was reinforced at the extrados with the bio composite material, and were subjected to increasing seismic loads up to near-to-collapse stage [4]. The vaults were equipped with accelerometers as well as a relevant number of spherical reflective markers for the 3D tracking of displacements. In this work, the effectiveness of the displacement measures in detecting the progressive structural damage induced by shake table tests has been investigated for both the unreinforced and the strengthened masonry vaults.

References

- [1] Giamundo V., Lignola G.P., Maddaloni G., Da Porto F., Prota A., Manfredi G., “Shaking table tests on a full-scale unreinforced and IMG-retrofitted clay brick masonry barrel vault”, *Bulletin of Earthquake Engineering*, 14(6), p. 1663–1693, (2016).
- [2] Giofrè M., Vincenzini A., Cavalagli N., Gusella V., Caponero M.A., Terenzi A., Pepi C., “A novel hemp-fiber bio-composite material for strengthening of arched structures: Experimental investigation”, *Construction and Building Materials*, 308, 124969, (2021).
- [3] Mendes N., Lourenço P., Campos-Costa A., “Shaking table testing of an existing masonry building: assessment and improvement of the seismic performance”, *Earthquake Engineering and Structural Dynamics*, 43(2), p. 247-266, (2014).
- [4] Giofrè M., Navarra G., Cavalagli N., Lo Iacono F., Gusella V., Pepi C., “Effect of hemp bio composite strengthening on masonry barrel vaults damage”, *Construction and Building Materials*, 367, 130100, (2023).

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Title: Evaluation of cracks in masonry arches with Artificial Neural Networks.

Author(s): Antonino Iannuzzo¹, Vincenzo Musone², Danilo Di Giacinto², Eugenio Ruocco^{*2}

¹ *Department of Engineering, University of Campania Luigi Vanvitelli, Aversa (Ce), Italy, eugenio.ruocco@unicampania.it*

² *Department of Engineering, University of Sannio, Benevento, Italy, iannuzzo @unisannio.it*

Keyword(s): Artificial Neural Network, Masonry Structures

Abstract

Masonry structures constitute a significant proportion of the built environment worldwide. Historic architectural heritage is heavily characterized by monumental masonry structures and, in many countries, residential buildings are predominantly constructed using masonry. Preservation of historical masonry structures has spurred a growing interest in studying this construction typology and devising new computational strategies to investigate their structural behaviour. Among the various methods for determining the causes of damage in structural mechanics, in recent years there has been a growing interest in exploring the enormous potential of Artificial Neural Networks (ANNs) [1,2] and their ability to provide reliable results even for extremely complex problems. When it comes to the application of Artificial Neural Networks (ANNs) to masonry structures, there is a relative lack of dedicated works in the literature. Although some research has been conducted, the number of studies remains limited, and the scope of these works is typically narrow. The limited number of studies that have been conducted to date is basically due to the difficulties in obtaining reliable results to feed the ANNs Net. The predictive power of ANNs is dependent on the quality and quantity of the data used for their training, and if the data used for training is inaccurate, incomplete, or biased, the neural network may produce unreliable results. In this paper a first attempt to apply the ANNs on the analysis of masonry structures is proposed. Adopting the limit analysis of masonry structures, as formalized by Heyman in the 1960s[3], can help overcome many of the challenges inherent in elastic models. The Heyman assumptions [4,5] state that the collapse of masonry structures is due to a lack of stability rather than insufficient material strength, and damage typically arises from differential settlements [3]. Today, this method is widely regarded as one of the most efficient algorithms for determining the type of settlement responsible for the observed crack patterns.

References

- [1] Simon Haykin, "Neural Networks: A Comprehensive Foundation", 1999.
- [2] Ian Goodfellow, Yoshua Bengio, and Aaron Courville, "Deep Learning", 2016.
- [3] Heyman, J. "The Stone Skeleton" International Journal of Solids and Structures, 2(2), 1966,249-279.
- [4] G. Tempesta, S. Galassi, "Safety evaluation of masonry arches. a numerical procedure based on the thrust line closest to the geometrical axis", International Journal of Mechanical Sciences 155 (2019) 206–221.
- [5] S. Huerta, "The analysis of masonry architecture: a historical approach", Architectural Science Review 51 (4) (2008) 297–328.

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Title: Probabilistic Response of Rigid Foundations on Uniform Soil with Uncertain Shear-Wave Velocities Under Horizontal Vibrations

Author(s): Jun-Yang Shi^{*1}, Chi-Chao Kao², Shi-Shuenn Chen³

¹ *Department of Civil and Environmental Engineering, National University of Kaohsiung, Kaohsiung, Taiwan, E-mail: jyshi@nuk.edu.tw*

² *Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan, E-mail: D10605004@mail.ntust.edu.tw*

³ *Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan, E-mail: sschen@mail.ntust.edu.tw*

Keyword(s): Soil-structure interaction, Simplified Models, Probability Distribution

Abstract

This study proposes an efficient method to calculate the probabilistic response of a rigid foundation on soil media subjected to horizontal harmonic vibrations. For the dynamic problem considered, the uncertainties come from the shear-wave velocities. Monte-Carlo simulations have been conducted to validate the effectiveness of the proposed method. The proposed method uses simplified models to simulate the dynamic force-displacement behavior of the unbounded soil. Numerical studies have been carried out to investigate the cumulative density function for the horizontal foundation displacement. The observations indicate that the proposed method may generate a probabilistic response close to the Monte-Carlo simulation result. It is also found that the simplified model's effectiveness significantly influences the computing accuracy of the probabilistic foundation responses in dynamic SSI analysis. Finally, the proposed method is further applied to evaluate the reliability of the foundation response satisfying the vibration criteria defined in the industrial standard.

References

- [1] Phoon, K. K.. Towards reliability-based design for geotechnical engineering. Special Lecture for Korean Geotechnical Society, Seoul, 9, 1-23.
- [2] Lutes, L. D., Sarkani, S., & Jin, S. (2000). Response variability of an SSI system with uncertain structural and soil properties. *Engineering Structures*, 22(6), 605-620.
- [3] Wolf, J. P. (1997). Spring-dashpot-mass models for foundation vibrations. *Earthquake engineering & structural dynamics*, 26(9), 931-949.
- [4] Chaudhuri, S. R. and Gupta, V.K. (2002). Variability in seismic response of secondary systems due to uncertain soil properties. *Engineering Structures*, 24(12), 1601-1613..
- [5] Moghaddasi, M., Cubrinovski, M., Chase, J. G., Pampanin, S., & Carr, A. (2011). Probabilistic evaluation of soil-foundation-structure interaction effects on seismic structural response. *Earthquake engineering & structural dynamics*, 40(2), 135-154.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Probabilistic response determination of high-dimensional nonlinear systems enforced by multiple Poisson white noises

Author(s): Jian-Bing Chen^{*1}, Meng-Ze Lyu².

¹ College of Civil Engineering, Tongji University, Shanghai, China, Email address: chenjb@tongji.edu.cn

² College of Civil Engineering, Tongji University, Shanghai, China, Email address: lyumz@tongji.edu.cn

Keyword(s): Poisson white noise, high-dimensional nonlinear stochastic dynamical system, partial differential-integral equation, globally-evolving-based generalized density evolution equation (GE-GDEE), dimension reduction.

Abstract

High-dimensional stochastic dynamical systems enforced by Poisson white noise have a wide range of applications in physics, chemistry, biology, and engineering fields [1]. Recently, the globally-evolving-based generalized density evolution equation (GE-GDEE) has shown significant advantages in probabilistic response determination of path-continuous processes, especially for systems of high-dimensions and strong nonlinearity [2], but there are still challenges in path-discontinuous processes, such as Poisson-excited systems, due to their random jumps [3]. In the present paper, the GE-GDEE governing the probability density function (PDF) of any single component of state vector of interest for a high-dimensional system enforced by Poisson white noise is established via dimension reduction. It is always a one-dimensional Kolmogorov-Feller-like partial differential-integral equation regardless of the dimensions of the system. The intrinsic drift function and intrinsic rate function (the latter is for parametric excitations) in the GE-GDEE can be identified numerically via data from representative deterministic dynamic analyses in the order of magnitude of $O(10^2)$ – $O(10^3)$. Then solving the GE-GDEE numerically yields the solution of transient PDF of the quantity of interest. A numerical example is illustrated to verify the efficiency and accuracy of the proposed method.

References

- [1] Gardiner C.W., Handbook of Stochastic Methods for Physics, Chemistry, and the Natural Sciences, 3rd Edn, Springer-Verlag, Berlin (2004).
- [2] Lyu M.Z., Chen J.B., “A unified formalism of the GE-GDEE for generic continuous responses and first-passage reliability analysis of multi-dimensional nonlinear systems subjected to non-white-noise excitations,” Structural Safety, 98, 102233, (2022).
- [3] Pirrotta A., “Multiplicative cases from additive cases: Extension of Kolmogorov–Feller equation to parametric Poisson white noise processes,” Probabilistic Engineering Mechanics, 22 (2), 127-135, (2007).

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Title: Generalized complex fractional moment for the probabilistic characteristic of random vectors

Author(s): Lizhi Niu¹, Mario Di Paola², Wei Xu³, Antonina Pirrotta⁴

¹ *Department of Applied Mathematics, Northwestern Polytechnical University, Xi'an 710129, PR China, niulizhi902@mail.nwpu.edu.cn*

² *Dipartimento di Ingegneria, Università degli Studi di Palermo, Palermo 90128, Italy, mario.dipaola@unipa.it*

³ *Department of Applied Mathematics, Northwestern Polytechnical University, Xi'an 710129, PR China, weixunpu@nwpu.edu.cn*

⁴ *Dipartimento di Ingegneria, Università degli Studi di Palermo, Palermo 90128, Italy, antonina.pirrotta@unipa.it*

Keyword(s): Generalized complex fractional moment; Joint probability density function.

Abstract

Complex Fractional moments(CFM) is an efficient procedure for the description of both Probability Density Function(PDF) and Characteristic Function(CF)[1], the CFMs are based on the Mellin Transform of the PDF that is related to the Riesz fractional operation, the appealing of the method is that with few complex number the PDF may be reconstructed. The CFM has been used for the stochastic response analysis of nonlinear systems enforced by normal colored noise[2] and Hamiltonian systems[3] Aim of the paper is the generalization of the CFM to multidimensional case representing the joint PDF of multidimensional random variable in terms of generalized CFM. In order to do this, the many-dimensional Mellin transform is applied[4]. Application of the generalized CFM to Normal and α -stable random vectors is presented.

References

- [1] M. Di Paola, and F. Pinnola, "Riesz fractional integrals and complex fractional moments for the probabilistic characterization of random variables," Probabilistic Engineering Mechanics, vol. 29, pp. 149-156, 2012.
- [2] I. Antipova, "Inversion of many-dimensional Mellin transforms and solutions of algebraic equations," Sbornik Mathematics, vol. 198, no. 3-4, pp. 447-463, 2007.
- [3] L. Niu, Y. Song, and W. Xu, "Application of Complex Fractional Moment in nonlinear system with Gaussian colored noise," International Journal of Non-Linear Mechanics, vol. 141, 2022.
- [4] L. Niu, W. Xu, T. Sun, Y. Song, and Y. Zhang, "Discussion on applicability of the complex fractional moment method in Hamiltonian system," Chaos, Solitons and Fractals, vol. 167, 2023.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A Bayesian approach for tie rod tensile force identification

Author(s): Chiara Pepi¹, Massimiliano Giofrè²

¹ *Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, chiara.pepi@unipg.it*

Keyword(s): tie rods, structural identification, uncertainty quantification, Bayesian approach

Abstract

Tie rods are common structural elements used to improve stability of arches and vaults of ancient and/or modern masonry buildings. The estimation of tensile axial force in tie rods has gained interest in literature since it is an important parameter to obtain information about the structural stability of the overall construction [1,2]. In addition to the tensile axial force, the unknown parameters characterizing the structural response of these metallic elements are the section shape and dimensions, the mass density, the elastic properties and the boundary conditions used to reproduce the tie rod insertion length in the lateral walls [3]. All these parameters can be estimated by means of deterministic optimization procedures aimed at minimizing the distance between the model (i.e. analytical or numerical model) predicted and measured tie rods modal response (i.e. different number of natural frequencies and associated mode shapes) [4,5]. However, these procedures are often ill-posed, not providing a unique solution, and the uncertainties related to the physical and mechanical tie rods parameters are completely neglected. A first attempt to completely characterize the uncertain features of the problem unknowns (i.e. mass per unit length, stiffness, boundary conditions and tensile force) using Monte Carlo simulations and measured natural frequencies of existing ancient tie rods [6] was carried out by these Authors in [7]. In this paper, a further step forward is set up: first, a numerical model of a slender beam constrained by two sets of elastic rotational springs at the ends is set up; second, the unknown analytical model parameters and their associated uncertainties are estimated using the Bayesian approach assuming different kind of noisy modal data as target.

References

- [1] Makoond N., Pelà L., Molins C. "Robust estimation of axial loads sustained by tie rods in historical structures using Artificial Neural Networks," *Structural Health Monitoring*, 14759217221123326, (2022).
- [2] Lucà F., Manzoni S., Cigada A., Frate L. "A vibration based approach for health monitoring of tie-rods under uncertain environmental conditions," *Mechanical System and Signal Processing*, 167, 108547, (2022).
- [3] De Falco A., Resta C., Sevieri G. "Sensitivity analysis of frequency based tie rod axial load evaluation methods," *Engineering Structures*, 229, 111568, (2021).
- [4] Lagomarsino S., Calderini C. "The dynamical identification of the tensile force in ancient tie-rods," *Engineering Structures*, 27(6), 846-856, (2005).
- [5] Rebecchi G., Tullini N., Laudiero F. "Estimate of the axial force in slender beams with unknown boundary conditions using one flexural mode shapes," *Journal of Sound and Vibration*, 332(18), 4122-41356, (2005).
- [6] Giofrè M., Cavalagli N., Pepi C., Trequattrini M. "Laser doppler vibrometer and radar interferometer for contactless measurements on unaccessible tie rods on monumental buildings: Santa Maria della Consolazione Temple in Todi," *Journal of Physics: Conference Series*, 778(1), 012008 (2017).
- [7] Pepi C., Grigoriu M.D., Giofrè M., "Identification of tie-rod properties in monumental buildings under uncertainty" in *Proceedings of AIMETA 2022 XXV Conference of the Italian Association of Theoretical and Applied Mechanics*, Palermo, 4-8 September 2022, (2023).

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Title: Probabilistic modelling of hemp ropes strength

Author(s): Maria Eleonora Pipistrelli^{*1}, Massimiliano Gioffrè¹, Mircea Dan Grigoriu²

¹ Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, mariaeleonora.pipistrelli@studenti.unipg.it, massimiliano.gioffre@unipg.it

² Department of Civil and Environmental Engineering, Cornell University, Ithaca, United States, mdg12@cornell.edu

Keyword(s): Hemp ropes, probabilistic modelling, random fields, organic composites, mechanical characterization, sustainable materials.

Abstract

In modelling and design of structures in the civil engineering field, most of the variables taken in account are affected by uncertainties. For instance, many materials' properties have some level of randomness due to the complex scatters of their mechanical behaviour. Dealing with these irregularities, the problem of the mechanical characterization requires the application of non-deterministic methods, that use the tools of probability and stochastic theory [1].

A very well-known case in point in building industry is represented by composite materials, used for retrofitting techniques. In such instance, mechanical properties variability is caused by the presence of two different material domains [2]. Traditional composite materials use a polymer matrix reinforced with synthetic fibres. However, in the last years they have been replaced by new low-impact composite materials made with natural fibres [3-5]. It is well known that fibres' mechanical behaviour is influenced by a large group of factors, such as age, climate, growing conditions, processing techniques, just to name a few [6], and this mutability has a high impact on natural fibres.

The objective of this study is to construct probabilistic models for natural fibres-based products used in composite materials, starting from experimental observations made on the capacities of hemp ropes with lengths of 50 and 200 mm. This type of ropes has been successfully used in recent civil engineering applications to reinforce masonry structures, such as arches and vaults [7-10]. A stationary random field $R(x)$ with $0 \leq x \leq l$ is used for rope capacity of length l , whose correlation and marginal distribution functions are fitted to the previously cited experimental observations. It is found that experimental and synthetic data are consistent and additional experiments on ropes longer than 200 mm need to be performed to assure that $R(x)$ provides a realistic representation of hemp ropes capacity.

References

- [1] Grigoriu M., "Stochastic mechanics", International Journal of Solids and Structures, 37, 197-214, (2000).
- [2] Torquato S., "Random Heterogeneous Materials: Microstructure and Macroscopic Properties", Applied Mechanics Reviews, 55, (2002).
- [3] Archana D.P., Jagannatha Reddy H. N., Prabhakara R., Aswath M. U., Chandrashekar A., "Processing and Properties of Biodegradable Composites to Strengthen Structures", Journal of The Institution of Engineers (India): Series C, 103, 39-52, (2022).
- [4] Ahmad J., Yu T., Muhammad N. S., "Effect of Natural Fiber Reinforced Polymer Confinement on Axial Compressive Strength of Concrete", Lectures Notes in Civil Engineering, 278, 131-137, (2023).
- [5] Selvan S.T., Mohandass M., Kousic M., "Study the mechanical properties of natural fiber of jute and kenaf in polymer composites" in Proceedings of Conference ICAMM, Chennai, (2021).
- [6] Schledjewski R., Medina L., Schlarb A. K., "Mechanical and morphological characterization of selected natural fibres", Advanced Composites Letters, 15, (2006).

- [6] Schledjewski R., Medina L., Schlarb A. K., "Mechanical and morphological characterization of selected natural fibres", *Advanced Composites Letters*, 15, (2006).
- [7] Gioffré M., Navarra G., Cavalagli N., Lo Iacono F., Gusella V., Pepi C., "Effect of hemp bio composite strengthening on masonry barrel vaults damage", *Construction and Building Materials*, 367, (2023).
- [8] Formisano A., Vaiano G., Petrucci N. J., "Hemp-FRP for Seismic Retrofitting of existing masonry buildings", *Lectures Notes in Civil Engineering*, 209, 402-417, (2022).
- [9] Gioffré M., Vincenzini A., Cavalagli N., Gusella V., Caponero M.A., Terenzi A., Pepi C., "A novel hemp-fiber biocomposite material for strengthening of arched structures: experimental investigation", *Construction and Building Materials*, 308, (2021).
- [10] Abdulla K. F., Cunningham L. S., Gillie M., "Out-of-plane strengthening of adobe masonry using hemp fibre ropes: an experimental investigation", *Engineering Structures*, 245, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Integer- and non-integer-order filter approximations for determining the stochastic response of wind-excited structural systems

Authors: Luca Roncallo^{*1}, Ilias Mavromatis², Ioannis A. Kouglioumtzoglou³, Federica Tubino⁴

¹*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy, luca.roncallo@edu.unige.it*

²*Department of Civil Engineering & Engineering Mechanics, Columbia University, New York City, New York (US), im2580@columbia.edu*

³*Department of Civil Engineering & Engineering Mechanics, Columbia University, New York City, New York (US), iak2115@columbia.edu*

⁴*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy, federica.tubino@unige.it*

Keywords: Wind engineering; stochastic dynamics; fractional derivative; filter approximation

Abstract

A filter approach is developed for approximating wind excitation power spectra and for determining efficiently the stochastic response of linear structural systems. Specifically, first, an integer-order filter model is employed for approximating a commonly used atmospheric turbulence power spectrum [1]. Next, it is shown that the integer-order filter approximation enables the analytical evaluation of pertinent random vibration integrals for determining in closed-form the response statistics of a linear oscillator subjected to the atmospheric turbulence power spectrum; see also [2-3] for some indicative relevant applications. Further, a non-integer-order filter model is also used for approximating the atmospheric turbulence power spectrum. It is shown that this model exhibits a higher degree of accuracy in approximating the power spectrum in the frequency domain compared to the integer-order filter. Furthermore, it allows for approximate analytical calculation of linear oscillator response statistics based on an appropriate state-variable formulation [4-5].

References

- [1] Solari G., Piccardo G., "Probabilistic 3-D turbulence modeling for gust buffeting of structures, Probabilistic Engineering Mechanics", Vol 16, page 73-86, (2001).
- [2] Spanos P. D., "Filter approaches to wave kinematics approximation", Applied Ocean Research, Vol 8, Pages 2-7, (1986).
- [3] Spanos P. D., Sun Y., Su N., "Advantages of Filter Approaches for the Determination of Wind-Induced Response of Large-Span Roof Structures", Journal of Engineering Mechanics, Vol. 143, 04017066, (2017).
- [4] Di Paola M., Pinnola F. P., Spanos. P. D., "Analysis of multi-degree-of-freedom systems with fractional derivative elements of rational order", in Proceedings of the ICFDA'14 International Conference on Fractional Differentiation and Its Applications, Catania, Italy, 23-25 June 2014, pages 1-6, (2014).
- [5] Pirrotta A., Kouglioumtzoglou I. A., Di Matteo A., Fragkoulis V., Pantelous A., Adam C., "Deterministic and random vibration of linear systems with singular parameter matrices and fractional derivative terms", ASCE Journal of Engineering Mechanics, vol. 147 (6), 04021031: 1-12, (2021).

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Palermo, Italy, August 27 - 30, 2023

Title: An adaptive Kriging-based approach for random vibration analysis of the freight wagon–turnout system

Author(s): Jun Lai^{1,2,3}, Yan Shi^{3,4,5}, Jingmang Xu^{1,2}, Ping Wang^{1,2}, Micheal Beer^{3,6,7}

¹ Key Laboratory of High-speed Railway Engineering Ministry of Education, Southwest Jiaotong University, Chengdu, 610031, China

² School of Civil Engineering, Southwest Jiaotong University, Chengdu, 610031, China

³ Institute for Risk and Reliability, Leibniz Universität Hannover, Callinstr. 34, Hannover, 30167, Germany

⁴ School of Mechanical and Electrical Engineering, University Electronic Science and Technology of China, Chengdu 611731, China

⁵ Center for System Reliability and Safety, University Electronic Science and Technology of China, Chengdu 611731, China

⁶ Institute for Risk and Reliability, University of Liverpool, Liverpool L69 7ZF, United Kingdom

⁷ International Joint Research Center for Resilient Infrastructure & International Joint Research Center for Engineering Reliability and Stochastic Mechanics, Tongji University, Shanghai 200092, China

Keyword(s): Freight wagon-turnout system, adaptive Kriging model, derailment assessment, reliability, random variables

Abstract

Railway turnouts (RTs) allow trains to switch from one track to another, enabling efficient use of rail infrastructure and enhancing the flexibility of the rail network. From field investigations of train derailments in recent years, it has become apparent that both the service condition of freight wagons and turnouts have significant impacts on the dynamic running safety of freight wagons passing through RTs. Although the random finite element and multibody coupled dynamic simulation method can be employed to measure uncertainty in rail vehicle and track parameters in the reliability analysis of the freight wagon-turnout system (FWTS), they generally require significant model evaluations and huge computational costs. With this consideration, this work presents an adaptive Kriging-based approach for analyzing random vibration of the FWTS. Firstly, two typical performance functions are established to assess the risk of wheel climbing and wheel jumping in the turnout area, respectively. Then, an initial Kriging surrogate model is constructed based on the geometric information of the freight wagon-turnout model and the corresponding dynamic responses, in which a 3-D finite element and multibody coupled dynamic model of the FWTS are established and solved with Simpack software so to obtain the dynamic responses of the wheel-rail coefficient and wheel load reduction rate. The effectiveness of the proposed freight wagon-turnout dynamic interaction model is verified by the field test data of wheel-rail contact forces. After that, an efficient learning function is used to identify new samples within the candidate sample set in order to improve the accuracy of the current surrogate model until a desirable level of predictive accuracy is achieved. The automatic repetitive operation is implemented by writing scripts to call each instruction of the Simpack pre-processor, solver and post-processor repeatedly. Finally, the final surrogate model is used to predict the maximum dynamic response and derailment probability of the FWTS, and statistical analysis is further performed on the dynamic response of the FWTS. The prediction accuracy of the adaptive surrogate model for the random characteristics during freight wagon passing over the RTs is evaluated. The proposed method can significantly reduce the number of finite element and multibody coupled dynamic analysis and obtain accurate results in reliability analysis of FWTS considering the uncertainty of parameters of railway vehicles and turnouts.

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Stick-slip and Fully-stuck motion regimes: can frictional nonlinearity enhance damage detection?

Giancarlo Santamato^{*1,2}, Massimiliano Solazzi^{1,2}, Antonio Frisoli^{1,2}.

¹Institute of Mechanical Intelligence, Scuola Superiore Sant'Anna, Pisa, Italy, giancarlo.santamato@santannapisa.it

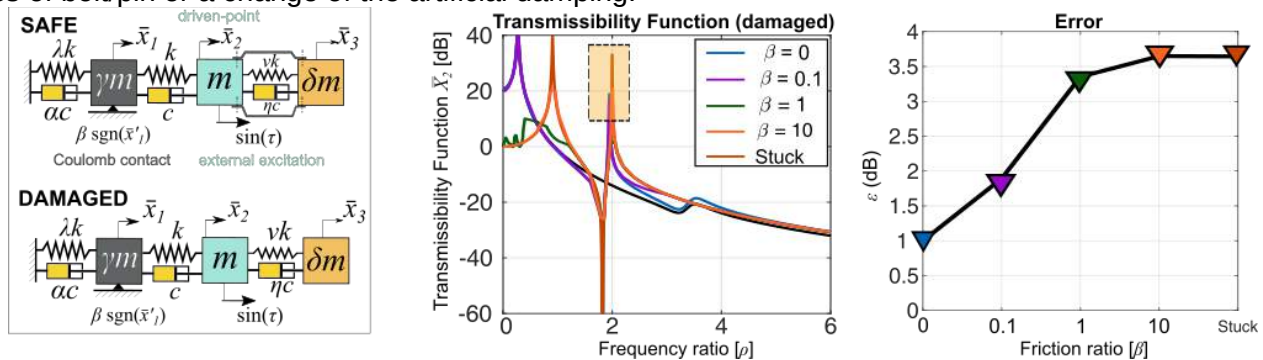
²Department of Excellence in Robotics and AI, Scuola Superiore Sant'Anna, Pisa, Italy

Keywords: stick-slip transition, dry-friction, damage detection

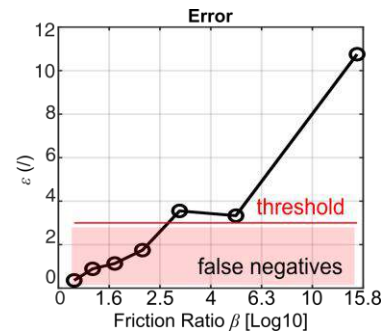
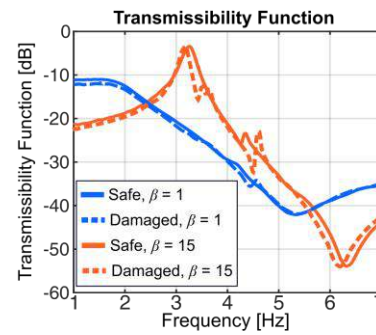
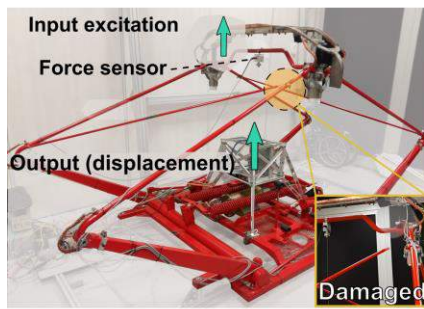
Abstract

Previous research studied the dynamics of frictional oscillators under external excitation to show that at each frequency stick-slip or fully-stuck regimes can occur depending on the ratio of the friction threshold over the excitation amplitude (friction ratio β) [1], [2]. Still, it lacks a focus on how these motion regimes can affect damage detection.

In this paper, we investigate the effects of a low or a high friction ratio on the damage feature extracted from structural health tests. To this end, we adopted a MDOF model with harmonic excitation at a single driven-point and a single Coulomb contact to simulate structural dynamics test on a general structure in the presence of dry friction. We assumed as the damage signature the average error on the transmissibility function at the driven-point. We refer to a frictionless ($\beta = 0$) and a fully-stuck configuration as auxiliary linear systems that resemble the response of the nonlinear structure for low or high friction ratio respectively. Our research focused on global modes behavior that falls at low frequencies (1 - 10 Hz). Consequently, the damage is represented by main faults, like a loss of bolt/pin or a change of the artificial damping.



It turns out that no optimal friction ratio exists for any frequency and any kind of damage. Indeed, for a given damage scenario, changing the location of the contact mass/driven-point modifies the impact of the friction ratio. Besides, when the properties of the frictionless and the fully-stuck systems coincide in the damaged condition, varying the friction ratio has no effect on the error function. Nevertheless, when the damage signature is emphasized by the fully-stuck system, then high friction ratios reveal more convenient. Experiments were also performed on a pantograph structure for railway applications. Tests were repeated in both the safe and damaged condition for several values of the external excitation so that the friction ratio ranged a variation of one order of magnitude, from 1.15 to 15. The same damage scenarios of the model were reproduced and the trends of the error function with the friction ratio were confirmed.



What is more, the emphasis on the friction revealed relevant statistical implications. Indeed, the damage could not be detected (false negatives) for low levels of the friction ratio in the case of the loss of the bolted connection connectivity.

References

- [1] Den Hartog, J. P. "Forced vibrations with combined Coulomb and viscous friction." Transactions of the American society of mechanical engineers 53.2 (1931)
- [2] Marino, Luca, and Alice Cicirello. "Dynamic response of multi-degree-of-freedom systems with a Coulomb friction contact under harmonic excitation." Nonlinear Dynamics 106 (2021): 1675-1709.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Effect of pre-existing crack on the negative stiffness characteristics of thermally actuated bistable composite laminate

Author(s): Amar Nath Roy Chowdhury^{*1}, Suraj K Singh²

¹ Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, amarrc@iitk.ac.in

² Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, surajks@iitk.ac.in

Keyword(s): composite shells, hairline crack, thermal actuation, bi-stability, negative stiffness

Abstract

Bistable shell structures have two non-adjacent stable equilibrium configurations. When subjected to displacement-controlled transverse loading the equilibrium configuration of a bi-stable shell passes through a limit point, and beyond the limit point the external load gradually drops with increasing displacement giving rise to a negative stiffness behavior. Various functional applications such as shape morphing, energy harvesting, vibration isolation etc., harnesses the negative stiffness of bistable shell [1]. In this work, we examine the effect of pre-existing straight hairline crack on the negative stiffness and energy absorption behaviour of thermally actuated bi-stable shells. All the analyses are carried out adopting pb2 Ritz [2,3] framework in conjunction with cylindrical arc-length method to obtain the post-critical force deformation paths. Cracked plates are modelled adopting a multi-domain method [4]. In this study, 0- and 90-degree crack orientations are considered. Parametric investigations are conducted to assess the effect of crack length as well. We demonstrate that the orientation of the crack may significantly reduce limiting force, and negative stiffness of a bi-stable composite laminate.

References

- [1] Cao Y., Derakhshani M., Fang Y., Huang G., Cao C., "Bistable structures for advanced functional systems", *Advanced Functional Materials*, Vol 31, Art No. 2106231, (2021).
- [2] Lim C.W., Liew K.M., "A pb-2 Ritz formulation for flexural vibration of shallow cylindrical shells of rectangular planform", *Journal of Sound and Vibration*, Vol 173, page 343, (1994).
- [3] Roy Chowdhury A.N., Wang C.M., "Bending, buckling, and vibration of equilateral simply supported or clamped triangular plates with rounded corners", *Journal of Engineering Mechanics*, Art No 04016074, (2016).
- [4] Milazzo A., Oliveri V., "Post-buckling analysis of cracked multi-layered composite plates by pb-2 Rayleigh Ritz method", *Composite Structures*, Vol 132, page 75, (2015).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Vibrations of shells interacting with a Non-Newtonian fluid

Author(s): Francesco Pellicano*¹, Antonio Zippo¹ and Giovanni Iariccio¹

¹ *Università degli Studi di Modena e Reggio Emilia, Dip. di Ingegneria Enzo Ferrari, Centre InterMech - MO.RE.*

Keyword(s): Fluid-Structure interaction, Nonlinear Dynamics, Shells

Abstract

The interaction of fluids with structures is of interest for several engineering fields such as bio-engineering or bio-mechanics but also in Medical Science. Several examples of Fluid Structure Interaction (FSI) problems can be found in Engineering: flutter (sub and supersonic), galloping, pipes instabilities, fully or partially filled tanks, heat exchangers. The human aorta is an important example of FSI with NN fluid (blood), which is highly viscous and non-Newtonian, the artery wall is hyper-elastic. The interaction with fluids can cause several dynamic phenomena: static and dynamic instabilities; inertial effects with change of the natural frequencies and mode shapes; possible increment of damping.

The literature on FSI is mostly focused on inviscid or Newtonian fluids (compressible or incompressible). However, the Nature shows many examples of NN fluids interacting with solids and structures: blood, blood plasma, toothpaste, starch suspensions, corn starch, paint, melted butter, shampoo.

This work is focused on nonlinear dynamics of a circular cylindrical shell interacting with a Non-Newtonian fluid (NN). The shell containing the fluid is harmonically excited from the base in order to investigate the complexity of the dynamic scenario. A dilatant NN fluid is considered, it is 60% corn-starch - 40% water mixture, commonly known as oobleck. The results show an extreme complexity of the dynamic scenario.

References

- [1] Amabili M., Païdoussis M.P. (2003) Review of studies on geometrically nonlinear vibrations and dynamics of circular cylindrical shells and panels, with and without fluid–structure interaction, *Applied Mechanics Reviews* **56** 349–381.
- [2] Zippo A., Barbieri M., Iariccio G., and Pellicano, F. (2020) Nonlinear vibrations of circular cylindrical shells with thermal effects: an experimental study. *Nonlinear Dyn*; **99**: 373–391. DOI:10.1007/s11071-018-04753-1.
- [3] Pellicano, F. & Avramov, K.V. (2007) Linear and nonlinear dynamics of a circular cylindrical shell connected to a rigid disk, Comm. in Nonlin. Science and Numerical Simulation, **12(4)**, 496-518 doi:10.1016/j.cnsns.2005.04.004.
- [4] Zippo, A., Iariccio, G., Bergamini, L., Colombini, E., Veronesi, P., & Pellicano, F. (2023). Fluid–Structure interaction of a thin cylindrical shell filled with a non-newtonian fluid. *Journal of Fluids and Structures*, 117doi:10.1016/j.jfluidstructs.2022.103829

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Non-linear metamaterials for shock absorption and locomotion

Authors: Andrea Colombi^{*1}, Bao Zhao²

¹ *Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Zurich, Switzerland, Email: colombia@ethz.ch*

² *Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Zurich, Switzerland, Email: bao.zhao@ibk.baug.ethz.ch*

Keyword(s): Metamaterials, Vibrations, Non-linearity

Abstract

The insertion of non-linearities in mechanical metamaterial enables novel applications for vibration control and energy conversion. Well known resonant metamaterial designs whose linear dynamic have been thoroughly studied in the past, are being currently tweaked or integrated in complex systems to embed non-linear characteristics.

We present two examples of this trend. One attempts to extend the application of so-called inertial resonators to the field impact absorption and high acceleration values. The proposed design combines a linear host cantilever beam and periodically distributed inertia amplifiers as nonlinear local resonators. We perform both analytical and numerical simulations to reveal the geometric nonlinearity induced by the inertia amplifiers and in particular the amplitude-dependent damping. Laboratory experiments reveals the limit of the design and the influence of the fabrication and testing set-up.

The second example revisits the classic metamaterial design made of a graded array of elastic beams. In this case the nonlinearity emerges as the result of the contact between the resonators and a surface on which the metamaterial is placed. The vibration of the beams is used to generate a net propulsion force that induces the metamaterial to move. Simulations and experimental tests will show whether this can be used to actuate and propel objects.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Hysteretic Tuned Mass Damper for seismic protection: Experimental investigation and Numerical modelling

Author(s): Pranath Kumar Gourishetty^{*1,2}, Vinay Yadav Janga², Biagio Carboni², Giuseppe Quaranta², Walter Lacarbonara²

¹ Dipartimento Ingegneria Civile e Architettura, Università di Catania, Catania, Italy,
pranath.gourishetty@phd.unict.it

² Dipartimento di Ingegneria Strutturale e Geotecnica, Sapienza Università di Roma, Rome, Italy,
pranathkumar.gourishetty@uniroma1.it

Keyword(s): Hysteresis, Tuned Mass Damper, Nonlinear Dynamics

Abstract

It has been demonstrated that a hysteretic tuned mass damper (HTMD) can be very effective to improve the seismic performance of buildings subjected to seismic ground motion [1,2]. In this regard, existing studies have considered a vibration absorber that consists of mixed NiTiNOL-steel wire ropes undergoing combined tension-flexure cycles [3,4]. The concurrent interwire friction and phase transformation of the shape memory material exhibited by these composite wire ropes generate a peculiar pinched hysteretic behaviour, which turned out especially beneficial to enhance the seismic effectiveness of the vibration absorber. Unfortunately, the use of mixed wire ropes might not be cost effective in civil engineering applications. A novel HTMD has been thus devised to overcome such drawback. This innovative seismic protection device leverages on a novel clamping mechanism that allows to generate the required pinched hysteretic behaviour using conventional steel wire ropes only. Within this framework, the present study provides an exploratory investigation about three alternative configurations of the clamping mechanism. The pinched hysteresis is modelled by means of a modified Bouc-Wen model [4] and the corresponding parameters have been identified from experimental force-displacement cycles by means of a Differential Evolution algorithm. Moreover, shaking table tests have been performed on a reduced-scale building model equipped with such innovative HTMD while the corresponding numerical model has been developed into OpenSEES. Preliminary results demonstrate the seismic effectiveness of the proposed HTMD and confirm a satisfactory agreement between experimental results and numerical predictions.

References

- [1] Boccamazzo, A., Carboni, B., Quaranta, G., & Lacarbonara, W. (2020). Seismic effectiveness of hysteretic tuned mass dampers for inelastic structures. *Engineering Structures*, 216, 110591.
- [2] De Domenico, D., Quaranta, G., Ricciardi, G., & Lacarbonara, W. (2022) Optimum design of tuned mass damper with pinched hysteresis under nonstationary stochastic seismic ground motion. *Mechanical Systems and Signal Processing*, 170, 108745.
- [3] Carboni, B., & Lacarbonara, W. (2016). Nonlinear vibration absorber with pinched hysteresis: theory and experiments. *Journal of Engineering Mechanics*, 142(5), 04016023.
- [4] Carboni, B., Lacarbonara, W., & Auricchio, F. (2015). Hysteresis of multiconfiguration assemblies of nitinol and steel strands: experiments and phenomenological identification. *Journal of Engineering Mechanics*, 141(3), 04014135.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Exploiting global nonlinear dynamics of mechanical systems and structures

Author: Giuseppe Rega¹

¹ *Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy, giuseppe.rega@uniroma1.it*

Keyword(s): global dynamics, deterministic/non-deterministic systems, structural robustness/safety

Abstract

Nonlinear dynamics in mechanics and engineering has reached a level of intrinsic full maturity such as to urgently demand for its full exploitation in a wide variety of technological areas across different space and time scales. Within this general framework, global dynamics can bring significant benefits to the analysis, control and design of mechanical systems and structures, mostly in the presence of strong nonlinearities. The talk will provide an overview of some main open research issues and related challenges, dealing with the following list of items.

- Ascertaining the actual long-term dynamics of multi-field systems/structures evolving over different time scales.
- Characterizing, predicting and quantifying some main topological phenomena of global response in phase space and parameter space.
- Evaluating robustness/overall stability of mechanical/structural responses across different space scales, via systematic (dynamical integrity) or sample-based (basin stability) computational tools.
- Exploiting global concepts/phenomena for control purposes, aimed at stabilizing specific solutions or modifying overall regions of stability.
- Interpreting/predicting global safety deficiencies induced by a solely localized control, as well as theoretical vs practical mismatches of global safety originated by disturbances/uncertainties.
- Addressing actually non-deterministic global frameworks via a transfer operator approach and its algorithmic implementation, providing stochastic attractors and basins of attraction in the presence of noise and/or parameter uncertainty.
- Assessing a possibly enhanced load carrying capacity of systems and structures via a novel, global dynamics-informed, paradigm for engineering design.
- Dealing with multidimensional systems by taking advantage of ongoing advancements. (i) In nonlinear model reduction, to formulate refined reduced order models also accounting for higher-order modal interactions and exploiting the potential of global dynamics for analysis/safety purposes. (ii) Data-driven approaches, for direct computational investigation of global properties, or formulation of more comprehensive low-dimensional models.

References

- [1] Rega G., "Nonlinear dynamics in mechanics and engineering: 40 years of developments and Ali H. Nayfeh's legacy," *Nonlinear Dynamics*, 99, 11–34, (2020).
- [2] Rega G., "Nonlinear dynamics in mechanics: State of the art and expected future developments," *Journal of Computational and Nonlinear Dynamics*, 17, 080802–1-15, (2022).
- [3] Rega G., Settini V., "Global dynamics perspective on macro- to nano-mechanics," *Nonlinear Dynamics*, 103, 1259–1303, (2021).
- [4] Benedetti K.C.B., Gonçalves P.B., Lenci S., Rega G., "An operator approach to the global dynamic analysis of stochastic nonlinear systems," *Theoretical and Applied Mechanics Letters*, 100419, (2022)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Optimal Control of a Swarm of Sensors for Structural Health Monitoring

Authors: Luigi Severa^{*1}, Silvia Milana¹, Nicola Roveri¹, Antonio Culla¹, Antonio Carcaterra¹

¹ *Department of Mechanical and Aerospace Engineering, University of Rome La Sapienza, Rome, Italy, luigi.severa@uniroma1.it.*

Keywords: SHM, Empirical Mode Decomposition, Hilbert Transform, Kalman filter, LQR.

Abstract

The present work brings an element of novelty in the field of SHM related to the optimal mobility of the sensors. The prototype system consists of a flexural beam observed through a movable swarm of sensors: the major task is the best characterization, the monitoring and the early-stage damage identification of the system, via the optimal deployment of the sensors. The acquired data is processed via data fusion and identification techniques, which are based on the combination of optimal control theory, to establish the optimal motion of the sensors in respect to the damage detectability, which is inferred by Empirical Mode Decomposition [1] and Hilbert Transformation algorithms. The problem is indeed tackled in a three-steps strategy: i) the best estimate of the state of the structure is provided by a Kalman Filter, ii) the damage estimation is performed via an EMD+HT algorithm and iii) a LQR control is employed to drive the available sensors along different regions of the system in order to maximize the damage detectability. The proposed technique has been validated with numerical simulations, which shows very good performance, also in respect of existing methods [2].

References

- [1] Huang, Norden E., et al. "The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis." *Proceedings of the Royal Society of London. Series A: mathematical, physical and engineering sciences* 454.1971 (1998): 903-995.
- [2] N. Roveri, A. Carcaterra, *Damage detection in structures under traveling loads by Hilbert–Huang transform*, *Mechanical Systems and Signal Processing*, Volume 28, 2012.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Vibration of shallow arches with an edge crack

Author(s): Uğurcan Eroğlu¹, Giuseppe Ruta², Ekrem Tüfekci³.

¹ Faculty of Mechanical Engineering, İstanbul Technical University, İstanbul, Türkiye, ueroglu@itu.edu.tr

² Dept. of Structural & Geotechnical Engng., University "La Sapienza", Roma, Italy, giuseppe.ruta@uniroma1.it

³ Faculty of Mechanical Engineering, İstanbul Technical University, İstanbul, Türkiye, tufekcie@itu.edu.tr

Keyword(s): damaged structures; health monitoring; closed-form solutions; shallow arches

Abstract

In the last decades, structural identification and health monitoring based on the measurements of some global dynamic response received a great interest for technical applications. This is due on the one hand to an easier implementation of such techniques in comparison to local detection ones, and on the other hand to a remarkable sensitivity of modal quantities to damage [1, 2]. In the literature it was shown that the accuracy of the identification procedure strongly depends on the mathematical description of the structure as well as of the damage, even in laboratory conditions [3].

Even though they are widely used as structural members, the investigation of shallow arches affected by crack-like damages did not receive much attention. For these structural elements, 1D models are available, as well as some simplifications regarding their geometrical properties [4]. As for the damage model, the spring analogy proved to be effective to investigate the natural frequency variations induced by the damage [5]. It is reported in the literature that the position of the damage on the cross-section may have a strong effect on frequency variations, especially when the arch is shallow [6].

This contribution aims at examining the dependency of the natural frequencies of shallow arches on the localised damage location both along the axis of the arch and on opposite sides of the cross-sections. To this aim, we start from a direct 1D continuum model and provide the field equations for linear and free vibrations of shallow damaged arches. By Galérkin's technique, we obtain their natural frequencies in closed form, thus explicitly providing the contribution of the damage location both along the axis and on opposite sides of the section on the frequency shifts. The results will be presented also in graphs, along with thorough comments and with a view towards their possible outcomes in structural identification problems and mode transition phenomena.

References

- [1] Doebling S.W., Farrar C.R., Prime M.B., Shevitz D.W., Damage identification and health monitoring of structural and mechanical systems from changes in their vibration characteristics: a literature review, Los Alamos National Laboratory report LA-13070-MS.
- [2] Farrar C.R., Doebling S.W., Damage detection II: field applications to large structures. In: J.M.M. Silva and N.M.M. Maia (eds.), Modal analysis and testing, NATO Science Series, Kluwer Academic Publishers, Dordrecht 1999.
- [3] Eroğlu U., Tüfekci E., Exact solution based finite element formulation of cracked beams for crack detection, Int. J. Solids and Structures 96:240-253 (2016).
- [4] Antman S.S., The Theory of Rods, Springer, Berlin 1973.
- [5] Dimarogonas A.D., Vibration of cracked structures: A state of the art review, Engineering Fracture Mechanics 55(5):831–857 (1996).
- [6] Eroğlu U., Ruta G., Tüfekci E., Natural frequencies of parabolic arches with a single crack on opposite cross-section sides, J. Vibration and Control 25(7):1313–1325 (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Numerical modelling of a benchmark wind turbine blade and damage detection from experimental benchmark data

Author(s): M Mohamed Sajeer^{*1}, Aniruddha Das¹, Dhiraj Ghosh¹, Adrita Kundu¹, Suparno Mukhopadhyay¹, Satish Nagarajaiah²

¹ Department of Civil Engineering, Indian Institute of Technology Kanpur, Uttar Pradesh, India.

² Department of Civil and Environmental Engineering and Mechanical Engineering, Rice University, Texas, USA.

Keyword(s): FE model, Wind turbine blade, modal parameters, damage detection, damage localization

Abstract

The last few decades have witnessed a tremendous increase in energy demand, which call for renewable sources of power generation such as solar, wind, and wave energies. Amongst these, wind energy has remained a popular source due to its commercial viability. In this context, horizontal axis wind turbines (HAWT) are most commonly used to harness wind energy. Due to continuous operation under cyclostationary loading and/or environmental effects, the HAWT blades can undergo damage. It is needless to mention that blades are the most critical component of HAWTs, and their damage leads to catastrophic failure of the whole system. In order to assess the condition of the blades, routine health monitoring is necessary. To that extent, modal parameters are first estimated from benchmark experimental data, consisting of both healthy and damaged scenarios. It is observed from the identified modal parameters that the structure is damaged compared to the healthy experimental data. In several damage localization techniques, a high-fidelity finite element (FE) model is required. For this purpose, an FE model of the Sonkyo Windspot 3.5kW wind turbine blade is developed in ANSYS. The identified modal parameters, along with the FE model, are then utilized in a popular damage localization technique. The developed FE model is able to reasonably capture the dynamic characteristics of the experimental model, and the obtained damage locations are validated with the benchmark data. The effectiveness of strain data versus acceleration data, and their fusion, in localizing damage is also studied.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: On the Use of Bartlett and MVDR Beamformers in Damage Identification by Modal Curvature Variations

Author(s): Uğurcan Eroğlu^{*1}, Annamaria Pau²

¹*Faculty of Mechanical Engineering, İstanbul Technical University, İstanbul, Türkiye, ueroglu@itu.edu.tr*

²*Department of Structural and Geotechnical Engineering, University of Roma "La Sapienza", Roma, Italy, annamaria.pau@uniroma1.it*

Keyword(s): damage identification, modal curvature variations, beamforming algorithms

Abstract

Initially developed for radar and sonar applications, beamforming is a technique which spatially filters signals from an array of sensors in order to focus the resulting image [1]. It found many applications in different fields of engineering, from photoacoustic imaging [2] to detection of moving sound sources [3,4]. Here, the use of beamforming algorithms is extended to the solution of an inverse problem of damage identification in a beam structure, considering the source as the damage itself and the outputs as the response in terms of modal quantities provided by a set of sensors.

The use of natural frequencies in structural identification has proven to be an effective strategy, since they are global quantities which convey information about the general state of the structure. Among modal quantities, modal curvatures are proven to be less sensitive to environmental and operational conditions. However, the effect of damage on modal curvatures is localized in the proximity of damage and weakly spreads over the structure, therefore it cannot be captured unless a high density of sensors is present [5,6]. In this case, the use of beamformers can be promising due to their excellent ability to localize the source, i.e. intensity and location of the damage, also based on weak modal curvature variations. Despite that, such an approach did not receive much attention to date. To fill this gap, we investigate the performance of Bartlett and Minimum Variance Distortionless Beamformers in damage identification problems in beams, using experimental data and a numerical model. We extend our previous study [7] which used directly the modal curvatures, to the use of modal curvature variations and assess the performance of the beamformers against traditional optimization techniques.

References

- [1] Chiariotti P., Martarelli M., and Castellini P., "Acoustic beamforming for noise source localization – reviews, methodology and applications," *Mechanical Systems and Signal Processing* 120, 422–448 (2019).
- [2] Shamekhi S., Periyasamy V., Pramanik, M., Mehrmohammadi, M. Asl, B. M., "Eigenspace-based minimum variance beamformer combined with sign coherence factor: Application to linear-array photoacoustic imaging," *Ultrasonics* 108: 106174, (2020)
- [3] Howell G.P., Bradley A.J., McCormick M.A, Brown J.D., "De-Dopplerization and acoustic imaging of aircraft flyover noise measurements," *Journal of Sound and Vibration*, 105(1): 151-167 (1986).
- [4] Barsikow B., King W.F., "On removing the Doppler frequency shift from array measurements of railway noise," *Journal of Sound and Vibration*, 120(1): 190-196 (1988).
- [5] De Roeck G., Reynders E., and Anastasopoulos D., "Assessment of small damage by direct modal strain measurements," *Lecture Notes in Civil Engineering* 5, 3–16 (2018).
- [6] Ciambella J., Pau A., and Vestroni F., "Modal curvature-based damage localization in weakly damaged continuous beams," *Mechanical Systems and Signal Processing* 473 121, 171–182 (2019).
- [7] Pau A., Eroglu U., "The minimum variance distortionless response beamformer for damage identification using modal curvatures," *Materials Research Proceedings* 26: 455-460 (2023).

EMI 2023 International Conference

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SmartRail: a system for the continuous monitoring of the track geometry based on embedded arrays of fiber optic sensors

Giancarlo Santamato^{*1,2}, Lorenzo Tozzetti^{1,2}, Massimiliano Solazzi^{1,2}, Fabrizio Di Pasquale^{1,2}, Gianluca De Vita³, Mirko Ermini³, Eugenio Fedeli³, Stefano Faralli^{1,2}

¹Institute of Mechanical Intelligence, Scuola Superiore Sant'Anna, Pisa, Italy, giancarlo.santamato@santannapisa.it

²Department of Excellence in Robotics and AI, Scuola Superiore Sant'Anna, Pisa, Italy

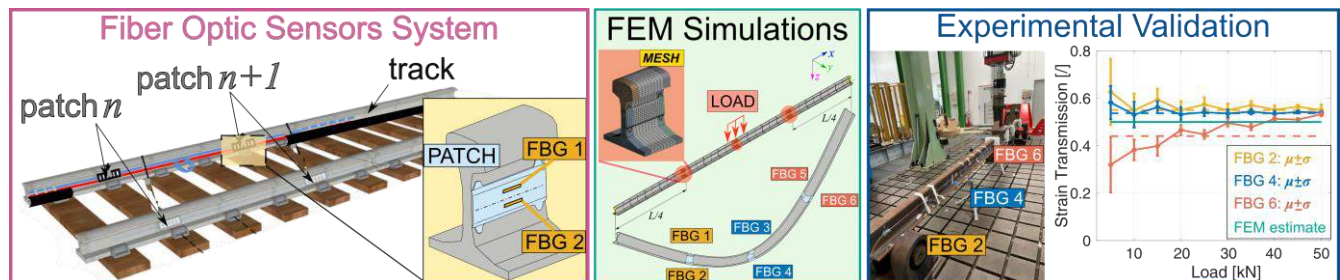
³Department of Research and Development, Rete Ferroviaria Italiana (RFI), Rome, Italy

Keywords: track defects, structural health monitoring, fiber-optic network sensors

Abstract

Nowadays, modern railway infrastructures ensure high-quality standards of track geometry. Nevertheless, enhancing the real-time monitoring of geometrical defects reveals crucial in the presence of extreme weather events and around critical areas such as bridges and viaducts [1]. At the State of the Art, several prototypes of monitoring systems have been proposed, based on arrays of fiber optic sensors installed on the railway track [2]. Still, the applicability of such prototypes requires optimization and improved robustness of the installation to preserve the fiber optic sensors from the extremely harsh environment of the railway.

In this work, we introduce the **Smart Rail**, an innovative system for the continuous monitoring of the track geometry based on embedded arrays of fiber optic sensors. We first discuss the choice of spatial sampling - the distance between FBG sensors - which represents a trade-off between the complexity of the system and the ability to sample also sharp defects in all the fields of wavelength.



Moreover, we introduce the concept of an embedded array, composed of metallic patches integrated into the rail and devoted to incorporating the sensors. In this regard, a finite element model has been formulated to simulate the mechanical interaction between the patch and the rail, which we quantify through the ratio of the patch-strain over the rail-strain (*strain transmission factor*).

Finally, we discuss the results of an experimental campaign, performed in a laboratory facility of Rete Ferroviaria Italiana, to validate the system on a rail beam of 6 m. The experimental results demonstrate the effectiveness of the Smart Rail system in accurately estimating the rail strains with low levels of noise and in good agreement with the numerical predictions.

References

- [1] EN 13848-5 – Railway applications - Track - Track geometry quality - Part 5: Geometric quality levels
- [2] Velha, Philippe, et al. "Monitoring large railways infrastructures using hybrid optical fibers sensor systems." IEEE Transactions on Intelligent Transportation Systems 21.12 (2019): 5177-5188

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Waste Feather Fibre Reinforcement for Cement-Based Materials

Author(s): Ruben Paul Borg¹, Elizabeth Spiteri Cornish^{1*}, Everaldo Attard²

¹ Faculty for the Built Environment, University of Malta, Tal-Qroqq, Msida, Malta, ruben.p.borg@um.edu.mt

² Institute of Earth Systems, University of Malta, Tal-Qroqq, Msida, Malta

Keyword(s): Chicken feather fibre, natural fibre, fibre reinforced concrete, biomaterials, biopolymers, keratin waste fibres, low-impact concrete, sustainable building materials.

Abstract

The poultry production industry is an economically important agriculture-based activity worldwide. The industry leads to the production of significant waste including large quantities of feathers with challenges associated with disposal. Keratin-rich feather fibre can be used in an innovative way as reinforcement in cement-based construction materials such as low-impact concrete addressing the principles of circular economy. Feathers have been utilised in different ways; as whole fibres, hand-cut rachis, ground fibres and a combination of both feather fibres and ground feathers. Feather fibre cement-based materials have been used for the creation of feather-board as a low-cost material which can be utilised for non-structural applications [1]. Investigations in feather fibre cement-based materials also refer to the effect on mechanical characteristics, setting time and hydration characteristics [2, 3]. The research project objective is to reutilise the biomaterial which would have otherwise reach its end-of-life stage. This study investigates the potential use of feather fibres in cement-based materials including self-compacting concrete and the effect on the fresh properties, early age characteristics and hardened properties including mechanical and durability properties. An operating procedure was developed including washing and shredding, to transform the feathers into a product ready for inclusion in concrete. The effects of different fibre lengths with varying fibre volume percentages were considered in the concrete mixes. An experimental investigation was conducted to assess the fresh properties, with reference to empirical tests and rheology. The introduction of fibres in the concrete mix led to a reduction in the workability and self-compacting characteristics. The early-stage characteristics of concrete were assessed using an environment chamber in a controlled environment. The fibre concrete was observed to influence the plastic shrinkage cracking. The restraining concrete ring tests confirmed the influence of the fibres on the strains exerted on the steel ring with varying percentage of fibres in the mix. The addition of fibres also influenced the concrete density, ultrasonic pulse velocity, compressive strength, flexural peak load and tensile splitting strength. The durability of feather-fibre concrete was assessed with reference to permeable porosity and permeability and chloride ion penetration. The inclusion of feathers as fibre reinforcement in concrete was found to have different effects on the fresh, early-stage and hardened properties of concrete, depending on fibre length and percentage volume fraction. However this research confirmed the potential of the exploitation of waste feather fibres as reinforcement in concrete supporting circularity in the agricultural and construction sectors.

References

- [1] M. N. Acda, 'Sustainable Use of Waste Chicken Feather for Durable and Low Cost Building Materials for Tropical Climates', *Sustainable Agriculture: Technology, Planning and Management*, pp. 353–366, 2009.
- [2] E. S. Ab Wahab and S. F. C. Osmi, 'Mechanical properties of concrete added with chicken rachis as reinforcement', in *Applied Mechanics and Materials*, 2012, pp. 37–41.
- [3] R. C. Mendoza, J. O. Grande, and M. N. Acda, 'Effect of Keratin Fibers on Setting and Hydration Characteristics of Portland Cement', *Journal of Natural Fibers*, vol. 18, no. 11, pp. 1801–1808, 2021.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Surface Erosion of Structured Coatings of Wind Turbine Blades: Computational Analysis

Author(s): Leon Mishnaevsky Jr.*¹, Nikesh Kuthe and Puneet Mahajan²

¹ *Department of Wind Energy, Technical University of Denmark, Department of Wind Energy, Roskilde, Denmark, lemi@dtu.dk*

² *Department of Applied Mechanics, Indian Institute of Technology, Hauz Khas, New Delhi 110016 India*

Keyword(s): wind energy; liquid impact; unit cell modelling; nanocomposites

Abstract

The objective of this paper is to explore the potential of structured, reinforced coatings to improve the erosion protection of wind turbine blades and prevent the surface degradation of wind turbine blades over a longer time. A multiscale computational model of the liquid impact of rain droplet on polymer coatings with internal structures is developed. The finite element model-based CEL (Coupled Eulerian-Lagrangian) approach combined with the sub-modeling technique allows the determination of the local stress distribution in the structured coatings. Wave reflection on particle reinforcement in coatings and stress concentration around the voids in the material were investigated in computational experiments. It is demonstrated that both fiber pulp reinforced polymer coatings and graphene particle reinforced coatings reduce stress concentration in the voids/air bubbles available in the polymer, as compared with the non-reinforced polymers. Given that the erosion of coatings is often initiated near the voids, the stress shielding effect on voids, caused by the fiber pulp or disc particles reinforcement, has a great potential to extend the lifetime and performance of anti-erosion coatings.

References

- [1] N. Kuthe, P. Mahajan, S. Ahmad and L. Mishnaevsky Jr, Engineered anti-erosion coating for wind turbine blade protection: Computational analysis, *Materials Today Communications*, Vol.31, 2022, 103362
- [2] L. Mishnaevsky Jr., C. Hasager, C. Bak, A.M. Tilg, J. I. Bech, S. Doagou Rad, S. Fæster, Leading edge erosion of wind turbine blades: Understanding, prevention and protection, *Renewable Energy* 169 (2021) 953e969
- [3] L. Mishnaevsky Jr., Root causes and mechanisms of failure of wind turbine blades: Overview, *Materials*, 2022, 15(9), 2959

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Dynamic Reliability Analysis of Large-Span Structures under Human Activities Considering the Uncertainties on Human-Structure Coupling System

Author(s): Dongjun Zeng¹, Haoqi Wang^{*2}

¹ Department of Structural Engineering, Tongji University, Shanghai, P.R. China, 2110005@tongji.edu.cn

² Department of Structural Engineering, Tongji University, Shanghai, P.R. China, 12wanghaoqi@tongji.edu.cn

Keyword(s): human-induced load, vibration serviceability, uncertainty propagation, reliability analysis

Abstract

Human activities on civil infrastructures, especially on those with light weight and large spans, generate dynamic loads on the structures and may cause unpleasant structural vibration, thus affecting the functionality of the structure or leading to panic of the crowd. Although researchers have studied human-induced vibration from many perspectives including load models, calculation methods, and criteria for serviceability evaluation, etc., there has been rare work regarding human-induced reliability analysis [1], mainly because the stochastic feature of the crowd excitation [2] considering the human-structure coupling system is still not clear [3]. In this paper, a method for uncertainty quantification and global sensitivity analysis for large-span floors under crowd excitation is proposed. Both the uncertainties from the structure and the human body are considered through an analytical model describing human-structure interaction. The Kullback–Leibler divergence indices and probability density evolution method (PDEM) are adopted for the uncertainty analysis. Dynamic properties and vibration responses of four structures with different characteristics are investigated, showing that a bouncing crowd may significantly increase the structural damping ratio and its variability, but has limited influence on structural frequency regardless of the structural characteristics. Also, the structural acceleration responses under crowd excitation are with large variability that needs to be considered in the structural vibration serviceability design in the engineering practice.

Based on the above analysis on the uncertainties, a framework to calculate crowd-induced structural vibration that considers the human-structure interaction effect is proposed [4]. The feasibility of PDEM is proved to be effective to calculate structural stochastic vibration under the bouncing crowd. The dynamic reliability of the structure is thus analysed based on the stochastic responses. Results show that the consideration of the crowd-structure interaction effect significantly affects the dynamic reliability, which is also dependent on various factors including bouncing frequency, failure criteria, limit threshold, human model parameter distribution, etc. This paper provides foundation for the performance-based vibration serviceability design of large-span structures.

References

- [1] Jia YT, Law SS, Yang N. Response and reliability analysis of a high-dimensional stochastic system. *Probabilistic Engineering Mechanics*, 2020, 61: 103077.
- [2] Tubino F, Pagnini L, Piccardo G. Uncertainty propagation in the serviceability assessment of footbridges. *Structural and Infrastructure Engineering*, 2020, 16:123-137.
- [3] Wang H, Chen J, Brownjohn JMW. Parameter identification of pedestrian's spring-mass-damper model by ground reaction force records through a particle filter approach. *Journal of Sound and Vibration*, 2017, 411: 409–421.
- [4] Zeng D, Wang H, Chen J. Dynamic reliability analysis of large-span structures under crowd bouncing excitation. *Buildings*, 2022, 12(232): 12030332.

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Title: First-passage reliability analysis of high-dimensional nonlinear systems involving randomness from both parameters and excitations

Author(s): Meng-Ze Lyu^{*1}, Jian-Bing Chen².

¹ College of Civil Engineering, Tongji University, Shanghai, China, Email address: lyumz@tongji.edu.cn

² College of Civil Engineering, Tongji University, Shanghai, China, Email address: chenjb@tongji.edu.cn

Keyword(s): first-passage reliability, high-dimensional nonlinear stochastic dynamical system, globally-evolving-based generalized density evolution equation (GE-GDEE), nonstationary non-white noise, dependent random parameter.

Abstract

The first-passage problem of high-dimensional nonlinear stochastic dynamical systems has long been a challenge in mechanics and engineering fields [1]. Both the randomness from system parameters, such as the material properties and component sizes, and external excitations, such as the earthquake ground motion or wind load, have significant effects on the dynamic behaviours of systems [2]. The globally-evolving-based generalized density evolution equation (GE-GDEE) gives the governing equation of the evolution of the transient probability density function (PDF) for a generic path-continuous response process with the random input both of parameters and excitations [3], which is a dimension-reduced partial differential equation in terms of any quantity of interest. In the present paper, a numerical method is developed for solving the first-passage dynamic reliability of high-dimensional nonlinear systems involving randomness from both parameters and excitations. For the system under consideration, the random parameters can be independent or dependent (e.g., characterized by hierarchy model or vine copulas); the stochastic excitation can be nonstationary and non-white, and modelled as the output of some linear filter to white noise. If the first-passage reliability of one response quantity of the system in a specified safe domain is of concern, the absorbing boundary processes (ABPs) of the quantity of interest and an adjoint process determined by the failure criterion can be constructed, and the GE-GDEE of the ABPs can be established. In general, the GE-GDEE is a one- or two-dimensional partial differential equation (PDE), in which the intrinsic drift coefficient is the global physical driving “force” for evolution of the PDF. It can be identified via hundreds of data points from representative deterministic dynamic analyses. The transient PDF of the ABP can be obtained by solving the GE-GDEE, and then the dynamic reliability is captured. An example is illustrated to verify the efficiency and accuracy of the proposed method.

References

- [1] Li J., Chen J.B., Stochastic Dynamics of Structure, John Wiley & Sons, Singapore (2009).
- [2] Chen J.B., Lyu M.Z., “Globally-evolving-based generalized density evolution equation for nonlinear systems involving randomness from both system parameters and excitations,” Proceedings of the Royal Society A - Mathematical Physical & Engineering Sciences, 478 (2264), 20220356, (2022).
- [3] Lyu M.Z., Chen J.B., “A unified formalism of the GE-GDEE for generic continuous responses and first-passage reliability analysis of multi-dimensional nonlinear systems subjected to non-white-noise excitations,” Structural Safety, 98, 102233, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Static analysis of steel frames with semi-rigid connections in the presence of interval uncertainties

Authors: Federica Genovese*, Alba Sofi

Department of Architecture and Territory, University "Mediterranea" of Reggio Calabria, Reggio Calabria, Italy, federica.genovese@unirc.it, alba.sofi@unirc.it

Keywords: semi-rigid connections, interval analysis, lower bound and upper bound

Abstract

The analysis and design of frame structures are commonly performed by idealizing the connections as perfectly rigid or ideally hinged. However, it is widely recognized that the actual behaviour ranges between these extreme cases, and connections can be more realistically modelled as semi-rigid or partially restrained (PR) joints (see e.g., [1]). The effect of connection flexibility can be incorporated into structural analysis by placing rotational springs at the end nodes of beams. Assuming a linear-elastic behaviour, such springs are characterized by their initial rotational stiffness. Experimental tests have shown that connection stiffness exhibits a great deal of scatter. This implies that deterministic models of semi-rigid connections may lead to misleading estimates of the actual stiffness of frame structures [2-4]. The characterization of uncertainties in connection stiffness by the classical probabilistic approach can hardly be pursued due to limited data availability. Some studies suggested the use of non-probabilistic approaches such as the interval model (see e.g., [5]) and fuzzy sets (see e.g., [6]) to deal with uncertain semi-rigid connections.

The present study addresses the non-deterministic static analysis of steel frames with semi-rigid connections by applying the interval model of uncertainty [7]. In the context of a linear-elastic analysis, the initial stiffness of semi-rigid connections as well as Young's moduli of beams and columns are modelled as interval variables. Uncertainties are incorporated into the classical matrix stiffness method by interval extension. The bounds of the interval displacements and nodal forces are estimated by applying a sensitivity-based procedure which yields accurate results as long as monotonic problems are dealt with. The accuracy of the proposed bounds is assessed by comparison with the vertex method [8].

References

- [1] Chen W.F., Kishi N., Komuro M., *Semi-Rigid Connections Handbook*, J. Ross Publishing (2011).
- [2] Sakurai S., Ellingwood B.R., Kushiya S., "Probabilistic study of the behavior of steel frames with partially restrained connections," *Engineering Structures*, 23, 1410-1417 (2001).
- [3] Hadianfard, M.A., Razani, R., "Effects of semi-rigid behavior of connections in the reliability of steel frames", *Structural Safety*, 25, 123-138 (2003).
- [4] De Domenico D., Falsone G., Laudani R., "Probability-based structural response of steel beams and frames with uncertain semi-rigid connections," *Structural Engineering and Mechanics*, 67(5), 439-455 (2018).
- [5] Tangaramvong S., Tin-Loi S., Yang C., Gao W., "Interval analysis of nonlinear frames with uncertain connection properties," *International Journal of Non-Linear Mechanics*, 86, 83-95 (2016).
- [6] de Luca di Roseto A., Palmeri A., Gibb A.G., "Performance-based seismic design of steel structures accounting for fuzziness in their joint flexibility," *Soil Dynamics and Earthquake Engineering*, 115, 799-814 (2018).
- [7] Moore R.E., Kearfott R.B., Cloud M.J., *Introduction to Interval Analysis*, SIAM, Philadelphia (2009).
- [8] Dong W., Shah H., "Vertex method for computing functions of fuzzy variables," *Fuzzy Sets and Systems*, 24, 65-78 (1987).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Inverse Uncertainty Quantification using Likelihood-free Inference for Automotive Passive Safety

Author(s): Maternus Herold^{*1,2}, Jonas Siegfried Jehle¹, Matthias Gerdts²

¹ *Research and Innovation Center, BMW Group, Munich, Germany, maternus.herold@bmw.de*

² *Department of Aerospace Engineering, Institute of Applied Mathematics and Scientific Computing, Universität der Bundeswehr München, Munich, Germany*

Keyword(s): Inverse Uncertainty Quantification, Likelihood-free, Passive Safety, Bayesian

Abstract

Inverse Uncertainty Quantification (IUQ) combines statistical inference and numerical simulations to determine variations in parameters and geometries defining real world objects or computer models.

Knowing the inputs' distributions allows to improve virtual testing by providing a systematic approach for calibrating and validating computer models, reducing the amount of hardware tests to conduct. Also, it allows to obtain sets of inputs which yield a certain observation with high likelihood, enabling optimization towards a certain target over a very complex domain.

We present a simulation-centric hierarchical Bayesian approach to IUQ for application in automotive passive safety, especially crash tests. To demonstrate the applicability of the approach, two common problems in the field of crash tests are modified to analyze the approach's performance. The proposed approach incorporates data from physical tests and computer models. Different methods for density estimation are compared and analyzed on the problems presented. Measurement errors and model discrepancies are modeled, and expert's knowledge is improved by evidence. Conditioning the posterior on anticipated values reduces the number of possible sets of inputs and provides distributions of parameters leading to the desired target values.

Due to data scarcity and computationally demanding simulations, efficient surrogate modelling is incorporated to allow for fast evaluations of a computer simulation. The sample efficiency of the approach is further increased via a sequential application of density estimation and sample selection based on information-gain.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Bayesian Updating of Overall Failure Probability Based on Gauss-Legendre Numerical Integration and Information Reuse

Author(s): Pei-Pei Li^{*1}, Matthias G.R. Faes¹, Marcos A. Valdebenito¹, Matteo Broggi²

¹ Chair for Reliability Engineering, TU Dortmund Univ., Leonhard-Euler-Straße 5, 44227 Dortmund, Germany

² Institute for Risk and Reliability, Leibniz Universität Hannover, Callinstr. 34, 30167 Hannover, Germany

Keyword(s): structural reliability analysis; overall failure probability; updating factor; information reuse; Gauss-Legendre numerical integration; Markov chain Monte Carlo simulation.

Abstract

In many cases, it is of interest to utilize the inspection data to reduce the uncertainty of the distribution parameters and thereby update the overall failure probability of the structure [1]. If the uncertainty of the distribution parameters is taken into account, the traditional failure probability turns into a function of these parameters, which is defined as the conditional probability of failure [2]. Updating the overall failure probability requires recalculating the conditional failure probabilities under different distribution parameter sample combinations, which significantly increases the high calculation cost of conventional reliability analysis, especially when multiple updates are involved. To address this issue, a few scholars recently indicated that the information obtained from previous reliability assessments can be reused by changing the probability measurement when updating structural reliability [1, 3]. However, all of these methods still need to repeatedly determine the posterior distributions/samples of uncertain distribution parameters through the Bayesian updating framework. Despite the fact that existing methods for obtaining posterior distributions have evolved significantly, they are still time-consuming in most cases. As a result, this study proposes a new effective method to directly update the overall failure probability based on inspection data. In the proposed method, an updating factor is proposed to quantify the updated information by separating the components to be updated from the reliability analysis with prior distribution, therefore, the information obtained from previous structural reliability analysis can be reused in subsequent updates. The Gauss-Legendre numerical integration [4] is used to estimate the overall failure probability of structures, from which only the representative points of the updating factor need to be recalculated, thus the need to determine the posterior distributions/samples each time of updating can be avoided. The efficacy and accuracy of the proposed method are verified using a numerical example by comparison with the results obtained from the conjugate distribution or Markov chain Monte Carlo simulations.

References

- [1] Ehre M., Papaioannou I., Willcox, K.E., Straub, D., "Conditional reliability analysis in high dimensions based on controlled mixture importance sampling and information reuse", *Computer Methods in Applied Mechanics and Engineering*, 381, 113826, 2021.
- [2] Li P.P., Lu Z.H., Zhao Y.G., "An effective and efficient method for structural reliability considering the distributional parametric uncertainty", *Applied Mathematical Modelling*, 106, 507-523, 2022.
- [3] Chen J., Wan Z., "A compatible probabilistic framework for quantification of simultaneous aleatory and epistemic uncertainty of basic parameters of structures by synthesizing the change of measure and change of random variables", *Structural Safety*, 78, 76-87, 2019.
- [4] Zhao Y.G., Lu Z.H., *Structural reliability: approaches from perspectives of statistical moments*. John Wiley & Sons, New York (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Analytical solution for non-stationary response of 1/2-order fractional linear stochastic MDOF dynamical systems

Author(s): Yi-jian Xu^{*1}, Fan Kong¹, Ren-jie Han²

¹ College of Civil Engineering, Hefei University of Technology, Hefei 230009, China,

² College of Civil Engineering, Tongji University, Shanghai 200092, China.

Keyword(s): Fractional derivatives; Laplace transform; Eigenvector expansion; Power spectral density; Stochastic excitation

Abstract

This article proposes a new analytical method for determining the non-stationary response of multi-degree-of-freedom (MDOF) systems equipped with 1/2 fractional derivative damping subjected to external stochastic excitation. The method utilizes eigenvector expansion in the state variables domain to derive a closed-form solution for the impulse response function. Additionally, the Laplace transform method is used to obtain an analytical solution for the response power spectral density (PSD). Evaluating the second-order response moment simply requires integrating the response PSD. A single-degree-of-freedom (SDOF) system subjected to stochastic excitation with different types of power spectrums is presented to demonstrate the effectiveness of this technique. The results obtained by this method show excellent agreement with Monte Carlo simulation results, indicating that it offers a valuable analytical tool for analyzing the non-stationary response of systems with fractional derivative damping under stochastic excitation.

References

- [1] Suarez L. E., Shokooh A., "An eigenvector expansion method for the solution of motion containing fractional derivatives." *Journal of Applied Mechanics*, 64(3):629-635, (1997).
- [2] Agrawal O. P., "An analytical scheme for stochastic dynamic systems containing fractional derivatives.", In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, volume 19777, pages 243–249. American Society of Mechanical Engineers, 1999
- [3] Di Paola M., Pinnola F. P., Spanos P. D., "Analysis of multi-degree-of-freedom systems with fractional derivative elements of rational order.", In *ICFDA'14 International Conference on Fractional Differentiation and Its Applications 2014* (pp. 1-6). IEEE.
- [4] Fenander A., "Modal synthesis when modeling damping by use of fractional derivatives." *AIAA journal*, 34(5):1051–1058, (1996).
- [5] Peng L. Y., Zhou X. Y., Li X. J., "Some improvements on exiting power spectral models of strong earthquake ground motion." *Journal of Beijing University of Technology*, 37:388–94, (2011).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: On the Use of Fractal Geometry for the Design of Tensegrity Braces

Author(s): Julia de Castro Motta^{*1}, Baidehi Das^{1,2}, Ada Amendola¹, Julian Rimoli³, Fernando Fraternali¹

¹*Department of Civil Engineering, University of Salerno, Fisciano (SA), Italy, jdecastromotta@unisa.it, adaamendola1@unisa.it, f.fraternali@unisa.it*

²*Department of Civil Engineering and Architecture, University of Catania, Catania, Italy, baidehi.das@phd.unict.it*

³*Samueli School of Engineering, University of California, Irvine, Irvine, CA 92697, USA, jrimoli@uci.edu*

Keyword(s): seismic design, bracing systems, tensegrity structures, fractal geometry

Abstract

This work focuses on tensegrity bracing systems aimed at forming innovative and sustainable structures of earthquake-proof buildings with energy dissipation capacity. This technology consists of lightweight and high-strength systems with re-centering capabilities formed by pretensioned cables, fixed and/or floating tubes, and a variety of tensegrity systems. The investigated braces incorporate energy dissipating cables and struts and are designed making use of parametric algorithms and fractal geometry concepts.

References

- [1] Santos, F., Benzoni, G., Fraternali, F., "Seismic performance of superelastic tensegrity braces", *Ingegneria Sismica – International Journal of Earthquake Engineering*, 36(3), 20-37, (2019).
- [2] Fraternali, F., Santos, F., "Mechanical modeling of superelastic tensegrity braces for earthquake-proof structures", *Extreme Mech Lett*, 33, 100578, (2019).
- [3] Santos, F., Caroco, C., Amendola, A., Miniaci, M., Fraternali, F., "3D tensegrity braces with superelastic response for seismic control", *Int J Multiscale Comput Eng*, 20(5), 53-64, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A multiscale approach to design of seismic metaisolators

Author(s): Valentina Adinolfi^{*1}, Saeedeh Qaderi¹, Giovanni Germano¹, Julia de Castro Motta¹, Gianmario Benzoni¹, Ada Amendola¹, Massimo Ruzzene², Fernando Fraternali¹

¹*Department of Civil Engineering, University of Salerno, Fisciano (SA), Italy, vadinolfi@unisa.it, sgghaderi@unisa.it, ggermano@unisa.it, jdecastromotta@unisa.it, gbenzoni@unisa.it, adaamendola1@unisa.it, f.fraternali@unisa.it*

²*College of Engineering and Applied Sciences, University of Colorado Boulder, massimo.ruzzene@colorado.edu*

Keyword(s): seismic isolation, nature inspired geometries, multiscale design, mechanical metamaterials

Abstract

This work investigates bio-inspired seismic isolators that protect next-generation buildings from seismic waves, through arrays of units replicating the mechanics of the human body. The design strategy of the investigated systems makes use of a form-finding procedure that leverages fractal geometry by introducing recursive subdivisions of basic modules that create smaller scale units with the same geometry. The design process involves the optimization of suitable complexity parameters, to conceive nature-inspired seismic metaisolators.

References

- [1] Fraternali, F., Singh, N., Amendola, A., Benzoni, G., Milton, G. W., *Nonlinear Dyn*, 106(4), 3147-3159 (2021), doi: 10.1007/s11071-021-06980-5.
- [2] Fraternali, F., Singh, N., Amendola, A., Benzoni, G., & Milton, G. W., *Nature* 600(7887), 10 (2021), doi:10.1038/d41586-021-03506-2.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Twisted nanobeams on rotation-driven nonlocal foundations

Author(s): Marzia Sara Vaccaro¹, Raffaele Barretta¹, Raimondo Luciano², Francesco Marotti de Sciarra¹

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, via Claudio 21, Naples, 80125, Italy. E-mail: marziasara.vaccaro@unina.it, rabarret@unina.it, marotti@unina.it*

² *Department of Engineering, University of Naples Parthenope, via Amm. F. Acton 38, Naples, 80133, Italy. E-mail: raimondo.luciano@uniparthenope.it*

Keyword(s): Integral elasticity theories; Nonlocal elastic foundations; Nanobeams.

Abstract

A wide range of nanomechanical applications concerns small-scale structures interacting with size-dependent elastic foundations [1-2]. Advanced constitutive theories of Nonlocal Continuum Mechanics can be exploited to effectively model these non-conventional phenomena, provided that the relevant structural problem is well-posed. The Eringen–Wieghardt [3,4] integral elasticity for twisted nanobeams on nonlocal foundations is improved in this work by proposing a consistent methodology leading to well-posed structural problems, thus extending the approach provided in [5]. The constitutive law relating torsional curvature and twisting interaction fields is expressed according to a stress-driven [6] spatial convolution. The interaction between beam and surrounding medium is modelled according to a novel approach, based on a spatial convolution driven by the torsional rotation field. The relevant problem, which is represented by an integro-differential formulation, is reverted into a simpler and computationally convenient differential formulation. Nonlocal continuum problems of small-scale twisted beams on rotation-driven nonlocal foundations are finally solved and discussed to show effectiveness of the proposed methodology.

References

- [1] Abdullah S.S., Hosseini-Hashemi S., Hussein N.A., Nazemnezhad R., “Temperature change effect on torsional vibration of nanorods embedded in an elastic medium using Rayleigh–Ritz method”, *Journal of the Brazilian Society of Mechanical Sciences* 42, 588, (2020).
- [2] Darban H., Luciano R., Caporale A., Basista M., “Modeling of buckling of nanobeams embedded in elastic medium by local-nonlocal stress-driven gradient elasticity theory”, *Composite Structures* 297, 115907, (2022).
- [3] Eringen A.C., “On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves”, *Journal of Applied Physics* 54, 4703–4710, (1983).
- [4] Wieghardt K., “Über den Balken auf nachgiebiger Unterlage”, *Zeitschrift für Angewandte Mathematik und Mechanik* 2, 165–184, (1922).
- [5] Barretta R., Čanadija M., Luciano R., Marotti de Sciarra F., “On the mechanics of nanobeams on nano-foundations”, *International Journal of Engineering Science* 180, 103747, (2022).
- [6] Romano G., Barretta R., “Nonlocal elasticity in nanobeams: the stress-driven integral model”, *International Journal of Engineering Science* 115, 14–27, (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Application of the surface stress-driven nonlocal theory of elasticity for the study of the bending response of FG cracked nanobeams

Author: Giuseppe Lovisi

Department of Civil Engineering, University of Salerno, Fisciano, Italy, glovisi@unisa.it

Keyword(s): Functionally graded material, cracked nanobeam, bending, stress-driven nonlocal model, surface effects

Abstract

In this study, the bending response of cracked Bernoulli-Euler functionally graded (FG) nanobeams is investigated by the stress-driven enriched model incorporating surface energy effects (SSDM) recently developed by Penna [1]. The approach represents a one-dimensional simplified method in which a discontinuity in rotation due to a crack in an internal point is modelled as a rotational spring connecting two segments into which the cracked FG nanobeam is divided [2-4]. Therefore, the governing equations and the related standard boundary conditions are derived by applying the principle of virtual work in each of the two parts of the FG nanobeam. Several results of a parametric bending analysis are presented to show the effectiveness of the proposed novel approach.

References

- [1] Penna R., Bending analysis of functionally graded nanobeams based on stress-driven nonlocal model incorporating surface energy effects, Int J Eng Sci, submitted (2023).
- [2] Freund, L. B., Herrmann, G. Dynamical fracture of a beam or plate in plane bending. J. Appl. Mech. 76-APM-15, 112 s1976d.
- [3] Valiente, A., Elices, M., Ustáriz, F. Determinación de esfuerzos y movimientos en estructuras lineales con secciones fisuradas. Anales de mecánica de la fractura vol.7 (1990).
- [4] Fernandez-Saez, J., Rubio, L., Navarro, C. Approximate calculation of the fundamental frequency for bending vibrations of cracked beams. Sound Vib. 225, 345s1999d.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Nonlinear Phenomena in Electrically Coupled MEMS Resonators

Author(s): Hassen M. Ouakad^{*1,2}, Ayman Al-Naimi³

¹ *Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Oman*
houakad@squ.edu.om

² *Mediterranean Institute of Technology, South Mediterranean University, Tunis 1053, Tunisia*

³ *Department of Mechanical Engineering, Jazan University, Jazan 45142, Saudi Arabia*

Keyword(s): MEMS; electrostatically coupled resonator; bi-stable; mode veering; mode crossing

Abstract

This work intends to introduce a novel, smart and innovative micro-sensor design consisting of two weakly electrostatically coupled initially curved-up microbeams and electrostatically excited using a single stationary electrode. The proposed design would develop certain nonlinear static and dynamic phenomena including the snap-through motion, veering and mode localization. The results shown that the device can exhibit these phenomena in the vicinity of the primary resonances of both beams. This can be useful to design a sensor that can detect two simultaneously objects due to its high sensitivity. The electrostatically coupled resonator consists of two micro-beams both initially curved-up and denoted as the upper and a lower microbeams. They are actuated by a single sidewall electrode. The beams' dimensions are listed in [1]. The sensor operational mechanism uses several nonlinear static and dynamic phenomena including snap-through, mode localization, hybridization, and veering [2]. The coupled nondimensional equations of the motion describing the transverse deflections of the two micro-beams were derived following the procedure [1]. A reduced-Order model (ROM) based on a Galerkin approximation is utilized to solve the equations of motion statically and as a function of the static voltages. Then, we realize the coupled resonator small vibrations problem by resolving the beams deflection into a static component and a dynamic component. The first three resonance frequencies were calculated using the ROM and they are corresponding to the first and second in-plane symmetric mode and the first in-plane anti-symmetric, respectively. Setting the initial curvature of the two beams to non-zero results in a static behavior consisting of two stable solutions. This is a standard characteristic of the snap-through motion. We note that the static stable deflection of the lower beam is small before and after the snap-through compared to that of the upper beam. This is true for the lower beam voltage that remains unactuated or biased. It is basically because the lower beam is curved toward the electrode which requires lower voltage to pull it down and to reach the snap-through state. Additionally, the first symmetric resonance frequency of the two beams were found to be similar at zero DC voltage. Then, the upper frequency decreases simultaneously as the voltage is increased until it reaches zero at the snap-through voltage. However, the lower beam frequency increases with the control parameter. This confirms that no veering or crossover is observed for the unactuated lower beam. In fact, this is not the case when the lower beam is biased. A veering zone is noticed as the upper static voltage approaches a threshold voltage. Furthermore, the variation of the second and third eigenvalues as a function of the upper static voltage increases is similar that of the first frequency. Indeed, we conclude that these dimensions are a suitable option to design a coupled electrostatically resonated that consists of two initially curved-up micro-beams.

References

- [1] A. Alneamy, H. Ouakad, Investigation into Mode Localization of Electrostatically Coupled Shallow Microbeams for Potential Sensing Applications. *Micromachines*, 13(7), 989, (2020).
- [2] Alcheikh, H. Ouakad, S. Mbarek, M. Younis. Crossover/veering in V-shaped MEMS resonators. *Journal of Microelectromechanical Systems*, 31(1), 74-86, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: On the effect of carbon nanotubes in Ultra-High Performance Fibers Reinforced Concrete: preliminary results.

Author: Annavirginia Lambiase^{*1}, Luciano Feo¹, Giuseppe Lovisi¹, Enzo Martinelli¹, Marco Pepe² and Rosa Penna¹

¹Department of Civil Engineering, University of Salerno, Fisciano, Italy, annlambiase@unisa.it, lfeo@unisa.it, e.martinelli@unisa.it, glovisi@unisa.it, rpenna@unisa.it

²TESIS s.r.l., 84084 Fisciano, Italy, mapepe@unisa.it

Keyword(s): Cracked-hinge approach; Experimental validation; UHPFRC; Meso-mechanical model; steel fibers; carbon nanotube

Abstract

The addition of carbon nanotubes has proven to be effective in enhancing mechanical properties and durability performance of structural concrete. More recently, the first experimental studies have investigated the behaviour of Ultra-High Performance fibers reinforced Concrete (UHPFRC) mixtures including steel fibers and the carbon nanotubes duly dispersed within their matrix.

The present paper proposed some preliminary results of numerical analyses carried out with the aim to scrutinise the effect of carbon nanotubes not only on the stress-strain behaviour of the matrix, but also on the bond interaction between the cementitious matrix and the steel fibers in Ultra-High Performance Fibers Reinforced Concrete mixtures. For this purpose, a meso-mechanical model, already formulated and adopted by the authors for interpreting the post-cracking response of ordinary UHPFRC specimens (also covering the possible effect of environmental degradation) is employed herein with the aim to investigate the effect of carbon nanotubes. Specifically, the experimental results available in the literature will be employed, on the one hand, for characterising the stress-strain relationships of the cementitious matrix, and, on the other hand, for back-calculating the bond-slip laws of steel fibers embedded within the latter. The comparisons of the obtained bond-slip laws will be considered with the aim to figure out their possible correlations with relevant parameters, such as the content of carbon nanotubes and the resulting.

EMI 2023 International Conference

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Title: Characterization of viscoelastic 3D printed metamaterials under impact loading

Author(s): Kaoutar Radi^{*1}, Lukas Morf, Dennis M. Kochmann.

¹ *ETH Zurich, 8092 Zurich Switzerland. E-mail: karadi@ethz.ch*

Keyword(s): Metamaterials, deformation, Image-Analysis, Energy absorption, 3D printing

Abstract

Three-dimensional (3D) truss-based metamaterials have been the subject of an increasing amount of studies [1, 2], owing to their impressive and tunable mechanical properties. While research on these metamaterials has largely focused on periodic assemblies, spatial variation in the structural architecture expand the design space and admit location-dependent mechanical properties. Examples include orthopedic implants [3], the soles of running shoes [4], and soft robots [5]. Due to the complex time-dependent correlation between the overall truss response and the deformation of individual beams and beam junctions, studying their mechanical multiscale behavior under dynamic loading presents a challenge. One of the most common techniques to track deformations is Digital Image Correlation (DIC) [6, 7], however tracking the time-dependent deformation of 3D-printed low-density trusses is challenging for DIC, owing to the discrepancy between typical feature sizes and the field of view of the overall truss, further difficulty in applying speckle patterns, as well as the lack of a stable bright background during testing---especially when high rates and large 3D deformation are involved. As a remedy, we present an efficient tracking method, which admits tracking the nodal displacements of points of interest (e.g., the strut junctions) in periodic and non-periodic assemblies across a range of loading rates. We use this technique to identify the time-dependent nodal displacements of different truss architectures, whose large deformation is of interest for energy absorption capabilities of truss metamaterials. The quality of results is assessed by performing multiple trackings on each truss topology, which reveals that errors are negligible for the reported range of conditions.

References

- [1] L. R. Meza, S. Das, J. R. Greer, "Strong, lightweight, and recoverable three-dimensional ceramic nanolattices", *Science* 345, 1322–1326, (2014).
- [2] J. Sun and N. M. Litchinitser, "3D Metamaterials", *Fundamentals and Applications of Nano-photonics*, 20, 25- 27, (2016).
- [3] H. M. Kolken, S. Janbaz, S. M. Leeflang, K. Lietaert, H. H. Weinans, "Rationally designed meta-implants: a combination of auxetic and conventional meta-biomaterials", *Materials Horizons* 5, 28–35, (2018)
- [4] D. J. N. Amorim, T. Nachtigall, M. B. Alonso, "Exploring mechanical meta-material structures through personalised shoe sole design", *ACM Symposium on Computational Fabrication*, 10, 1–8, (2019).
- [5] C. Laschi, M. Cianchetti, "Soft robotics: new perspectives for robot bodyware and control, *Frontiers in bioengineering and biotechnology*", 3, 120-130, (2014).
- [6] P. Bai, F. Zhu, and X. He, "Out-of-plane displacement field measurement by shearography", *Optics and Laser Technology* 73, 29 (2015).
- [7] B. Bhaduri, C. J. Tay, C. Quan, H. Niu, and M. Sjödaahl, "High-speed ESPI and related techniques: Overview and its application in the automotive industry", *Optics Communications* 284, 24-37, (2011).
- [8] B. Yuan, M. Sun, Y. Wang, L. Zhai, Q. Luo, and. Zhang, "Particle Shape Effect on Macro-and Micro Behaviors of Monodisperse Ellipsoids", *International Journal of Geomechanics* 19, 10-12, (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: An axisymmetric problem for a nano-sized material surface on a boundary of an elastic semi-space

Author(s): Anna Zemlyanova*¹

¹ *Department of Mathematics, Kansas State University, Manhattan, KS, USA, azem@ksu.edu*

Keyword(s): Steigmann-Ogden surface energy, Gurtin-Murdoch surface energy, material surface, nanoinclusion, axisymmetric problem, singular integral equations.

Abstract

A problem for a nano-sized penny-shaped material surface attached to the boundary of an elastic isotropic semi-space is considered. An axisymmetric normal traction is applied to a material surface. The surface is modeled using the Steigmann-Ogden form of surface energy. The problem is solved by using the Boussinesq potentials represented by the Hankel transforms of certain unknown functions. With the help of these functions, the problem can be reduced to a system of two singular integral equations. Two types of material surface tip boundary conditions are considered: free tip conditions and conditions with compensated surface prestress term. The numerical solution of this system is obtained by expanding each unknown function into a series based on Chebyshev polynomials. Then the approximations of the unknown functions can be obtained from a system of linear algebraic equations. Accuracy of the numerical procedure is studied. Various numerical examples for different values of the surface energy parameters are considered. It is shown that both the surface parameters and the type of tip conditions have significant influence on the behavior of the material system. This is a joint work with Lauren M. White.

EMI 2023 International Conference

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Title: Stability during fracture-like nucleation in frictional sliding

Author(s): David S. Kammer^{*1}, Gabriele Albertini², Miguel Castellano¹, Flavio Lorez¹

¹ *Institute for Building Materials (IfB), ETH Zurich, Switzerland, dkammer@ethz.ch*

² *University of Nottingham, Nottingham, UK*

Keyword(s): friction, nucleation, fracture mechanics theory

Abstract

The onset of frictional sliding between two solid bodies has been shown to follow a fracture-like process. Local sliding initiates as slowly growing slip patches, which, after reaching a critical size, become unstable and grow dynamically causing eventually global sliding. While the dynamic process presents all the characteristics of dynamic fracture and is qualitatively described by linear elastic fracture mechanics theory despite the existence of residual friction, a precise theoretical foundation for the slow nucleation process remains missing.

The critical nucleation length is commonly described by two different theories. If the entire nucleation patch is yielding [1-2], i.e. all asperities continue to weaken and residual friction is not reached anywhere, nucleation is well described by large-scale yielding which results in a stress criterion based on linear stability analysis. If most of the nucleation patch experiences residual friction, nucleation is well described by small-scale yielding and an energy criterion based on fracture mechanics theory (analog to Griffith's criterion). While these theories are applicable under well-defined initiation conditions that agree with the underlying assumptions, it remains unknown how more realistic conditions with heterogeneous interfaces nucleate? More specifically, what type of regime heterogeneous interfaces favor and how it depends on the properties of the interface.

Here, we use numerical simulations to study the nucleation process at interfaces with heterogeneous strength profiles and analyze the occurrence of the different nucleation regimes [3]. We show that depending on the amplitude and the spatial correlation length of the heterogeneous strength profile, the nucleation either occurs through a yielding-driven or a fracture-driven mechanism. Furthermore, we find that larger correlation lengths lead to an unstable transition between a yielding slip patch and a fracture-like one.

References

- [1] Albertini, G., Karrer, S., Grigoriu, M., and Kammer, D.S., "Stochastic properties of static friction", J. Mech. Phys. Solids, 147, 104242, 2021. <https://doi.org/10.1016/j.jmps.2020.104242>
- [2] Schär, S., Albertini G., and Kammer, D.S., "Nucleation of frictional sliding by coalescence of microslip", Int. J. Solids Structures, 220, 111059, 2021. <https://doi.org/10.1016/j.ijsolstr.2021.111059>
- [3] Castellano, M., Lorez, F., & Kammer, D. S. (2023). Nucleation of frictional slip: A yielding or a fracture process?. J. Mech. Phys. Solids, 105193. <https://doi.org/10.1016/j.jmps.2022.105193>

EMI 2023 International Conference

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Title: Modelling damage in adhesive joints via asymptotic methods

Author(s): Maria Letizia Raffa^{1*}, Raffaella Rizzoni², Frédéric Lebon³, Michele Serpilli⁴, Reinaldo Rodriguez-Ramos⁵

¹ Laboratoire QUARTZ, EA 7393, ISAE-Supméca, France, 93400 Saint-Ouen-sur-Seine

² Department of Engineering, University of Ferrara, Ferrara, Italy, Via Saragat 1, 44122 Ferrara

³ Aix Marseille University, CNRS, Centrale Marseille, LMA, France, 4 impasse Nikola Tesla 13453 Marseille Cedex 13

⁴ Department of Civil and Building Engineering, and Architecture, Università Politecnica delle Marche, Italy, via Brecce Bianche 10, 60131 Ancona

⁵ Facultad de Matemática y Computación, Universidad de La Habana, Cuba, San Lázaro y L, Vedado, La Habana, CP 10400

Keyword(s): bonding; damage; microcracking; asymptotic analysis

Abstract

In the last decades, structural bonding became a suitable alternative to more traditional assembly techniques, such as bolting and riveting. Within this context, the prediction of the damage behaviour of adhesive joints is crucial. To this aim, it is often useful to rely on multiscale mathematical models that enable a link to be made with experimentally observed phenomena [1]. The present work focuses on the derivation by asymptotic methods of a general imperfect interface model accounting for microcracking damage. This general law includes both hard and soft imperfect interfaces with damage. The proposed damage evolution law is consistent with continuum thermodynamics requirements and it governs the rate-dependent evolution of a scalar damage parameter as a function of mechanical loadings. Moreover, it depends on some physical parameters such as the damage viscosity and the damage activation energy, which can be identified experimentally [2]. This work shows that such an imperfect interface model can describe both ductile and quasi-brittle damage occurring in adhesive joints [3].

References

- [1] Ramalho, L. D., Campilho, R. D., Belinha, J. A. O. P., & da Silva, L. F., "Static strength prediction of adhesive joints: A review", *International Journal of Adhesion and Adhesives*, 96, 102451, (2020).
- [2] Raffa, M. L., Rizzoni, R., & Lebon, F., "Numerical Assessment of Damage Parameters for a Hard Interface Model", *Materials*, 15(15), 5370, (2022).
- [3] Raffa, M. L., Lebon, F., & Rizzoni, R., "A micromechanical model of a hard interface with micro-cracking damage", *International Journal of Mechanical Sciences*, 216, 106974, (2022).

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Non-linear analysis of quasi-brittle materials through a FEM-VEM approach

Giuseppe Giambanco¹, Marianna Puccia¹, Elio Sacco², Antonino Spada^{*1}

¹ *Engineering Department, University of Palermo, Ed. 8, 90128, Palermo, Italy.*

E-mails: giuseppe.giambanco@unipa.it, marianna.puccia@unipa.it, antonino.spada@unipa.it

² *Department of Structures for Engineering and Architecture, University of Naples Federico II, Via Claudio 21, 80125 Naples, Italy. E-mail: elio.sacco@unina.it*

Keywords: Embedded interphases, Strain localization, Quasi-brittle materials, VEM, FEM

Abstract

Among the computational strategies able to simulate crack propagation in solids, discrete crack models introduce a strong or weak discontinuity along the inter-element boundaries or inside the elements. The Augmented-FEM strategy (A-FEM) separates an element in two standard finite elements and a nonlinear interface where discontinuities localize. An advancement of A-FEM was proposed in [1] and consisted in the use of a zero-thickness interphase model (IPH) in place of the interface (ZTI), adding internal stresses and strains to the contact ones. Unlike ZTI models, IPH does not require a specific traction-displacement jump constitutive law and the constitutive laws adopted for IPH can correspond to those of bulk material.

In this work a new crack tracking algorithm is proposed, in a continuous FEM – discontinuous VEM description. VEM [2] is more flexible than standard FEM, since the element can be a polygon characterized by any number of edges, without constraints. The process starts with a discretization of the domain using standard FEM. Localization criteria and the spectral analysis of the fracture tensor built at the element level identify those elements crossed by a crack and crack orientation, respectively. Localized elements are then grouped to align localization bands into unique cracks, based on simple heuristic criteria. Substructures are therefore created, composed of virtual elements and IPHs representing discontinuities. At the global level, equilibrium is iteratively achieved by considering internal forces from substructures. These are solved in a VEM framework by imposing, as essential boundary conditions, displacements at nodes shared with the rest of the structure. Because the original element could be divided into very distorted sub-elements or non-standard elements, the VEM is more performant than the FEM. The main features of the adopted strategy are illustrated through benchmark examples.

References

- [1] Puccia M., Spada A., Giambanco G., “Finite elements with embedded interphases for strain localization in quasi-brittle materials”, *Eng. Fract. Mech.*, 277, 108956, 2023.
- [2] Artioli E., Marfia S., Sacco E., “VEM-based tracking algorithm for cohesive/frictional 2D fracture”, *Comp. Meth. Appl. Mech. Engrg.*, 365, 112956, 2020.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Numerical modeling of thermoelastic nanocomposites

Author(s): Fahmi Grine^{*1}, Ludovic Cauvin¹, Delphine Brancherie¹, Djimédo Kondo²

¹ *Université de Technologie de Compiègne, Roberval (Mechanics, energy and electricity), Centre de recherches, CS 60319, 60203 Compiègne Cedex, France, fahmi.grine@utc.fr, ludovic.cauvin@utc.fr, delphine.brancherie@utc.fr*

² *Sorbonne Universités, Institut Jean Le Rond d'Alembert, UMR 7190 CNRS-SU, F-75005, Paris, France djimedo.kondo@sorbonne-universite.fr*

Keyword(s): Nanocomposites, size effect, homogenization, finite element method, thermoelasticity.

Abstract

Nanocomposites have drawn much attention due to their excellent properties for the same reinforcement volume fraction compared to classical composites. Moreover, they can integrate multi-physical properties for multifunctional applications. Such improvement in the material properties is usually explained by the important interface surface/bulk volume ratio in the case of nanocomposites. To study such a class of materials, imperfect interfaces are usually introduced. In the case of thermoelastic materials, such a hypothesis implies discontinuities of the different thermomechanical fields. Nevertheless, the analytical solutions hold only for simple boundary conditions and for spherical or cylindrical inclusions. Therefore, numerical tools are necessary to study nanocomposite materials behavior. Restricted to the linear elasticity and using the generalized Young-Laplace equation for the interface equilibrium, a numerical strategy for nanomaterials modeling is developed in [1] using three numerical methods: interface finite element method, extended finite element and embedded finite element methods.

Focusing on thermoelasticity, the formulation derived in [2], based on the introduction of interfacial energy, is considered here. In addition, the hypothesis of continuous displacement and temperature fields holds. Using the interface finite element method, we propose in the present study a numerical tool to deal with coupled time-dependent thermoelastic behavior in the presence of imperfect interfaces. Considering a unidirectional nanofibrous composite, we show that the interface has an important influence on the thermomechanical fields and then on the effective response of the REV. Besides, a numerical homogenization scheme is used with different boundary conditions as illustrated in [3]. Taking advantage of the proposed numerical tool, the effect of the reinforcement size on the effective thermoelastic parameters is studied for different fibers shapes. It is noteworthy that even if the interface behavior is restricted to linear elasticity, all the thermoelastic parameters are dependent on the fibers cross section radius. Moreover, the qualitative effect of the reinforcement size on the material parameters depends essentially on the different interface moduli.

References

- [1] Bach, D. P. "Development of a finite element strategy for the modeling of nano-reinforced materials" (Doctoral dissertation, Université de Technologie de Compiègne), (2020).
- [2] Moeckel, G. "Thermodynamics of an interface." *Archive for Rational Mechanics and Analysis* 57.3, 255-280, (1975).
- [3] Quang, H. L., & He, Q. C. "Estimation of the effective thermoelastic moduli of fibrous nanocomposites with cylindrically anisotropic phases" *Archive of Applied Mechanics*, 79, 225-248, (2009).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Asymptotic behaviour of micro-scale adhesively bonded joints based on strain gradient elasticity

Authors: Michele Serpilli^{*1}, Raffaella Rizzoni², Frédéric Lebon³, Maria-Letizia Raffa⁴, Reinaldo Rodriguez-Ramos⁵

¹ Department of Civil and Building Engineering, and Architecture, Università Politecnica delle Marche, Ancona, Italy, m.serpilli@univpm.it

² Department of Engineering, University of Ferrara, Ferrara, Italy, raffaella.rizzoni@unife.it

³ CNRS, Centrale Marseille, Laboratoire de Mécanique et d'Acoustique, Aix Marseille Univ, CEDEX 13, 13453 Marseille, France, lebon@lma.cnrs-mrs.fr

⁴ Laboratoire QUARTZ, EA 7393, ISAE-Supméca, 93400 Saint-Ouen-sur-Seine, France, maria-letizia.raffa@isae-supmeca.fr

⁵ Facultad de Matemática y Computación, Universidad de La Habana, San Lázaro y L, Vedado, La Habana 10400, CP, Cuba, rerora2006@gmail.com

Keyword(s): adhesives; asymptotic analysis; strain gradient elasticity

Abstract

As a bonded structure scales down to the microscale, the role of the adhesive joint becomes more relevant concerning the overall performance of the microdevice. At the small scale, the microstructural and size-dependent properties of thin adhesive start to play a key role in the mechanical response of the layered assembly [1]. The present work focuses on the derivation of a soft imperfect interface law in a composite, constituted by two solids, separated by a thin adhesive layer in the framework of strain gradient elasticity. The model is obtained by means of the asymptotic methods. The contact laws, expressed in terms of the jumps and means values of the displacements, normal derivatives of the displacements, represent a formal generalization of the soft elastic interface conditions [2]. The present study reveals the stiffening behaviors of layered structures and size-dependent phenomena, typical of micro-scale structures [3].

References

- [1] Long H., Ma H., Wei Y., Liu Y., "A size-dependent model for predicting the mechanical behaviors of adhesively bonded layered structures based on strain gradient elasticity", *Int. J. Mech. Sci.*, 198, 106348, (2021).
- [2] Serpilli M., Rizzoni R., Lebon F., Dumont S., "An asymptotic derivation of a general imperfect interface law for linear multiphysics composites", *Int. J. Solids Struct.*, 180-181, 97-107 (2019).
- [3] Serpilli M., Rizzoni R., Rodriguez-Ramos R., Lebon F., Dumont S., "A novel form of imperfect contact laws in flexoelectricity", *Composite Structures*, 300, 116059 (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Concentration tensors in micropolar periodic laminates with imperfect interfaces

Author(s): Raffaella Rizzoni¹, Michele Serpilli², Reinaldo Rodriguez-Ramos³, Frédéric Lebon⁴, Yoanh Espinosa-Almeyda⁵, Maria Letizia Raffa⁶

¹ *Department of Engineering, University of Ferrara, Ferrara, Italy, Via Saragat 1, 44122 Ferrara,*

² *Department of Civil and Building Engineering, and Architecture, Università Politecnica delle Marche, Italy, via Brecce Bianche 10, 60131 Ancona*

³ *Facultad de Matemática y Computación, Universidad de La Habana, Cuba, San Lázaro y L, Vedado, La Habana, CP 10400*

⁴ *Aix Marseille University, CNRS, Centrale Marseille, LMA, France, 4 impasse Nikola Tesla 13453 Marseille Cedex 13*

⁵ *Instituto de Ingeniería y Tecnología, Universidad Autónoma de Ciudad Juárez, Mexico, Av. Del Charro 450 Norte Cd. Juárez, Chihuahua, CP 32310*

⁶ *Laboratoire QUARTZ, EA 7393, ISAE-Supméca, France, 93400 Saint-Ouen-sur-Seine*

Keyword(s): micropolar media; periodic laminate; spring-type interface; surface partition; concentration tensor.

Abstract

Homogenization theory has been recently applied within the framework of three-dimensional linear micropolar media to compute the effective engineering moduli for a laminated micropolar elastic composite with centre-symmetric isotropic layers and imperfect (spring-type) contact between them [1, 2]. The contact between the layers is characterized by a non-uniform distribution of imperfections, given by a surface periodic partitioning with different imperfection parameters and cell lengths. The microstructural imperfection affects the engineering constants related to the stiffness and torque. In this work, we calculate the concentration tensors linking the macroscopic averaged quantities (stress and strain) with their microscopic counterparts. Examples are proposed, revealing the influence of material constants and microstructural parameters.

References

[1] Y. Espinosa-Almeyda, V. Yanes, R. Rodríguez-Ramos, J.A. Otero, C.F. Sánchez-Valdés, H. Camacho-Montes, P.P. Longoria, F.J. Sabina, "Effect of imperfect interface on the effective properties of elastic micropolar multilaminated nanostructures" *Z Angew Math Mech.* 00, e202200368 (2023).

[2] R. Rodríguez-Ramos, V. Yanes, Y. Espinosa-Almeyda, C. F. Sánchez-Valdés, F. Lebon, R. Rizzoni, M. Serpilli, S. Dumont, F. J. Sabina "Effective engineering constants for micropolar composites with imperfect contact conditions" submitted to *Advanced Structured Materials*.

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Monitoring of trees in urban areas for the assessment of the global stability and the evaluation of the efficacy of safeguard interventions

Andrea Santacroce¹, Raffaella Franceschini², Ernesto Grande^{*3}

¹ Department of Engineering Science, University Guglielmo Marconi, Rome, Italy, a.santacroce@unimarconi.it

² Department of Engineering Science, University Guglielmo Marconi, Rome, Italy, r.franceschini@unimarconi.it

³ Department of Engineering Science, University Guglielmo Marconi, Rome, Italy, e.grande@unimarconi.it

Keyword(s): Pulling Test; Dynamic Test; Trees stability assessment; roots consolidation

Abstract

The studies available in literature testify the attention of the Scientific Community toward the safeguard of trees in urban areas (Reubens et al. 2007; Ow et al. 2010; Abbas et al. 2020). Procedures based on visual inspections and, also, on the use of modern instruments for measuring the complex dynamic behaviour of trees under wind actions, are nowadays available (Baker and Bell 1992). Among these, the static pulling test (Krišāns et al. 2022), where the monitoring of the tilt angle of the root collar is carrying out by applying a concentrate force to the trunk, and the dynamic test (DynaRoot system (Fakopp Ltd.)), where wind actions are instead directly accounted for measuring the root movements, are the most used ones.

The paper here presented is part of a research activity concerning the monitoring of trees in urban and archaeological areas. Here, in particular, the attention is focused to static and dynamic monitoring techniques for assessing the level of safety of trees in terms of global stability and, moreover, to evaluate the efficacy of intervention solutions devoted to improve the level of anchorage of the root system toward wind actions.

A case study concerning the monitoring of a group of *Stone pine (Umbrella pine)* trees (*Pinus pinea*) located in an archaeological zone of the city of Rome is presented in the paper. The results obtained from static pulling-test and dynamic tests, both carried out before and after introducing innovative safeguard interventions at the root level, are presented in detail and compared among them.

References

- Abbas S, Kwok CYT, Hui KKW, Li H, Chin DCW, Ju S, Heo J, Wong MS (2020) Tree tilt monitoring in rural and urban landscapes of Hong Kong using smart sensing technology. *Trees, For People* 2:100030.
<https://doi.org/https://doi.org/10.1016/j.tfp.2020.100030>
- Baker CJ, Bell HJ (1992) The aerodynamics of urban trees. *J Wind Eng Ind Aerodyn* 44(1):2655–2666.
[https://doi.org/https://doi.org/10.1016/0167-6105\(92\)90057-H](https://doi.org/https://doi.org/10.1016/0167-6105(92)90057-H)
- Fakopp Ltd. DynaRoot Dynamic Root Evaluation System, User's manual
- Krišāns O, Čakša L, Matisons R, Rust S, Elferts D, Seipulis A, Jansons Ā (2022) A Static Pulling Test Is a Suitable Method for Comparison of the Loading Resistance of Silver Birch (*Betula pendula* Roth.) between Urban and Peri-Urban Forests. *Forests* 13
- Ow LF, Harnas FR, Indrawan IGB, Sahadewa A, Sim EK, Rahardjo H, Leong EC, Fong YK, Tan PY (2010) Tree-pulling experiment: an analysis into the mechanical stability of rain trees. *Trees* 24(6):1007–1015.
<https://doi.org/10.1007/s00468-010-0470-5>
- Reubens B, Poesen J, Danjon F, Geudens G, Muys B (2007) The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. *Trees* 21(4):385–402.
<https://doi.org/10.1007/s00468-007-0132-4>

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Title: Output-only tree dynamic experimental investigation

Author(s): Giacomo Zini¹, Gianni Bartoli¹, Michele Betti¹, Francesco Clementi², Luca Facchini¹, Francesco Ferrini³, Andrea Giachetti¹, Ernesto Grande⁴

¹ *Department of Civil and Environmental Engineering, University of Florence, Firenze, Italy, (giacomo.zini, gianni.bartoli, michele.betti, luca.facchini, andrea.giachetti)@unifi.it*

² *Department of Civil and Building Engineering and Architecture, Polytechnic University of Marche, Ancona, Italy, francesco.clementi@staff.univpm.it*

³ *Department of Agriculture, Food, Environment and Forestry, University of Florence, Firenze, Italy, francesco.ferrini@unifi.it*

⁴ *Department of Engineering Science, University Guglielmo Marconi, Roma, Italy, e.grande@unimarconi.it*

Keyword(s): Structural Health Monitoring (SHM); Ambient Vibration Tests (AVTs), Tree Dynamics, Environmental Effects.

Abstract

The load-bearing capacity and stability of a tree depend on several factors, among which: size and shape of the trunk, material properties of the wood (modulus of elastic and strength), root-soil mechanical interaction, etc. As the tree grows, the trunk grows and branches and roots increase in diameter and architecture thus expecting that its load-bearing capacity together with global stability increase. At the same time, the growth of trees may be accompanied by a decay of stiffness and strength of the wood and anchoring capacity of roots with a consequent reduction of its load-bearing capacity and stability.

By using an engineering approach, since the tree can be modelled as an evolutionary mechanical system, useful information about its load-bearing capacity can be obtained by monitoring its dynamic properties over time (e.g. trunk and branches structural frequencies). Moving in this direction, however, there is still a lack of experimental data that allow to correlate the physical-mechanical decay of wood stiffness and strength of the tree with the changes of its dynamic properties.

This paper aims to contribute to cover this issue by reporting the results of three-days continuous monitoring performed on a tree over two periods (March 2-4 and June 2-4, 2023). In the first period the tree had no leaves, while in the second period it had leaves. To perform the experimental tests, 8 seismic high-sensitivity accelerometers were employed and acceleration time histories of selected sections of the tree under ambient vibration were recorded. In particular the collar, the diameter at breast height, and the tree fork of the trunk were monitored in order to obtain lateral and torsional vibration modes. The results confirm that it is possible to identify main frequency of the tree under ambient vibration and report variation of main frequency over the measurement period.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Rapid Assessment of Serviceability Requirements for Buildings under Geothermally Induced Micro-seismic Events

Author(s): Aditi Kumawat*¹, Francesca Taddei¹, Gerhard Müller¹

¹ *Chair of Structural Mechanics, Technical University of Munich, Munich, Germany, Aditi.kumawat@tum.de*

Keyword(s): Serviceability, Geothermal energy, Finite element model, Lumped-parameter model

Abstract

An approach to modeling buildings is presented in this paper by combining frequency-dependent lumped-parameter and finite element models. The objective is to create a more accurate and efficient representation of building behavior by leveraging the strengths of each model. The substructure, including the foundation and underlying soil, is modeled using a frequency-dependent lumped-parameter model, which captures the complex dynamic behavior resulting from soil-structure interaction. In contrast, the superstructure, comprising the above-ground portion of the building, is modeled using the finite element model to provide a detailed representation of geometry, material properties, and boundary conditions.

The hybrid FEM-LPM building model is utilized in this paper to evaluate the building's response to input excitations, explicitly focusing on free-field vibrations caused by geothermally induced earthquakes. The intricate interplay between the input excitations and the structural behavior of the building is investigated using frequency domain transfer functions evaluated at various locations within the building model. To comprehensively assess the building's response, several factors influencing the transfer functions are examined in this paper, including:

- (a) Variation of soil parameters, which can impact the behavior of the substructure and the overall system response.
- (b) Geometric variation, considering the effects of slab size and non-uniformity on the building's performance.
- (c) Structural stiffness, analyzing the influence of introducing walls on the building's ability to withstand external excitations.
- (d) Material parameters and damping, accounting for the inherent properties of the construction materials and their contribution to the overall response.

A parametric study of the building's response under induced seismicity due to variation of these factors and their interaction is presented in this paper. The comfort criteria in low- and mid-rise residential buildings are also examined using the derived transfer functions and incorporating existing free-field data from seismic events. The findings contribute valuable knowledge to the field of structural design in terms of serviceability requirements.

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Integrated 3D-Printed components for monitoring cultural heritage

Michele Arturo Caponero¹, Ernesto Grande^{2*}, Maura Imbimbo³, Valentina Tomei⁴

¹*Centro Ricerche Frascati, ENEA, Frascati RM; Italy, michele.caponero@enea.it*

²*Dipartimento di Scienze Ingegneristiche, Università degli Studi Guglielmo Marconi, Roma, Italia, e.grande@unimarconi.it*

³*Dipartimento di Ingegneria Civile e Meccanica, Università di cassino e del lazio meridionale, Cassino, Italia, v.tomei@unicas.it*

⁴*Dipartimento di Ingegneria Civile e Meccanica, Università di cassino e del lazio meridionale, Cassino, Italia, mimbimbo@unicas.it*

Keyword(s): Structural Monitoring; 3D Printing; fibre optic sensors; tensile tests

Abstract

Nowadays the monitoring of existing structures is a topic of particular relevance, mainly in the context of preservation of cultural heritage [1, 2]. Innovative, non-invasive and efficient modern instruments allow for obtaining detailed information regarding the behaviour of structures toward service and exceptional load conditions, useful for identifying structural deficiencies and, then, to prevent severe damages and collapses [3, 4]. In case of historical structures, the invasiveness of the installation of monitoring instruments could represent a serious obstacle, particularly in case of long-term monitoring. In this paper it is presented an innovative *integrated system* for the monitoring of historical structures based on the use of fibre optic sensors embedded into elements reproducing the shape of missing parts of damaged structures obtained throughout the 3D printing technique [5]. The 3D printed element incorporating the sensors results an integrated component of the structure (but preserving its recognizability and removability) by allowing long-term monitoring or monitoring activities carried out at specific time periods. In the paper are outlined the activities specifically concerning the assessment of the test setup carried out for including fibre optic sensors into the element during the 3D printing process and, moreover, preliminary experimental tests devoted to validate the reliability of the *integrated system*. The outcomes emerged from both activities represent a valuable basis for the application of this type of integrated system to real cases, a further step of the research activity.

References

- [1] Caponero M.A., Grande E., Imbimbo M., Modoni G., Mongelli M., Polito E., "Structural health monitoring of the Ninfeo Ponari by combined use of fibre optic sensors, photogrammetry and laser scanning" in Proceedings of 2019 IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage, MetroArchaeo, Florence (Italy), December, 4-6, page 229–233, (2019).
- [2] Caponero M.A., Mongelli M., Imbimbo M., Modoni G., Polito E., Grande E. "Structural monitoring of the Ninfeo Ponari by fibre optic sensors, photogrammetry and laser scanning", *Archeol e Calc*, 223–232, (2021).
- [3] Grande E., Imbimbo M., "A multi-stage approach for damage detection in structural systems based on flexibility", *Mech Syst Signal Process*, 76–77, 455–475, (2016).
- [4] Grande E., Imbimbo M., "A multi-stage data-fusion procedure for damage detection of linear systems based on modal strain energy", *J Civ Struct Heal Monit*, 4(2), 107–118, (2014).
- [5] Caponero M.A., D'Amato R., Graziani A., Marfia S., Monaldo E., Imbimbo M., Nitiffi R., Tomei V., Grande E., "3D-printing for Cultural Heritage. Structural Recovery and Monitoring Applications of Architectural and Decorative Elements", in Proceedings of International Conference on Cultural Heritage and New Technologies, Vienna (Austria), November, 10-12, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A novel mode shape identification approach for operation modal analysis of structures

Authors: Domenico Camassa^{*1}, Anna Castellano², Aguinardo Fraddosio³, Mario Daniele Piccioni⁴

¹ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, domenico.camassa@poliba.it

² Department of Mechanics, Mathematics and Management, Polytechnic University of Bari, Bari, Italy, anna.castellano@poliba.it

³ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, aguinaldo.fraddosio@poliba.it

⁴ Department of Civil Engineering Sciences and Architecture, Polytechnic University of Bari, Bari, Italy, mariodaniele.piccioni@poliba.it

Keywords: operational modal analysis, modal testing, dynamic identification, mode shapes

Abstract

Mode shapes of structures provide valuable information for structural assessment and structural analysis. Their identification is based on the measurement of structural dynamic response at several Degrees Of Freedoms (DOFs). In practical applications, the number of sensors is limited, so it is usually necessary to perform different acquisitions to cover all the DOFs of interest. Operational Modal Analysis (OMA) only provides unscaled mode shapes and leaves the scaling factors unknown; therefore, suitable merging techniques should be employed in OMA to assemble partial mode shapes obtained from different acquisitions [1]-[3]. These techniques typically require that during acquisitions one group of sensors (reference sensors) be kept fixed at some points and the other sensors (roving sensors) be moved to cover all the DOFs of interest. Partial mode shapes are then assembled by scaling the different datasets with respect to the overlapping DOFs.

In this work, we propose a novel mode shape identification approach that can be effectively applied to structures that satisfy specific kinematic assumptions. Here, we first show that, for such structures, mode shapes can be decomposed into two components. One of the two components depends on the scaling factors of mode shapes, while the other turns out to be independent on it. In view of such decomposition, we then propose a method to identify the two components of a mode shapes from vibration measurements. In particular, we show that the independent component is able to catch the main features of mode shapes and to provide a deeper insight on the interpretation of mode shapes. Moreover, contrary to the dependent component, the independent component can be identified from datasets having no overlapping DOFs. These features make our approach more efficient than classical mode shape identification and merging techniques. The approach has been validated through numerical simulations.

References

- [1] Brincker R., Ventura C.E., Introduction to Operational Modal Analysis, Wiley (2015).
- [2] Rainieri C., Fabbrocino G., Operational Modal Analysis of Civil Engineering Structures, Springer New York (2014)
- [3] Parloo E., Guillaume P., Cauberghes B., "Maximum likelihood identification of non-stationary operational data," Journal of Sound and Vibration, 268, 971-991 (2003)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Low-Cost Vibration Monitoring for Anomaly Detection and Localization on Masonry Towers

Author(s): Francesca Bianconi¹, Gianluca Standoli¹, Mattia Schiavoni¹, Francesco Clementi^{*1}

¹ *Dep. of Civil and Building Engineering and Architecture, Polytechnic University of Marche, Ancona, Italy, f.bianconi@pm.univpm.it, g.standoli@pm.univpm.it, m.schiavoni@pm.univpm.it, francesco.clementi@univpm.it*

Keyword(s): Ambient Vibration Tests (AVTs), Structural Health Monitoring, Environmental Effects

Abstract

Actually, it is crucial to detect and forecast the progressive degradation of structures caused by natural material decay or unexpected vibrations, such as those arising from earthquakes or explosions. However, identifying structural damage by analyzing changes in modal parameters, without being influenced by external factors such as environmental effects, can be a complex and time-consuming process [1, 2].

On the other hand, the ability to promptly determine the new behavior of a structure is crucial for protecting human lives and implementing accurate and timely improvements. Rapid response in critical situations can prevent prolonged interruptions in the functioning of a structure and enable quicker recovery, if feasible.

This paper employed methods that directly processed data [3] from a continuous monitoring system, which reduced computational workload. It eliminated the need to extract modal characteristics of the system from the acquired data and provided almost instant feedback on changes in dynamic behavior. These aspects are crucial for developing sustainable monitoring practices that are both cost-effective and timely.

References

- [1] Garcia-Macias, E., Ubertini, F. 2020. "MOVA/MOSS: Two integrated software solutions for comprehensive Structural Health Monitoring of structures." *Mechanical Systems and Signal Processing*, 143. <https://doi.org/10.1016/j.ymssp.2020.106830>.
- [2] Magalhaes, F., Cunha, A. & Caetano, E. 2012. "Vibration based structural health monitoring of an arch bridge: From automated OMA to damage detection." *Mechanical Systems and Signal Processing*, 28:212-228. <https://doi.org/10.1016/j.ymssp.2011.06.011>.
- [3] Döhler, M., Mevel, L., Hille, F. "Subspace-based damage detection under changes in the ambient excitation statistics." *Mechanical Systems and Signal Processing*, 45:207–224. <https://doi.org/10.1016/j.ymssp.2013.10.023>.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Dunes interacting with obstacles

Author(s): Willian Righi Assis^{1*}, Danilo da Silva Borges¹ and Erick Franklin¹

¹ School of Mechanical Engineering, UNICAMP – University of Campinas, Campinas, Brazil, righiassis@gmail.com

Keyword(s): dunes, obstacles, patterns, classification

Abstract

Barchans are crescentic dunes formed under unidirectional fluid flow and limited sand supply, being common in deserts, oceans, rivers, and coastal environments [1]. In nature, they can approach large obstacles, such as oil risers (subaqueous cases) or houses (in Aeolian environment). The aim of this study is to investigate how subaqueous barchans interact with obstacles whose sizes are comparable to their own. To accomplish it, we performed experiments [2] where we varied the obstacle shapes and sizes, and found that subaqueous barchans may either pass over or bypass the obstacle, with some transient behavior in some cases, or even be blocked by the obstacle. We propose a classification map in which the behavior of dunes depends on the relation between the obstacle and dune sizes, and the stokes number. Our results provide new insights into how 3D bedforms interact with static objects.

References

- [1] Bagnold, R.A., The physics of blown sand and desert dunes, William Morrow & Company, New York (1941).
- [2] Assis, W.R and Franklin, E.M., “A comprehensive picture for binary interactions of subaqueous barchans”, Geophysical Research Letters, 47, e2020GL089464 (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The cooperative nature of the motion of sets of intruders moving amid grains

Author(s): Douglas Carvalho^{*1}, Erick Franklin¹

¹ School of Mechanical Engineering, UNICAMP - University of Campinas, Campinas, Brazil, d209487@dac.unicamp.br

Keyword(s): granular materials, cooperative motion, optimal drag, pattern formation

Abstract

The movement of solid objects (intruders) in the midst of granular materials is omnipresent in nature. Some examples are the impact onto the ground of projectiles that penetrate afterward the ground (collisional regime, relatively fast) and the locomotion of animals within sand (frictional regime, relatively slow). In this communication, we investigate the motion in the frictional regime of sets of intruders in a two-dimensional granular system using discrete numerical simulations (DEM) [1]. When these objects are forced to move within the smaller grains, we observe that they tend to mutually cooperate in their movement, even when placed at relatively large distances from each other. We also observed the existence of an optimal separation between them in order to achieve a minimum drag, which can be useful for devices that stir the soil or other granular surfaces. Furthermore, depending on their initial placement in space, different final configurations (patterns) are observed, revealing an intricate nature of collaboration and grouping of these objects [1].

References

[1] Carvalho, D., Franklin, E., "Collaborative behavior of intruders moving amid grains," Physics of Fluids, Vol. 34, n. 12, page 123306, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Cratering by the impact of aggregates

Author(s): Erick Franklin^{*1}, Douglas Carvalho¹, Nicolao Lima¹

¹ School of Mechanical Engineering, UNICAMP – University of Campinas, Campinas, Brazil, erick.franklin@unicamp.br

Keyword(s): Impact crater, aggregates, morphology, projectile dynamics

Abstract

The formation of craters by impacting projectiles is ubiquitous in nature, occurring in very distinct scales: from cm-size objects with impact energies as low as 10^{-7} J (such as seeds falling on the ground) to km-size bodies with energies within 10^{16} - 10^{18} J (such as km-size asteroids impacting planets and moons), or even more. In many instances, the projectile consists of an agglomerated material and spins with respect to the target ground, but most of previous investigations, however, dealt with solid non-rotating projectiles. In this communication, we investigate the formation of craters due to spinning aggregates impacting vertically onto a bed consisting of cohesionless grains. We carried out DEM (discrete element method) simulations for different bonding stresses (within the aggregate), initial spins and velocities. For solid projectiles, we show that the crater diameter and penetration depth increase with the initial spin imposed on the projectile, and that the final rebound of the projectile is suppressed by the spin [1]. For aggregates, we show that the crater shape changes significantly as the bonding stress decreases and the initial spin increases: the crater becomes flatter, with peaks around its rim and in its center. We also show that the penetration depth of rotating aggregates varies with their angular velocity and degree of collapse, and reveal how the projectile material is distributed under the ground. These results have potential applications in geophysics and mining.

References

[1] Carvalho, D. D., Lima, N. C., Franklin, E. M., “Roles of packing fraction, microscopic friction, and projectile spin in cratering by impact”, Phys. Rev. E, DOI: 10.1103/PhysRevE.00.004900, (2023).

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Multi-scale investigation of clay behaviour related to particle structuring

Mengyu Ma^{*1}, Hakim Naoui¹, Fares Bennai¹, Mahdia Hattab¹, Pierre Yves Hicher²

¹Université de Lorraine, CNRS, Arts et Métiers ParisTech, LEM3, F-57000 Metz, France

²Ecole Centrale de Nantes, CNRS, Research Institute of Civil Engineering and Mechanics (GeM), Nantes, France

Keyword(s): Clay, multi-scale investigation, micro-mechanisms, images processing, pore orientation

Abstract

This study focuses on an experimental investigation aiming to link the local structuration of clay particles to the mechanical behaviour obtained at the macro scale of the specimen. To do this, two types of initial particle structuration of the sample were performed by sedimentation in an adequate solution creating flocculated particles or deflocculated particles. Samples thus manufactured with saturated clayey material, were submitted to oedometric loading.

Sedimentation processes of the kaolinite powder with flocculant solution provides acidic environment whereas dispersant solution provides alkaline environment. The samples were recovered when the sediment height becomes constant. During sedimentation the particles will adopt different configurations depending on the charge around generated by the solution. Flocculated specimens develop edge-to-face configuration, and finally flocs, which progressively sediment in the solution [1], whereas the dispersed specimens develop a face-to-face configuration and particles sediment individually [2].

Oedometer tests were carried out on these two kinds of sedimented specimens, at the following levels of effective stress: 120, 600, 1000 and 2000 kPa. The evolution of void ratio versus the effective vertical stress allows to analyze the compressibility and swelling properties of the specimens depending on their initial microstructure, and compared them to the mechanical behaviour reference of Biarez & Hicher (1994) [3].

Scanning Electron Microscope (SEM) observations coupled to an adapted method of 2D image processing were used to identify the micro properties of particle orientation and pore network. Mercury intrusion porosimetry (MIP) tests was performed to support the SEM observations.

References

- [1] Shakeel A., Safar Z., Ibanez M., Van Paassen L., Chassagne C. "Flocculation of clay suspensions by anionic and cationic polyelectrolytes: A systematic analysis" Minerals, Volume 10 Issue 11(2020).
- [2] Pedrotti M., Tarantino A., "An experimental investigation into the micromechanics of non-active clays" Géotechnique, Volume 68 Issue 8 (2018).
- [3] Biarez J., Hicher P.Y., "Elementary mechanics of soil behaviour: saturated remoulded soils", A.A. Balkema, Rotterdam (1994).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Granular-based continuum elasto-plastic–damage variational formulation for strain gradient solids

Authors: Luca Placidi^{*1}, Anil Misra², Francesco dell'Isola³, Emilio Barchiesi⁴, Erden Yıldızdağ³, Valerii Maksimov¹, Dmitry Timofeev³, Nurettin Yilmaz³, Abdou Kandalafi¹.

¹Università Telematica Internazionale Uninettuno, Facoltà di Ingegneria, Roma, Italy. E-mail: luca.placidi@uninettunouniversity.net, v.maksimov@students.uninettunouniversity.net, abdokandalafi@gmail.com

² University of Kansas, Lawrence, KS, USA. E-mail: amisra@ku.edu

³ Università degli studi dell'Aquila, Dipartimento di Ingegneria Civile, Edile - Architettura, Ambientale, L'Aquila, Italy. E-mail: francesco.dellisola@univaq.it, erdenyildizdag@gmail.com, dima_timofeev@mail.ru, nurettin.yilmaz@graduate.univaq.it

⁴ Università degli studi di Sassari, Dipartimento di architettura, design e urbanistica, E-mail: ebarchiesi@uniss.it

Keywords: Hysteretic cycles, hemivariational approach, thermodynamics

Abstract

This work is devoted to the presentation of a continuum theory [1,2] for materials having granular microstructure [3,4]. It accounts for tension–compression asymmetry of grain interactions and for dissipative phenomena like damage and plasticity. The continuum description is constructed by assuming expressions of elastic and dissipation energies as well as postulating a hemi-variational principle. Granular micromechanics is connected kinematically to the continuum scale through Piola's ansatz. Karush–Kuhn–Tucker (KKT)-type conditions, providing evolution equations for damage and plastic variables associated with grain–grain interactions, are derived solely from the fundamental postulates. Numerical experiments have been performed to investigate the applicability of the model. Results show: (i) damage and plastic induced anisotropy evolution including the emergence of a type of chiral behavior. (ii) formation of finite localization zones. (iii) loading–unloading histories have been considered to elucidate the material hysteretic features of the continuum. (iv) The interaction between damage and plasticity, each having an effect on the other, shows the fatigue behavior of the material. (v) A particular expression for the dissipation energy results in numerical simulations of the experimental behavior of the Ultra High Performance Concrete. (vi) Emergence of the critical state of a granular assembly has been derived with a systematic parametric analysis.

References

- [1] Navier, CL. Sur les lois de l'équilibre et du mouvement des corps solides elastiques. Memoire de l'Academie Royale de Sciences 1827; 7: 375–393.
- [2] Cauchy, A-L. Sur l'équilibre et le mouvement d'un systeme de points materiels sollicités par des forces d'attraction ou de repulsion mutuelle. Exercices de Mathematiques 1826–1830; 3: 188–212
- [3] Placidi L, Emilio Barchiesi, Anil Misra, Dmitry Timofeev (2021). Micromechanics-based elasto-plastic–damage energy formulation for strain gradient solids with granular microstructure. CONTINUUM MECHANICS AND THERMODYNAMICS, vol. 33, p. 2213-2241, ISSN: 0935-1175, doi: 10.1007/s00161-021-01023-1
- [4] Placidi L, Dmitry Timofeev, Emilio Barchiesi, Alessandro Ciallella, Anil Misra, Francesco dell'Isola (2022). Micro-mechano-morphology-informed continuum damage modeling with intrinsic 2nd gradient (pantographic) grain-grain interactions. INTERNATIONAL JOURNAL OF SOLIDS AND STRUCTURES, vol. 254-255, ISSN: 0020-7683, doi: 10.1016/j.ijsolstr.2022.111880

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Effects of Graphene Nanoplatelets on Rheological and Mechanical Properties of 3D Printed Cementitious Composites

Author(s): Ugur Kilic¹, Mahyar Ramezani², Muhammad M. Sherif³, Osman E. Ozbulut^{1*}

¹*Department of Civil and Environmental Engineering, University of Virginia, Charlottesville, VA, USA*

²*Department of Civil Engineering, New Mexico State University, Las Cruces, NM, USA*

³*Department of Civil, Construction, and Environmental Engineering, School of Engineering, University of Alabama at Birmingham, Birmingham, AL, USA*

Keyword(s): graphene, 3D concrete printing, rheology, tensile, mechanical

Abstract

This study explores the effects of graphene nanoplatelets on the rheological and mechanical properties of cementitious composites. First, mortar mixtures with varying ratios of GNPs are prepared. The rheology of the GNP-reinforced mortar mixtures is thoroughly assessed using a shear rheometer with a building materials cell and vane motor. A shear testing protocol that consists of a ramp-up and ramp-down shear rates from 0 s^{-1} to 100 s^{-1} for 30 s is conducted, and dynamic yield stress and plastic viscosity are determined using Bingham visco-plastic material model. A stress growth test is carried out to quantify static yield stress and thixotropy of the cementitious mixtures. The viscoelastic properties of the mortar mixes, including storage modulus, are also determined. Then, 3D printed specimens with GNP ratios at 0%, 0.025%, 0.05%, 0.1%, 0.15%, and 0.2% are prepared to assess the effects of GNPs on compressive, flexural, and tensile properties of printed specimens. All the mechanical tests are conducted in two directions to evaluate the effect of anisotropy in 3D printed specimens. Results indicates a maximum increase of 106% and 90% in compressive strength with 0.1% GNP addition for perpendicular and parallel to filament directions, respectively compared to plain printed specimens. Further increasing GNP content decreases the compressive strength of printed specimens. On the other hand, both tensile and flexural strength exhibit almost steady increase with increasing GNP content and reach their peak values for the specimens with 0.2% GNPs. Compared to plain printed specimens, tensile strength of printed specimens with 0.2% GNPs increases 54% and 61% for perpendicular and parallel to filament directions, respectively, while the same increases for flexural strength are 46% and 34%. For all printed specimens, a pronounced anisotropy is observed for tensile and flexural response of printed specimens, while the variations in compressive strength for two test directions are not significant. Finally, results reveal that plain 3D printed specimens have lower mechanical properties than cast specimens, while the addition of GNPs considerably improve the compressive, tensile, and flexural behavior of printed specimens.

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Identification of kaolinite fabric – 3D reconstruction from SEM-FIB images

Fares Bennai^{*1}, Ismail Myouri¹, Julien Guyon¹, Mahdia Hattab¹

¹*Université de Lorraine, CNRS, Arts et Métiers ParisTech, LEM3, F-57000 Metz, France*

Keywords: Clay, Curtain effect, Machine learning (ML), Artificial Intelligence (AI), particles orientation.

Abstract

This study focuses on the 3D identification of the spatial orientation of particles in a saturated remolded clay from images captured with FIB-SEM observation. The treatment allows to get tridimensional reconstruction of a clay subsample that combines Focus Ion Beam abrasion and Scanning Electron Microscopy. The clay is a saturated kaolin K13 under one-dimensional compression up to vertical stress of 120 kPa. A new methodology has been established for the 3D images processing, the approach involves first removing the “curtain effects”, which are a particular type of noise commonly observed in images obtained using FIB-SEM technique. Two approaches were used and compared for this purpose: The first is based on Fourier Transformation and Total Variational reconstruction method, the second on stochastic approach formulated as convex optimization problem. Machine learning images segmentation technique was used on the denoised images for an adequate segmentation to finely separate and identify the clay particles. Since kaolinite particles have a flat plate-like structure, their 3D orientation was determined through normal vector to the basal plane of each particle. The global distribution of the normal vector orientation is presented in the form of a 3D hemisphere.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A simulation-based study to assess safety and performance efficiency of Traffic Calming Measures combined with Connected and Automated Vehicle Technologies

Author(s): Maria Luisa Tumminello ^{1*}, Elżbieta Macioszek ², Anna Granà ¹, and Tullio Giuffrè ³

¹ Department of Engineering, University of Palermo, Viale delle Scienze ed 8, 90128 Palermo, Italy; marialuisa.tumminello01@unipa.it, anna.grana@unipa.it

² Department of Transport Systems, Traffic Engineering and Logistics, Faculty of Transport and Aviation Engineering, Silesian University of Technology, Krasińskiego 8 Street, 40-019 Katowice, Poland; elzbieta.macioszek@polsl.pl

³ Faculty of Engineering and Architecture, University of Enna Kore, Viale della Cooperazione, 94100 Enna, Italy; tullio.giuffre@unikore.it

Keyword(s): Connected and Automated Vehicle, Traffic Calming Measures, roundabout, microscopic traffic simulation, surrogate measures of safety.

Abstract

In the last decade, following growing fleet of vehicles, researchers and practitioners in the field of road engineering have increasingly focused their efforts on appropriate design solutions to supply safe, functional, sustainable and aesthetically appealing urban spaces to citizens. In this framework are placed Traffic Calming Measures (TCMs) as a useful and non-invasive tool aimed to improving mobility conditions for non-motorized road users [1-3]. TCMs have been placed for a long time, and now have to deal with one of the latest innovate technologies in the automotive field as Autonomous and Connected Vehicles (CAVs). In this regard, it would be interesting to know how CAVs behave in the face of TCMs and what contribution they can bring to increasing or integrating their benefits. The goal of this research activity is to explore safety and performance efficiency of TCMs combined with CAVs technology in urban area. A small road network close to the seaside area in the City of Mazara del Vallo, Italy, was chosen as a case study and properly remodelled by inserting a limited traffic zone with roundabouts as TCMs. Microscopic traffic simulation modelling was helpful to assess the feasibility of the designed alternatives under examination, where CAVs have been employed as public transportation system at the service of the seaside area. Based on the Highway Capacity Manual [4], the fine-tuning process of the model parameters has been also executed. In this way, the operational performance and environmental impact of CAV technology combined with TCMs have been analysed. At last, the potential safety benefits of this combination were explored through surrogate measures of safety. The simulation approach discussed in this study could be helpful in leading the designers and analysts to know in advance and compare the operational response and safety performance of design alternatives, involving TCMs and CAVs, to be implemented in future urban mobility management strategies.

References

- [1] Wang, J.; Ying, J.; Jiang, S. An Adaptive Traffic-Calming Measure and Effectiveness Evaluation in a Large Urban Complex of Shanghai, China. *Sustainability* 2022, 14, 13023. <https://doi.org/10.3390/su142013023>
- [2] Juhász, M.; Koren, C. Getting an insight into the effects of traffic calming measures on road safety. *Transportation Research Procedia* 2016, 14, 3811-3820
- [3] Sołowczuk, A. Effect of Traffic Calming in a Downtown District of Szczecin, Poland. *Energies* 2021, 14, 5838. <https://doi.org/10.3390/en14185838>
- [4] National Academies of Sciences, Engineering, and Medicine. 2022. Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis. Washington, DC: The National Academies Press <https://doi.org/10.17226/26432>

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Walking to access shared mobility services: a case study in Palermo, Italy

Authors: Gabriele D'Orso^{*1}, Marco Migliore²

¹ *Department of Engineering, University of Palermo, Palermo, Italy, gabriele.dorso@unipa.it*

² *Department of Engineering, University of Palermo, Palermo, Italy, marco.migliore@unipa.it*

Keyword(s): Pedestrian accessibility; Walkability; Carsharing; Bikesharing.

Abstract

Walking is the main mode to access shared mobility services like carsharing and bikesharing. Indeed, before starting the in-vehicle trip, carsharing and bikesharing users must reach the pick-up stations in the station-based systems or the locations where the shared vehicles were parked by other users inside the service area in the free-floating services.

Although the ease with which individuals can access shared vehicles appears to be fundamental, few researchers have specifically investigated how to measure station and vehicle accessibility [1]. The study aims to analyze how much the pedestrian accessibility and the walkability of the urban areas around the carsharing stations and bikesharing docks affect the use of these services by citizens. The physical characteristics of the built environment are widely recognized to influence people's willingness to walk and cycle in urban neighborhoods and could affect the access to shared mobility, their use, and the membership rate. Thus, the research used Palermo, Italy, as a case study to assess and compare the contribution of different accessibility indicators to modeling carsharing and bikesharing use, considering some indicators deriving from the literature, like the Pedestrian Catchment Area ratio used by Schlossberg [2]. In Palermo, the municipal public transportation company AMAT manages a dock-based bikesharing service and a carsharing service, called Amigo, which can be used as a station-based service but also as a free-floating service, using in the latter case a fleet of 24 electric vehicles. The 2019 data of the Palermo shared mobility services were analyzed; using this period of time, the behaviors by users were not affected by the Covid-19 pandemic and the launching of several scooter-sharing and dockless bikesharing services in 2021, which reduced the carsharing and bikesharing use in some parts of the city. The analysis was conducted using GIS software to assess the indicators. The findings of the study are useful to identify the areas that should be improved in terms of walkability and pedestrian accessibility in order to increase the use of shared mobility services in Palermo.

References

- [1] Roblot M., Boisjoly G., Francesco C., Martin T., "Participation in Shared Mobility: An Analysis of the Influence of Walking and Public Transport Accessibility to Vehicles on Carsharing Membership in Montreal, Canada", *Transportation Research Record*, 2675(12), (2021).
- [2] Schlossberg M., Brown N., "Comparing Transit-Oriented Development Sites by Walkability Indicators", *Transportation Research Record*, 1887, 34-42 (2004).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Performance Analysis of a Cascaded H-Bridge Multilevel Inverter in Asymmetric Configuration

Authors: Massimo Caruso¹, Antonino Oscar Di Tommaso¹, Gerlando Frequente¹, Rosario Miceli¹, Gioacchino Scaglione¹, Giuseppe Schettino¹, Nicola Campagna¹.

¹ Department of Engineering, University of Palermo, Palermo, Italy,

massimo.caruso16@unipa.it, antoninooscar.ditommaso@unipa.it, gerlando.frequente@unipa.it,
rosario.miceli@unipa.it, gioacchino.scaglione@unipa.it, giuseppe.schettino@unipa.it,
nicola.campagna@unipa.it.

Keywords: Multilevel converter, asymmetric cascaded H-Bridge multilevel inverter, pulse with modulation (PWM)

Abstract

This paper presents the performance analysis of Cascaded H-Bridge Multilevel Inverters (CHBMLI) structured with an asymmetric configuration. The aim of this work is to understand their potential and the applications in which they can play a prominent role, as well as the limitations that could possibly limit their usage. This topology of multilevel inverter, due to its reduced number of required components and simple structure, allows the development of a reliable and efficient conversion system that can be further improved in its asymmetric variation.

Therefore, the main objective of this study is to determine the model of a single-phase, seven levels, asymmetric CHBMLI in order to evaluate its performance and compare it with its symmetric counterpart. Simulations were conducted using MATLAB/Simulink® to gather the needed data for comparing the two types of CHBMLI. It can be concluded that the asymmetric seven-level model has the same performance as the symmetric model, but with a reduced number of components and a simpler hardware structure.

Comparing the asymmetric seven-level CHBMLI with the symmetric configurations, it can be noted that when the modulation indexes in terms of amplitude and frequency, namely m_a and m_f , are equal to 0.9 and 200, respectively, with a Total Harmonic Distortion (THD) of the voltage for the asymmetric configuration is slightly lower. When examining the root-mean-square value of the first harmonic voltage and the THD of the load voltage for both configurations, it is evident that the trends and values achieved are almost identical for both the symmetric and asymmetric CHBMLIs. Thus, based on the conducted simulations, it can be stated that the asymmetric seven-level CHBMLI has comparable performance to the symmetric seven-level CHBMLI, but with a simpler hardware complexity. By considering equal performance between the symmetric and asymmetric configurations, it has to be highlighted that a simpler structure with fewer components offers increased reliability, compactness and lightweight characteristics compared to other types of inverters, such as diode-clamped and flying capacitors multilevel inverters. This suggests the use of asymmetric CHBMLIs in applications where these features are crucial factors in the choice of the converter, such as the automotive industry.

References

- [1] A. Akbari, F. Poloei e A. Bakhshai, "A Brief Review on State-of-the-art Grid-connected Inverters for Photovoltaic Applications", 2019 IEEE 28th International Symposium on Industrial Electronics (ISIE) , Vancouver, BC, Canada , 2019, pp. 1023-1028, doi: 10.1109/ISIE.2019.8781166.
- [2] A. Poorfakhraei, M. Narimani and A. Emadi, "A Review of Multilevel Inverter Topologies in Electric Vehicles: Current Status and Future Trends," in IEEE Open Journal of Power Electronics, vol. 2, pp. 155-170, 2021, doi: 10.1109/OJPEL.2021.3063550.
- [3] F. Chang, O. Ilina, M. Lienkamp and L. Voss, "Improving the Overall Efficiency of Automotive Inverters Using a Multilevel Converter Composed of Low Voltage Si mosfets," in IEEE Transactions on Power Electronics, vol. 34, no. 4, pp. 3586-3602, April 2019, doi: 10.1109/TPEL.2018.2854756.
- [4] R. Teichmann and S. Bernet, "A comparison of three-level converters versus two-level converters for low-voltage drives, traction, and utility applications," in IEEE Transactions on Industry Applications, vol. 41, no. 3, pp. 855-865, May-June 2005, doi: 10.1109/TIA.2005.847285.
- [5] E. Rodriguez, R. Leyva, G. G. Farivar, C. D. Townsend and J. Pou, "Negative-Sequence Current Range in Low-Capacitance Cascaded H-Bridge STATCOMs with Peak Arm Current Limitation," 2022 IEEE 13th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Kiel, Germany, 2022, pp. 1-5, doi: 10.1109/PEDG54999.2022.9923219.
- [6] M. Rashid, Power Electronics: Devices, Circuits, and Applications, IV ed.: Peason, 2014.
- [7] N. Mohan, T. M. Undeland e a. altri, Elettronica di potenza: convertitori e applicazioni, Hoepli, 2005.
- [8] S. Kouro, M. Malinowski e altri, «Recent Advances and Industrial Applications of Multilevel Converters,» IEEE Transactions on Industrial Electronics, vol. 57, no. 8, pp. 2553-2580, 2010.
- [9] A. Nabae, I. Takahashi e H. Akagi, «A New Neutral-Point-Clamped PWM Inverter,» IEEE Transactions on Industry Applications, vol. IA-17, no. 5, pp. 518-523, 1981.
- [10] A. Busacca, A. O. Di Tommaso, R. Miceli, C. Nevoloso, G. Schettino, G. Scaglione, F. Viola e I. Colak, «Switching Frequency Effects on the Efficiency and Harmonic Distortion in a Three-Phase Five-Level CHBMI Prototype with Multicarrier PWM Schemes: Experimental Anlysis,» Energies, 2022.
- [11] G. Ala, M. Caruso, M. Rosario, F. Pellitteri, G. Schettino, M. Trapanese e F. Viola, «Experimental Investigation on the Performances of a Multilevel Inverter Using a Field Programmable Gate Array-Based Control System,» Energies, 2019.
- [12] V. A. Kumar and M. Arounassalame, "Comparison of CHB Multi level inverters using Level shifted Modulation techniques with closed loop PI control," 2018 4th International Conference on Electrical Energy Systems (ICEES), Chennai, India, 2018, pp. 168-172, doi: 10.1109/ICEES.2018.8443288.
- 69
- [13] S. S. Bharatkar, R. R. Bhoyar and S. A. Khadtare, "Analysis of three phase cascaded H-bridge multilevel inverter for symmetrical & asymmetrical configuration," 2014 First International Conference on Automation, Control, Energy and Systems (ACES), Adisaptagram, India, 2014, pp. 1-6, doi: 10.1109/ACES.2014.6807993.
- [14] A. O. Di Tommaso, R. Miceli, C. Nevoloso, G. Scaglione, G. Schettino, F. Viola e altri, «Enhanced modulation strategy for 7-level voltage waveform in asymmetrical 5-level Cascaded H-Bridge Inverters,» 2022 Second International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART), 2022.

EMI 2023 International Conference

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Title: Comparison between Voltage Oriented Control and Synchronous Power Control for Grid-Connected Inverter Applications.

Author(s): Antonino Oscar Di Tommaso¹, Rosario Miceli¹, Giuseppe Sorrentino¹, Giuseppe Schettino¹, Claudio Nevoloso¹, Gioacchino Scaglione¹, Nicola Campagna¹.

¹ *Department of Engineering, University of Palermo, Palermo, Italy*

Antoninooscar.ditommaso@unipa.it, rosario.miceli@unipa.it, giuseppe.sorrentino03@unipa.it,
giuseppe.schettino@unipa.it, claudio.nevoloso@unipa.it, gioacchino.scaglione@unipa.it,
nicola.campagna@unipa.it.

Keyword(s): Inertia, Phase-Locked Loop, Synchronous Power Control, Voltage Oriented Control.

Abstract

Renewable energy sources are fundamental to achieve the electrical system decarbonization. According to [1]-[4], these new ways to produce electrical energy require innovative solutions to overcome the operative limits due to the sources aleatority. As these power plants substitute the traditional ones, electrical system operation becomes more challenging.

In particular, the major challenges are frequency and voltage regulation [5]. This is because, as of today, most renewable energy sources inverters are controlled by a technique called grid-following control where the inverter is controlled to inject the maximum amount of active power available without caring for frequency or voltage regulation. Thus, in this case, they can't provide inertia to the grid [6].

Inertia is a fundamental characteristic of traditional synchronous generators. Since they are rotational machines, they are able to store rotational kinetic energy. This feature is very important for the electrical system frequency dynamics and stability because it helps by reducing the frequency deviations caused by power imbalances [7].

To face these new challenges, new control strategies have been developed in literature, which are called grid-forming or grid-supporting control techniques. In this case, the main objective of the inverter control is to provide active power injection for frequency regulation and reactive power injection for voltage regulation to offer grid support. In some cases, these techniques can also provide inertia to the grid [6].

The grid-forming technique taken into consideration falls into the Synchronous machine-based control and, in particular, it is a Virtual Synchronous Generator control technique that uses the virtual admittance block instead of the virtual impedance block for the inner control [8]. The concept of the Virtual Synchronous Generator was first introduced in [9].

In this work, a comparison between Voltage Oriented Control [10] and Synchronous Power Control [11] has been conducted. In detail, an extensive simulation analysis has been carried out on Matlab/Simulink environment for performance comparison purposes by considering frequency and voltage disturbances.

References

- [1] M. Busu, "The role of renewables in a low-carbon society: Evidence from a multivariate panel data analysis at the EU level," *Sustainability*, vol. 11, no. 19, p. 5260, Sep. 2019.
- [2] M. Caruso, A. O. Di Tommaso, F. Genduso and R. Miceli, "Experimental investigation on high efficiency real-time control algorithms for IPMSMs," 2014 International Conference on Renewable Energy Research and Application (ICRERA), Milwaukee, WI, USA, 2014, pp. 974-979, doi: 10.1109/ICRERA.2014.7016531.
- [3] V. Di Dio, R. Miceli, C. Rando and G. Zizzo, "Dynamics photovoltaic generators: Technical aspects and economical valuation," *SPEEDAM 2010*, Pisa, Italy, 2010, pp. 635-640, doi: 10.1109/SPEEDAM.2010.5542261.
- [4] V. Di Dio, D. La Cascia, R. Liga and R. Miceli, "Integrated mathematical model of proton exchange membrane fuel cell stack (PEMFC) with automotive synchronous electrical power drive," 2008 18th International Conference on Electrical Machines, Vilamoura, Portugal, 2008, pp. 1-6, doi: 10.1109/ICELMACH.2008.4800045.
- [5] Y. Lin, J. H. Eto, B. B. Johnson, J. D. Flicker, R. H. Lasseter, H. N. V. Pico, G.-S. Seo, B. J. Pierre, and A. Ellis, "Research roadmap on grid-forming inverters," *Nat. Renew. Energy Lab.*, Golden, CO, USA, Tech. Rep. NREL/TP-5D00-73476, 2020.
- [6] D. B. Rathnayake et al., "Grid Forming Inverter Modeling, Control, and Applications," in *IEEE Access*, vol. 9, pp. 114781-114807, 2021, doi: 10.1109/ACCESS.2021.3104617.
- [7] Ulbig, Andreas & Borsche, Theodor & Andersson, Göran. (2013). Impact of Low Rotational Inertia on Power System Stability and Operation. IFAC Proceedings Volumes (IFAC-PapersOnline). 19.
- [8] P. Rodriguez, I. Candela, C. Citro, J. Rocabert, and A. Luna, "Control of grid-connected power converters based on a virtual admittance control loop," in *Proc. Eur. Conf. Power Electron. Appl.*, 2013, pp. 1–10.
- [9] J. Driesen and K. Visscher, "Virtual synchronous generators," in *Proc. IEEE Power Energy Soc. Gen. Meeting-Convers. Del. Electr. Energy 21st Century*, Jul. 2008, pp. 1–3.
- [10] *Grid Converters for Photovoltaic and Wind Power Systems* © 2011 John Wiley & Sons, Ltd
- [11] W. Zhang, A. M. Cantarellas, J. Rocabert, A. Luna, and P. Rodriguez, "Synchronous Power Controller With Flexible Droop Characteristics for Renewable Power Generation Systems," in *IEEE Transactions on Sustainable Energy*, vol. 7, no. 4, pp. 1572-1582, Oct. 2016, doi: 10.1109/TSTE.2016.2565059.

EMI 2023 International Conference

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Title: Development of a Decision Support System for increasing the resilience of urban road network

Author(s): Giuseppe Salvo¹, Luigi Sanfilippo^{*2}

¹ *Department of Ingegneria, University of Palermo, giuseppe.salvo@unipa.it*

² *citiEU Consultancy LTD, Guildford, United Kingdom, lsanfilippo@citieume.com*

Keyword(s): road vulnerability, road network resilience, urban mobility, climate change, decision support system, transport microsimulation

Abstract

Emergency preparedness is essential to ensure the population's safety, security and protection in the event of disasters. Appropriate response scenarios must be planned and assessed to develop effective emergency preparedness plans.

The occurrence of an incident (accident or weather event) in a primary roadway could cause its partial or complete closure to vehicular transit for several hours or days, with negative consequences on vehicular traffic along the road network containing the structure itself.

Therefore, in addition to recovering the functionality of the affected arterial road, identifying possible alternative routes capable of providing an adaptive response to the disruption is of great importance.

This study proposes new ways of exploiting existing technologies to strengthen the resilience of the urban road network against the growing threat of climate change.

The paper aims to improve the road infrastructure's resiliency (ability to adapt) and ensure reliable network availability under unfavourable conditions, such as extreme weather.

The study was conducted on Viale Regione Siciliana, the major arterial road in Palermo, and it connects two important highways: A19 Palermo-Catania and A29 Palermo-Mazara del Vallo. Viale Regione Siciliana is characterised by numerous subways not driving during heavy rain. When subways are closed, queues and delays of several hours occur, making it difficult or impossible to rescue operations.

The study presented the development of emergency response scenarios for heavy rainfall to provide alternative access to the city centre. To model the main traffic corridors in the area at risk, a dynamic microsimulation model was developed and implemented using the software Dynasim, which allowed the evaluation of the impact on cycling resulting from different emergency management strategies in response to natural disasters.

Traffic simulation is a numerical technique for conducting experiments on a computer. It involves replicating the real-world transport system through mathematical and logical representations of the traffic flows in the system.

This work demonstrates the utility of microscopic traffic simulation for emergency preparedness and highlights the challenges of developing large-scale microscopic simulation models. Finally, the results can guide local agencies in implementing effective traffic management strategies in the event of an actual emergency.

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Title: Effectiveness of rubber bearings on the response of seismic isolation system in the case of vertical actions

Author(s): Rossella Laudani*¹, Giovanni Falsone¹

¹ *Department of Engineering, University of Messina, Messina, Italy*

E-mail: rlaudani@unime.it, gfalsone@unime.it

Keyword(s): Seismic Isolation, rubber isolation bearings and vertical ground motion

Abstract

For the seismic analyses of most structures, the vertical component of seismic excitation is generally ignored by codes. Nevertheless, due to catastrophic seismic events that occurred in Italy and around the world in recent years, an increasing number of researchers agree that the vertical component was a not negligible contributor, along with severe horizontal ground motion, to the destructive structural effects observed during such extreme earthquakes [1]. Consequently, the study of the role of vertical acceleration in the seismic phenomenon and its impact on the structures has been played great attention. On the other hand, several research has been carried out about the impact of the vertical component of the ground motion on seismic isolation systems [2]. While there have been different studies on the effect of vertical load on the displacement of isolation bearings, most of the existing studies focused on friction isolation bearings. In contrast, studies on rubber isolation bearings are very limited. In general, it has been observed that the response characteristics of elastomeric bearings are significantly influenced by the weight or axial load carried, although the effects this entails have not yet been fully investigated. In the present work, the effects of the axial load on the elastomeric bearings have been studied starting from the analysis of the stability of a simplified two-spring model of the bearing proposed by Kelly [3], according to which the horizontal stiffness of the system depends on the vertical load. In particular, the effects of the vertical component of earthquakes on the behavior of structures isolated through elastomeric isolators and the consequent design implications will be investigated.

References

- [1] Falsone, G. Recupero A., and Spinella N. "Effects of near-fault earthquakes on existing bridge performances." *Journal of civil structural health monitoring*, 10,165-176, (2020).
- [2] Zhong, J., Zhu, Y., & Han, Q.. Impact of vertical ground motion on the statistical analysis of seismic demand for frictional isolated bridge in near-fault regions. *Engineering Structures*, 278, 115512, (2023)
- [3] Kelly, James M. *Earthquake-resistant design with rubber*. London: Springer-Verlag (1993).

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Title: Performance-based seismic design of self-centering dissipative braces for seismic retrofit of substandard reinforced concrete buildings

Author(s): Dario De Domenico^{*1}, Alberto Gioitta², Antonino Recupero³

¹ *Department of Engineering, University of Messina, Italy, dario.dedomenico@unime.it*

² *Department of Engineering, University of Messina, Italy, albertogioitta@gmail.com*

³ *Department of Engineering, University of Messina, Italy, antonino.recupero@unime.it*

Keyword(s): Self-centering dissipative braces, Seismic protection, Reinforced concrete frames, Elasto-plastic dissipative braces, Displacement-based seismic design, Recentering behavior

Abstract

Several existing reinforced concrete (RC) framed buildings require urgent retrofit interventions to meet modern seismic-performance requirements because of poor construction details, increased seismic hazard, change of intended use over their service life, or occurrence of material degradation phenomena. Furthermore, these structures were designed considering outdated principles or even totally ignoring the seismic action. Among the possible retrofit strategies, an effective technique implies the use of metallic dampers installed in chevron braces and optimally distributed in the structure to provide supplemental energy dissipation (and stiffening) effects. However, such conventional elasto-plastic dissipative braces (EPDBs) may suffer from recentering issues, because their working mechanism is, in general cases, based on the plastic deformation of steel. Consequently, they exhibit permanent displacements at the end of the seismic event and need to be restored after each shaking. As an alternative, this contribution deals with the seismic protection of existing RC buildings through self-centering dissipative braces (SCDBs) that are featured by internal mechanisms nullifying the permanent deformation after their activation, thus offering significant advantages over EPDBs. We present a displacement-based design procedure [1] for SCDBs [2] implemented in RC framed structures targeting two performance requirements, namely the control of the roof displacement and the good recentering behavior of the structure after the seismic event. Then, we apply this procedure to the seismic protection of an archetypal building, representative of substandard RC frames built in 1960s-1970s in Italy [3], by comparatively illustrating the seismic performance of SCDBs and EPDBs through nonlinear time-history analyses.

References

- [1] Priestly, M. J. N., Calvi, G. M., & Kowalsky, M. J. (2007). Displacement-based seismic design of structures. Displacement-Based Seismic Design of Structures, IUSS PRESS, Pavia, Italy.
- [2] Bagheri, H., Hashemi, A., Yousef-Beik, S. M. M., Zarnani, P., & Quenneville, P. (2020). New self-centering tension-only brace using resilient slip-friction joint: Experimental tests and numerical analysis. Journal of Structural Engineering, 146(10), 04020219.
- [3] Masi, A., & Vona, M. (2012). Vulnerability assessment of gravity-load designed RC buildings: Evaluation of seismic capacity through non-linear dynamic analyses. Engineering Structures, 45, 257-269.

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Palermo, Italy, August 27 - 30, 2023

Title: A Floating Absorber for Motion Mitigation in Floating Wind Turbines

Authors: Giuseppe Failla*, Gioacchino Alotta, Valentina Laface, Carlo Ruzzo, Felice Arena

¹ *Department of Civil, Energy, Environmental and Materials Engineering (DICEAM), University of Reggio Calabria, Italy, giuseppe.failla@unirc.it, gioacchino.alotta@unirc.it, valentina.laface@unirc.it, carlo.ruzzo@unirc.it, arena@unirc.it*

Keywords: floating wind turbine, spar, floating absorber, tuned mass, motion mitigation.

Abstract

An innovative concept of floating absorber is proposed for motion mitigation in floating wind turbines on spar-type supports [1-4]. The floating absorber consists in a spar floater coupled with the floating wind turbine by an elastic spring and a viscous damper in parallel. It is conceived to act as a resonant mass tuned to the pitch frequency of the floating wind turbine and its parameters are selected via an ad hoc fixed point tuning procedure. For validation, time-domain numerical simulations are performed on a multi-degree-of-freedom model of the coupled system, considering different configurations of the floating absorber and various wind-wave states. The results demonstrate a considerable effectiveness of the floating absorber in reducing the pitch motion of the floating wind turbine. A main advantage over conventional tuned mass devices is that the absorber is not housed in the nacelle of the wind turbine but floats close to the floating wind turbine, which reduces the costs of installation and maintenance and allows to increase its mass without causing extra weight on the floating wind turbine; additionally, it exploits hydrodynamic added mass as well, with consequent benefits in terms of motion mitigation in the floating wind turbine. Another relevant result is that, for a given mass of the floating absorber and a given attachment point of the parallel spring-dashpot, the performances of the floating absorber do not vary significantly with its geometry. This feature facilitates design and manufacturing of the floating absorber, confirming the robustness of the proposed concept and its great potential for motion mitigation in floating wind turbines.

References

- [1] Sarkar S., Fitzgerald B., "Vibration control of spar-type floating offshore wind turbine towers using a tuned mass-damper-inerter," *Structural Control and Health Monitoring*, 27(1), e2471, (2020).
- [2] Lackner M.A., Rotea M.A., "Structural control of floating wind turbine," *Mechatronics*, 21, 704-719, (2011).
- [3] Jahangiri V., Sun C., "Three-dimensional vibration control of offshore floating wind turbines using multiple tuned mass dampers," *Ocean Engineering*, 206, 107196, (2020).
- [4] He J., Jin X., Xie S.Y., Cao L., Lin Y., Wang N., "Multi-body dynamics modeling and TMD optimization based on the improved AFSA for floating wind turbines," *Renewable Energy*, 141, 305-321, (2019).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Experimental investigation of surface wave propagation in locally resonant metamaterials

Author(s): Farhad Zeighami^{*1}, Antonio Palermo¹, Denis Bogomolov², Alessandro Marzani¹.

¹ Department of Civil, Chemical, Environmental, and Materials Engineering (DICAM), University of Bologna, Bologna, Italy, farhad.zeighami3@unibo.it, Antonio.palermo6@unibo.it, Alessandro.marzani@unibo.it.

² Advanced Research Center on Electronic Systems "Ercole De Castro" (ARCES), University of Bologna, Bologna, Italy, denis.bogomolov2@unibo.it

Keyword(s): Locally resonant metamaterials, Surface waves, Band gap, Laser Doppler vibrometry.

Abstract

Locally Resonant Metamaterials (LRMs) are composite structures with uncommon mechanical properties, such as zero or negative mass density [1] and negative bulk modulus [2]. Recently, LRMs have gained increasing attention in applications related to the control of surface waves across different frequency ranges. In this context, most of the available studies discuss the design and analysis of locally resonant metasurfaces, namely thin resonant layers attached to the surface of elastic waveguides [3]. Given their reduced thickness w.r.t. to the wavelengths of surface waves, these metasurfaces are conveniently modelled as simple dynamic boundary conditions.

In this study, we release this modelling assumption to investigate surface wave propagation in thick metasurfaces coupled to elastic half-spaces. The resonant layer consists of an array of sub-wavelength resonators attached to the host material via elastic connectors and periodically arranged in the hosting medium [4]. First, an analytical model is proposed to predict the dispersive features of such resonant composite medium. Next, numerical simulations are performed to confirm the dispersion properties predicted by the developed model and to evaluate the attenuation performance of such LRMs. Finally, a small-scale prototype is fabricated and tested experimentally, exploiting the Laser Doppler vibrometry technique to reconstruct the dispersion curves.

The combination of analytical/numerical analyses and experimental evidence reveals that a narrow bandgap is generated in the frequency range of the LRM resonance. Parametric studies show that increasing the thickness of the resonant layer results in an extended frequency range of the bandgap, leading to a more effective attenuation of incoming surface waves. In summary, the developed framework provides a practical and efficient approach for the design and fabrication of LRMs with desirable filtering capability, which could find promising engineering applications in surface acoustic wave (SAW) filters, seismic wave barriers, and ground-borne vibration mitigation systems.

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References

- [1] Huang H., Sun C., Huang G., "On the negative effective mass density in acoustic metamaterials," *International Journal of Engineering Science*, 47, 610 – 617, 2009.
- [2] Fang N. X., Xi D., Xu J., Ambati M. S., Srituravanich W., Sun C., Zhang X., "Ultrasonic metamaterials with negative modulus," *Nature Materials*, 5, 452–456, 2006.
- [3] X Pu, A Palermo, A Marzani, "A multiple scattering formulation for finite-size flexural metasurfaces," *Proceedings of the Royal Society A*, 478, 2262, 2022.
- [4] Zeighami F., Palermo A., Marzani A., "Rayleigh waves in locally resonant metamaterials," *International Journal of Mechanical Sciences*, 195, 106250, 2021.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Vibration mitigation in pipelines by resonant supports with inerter devices

Author(s): Silvia Scutтери^{*1}, Andrea Francesco Russillo², Roberta Santoro¹, Giuseppe Ricciardi¹, Giuseppe Failla²

¹ *Dipartimento di Ingegneria, Università di Messina, Messina, Italy*
E-mail: silvia.scutтери@unime.it, roberta.santoro@unime.it, gricciardi@unime.it

² *Dipartimento di Ingegneria Civile, dell'Energia, dell'Ambiente e dei Materiali (DICEAM), Università Mediterranea di Reggio Calabria, Reggio Calabria*
E-mail: andreaf.russillo@unirc.it, giuseppe.failla@unirc.it

Keyword(s): resonators, inerter, band gap.

Abstract

In this work we study the control of the flexural vibrations of a pipeline that transports a fluid under pressure at a given speed, through resonant supports with inerter devices.

The pipeline is modeled as an Euler beam resting on the ground through resonant supports arranged periodically, at constant distance.

The frequency response of the pipe is characterized by the presence of a band gap of significant amplitude, at low frequency, within which the elastic waves do not propagate. Two methods are used to study the amplitude of the band gap: the homogenization method and the transfer matrix method.

The effect of various parameters on the band gap width is investigated: the structural characteristics of the pipeline, the specific weight of the fluid and its velocity, as well as the mechanical parameters of the resonant supports. Two types of resonant supports are considered, characterized by different arrangements of elastic and inerter components.

Furthermore, for greater generality, the problem is dimensionless.

References

- [1] De Domenico, D., Ricciardi, G., "An enhanced base isolation system equipped with optimal tuned mass damper inerter (TMDI)", *Earthquake Engineering and Structural Dynamics*, 47 (5), 1169-1192 (2018).
- [2] De Domenico, D., Ricciardi, G., "Optimal design and seismic performance of tuned mass damper inerter (TMDI) for structures with nonlinear base isolation systems", *Earthquake Engineering and Structural Dynamics*, 47(12), 2539-2560 (2018).
- [3] Mingyao L., Zechao W.,*, Zude Z., Yongzhi Q., Zhaoxiang Y., Qin W., Ling . "Vibration response of multi-span fluid-conveying pipe with multiple accessories under complex boundary conditions", *European Journal of Mechanics / A Solids* 72 (2018) 41–56 (2018).
- [4] Failla, G., Santoro, R., Burlon, A. and Russillo, A.F., "An exact approach to the dynamics of locally-resonant beams", *Mechanics Research Communications*, 103, 103460 (2020).
- [5] Alotta, G. and Failla, G., "Improved inerter-based vibration absorbers", *International Journal of Mechanical Sciences*, 192, 106087 (2021).
- [6] Russillo, A.F., Failla, G. and Alotta, G., "Ultra-wide low-frequency band gap in locally-resonant plates with tunable inerter-based resonators", *Applied Mathematical Modelling*, 106, 682-695 (2022).

EMI 2023 International Conference

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Title: Architected plates based on the Schwarz primitive cell for elastic wave mitigation and guiding

Author(s): Aida Hejazi Nooghabi¹, Henrik Thomsen², Andrea Colombi¹

¹*Department of Civil, Environmental and Geomatic Engineering, ETH Zürich, Zürich, Switzerland*

²*Institute for Geophysics, ETH Zürich, Zürich, Switzerland*

Keyword(s): Schwarz primitive cell, Dispersion relation, Bandgap, Metabarrier, Metalens

Abstract

Thanks to the progress in additive manufacturing and computational performance, the dynamic behaviour of a multitude of architected structures can be investigated. Among these are shell-like structures and octet-based lattices, known for their exotic ability to manipulate waves via so-called bandgaps, frequency ranges in which the wave propagation is forbidden.

In this work, we focused on a shell-based unit cell of Schwarz primitive type. Using the finite element method and Bloch's theorem, we first compute the dispersion curves of the unit cell to unravel its dynamic behavior. Bandgaps of Bragg type emerge for this unit cell. The frequency range and the mechanism of the bandgap are further validated on 3D-printed prototypes using a Laser Doppler Vibrometer (LDV). By leveraging the revealed mechanism, we designed two metadevices for wave mitigation and control based on the grading concept [1]: metabarrier and metalens, respectively. These are built by adding or removing masses to and from the shell surface of the Schwarz cell. The lens leverages the gradual spatial variation of the mass in order to realize the refraction index profile necessary for focusing the incoming waves.

In the context of vibration isolation, our analyses reveal that shell-based plates can have excellent control over wave propagation or, alternatively, can focus their energy, features previously proved in octet lattice based plates [2], thereby paving the way for the development of novel wave control devices.

References

- [1] Colombi, A., Craster, R. V., Colquitt, D., Achaoui, Y., Guenneau, S., Roux, P., and Rupin, M. Elastic wave control beyond band-gaps: shaping the flow of waves in plates and half-spaces with subwavelength resonant rods, *Frontiers in Mechanical Engineering*, 3, 10 (2017)
- [2] Aguzzi, G., Kanellopoulos, C., Wiltshaw, R., Craster, R. V., Chatzi, E. N., and Colombi, A. Octet lattice-based plate for elastic wave control, *Scientific Reports*, 12(1), 1-14 (2022)

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Experimental investigation of progressive collapse of precast concrete beam-column assemblies using dry connections

Zidong Zhao^{*1}, Xiaowei Cheng², Yi Li³, Yi An⁴

¹ Beijing Key Laboratory of Earthquake Engineering and Structural Retrofit, Beijing University of Technology, Beijing 100124, China. zidong-zhao@emails.bjut.edu.cn

² Beijing Key Laboratory of Earthquake Engineering and Structural Retrofit, Beijing University of Technology, Beijing 100124, China. chengxw@bjut.edu.cn

³ Beijing Key Laboratory of Earthquake Engineering and Structural Retrofit, Beijing University of Technology, Beijing 100124, China. yili@bjut.edu.cn

⁴ Beijing Key Laboratory of Earthquake Engineering and Structural Retrofit, Beijing University of Technology, Beijing 100124, China. anyi94214@163.com

Keyword(s): Precast concrete structures, progressive collapse, experimental test, unbonded post-tensioning tendons

Abstract

Beam-column joints using dry connections usually exhibit complex mechanical performance and experience severe damage under large deformations. Therefore, the precast concrete (PC) frames with dry connections are highly vulnerable to progressive collapse triggered by the local failure of structural components. To investigate the collapse-resisting behavior of PC frames with dry connections under the middle-column removal scenario, a static pushdown test was conducted on four half-scaled precast beam-column assemblies with different joint details, including top-and-seat angle connection (TA), strengthened top-seat angle connection (STA), and two refined connections with unbonded post-tensioning tendons (UPTA and UPSTA, respectively), and one reinforced concrete (RC) substructure. A four-point load scheme applied on one span of framed beam was adopted to simulate the close-to-real uniformly distributed load condition. Results showed that compared with RC, the resistance of TA at the beam flexural and compressive arch action (B-CAA) stage and catenary action (CA) stage dropped by 41% and 27% due to the buckling of steel angles and endplates and the fracture of steel angles and bolts, respectively; after strengthening the steel angles, the resistance of the B-CAA of STA increased by 7%, whereas the ductility decreased, with the displacement of rebar fracture decreasing by 37%, leading to a 30% resistance reduction of CA; unbonded post-tensioning tendons dramatically improved the structural integrity, contributing to the 52% and 97% resistance increase of the CA of UPTA and UPSTA, respectively.

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Title: Response of structures subjected to debris impact: a simplified model

Authors: Elahe Zeinali^{*1}, Foad Kiakojouri², Valerio De Biagi³.

¹ Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy, email: elahe.zeinali@polito.it

² Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy, email: foad.kiakojouri@polito.it

³ Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy, email: valerio.debiagi@polito.it

Keywords: Falling debris, Impact, Pancake-type collapse, Progressive collapse, Concrete slab

Abstract

Falling debris impact is a significant threat to building safety. Such debris can result from various sources, including natural disasters and man-made events. The current state of research on this topic is limited due to the complex nature of the behaviour of structures during such an event [1]. Falling debris are part of the propagation mechanism in pancake-type progressive collapse [2, 3]. To prevent such collapse mechanism, specific studies are needed on the behavior of impacted structures. The limited number of studies found in the literature on the topic reflects that experiments on impact response and subsequently pancake-type collapse are expensive and time-consuming. In addition, existing research has mainly focused on simplified scenarios. In the progressive collapse discipline, most studies have been conducted on structural response after column removal, i.e., redistributional collapses. Research on vertical debris impact and subsequent pancake-type collapse is very limited [4].

Although the literature on this topic is growing, further investigation is necessary to identify suitable analysis methods to understand the propagation mechanisms in pancake-type collapses. The present work aims at developing a simple analytical model that describes the behavior of a slab subjected to the impact of a falling body. The problem is modelled as a set of lumped masses. Contact stiffness properties for concrete-concrete impacts are the outputs of an experimental campaign on reduced scale models. Preliminary results are proposed and suggestions for future studies on the analysis of pancake-type collapse mechanism are provided.

References

- [1] Kiakojouri, F., De Biagi, V., Chiaia, B. and Sheidaii, M.R., "Strengthening and retrofitting techniques to mitigate progressive collapse: A critical review and future research agenda", *Engineering Structures*, 262, p.114274, (2022).
- [2] Kiakojouri, F., De Biagi, V., Chiaia, B. and Sheidaii, M.R., "Progressive collapse of framed building structures: Current knowledge and future prospects", *Engineering Structures*, 206, p.110061, (2020).
- [3] Lalkovski, N. and Starossek, U., Vertical building collapse triggered by loss of all columns in the ground story—Last line of defense. *International journal of steel structures*, 16, pp.395-410, (2016).
- [4] Lu, Z., Rong, K., Zhou, Z. and Du, J., Experimental study on performance of frame structure strengthened with foamed aluminum under debris flow impact. *Journal of Performance of Constructed Facilities*, 34(2), p.04020011, (2020).

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Title: Seismic-collapse selective retrofitting using the Applied Element Method

Author(s): Cosimo Pellecchia^{*1}, Gian Paolo Cimellaro¹, Alessandro Cardoni¹, Ahmed Amir Khalil², Emiliano De Iuliis²

¹ *Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Turin, Italy e-mail: {cosimo.pellecchia, gianpaolo.cimellaro, alessandro.cardoni}@polito.it*

² *Applied Science International, LLC, 2012 TW Alexander Dr., P.O. Box 13887, Durham, NC, USA e-mail: {akhalil, edeluliis}@appliedscienceint.com*

Keyword(s): Progressive Collapse, Seismic Analysis, Selective Retrofitting, Applied Element Method

Abstract

More than 160,000 buildings collapsed in the recent magnitude-7.8 earthquake in Turkey [1]. Although most of the collapsed buildings were of poor construction quality and built with no reference to the current seismic standards, also several newly constructed buildings stroke to the ground [2]. Even considering the exceptional magnitude of the strike, the number of collapsed buildings and related victims raises several concerns about the current component-based code compliance approach. In fact, while providing enough strength to each of the building's elements can be crucial in avoiding diffuse damage states, the final collapse of the entire structure is often the result of damage propagation from one single structural failure. Being able to detect the specific structural failure, could help improve the seismic response of entire regions subject to high seismic risk and avoid catastrophic collapses with relatively reduced economic resources, if compared to global retrofitting strategies. This paper focuses on the selective retrofitting of two widely known buildings, that collapsed in recent years, the Pyne Gould Building and the Champlain Tower South. The Pyne Gould Building collapsed after the February 2011 New Zealand earthquake; researchers have shown how the collapse originated from a vertical discontinuity in the RC shear core of the building [3]. The Champlain Tower South collapsed in 2021 due to unknown reasons; however, poor punching shear reinforcement and insufficient design of the shear walls were among the causes investigated after the collapse [4]. This work provides a selective retrofitting strategy for the seismic-collapse retrofit of the two buildings using the Applied Element Method, AEM, approach. Thanks to the advances in computational capabilities, the AEM method allows for the development of high-refined 3D numerical models of buildings, including detailed representations of reinforcement and peculiar structural details. The non-linear dynamic analysis in the AEM solver was able to reliably represent the generation of plastic hinges, and the development of cracks, till damage propagation, and subsequent structural failure [5]. After detecting the initial structural failure of the buildings, selective retrofitting strategies were developed to avoid the initial triggering event and improve the performance of the building. After avoiding the initial structural failure, analyses showed that the two buildings could have also withstood catastrophic earthquakes such as the latest time history record from the magnitude-7.8 earthquake in Turkey.

References

- [1] BBC News, "Turkey earthquakes: Collapsed buildings investigation widens", Online article: <https://www.bbc.com/news/world-europe-64774726>, 26 February, (2023).
- [2] BBC News, "Turkey earthquake: Why did so many buildings collapse?", Online article: <https://www.bbc.com/news/world-europe-64774726>, 9 February, (2023).
- [3] Grunwald, C., Khalil, A. A., Schaufelberger, B., Ricciardi, E. M., Pellecchia, C., De Iuliis, E., & Riedel, W., "Reliability of collapse simulation – Comparing finite and applied element method at different levels" Engineering

Structures, 176, 265-278, (2018).

[4] Lu, X., Guan, H., Sun, H. et al. "A preliminary analysis and discussion of the condominium building collapse in surfside, Florida, US, June 24, 2021", Front. Struct. Civ. Eng. 15, 1097–1110 (2021).

[5] El-Mahdy, Osama & El-kasaby, El-sayed & Abusafa, Hala & Elgamal, Amr, "Application of AEM in Progressive Collapse Dynamics Analysis of R.C. Structures", The Civil Engineering Journal. 3, 315-332, (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Threat-dependent and Threat-independent Progressive Collapse Study: Analogy and Contrast in Methodology and Results

Authors: Foad Kiakojouri^{*1}, Valerio De Biagi¹, Bernardino Chiaia¹

¹ *Department of Structural, Geotechnical and Building Engineering (DISEG) - Politecnico di Torino, Torino, Italy*

Keywords: Progressive collapse, Robustness, Frame structure, Initial failure, Blast, Impact

Abstract

Progressive collapse is a term used to describe the failure of a structure due to the failure of a single or a few structural elements, which then leads to the cascading failure of other elements. This can result in the collapse of the entire structure or a significant portion of it [1]. Progressive collapse can occur due to various natural and anthropogenic hazards like explosion, fire, impact, and earthquake. While a real collapse scenario occurs necessarily under a specific threat, current approach for structural design is threat-independent [2, 3]. In the threat-independent methodology, the acting threat is ignored, and instead the emphasis is put on the structural performance after an initial failure. This initial failure is usually assumed as a single column loss. This assumption can lead to underestimation or overestimation in structural response based on the acting threat. In other words, a single and sudden column loss is only possible under very specific circumstances, i.e., a local extreme events like a high-speed impact or a near-field small blast scenario [1]. In other scenarios, different levels of inaccuracy are inevitable. While the body of the literature still focuses on the threat-independent methods, the differences between two philosophies are already highlighted [4].

The current study tries to highlight these differences and explain the involved mechanisms. To this aim, structural performance and progressive collapse response of steel moment-resisting frames are considered. Both threat-independent and threat-dependent approaches are contemplated. For the former, dynamic column removal based on the code recommendation is performed. For the latter, the model structures are analyzed under different blast and impact scenarios. Several cases i.e., different stand-off distances and explosive charge weights for blast scenarios, and various velocities and weights for the impact scenarios, are considered. The results of threat-dependent blast- and impact-induced progressive collapse analyses reveal that the progressive collapse response in threat-dependent methodology can be meaningfully different, both in quantity and quality, compared with the one obtained by code-based threat-independent approach. The maximum response of the former can be larger or smaller referring to the threat-independent method.

References

- [1] Kiakojouri, F., Sheidaii, M. R., De Biagi, V., & Chiaia, B. (2021). Progressive collapse of structures: A discussion on annotated nomenclature. *Structures*, 29, 1417-1423.
- [2] Kiakojouri, F., De Biagi, V., Chiaia, B., & Sheidaii, M. R. (2020). Progressive collapse of framed building structures: Current knowledge and future prospects. *Engineering Structures*, 206, 110061.
- [3] Kiakojouri, F., De Biagi, V., Chiaia, B., & Sheidaii, M. R. (2022). Strengthening and retrofitting techniques to mitigate progressive collapse: A critical review and future research agenda. *Engineering Structures*, 262, 114274.
- [4] Kiakojouri, F., Sheidaii, M. R., De Biagi, V., & Chiaia, B. (2021). Blast-induced progressive collapse of steel moment-resisting frames: Numerical studies and a framework for updating the alternate load path method. *Engineering Structures*, 242, 112541.

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Title: Progressive collapse resistance mechanism and design method considering RC beams, floor slabs and infill walls

Author(s): Shuang Li¹, Sidi Shan², Haoran Wang³

¹ School of Civil Engineering, Harbin Institute of Technology, Harbin, China, shuangli@hit.edu.cn,

² School of Resources and Civil Engineering, Northeastern University, Shenyang, China, shansidi@163.com

³ School of Civil Engineering, Harbin Institute of Technology, Harbin, China, haoranwang2019@163.com

Keyword(s): progressive collapse; RC frame; beam; floor slab; infill wall

Abstract

This study aims to present practical calculation models to predict the deformation capacity and the progressive collapse resistance of reinforced concrete (RC) frames for design purpose. It is well known that beams, floor slabs and infill walls have significant contributions to progressive collapse resistance of RC frame structures. Considering contributions from RC beams, floor slabs and infill walls, calculation models are proposed based on the summary of available experimental phenomena and data in existing studies. It is shown that the proposed calculation models give acceptable predictions to experimental and numerical data, which can be used as alternative methods for evaluations of RC frame structures in the collapse-resistance design. Specifically, (1) A criterion was proposed to estimate the deformation capacity of RC frame structures under progressive collapse scenarios; (2) A criterion was proposed to estimate the vertical displacement of beams corresponding to their maximum loading capacity during compressive arch action stage. By using this criterion, an analytical model was developed to predict the progressive collapse resistance of RC beams during the compressive arch action stage; (3) Analytical methods were proposed to predict contributions of floor slabs and infill walls to the resistances of RC frames against progressive collapse, respectively; (4) A reduction factor was proposed to consider the influence of openings in infill walls on the progressive collapse resistance of infilled frame

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Palermo, Italy, August 27 - 30, 2023

Title: Multi-phase Image Degradation Modelling and Abnormal Detection based on Change-Point Spatio-Temporal Process (CP-STP)

Author(s): Munwon Lim^{*1} and Suk Joo Bae¹

¹ Department of Industrial Engineering, Hanyang University, Seoul, Korea, moonmunwon@psm.hanyang.ac.kr

Keyword(s): Change-point detection, bi-phase degradation modeling, image processing, stochastic process, abnormal detection

Abstract

With the development of smart factory technology, data-based maintenance systems that automatically control production processes are being developed. In general manufacturing, the performance of production equipment gradually degrades due to the wear or the deterioration of equipment. Recently, condition-based maintenance (CBM) based on degradation modelling has been developed to focus on real-time diagnosis for production process using the obtained data from sensors. To describe the deterioration and detect the abnormality in manufacturing process, degradation model-based optimal maintenance plan should be established. In this paper, we propose image-based degradation modelling and condition-based maintenance scheme via change-point spatio-temporal process (CP-STP). To explain the multi-phase degrading pattern in both of normal and abnormal state, image-based degradation modelling based on stochastic process is conducted. At the same time, the change-point distinguishing the production status is estimated. According to the real data application in automobile production industry, the proposed monitoring scheme effectively detects the change point from in- to out-of-control state and replacement time for manufacturing tools.

References

- [1] Fang X., Paynabar, K., and Gabraeel, N., "Image-based Prognostics using Penalized Tensor Regression", *Technometrics*, 61(3), 369-384.
- [2] Sigrist, F., Künsch, H. R., and Stahel, W. A., "Stochastic partial differential equation based modelling of large space-time data sets", *Journal of the Royal Statistical Society. Series B (Statistical Methodology)*, 77(1), 3-33.
- [3] Majumdar, A., Gelfand, A. E., and Banerjee, S., "Spatio-temporal change-point modeling", 130, 149-166.

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Title: Neural Network based reliability analysis of pipelines with randomly distributed internal corrosion.

Author(s): Michael Olatunde^{*1,2}, Srinivas Sriramula², Amir M Siddiq², Alfred R Akisanya²

¹ *National Decommissioning Centre, University of Aberdeen, Newburgh AB41 6AA, United Kingdom, m.olatunde.20@abdn.ac.uk*

² *School of Engineering, University of Aberdeen, Aberdeen AB24 3UE, United Kingdom.*

Keyword(s): Collapse pressure; pipelines; uncertainty; reliability analysis; artificial neural networks

Abstract

Low carbon steel pipelines deteriorate with time and widespread random corrosion of carbon steel has been well reported [1]. The performance of such pipelines is affected by the uncertainties in geometric, material and loading parameters. In understanding the reliability of the pipelines, a clear pathway to failure modelling is essential. The development of closed form analytical functions for determining the characteristic collapse pressures of pipelines subject to randomly distributed internal corrosion defects is impractical because of the geometrical complexities involved [2]. Surrogate models developed with regression analysis can be used but with the disadvantage of comparative high-cost functions (mean square errors) in some instances. Artificial Neural Networks (ANN) on the other hand can be used to develop more suitable surrogate models which can be readily utilised for reliability analysis [3]. In this work, response surface data of collapse pressure from the finite element analysis of a pipeline with randomly distributed internal corrosion defects is used to develop an ANN model which is applied to perform reliability analysis. The results reveal that the reliability of deteriorating pipelines subject to random corrosion is underestimated if a uniform corrosion is assumed. This method of performing reliability analysis provides a more economical and practical alternative for complex structures than the traditional approaches which require multiple expensive simulations for each analysis instance.

References

- [1] Y. Zhu, X. He, W. Liu, W. Guan, M. Zhao, and J. Zhang, "Ultimate strength of cylindrical shells with corrosion damage: Comparing theoretical and experimental results," *International Journal of Pressure Vessels and Piping*, vol. 202, 104888, 2023.
- [2] A. H. Elhewy, E. Mesbahi, and Y. Pu, "Reliability analysis of structures using neural network method," *Probabilistic Engineering Mechanics*, vol. 21, no. 1, pp. 44–53, 2006.
- [3] M. E. Tawfik, P. L. Bishay, and E. E. Sadek, "Neural network-based second order reliability method (NNBSORM) for laminated composite plates in free vibration," *CMES - Computer Modeling in Engineering and Sciences*, vol. 115, no. 1, pp. 105–129, 2018.

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Palermo, Italy, August 27 - 30, 2023

Title: A Graph Neural Network-Based Model for Elastic Structural Analysis

Author(s): Ling-Han Song^{*1}, Chen Wang², Jian-Sheng Fan³

¹ *Department of Civil Engineering, Tsinghua University, Beijing, China, songlh19@mails.tsinghua.edu.cn.*

² *Department of Civil Engineering, Tsinghua University, Beijing, China, qtwjy309@163.com.*

³ *Department of Civil Engineering, Tsinghua University, Beijing, China, fanjsh@tsinghua.edu.cn.*

Keywords: structural system; structural analysis; graph neural network; deep learning

Abstract

With the growing need for innovative analytical approaches in the field of civil engineering, this study proposes a physics-informed model named SAGNN that uses graph neural network architecture to perform elastic analysis of structural systems. The model is designed to explore appropriate data representation scheme, address the paucity of labelled data and provide physical interpretability of computation process, therefore establishing a universal deep learning-based analytical framework for arbitrary structures composed of bar members. First, the main characteristics of the concerned field and the limitations of typical neural networks in capturing structural features are summarized. As a result, topologies and member configurations are represented as graph data and processed using a modified graph isomorphism network. The method accurately retains the non-seriality and non-transitional-invariance features of complex structures. Next, the model incorporates mechanics into deep learning through a physics-informed paradigm to guarantee the theoretical correctness of the results and avoid laborious data labelling work. Numerical experiments and ablation studies demonstrate that SAGNN achieves high accuracy and considerable computational efficiency for large-scale frame structures, surpassing conventional neural networks. For further application, the model has potential in developing new methods for end-to-end structural optimization and building high-fidelity digital twins of structure systems.

References

- [1] Salehi H., Burgueño R., "Emerging artificial intelligence methods in structural engineering". *Engineering Structures*, 171, 170-189, (2018).
- [2] Xu K., Hu W., Leskovec J., et al., "How Powerful are Graph Neural Networks?." in *Proceedings of International Conference on Learning Representations*, New Orleans, May 6th - May 9th, (2019).
- [3] Wang C., Song L., Fan J., "End-to-End Structural analysis in civil engineering based on deep learning". *Automation in Construction*, 138, 104255, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Reliability-based sizing optimization of an exhibition center

Authors: Luca Rizzian*¹, Mariapia Marchi¹

¹ *Engineering & Support, ESTECO SpA, Trieste, Italy, rizzian@esteco.com*

² *Numerical Methods, ESTECO SpA, Trieste, Italy, rizzian@esteco.com*

Keyword(s): Multiobjective design optimization, Optimization under uncertainty, Civil engineering design process automation, Sizing optimization

Abstract

In contrast to the common practice of over-sizing, the use of design optimization since in the early design phases of Civil Engineering is beneficial. Indeed, it allows one to consider one or more objectives and constraints at the same time and to find an optimal sizing of the structures with a reduction of realization costs while preserving the structure stability and safety.

The benefits of such a process are shown in this paper by an example: the design optimization of an exhibition center made of prefabricated columns and wall panels, and a coverage made of prestressed reinforced concrete elements.

We took into account the structural loads and combination coefficients prescribed by the Italian law NTC2018. We carried out a multiobjective sizing optimization under uncertainty with the optimization and integration software platform modeFRONTIER combined with the finite-element software SAP2000. As an optimizer we used the in-house multi-strategy self-adapting optimization algorithm pilOPT[1]. First, we carried out a deterministic sizing optimization to minimize the maximum vertical displacement of the v-shaped sections of the roof, the overall area of the tendons in a v-shaped beam, and the total weight of the columns. The optimal solutions found with this method clearly show the conflicting nature of the three objectives. Then, we performed a Reliability-Based Design Optimization (RBDO) using polynomial chaos methods [2] starting from a subset of the optimal solutions found with the deterministic optimization as initial population for pilOPT. The goal was to assess the effect of an uncertain snow load and tendon pre-tension loads. In terms of objective values, we did not observe a dramatic change w.r.t. the values found with the deterministic optimization, but an a-posteriori validation showed that the solutions found with RBSO proved to respect the reliability constraints, whereas the solutions found with the deterministic optimization show no guarantee of reliability.

References

- [1] Costanzo, S., Xue, Z., Engel, M., Chuang, CH., "MultiStrategy Intelligent Optimization Algorithm for computationally expensive CAE simulations", NAFEMS World Congress, (2015)
- [2] Léger, N., Rizzian, L., Marchi, M., "Reliability-based design optimization of reinforced concrete structures with elastomeric isolators", *Procedia Engineering*, 199, 1193–1198, (2017)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Parametric design and structural optimization of arches with the Estimation of Distribution Algorithm (EDA)

Author(s): Jonathan Melchiorre^{*1}, Amedeo Manuello¹, Marco Martino Rosso¹, Vincenzo Morganti¹, Gabriele Rosi¹ and Giuseppe Carlo Marano¹.

¹ DISEG, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy,
*jonathan.melchiorre@polito.it, amedeo.manuellobertetto@polito.it, marco.rosso@polito.it,
morgantivincenzo@gmail.com, gabrielerosi93@gmail.it, giuseppe.marano@polito.it

Keyword(s): Structural Optimization, Arch, Metaheuristic algorithms, Parametric design, Grasshopper

Abstract

In recent decades, the architecture, engineering, and construction (AEC) industry has placed increasing emphasis on sustainability and efficiency due to the substantial consumption of resources. To achieve performance targets with minimal use of structural material, efficiency is a primary requirement for designing large-scale structures. The advent and development of computational tools have led to the widespread use of mathematical computation-based structural optimization as a method for designing sustainable and efficient buildings. However, due to the complexity of optimization problems, classical and traditional techniques may not always yield an optimal solution efficiently. Metaheuristic algorithms have therefore become increasingly prevalent, particularly in the engineering field, as they can be applied to a broad range of situations. This study investigates the efficacy of several metaheuristic algorithms, including Genetic Algorithm (GA), Simulated Annealing (SA), and Estimation of Distribution Algorithm (EDA) [1], in solving size and shape optimization problems. A parametric arch structure is used as a case study [2,3], and numerical results are obtained by minimizing structural weight and imposing a constraint on the Von Mises stresses along the arch. The study employs three single-objective algorithms, and the performance of each is objectively evaluated. The parametric modelling, structural analysis, and optimization phases are completed entirely in the virtual environment provided by Rhino, Grasshopper, Karamba, and Galapagos software packages. These interoperable software packages are selected for their high versatility, customizability, and widespread use in engineering and architecture offices, making the procedures and results of this study useful to design practitioners.

References

- [1] Rosso, Marco Martino, et al. "Estimation of distribution algorithm for constrained optimization in structural design." WCCM-APCOM 2022 900 (2022).
- [2] Melchiorre, J., et al. "Differential formulation and numerical solution for elastic arches with variable curvature and tapered cross-sections." *European Journal of Mechanics-A/Solids* 97 (2023): 104757.
- [3] Melchiorre, Jonathan, Amedeo Manuello Bertetto, and Giuseppe Carlo Marano. "Application of a machine learning algorithm for the structural optimization of circular arches with different cross-sections." *Journal of Applied Mathematics and Physics* 9.5 (2021): 1159-1170.

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Palermo, Italy, August 27 - 30, 2023

Title: Reliability-based structural optimization framework for seismic retrofitting of non-ductile reinforced concrete frame structures

Author(s): Antonio P. Sberna^{*1}, Angshuman Deb², Fabio Di Trapani³, Joel P. Conte⁴

¹*Department of Structural, Geotechnical, and Building Engineering, Politecnico di Torino, Turin, Italy, antonio.sberna@polito.it*

²*Department of Structural Engineering, University of California San Diego, San Diego, United States of America, adeb@eng.ucsd.edu*

³*Department of Structural, Geotechnical, and Building Engineering, Politecnico di Torino, Turin, Italy, fabio.ditrapani@polito.it*

⁴*Department of Structural Engineering, University of California San Diego, San Diego, United States of America, jpconte@ucsd.edu*

Keywords: performance-based earthquake engineering, performance-based seismic design, seismic retrofitting, existing structures, structural optimization.

Abstract

Despite being initially developed for seismic safety assessments, the Pacific Earthquake Engineering Research Center's (PEER) performance-based earthquake engineering (PBEE) framework has recently sparked scientific interest in the development of novel performance-based seismic design (PBSD) frameworks. Notable applications have been developed, particularly for new building design [1] and, more recently, for bridge design [2]. In recent years, there has been a noticeable increase in interest in the design of seismic retrofit for existing structures.

Although the full-fledged parametric PBSD method has proven to be a powerful tool for the design of multiple risk-based performance objectives in this framework, it is so computationally demanding that it does not appear to be easily feasible for real-world applications.

This study proposes using an optimization framework to determine the boundary of the feasible design domain without performing a full-fledged parametric performance assessment of the design parameter space. The optimization method takes into account both seismic performance and the retrofitting costs of non-seismic reinforced concrete frame structures. mean return period (MRP) of exceeding at least one limit state (LS) in a selected set of several limit states is considered the seismic performance metric. The optimization procedure seeks the optimal retrofit topology and component sizing for which all MRPs of limit state exceedances are greater than the corresponding target MRP while having the lowest cost. The results will demonstrate that the proposed optimization procedure can effectively use soft computing [3] for the application of performance-based seismic retrofit design in a computationally efficient framework without significant accuracy loss.

References

- [1] Deb A., Zha A.L., Caamaño-Withall Z.A., Conte J.P., Restrepo J.I., "Simplified Risk-Targeted Performance-Based Seismic Design Method for Ordinary Standard Bridges", J Bridge Eng, 27, 04022089, (2022).
- [2] Franchin P., Petrini F., Mollaioli F., "Improved risk-targeted performance-based seismic design of reinforced concrete frame structures", Earthquake Eng Struct Dyn, 47, 49–67, (2018).
- [3] Di Trapani F., Sberna A.P., Marano G.C., "A genetic algorithm-based framework for seismic retrofitting cost and expected annual loss optimization of non-conforming reinforced concrete frame structures", Computers & Structures, 271, 106855, (2022).

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Title: Interpretable Machine-Learning Models for Damage Assessment and Predicting Maximum Displacements in RC Beams Under Impact Loading

Author(s): Cristoforo Demartino¹ and Dade Lai^{1,2}

¹ Zhejiang University - University of Illinois at Urbana Champaign Institute, 718 East Haizhou Road, Haining, 314400 Zhejiang, PR China

² College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, 310058 Zhejiang, PR China

Keyword(s): Machine learning (ML); Interpretation models; RC beam; Maximum displacements; Stacking model; SHapley Additive exPlanation (SHAP).

Abstract

Estimating the maximum displacements of RC beams subjected to impact loads is crucial for defining demand models in structural design [1]. However, the dynamic behavior is complex, and obtaining maximum displacements through experimental tests or high-fidelity FEM models can be challenging. Simplified analytical models with few degrees of freedom often have low accuracy. This paper presents a machine-learning model that strategically combines multiple algorithms for improved accuracy in estimating maximum displacements.

A comprehensive database of 342 samples of rectangular simply supported beams under rigid impact loads is used for model training. Seven machine learning regression algorithms are employed: Support Vector Regression (SVR), Gaussian Process Regression (GPR), Random Forest Regressor (RFR), XGBoost, CatBoost, LightGBM, and Artificial Neural Networks (ANN). A stacking model combining SVR, GPR, RFR, XGBoost, CatBoost, and ANN is built to enhance accuracy, using 75% of the data for training and 25% for validation, in conjunction with 5-fold cross-validation. This approach achieves approximately 90% validation accuracy, surpassing current mechanics-based/semi-empirical models. The SHapley Additive exPlanations (SHAP) algorithm is utilized to estimate the relative importance of input features, identifying impact velocity and impactor mass as the most influential factors. A full parametric analysis is provided, discussing the influence of each input. The model is then applied to perform a structural check for three damage levels. The proposed model offers a reliable estimation of maximum displacements for RC beams under impact loading, making it suitable for practical applications.

In addition to estimating maximum displacements, this study also explores the application of the machine learning model for damage classification in RC beams under impact loading. By analyzing different damage levels, the model aids in understanding the severity of the structural damage and helps engineers to make informed decisions regarding necessary repairs or reinforcements. The classification of damage levels provides valuable insights into the structural behavior and allows for more targeted and efficient interventions, ultimately enhancing the safety and performance of RC beams under various impact load scenarios.

References

[1] Lai, D., Demartino, C., & Xiao, Y. (2023). Interpretable machine-learning models for maximum displacements of RC beams under impact loading predictions. *Engineering Structures*, 281, 115723.

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Title: A derivative-free directionality-based paradigm for solving inverse problems: Application in structural engineering.

Author(s): Saikat Sarkar^{*1}

¹ *Department of Civil Engineering, Indian Institute of Technology Indore, India, Email address- saikat.mailbox@com, saikat@iiti.ac.in*

Keyword(s): Particle filtering, Evolutionary optimization, Structural health monitoring and damage detection, Parameter estimation, Truss optimization.

Abstract

Inverse problems, e.g. structural health monitoring and damage detection, constitutive parameter estimation etc. are among the major challenges in structural engineering. These problems are typically large dimensional and/or nonconvex in nature, plagued with uncertainty and sparse data. Towards addressing such issues, we propose and explore efficient inverse algorithms within particle filtering and optimization frameworks. An important aspect in these algorithms is the proposal of a derivative-free directionality term, which is derived by effecting an appropriate change of measures.

First, we propose a novel Monte Carlo (MC) particle filter with strictly additive updates, which attempts at driving the measurement-prediction misfit to a zero-mean martingale by effecting a change of measure. Such additive update-based strategy eliminates the bottleneck of particle impoverishment, often experienced by the conventional weight-based particle filters. Performance of the proposed filter is numerically assessed against large dimensional nonlinear filtering problems, e.g. state-parameter estimation and damage detection in structures [1].

The notion of change of measure is further exploited in the proposal of novel evolutionary optimization paradigm within a Monte Carlo setup. Solutions are guided mainly through the derivative-free directional information such that the design variables behave like martingale at an extremal point. In order to preempt possible stalling at local extrema, layers of random perturbation of the martingale problem, herein called the 'scrambling' and 'coalescence' strategies, are also suggested. As demonstrated via numerical exercises, the approach appears to substantively improve upon the performance of many of the most well known evolutionary schemes. The proposed scheme, which we call as change of measure-based evolutionary optimization (COMBEO) is also applied to the problem of buckling-restrained optimization of truss structures [2,3,4].

References

- [1] S Sarkar, SR Chowdhury, M Venugopal, RM Vasu, D Roy, "A Kushner–Stratonovich Monte Carlo filter applied to nonlinear dynamical system identification", *Physica D: Nonlinear Phenomena* 270, 46-59, 2014.
- [2] S Sarkar, D Roy, RM Vasu, "A perturbed martingale approach to global optimization", *Physics Letters A* 378 (38-39), 2831-2844, 2014.
- [3] S Sarkar, D Roy, RM Vasu, "A global optimization paradigm based on change of measures", *Royal Society Open Science* 2, 150123, 2015.
- [4] T Venkatesh Varma, S Sarkar, G Mondal, "Buckling restrained sizing and shape optimization of truss structures", *Journal of Structural Engineering* 146 (5), 04020048, 2020.

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Title: Reinforcement learning for the rational design of metamaterials: applications to wave control and energy harvesting

Author(s): Luca Rosafalco¹, Jacopo M. De Ponti², Luca Iorio³, Richard V. Craster^{4,5,6}, Alberto Corigliano⁷, Raffaele Ardito^{*8}

¹ Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy, luca.rosafalco@polimi.it

² Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy, jacopomaria.deponti@polimi.it

³ Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy, luca.iorio@polimi.it

⁴ Department of Mathematics, Imperial College London, London, United Kingdom, r.craster@imperial.ac.uk

⁵ Department of Mechanical Engineering, Imperial College London, London, United Kingdom

⁶ Abraham de Moivre International Research Laboratory, Imperial College London, London, United Kingdom

⁷ Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy, alberto.corigliano@polimi.it

⁸ Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy, raffaele.ardito@polimi.it

Keyword(s): structural optimisation; Markov decision process; reinforcement learning; metamaterials; energy confinement and amplification, energy harvesting.

Abstract

A Reinforcement Learning (RL)-based approach for optimal design search is illustrated. First, the structural optimisation problem, tackled in a mechanical and in a multiphysics domain, is formalised in a Markov decision process [1]. Then, the design space is constrained by exploiting physical information on the problem. Finally, an actor-critic RL algorithm, namely the proximal policy optimisation algorithm, is applied to discover the sequence of decisions leading to the best design. Due to its gradient-free nature, the employed optimisation strategy can simultaneously handle continuous and discrete dependence on the design parameters. The procedure has been applied to the optimal design of a graded metamaterial consisting of a waveguide with attached a set of beam-like resonators of variable length. Two goals have been separately pursued. First, the length, spacing and number of resonators have been calibrated to maximise the confinement and amplification of the mechanical energy of a flexural wave [2]. Second, a multiphysics setting has been addressed by equipping each resonator with a piezoelectric patch, and by requiring to maximise the electrical power harvested from random vibrations [3]. In both cases, the metamaterial performance has been enhanced by unexpected designs that have found a clear physical interpretation.

References

- [1] Ororbia M.E., Warn G.P., "Design synthesis through a Markov decision process and reinforcement learning framework", J. Comput. Inf. Sci. Eng., 22(2), 021002, (2021).
- [2] Rosafalco L., De Ponti J.M., Iorio L., Ardito R., Corigliano A., "Optimised graded metamaterials for mechanical energy confinement and amplification via reinforcement learning", Eur. J. Mech. A Solids, 99, 104947, (2023).
- [3] Rosafalco L., De Ponti J.M., Iorio L., Craster R.V., Ardito R., Corigliano A., "Reinforcement learning optimisation with variance reduced by physical information: design of graded metamaterials for energy harvesting", submitted.

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Title: System Identification and Model Updating of Cross-Laminated Timber Floating Floors

Author(s): Thomas Furtmüller¹, Michael Kawrza², Christoph Adam³

¹ Unit of Applied Mechanics, Universität Innsbruck, Innsbruck, Austria, thomas.furtmueller@uibk.ac.at

² Unit of Applied Mechanics, Universität Innsbruck, Innsbruck, Austria, michael.kawrza@uibk.ac.at

³ Unit of Applied Mechanics, Universität Innsbruck, Innsbruck, Austria, christoph.adam@uibk.ac.at

Keyword(s): Cross-laminated timber, non-classically damped system, experimental modal analysis, system identification, model updating

Abstract

Floors in residential or commercial buildings are often prone to vibrations and/or excessive footfall sound transmission, particularly lightweight systems such as timber floors. For assessing the effect of structural changes to mitigate these problems, numerical methods such as finite element simulations can be used, provided the numerical model is accurate. To this end, model updating based on experimental data typically is performed.

In this contribution cross-laminated timber floors augmented by a floating floor consisting of a resilient layer and a screed plate, representing a common flooring setup, are addressed. From this structural setup, experimental data is obtained by experimental modal analysis.

System identification for these types of floors is complicated by the fact that typically only a few modes can be identified in the low-frequency range while for higher frequencies, the highly viscous sound insulation layer yields a behavior where individual modes cannot be distinguished. Therefore, a combination of modal quantities (natural frequencies, mode shapes) and frequency response function envelopes is used.

For model updating of floors, typically a number of stiffness as well as mass properties are unknown. By means of Bayesian model updating, it is shown that for these cases, model updating solely based on modal quantities yields ambiguous results. In this contribution, the so-called cross-signature correlation is used, representing a measure of fit based on frequency response function data.

In practice, experimental data is typically only available at the surface of the screed, but not on the timber plate. In view of this incomplete data, numerical simulations are conducted to investigate the number of necessary mass and stiffness properties which have to be known such that system identification yields unambiguous results.

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Title: Structural identification of a hospital building under unknown excitation induced by air conditioning systems and elevators

Author(s): C. Rinaldi¹, A. Talebi¹, F. Potenza², V. Gattulli¹

¹ *Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, cecilia.rinaldi@uniroma1.it, aliasghar.talebi@uniroma1.it, vincenzo.gattulli@uniroma1.it*

² *Department of Engineering and Geology, University of Chieti-Pescara, Pescara, Italy, francesco.potenza@unich.it*

Keyword(s): Operational modal analysis, dynamic testing, model updating, artificial neural network

Abstract

In vibration-based structural health monitoring, the measurement of the dynamic response under ambient excitation allows to identify modal parameters of structures through operational modal analysis procedures. In some cases, vibrations induced by mechanical equipment could make the process of structural identification more difficult. This contribution aims to investigate the identification of the natural frequencies of the “Cardinal Massaia” hospital in Asti (Italy) based on vibrations measurement induced by air conditioning systems and elevators. First, depending on the location of sensors, the signals acquired have been classified in several groups and, through the evaluation of their power spectral density, a primary observation of the influence of the machinery have been described. Then, a numerical dynamic analysis has been conducted to obtain acceleration time series response under white noise excitation and to train a neural network model for further investigation on the measured accelerations. Indeed, the network trained on numerical model results under white noise excitation is applied to experimental data and an increasing prediction error related to the influence of the air conditioning system and elevator frequencies has been observed. Therefore, the performance of the network prediction can be considered a suitable indicator in determining the experimental signals affected by colored noise excitation. Finally, further considerations concerning the use of harmonic removal methods in measured signals have been illustrated.

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Palermo, Italy, August 27 - 30, 2023

Title: A reliable low-cost structural health monitoring system based on Siemens IOT 2020

Author(s): Francesco Maria Raimondi^{*1}, Gaetano D'Alessandro², Francesco Oddo³

¹ Department of engineering, University of Palermo, Palermo, Italy, francescomaria.raimondi@unipa.it

² Department of engineering, University of Palermo, Palermo, Italy, gaetano.dalessandro05@community.unipa.it

³ Department of engineering, University of Palermo, Palermo, Italy, francesco.oddo@community.unipa.it

Keyword(s): structural health monitoring, real time acquisition, long term evolution

Abstract

Monitoring systems play a key role in supervising, controlling and monitoring the state of health of structures. In this study is proposed a very low-cost, reliable and versatile solution, different by others [1] - [2], which employs a Siemens IOT 2020 industrially certified programmable controller [3], linked to a triaxial accelerometer-gyroscope-magnetometer [4] - [5]. The aim of this work is to perform continuous and real-time acquisition of data to generate a health report to ensure the longevity of civil, historic buildings and industrial infrastructures. This objective is carried out with the possibility to expand the system integrating more sensors and, furthermore, remote acquisition is possible through the built-in LAN network in the programmable controller. This paper is supported by experimental tests which demonstrate the system's extraordinary flexibility and ease of installation. The system's software, used for data acquisition and processing, performs a reliability index for the structure under investigation. This system is currently patent pending.

References

- [1] T. D. Tan, N. T. Anh and G. Q. Anh, "Low-cost Structural Health Monitoring Scheme Using MEMS-based Accelerometers," 2011 Second International Conference on Intelligent Systems, Modelling and Simulation, Phnom Penh, Cambodia, (2011).
- [2] A. Toscani et al., "Low-cost Structural Health Monitoring System for Smart Buildings," 2022 Second International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART), Cassino, Italy, (2022).
- [3] SIEMENS, "SIMATIC IOT2020, SIMATIC IOT2040", (2022).
- [4] A. Guercio, D. M. Kumar, M. Cirrincione, F. M. Raimondi, A. Montalbano and V. Frazitta, "Improvement of a low-cost buoy for the measurement of the sea wave weather," OCEANS 2021: San Diego – Porto, San Diego, CA, USA, (2021).
- [5] STMicroelectronics, "iNEMO inertial module:LSM9DS1." (2015).

EMI 2023 International Conference

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Title: Truncated Unscented Kalman Filter for Incorporating Constraints in Joint State-Parameter Estimation

Author(s): Adrita Kundu^{*1}, Suparno Mukhopadhyay²

¹ *Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, adkundu@iitk.ac.in*

² *Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, suparno@iitk.ac.in*

Keyword(s): Truncated Unscented Kalman Filter, Joint state-parameter estimation, Constraints, Bouc-Wen hysteresis, Damage assessment, Train-bridge system

Abstract

In joint state-parameter estimation using the Unscented Kalman Filter (UKF), considerable tuning of the initial state vector and covariance matrices may be required to ensure proper convergence. Constraints on the parameters, e.g. bounds on stiffness values, which may be known a priori from physics or engineering judgement, can be incorporated to have improved and more controlled convergence. In this work, the Truncated Unscented Kalman Filter (TUKF) is introduced to handle such constraints within the UKF framework. The constraints are enforced by appropriately truncating the conditional posterior probability density functions of the system states. The method is illustrated using two different class of systems: 1) shear frames with hysteretic Bouc-Wen elements exhibiting degradation and pinching; and 2) train-bridge systems, which can behave as linear time-varying systems because of the moving heavy train masses. Numerical examples are used to illustrate the robustness of the TUKF against noisy measurements and high uncertainty in the initial state vector. For the hysteretic models, it is shown that a complex model class may lead to numerical instabilities or incorrect estimation of some states. This might be possibly owing to insensitivity or unidentifiability associated with the model parameters. However, in such cases, assuming a simplified, albeit inaccurate model class, can still lead to tracking of the resultant hysteretic forces and dynamic states (displacement and velocities) with high accuracy. Further, shake table tests on a reinforced concrete frame, progressive damaged using inputs of increasing amplitude, are used to illustrate the effectiveness of the method in assessing the level of damage through estimated damage indices. For the train-bridge system also, the method is illustrated using experimental data from a lab-scale two-span continuous bridge, excited using a moving train. Overall, the results show that the TUKF improves on the convergence of the UKF, while maintaining the same level of accuracy in the state and parameter estimates.

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Title: Observing Fracture of Brittle Materials

Author(s): Xiaoran Wang¹, Luigi Biolzi², Joseph Labuz^{*3}

¹ School of Safety Engineering, China University of Mining and Technology, Xuzhou 221116, China

² Department of Structural Engineering, Politecnico di Milano, Milano, 20133, Italy

³ Department of Civil, Environmental, and Geo- Engineering, University of Minnesota, Minneapolis, 55455, USA

Keyword(s): acoustic emission, microcracking, moment tensor, source mechanisms

Abstract

Three-point bending experiments were performed in a closed-loop, servo-hydraulic load frame to observe mode I fracture in a series of geometrically similar, center-notched rectangular beams composed of either Sioux quartzite [1] or borosilicate glass. Sioux quartzite consists almost entirely of tightly packed quartz, grain size = 0.2 – 0.6 mm, with the following properties: density $\rho = 2630 \text{ kg/m}^3$, Poisson's ratio $\nu = 0.13$, Young's modulus in compression $E_c = 70.0 \text{ GPa}$, Young's modulus in tension $E_t = 55.0 \text{ GPa}$, P-wave velocity $c_p = 5.4 \text{ km/s}$, with elastic anisotropy less than 2%; uniaxial compressive strength = 336 MPa, flexural tensile strength = 33 MPa, fracture toughness $K_{Ic} = 2.0 \text{ MPa-m}^{0.5}$. Borosilicate glass is typically composed of 80% silica, 10% boric oxide, and other oxides (sodium or potassium and aluminium oxides) with the following properties: $\rho = 2210 \text{ kg/m}^3$, $\nu = 0.17$, $E = 72.0 \text{ GPa}$, $c_p = 5.95 \text{ km/s}$, $K_{Ic} = 0.8 \text{ MPa-m}^{0.5}$. A precracking procedure [2] was successfully implemented on four glass specimens. Fracture was monitored using acoustic emission (AE) and digital image correlation techniques and controlled crack growth was achieved by prescribing a constant rate of crack opening displacement as the feedback signal. Analyses involved AE rates, AE locations, and AE source mechanisms, along with DIC results that support the AE statistics. Through calibration of the amplitude sensitivity for each AE sensor, the kinematics, orientation, and magnitude (energy) of the microcracks were determined from the moment tensor consistent with a displacement discontinuity (crack-only) model [1]. The fracture processes of both material showed crack details such as microcrack mechanisms that were mixed-mode locally but the displacement resultants were consistent with mode I opening fracture.

References

- [1] Wang X, Asem P, Hu C, Labuz JF. 2021. Microcracking in tensile fracture of a brittle rock. *Engineering Fracture Mechanics*, 251: 107789. doi.org/10.1016/j.engfracmech.2021.107789
- [2] Sglavo VM, Bosetti P, Trentini E, Ceschini M. 1999. Sandwiched-beam procedure for precracking brittle materials. *Journal American Ceramic Society*, 82: 2269-2272. doi.org/10.1111/j.1151-2916.1999.tb02077

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Title: Error-in-constitutive-relation framework for the characterization of viscoelastic solids

Author(s): Bojan Guzina^{*1}, Marc Bonnet², Prasannakumar Salasiya¹,

¹ Civil, Environmental and Geo- Engineering, University of Minnesota (guzin001@umn.edu, salas086@umn.edu)

² POEMS, Dept. of Applied Mathematics, ENSTA Paris, Palaiseau, France (marc.bonnet@ensta-paris.fr)

Keyword(s): Error in constitutive relation, viscoelastic material characterization, thermodynamics

Abstract

We consider an error-in-constitutive-relation (ECR) approach toward the full-field characterization of linear viscoelastic solids belonging to the class of *standard generalized materials*. To this end, we describe the viscoelastic behavior in terms of the (Helmholtz) free energy potential and a dissipation potential, each characterized by three fourth-order tensors endowed with major and minor symmetries. Assuming the availability of the full-field interior kinematic data, the constitutive mismatch between the kinematic quantities (strains and internal thermodynamic variables) and their “stress” counterparts (the Cauchy stress tensor and that of thermodynamic tensions), commonly referred to as the ECR functional, is established via the *Legendre-Fenchel (LF) gap* functionals featuring the thermodynamic potentials and their conjugates – as defined via the LF transform. We then proceed by deploying the modified ECR (MECR) functional as a linear combination of its ECR predecessor and a mismatch between the observed displacements and their simulations, computed for a trial set of constitutive parameters. Since the stress tensor must satisfy the balance of linear momentum, the analysis proceeds in a standard fashion by introducing the Lagrangian that incorporates a weak statement of the latter. The affiliated stationarity conditions then yield two coupled evolution problems, namely (i) the forward evolution problem for the (trial) displacement field driven by the *constitutive mismatch*, and (ii) the backward evolution problem for the adjoint field driven by the *data mismatch*. This allows us to establish compact expressions for the MECR functional and its derivatives with respect to the viscoelastic constitutive parameters. For generality, the formulation is established assuming both time-domain (i.e. transient) and frequency-domain data. The general material identification framework is then specialized to the classical continuum extensions of (a) standard linear solid, and (b) Zener viscoelastic model. We illustrate the developments numerically in a 2D setting by considering the full-field characterization of piecewise-homogeneous and smoothly-varying viscoelastic solids.

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Title: Generative AI for Modeling Earthquake Damage

Author(s): Vedhus Hoskere*, Reza Bazrygary, Subin Varghese

¹ *Department of Civil and Environmental Engineering, University of Houston, Texas 77098, vhoskere@uh.edu*

² *Department of Civil and Environmental Engineering, University of Houston, Texas 77098, rbazrygary@central.uh.edu*

³ *Department of Electrical and Computer Engineering, University of Houston, Texas 77098, svargh2@central.uh.edu*

Keyword(s): keywords list (Arial font – 11 point size)

Abstract

Nonlinear time-history analysis is a powerful method for simulating the behavior of structures during an earthquake. However, it can be computationally intensive, requiring significant computational resources and time to produce results. Data-driven approaches, on the other hand, can be much faster and more efficient, making them an attractive alternative for quick analysis. Generative AI has the potential to significantly improve the speed and efficiency of data-driven approaches for modeling earthquake damage. By training a generative model on a large dataset of earthquake damage images, we can generate new images of damage with different characteristics and severities. This could allow us to simulate a wide range of damage scenarios and study their effects on the behavior of structures in a short span. This can be done much faster than traditional time-history analysis, allowing for more efficient and effective design and analysis of structures in earthquake-prone areas. Generative AI could be used to replace various aspects of the analysis process. Here we conduct an exploratory study on the use of generative AI to generate image-based damaged representation of an earthquake damaged structure. Details of the methods used are presented and results are qualitatively and quantitatively analyzed.

The mechanics of a photo induced hydrogel swimming robot

Chen Xuan

Chen.xuan@xjtlu.edu.cn

¹Department of Foundational Mathematics, Xi'an Jiaotong-Liverpool University, Suzhou, 215123, China

²Leonard S. Ornstein Laboratory, Utrecht University, Princetonplein 1, 3584 CC Utrecht, The Netherlands

Certain hydrogel is light sensitive, since light provides heat and hydrogel shrinks under high temperature thus making the hydrogel photosensitive. When light shines on the hydrogel, the hydrogel shrinks and as light propagates through the hydrogel shrinks less thus bending towards the light. This hydrogel beam undergoes a vibration, a result of a competition between the elasticity of the beam and the photo induced bending. This photo induced vibration enables the hydrogel beam to swim in water. This photothermally responsive hydrogel cantilever as a model system also helps investigate the mechanism and energy flow in self-excited oscillation under a constant light source. Based on an analytical model, we show that a periodic photomoment, produced by nonuniform water concentration across the cantilever's thickness driven by diffusion, is imposed on the cantilever by the ever-switching light incidence between the top and bottom surfaces. The synergy between the photomoment and oscillation ensures positive work input to the beam when the diffusion timescale is comparable to the period of free vibration. When the input energy is higher than the damping energy, the vibration amplitude increases, while, when the input energy is lower, the amplitude decreases. Based on dimensional energy analysis, we determine the stable vibration amplitude and construct phase diagrams for the increase and decrease of the oscillation amplitude, which are further confirmed experimentally. A mass-spring-damper system subjected to a displacement dependent excitation force is developed to investigate the features in generalized self-excited oscillating systems. This work lays a solid foundation for understanding self-excited oscillation and provides design guidelines for self-sustainable soft robots.

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Title: Novel perspectives for developing rocking and overturning spectra associated with nonstructural elements housed in buildings

Author(s): Danilo D'Angela^{*1}, Gennaro Magliulo^{1,2}, and Francesco Mario Calenzo¹

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy, {danilo.dangela,gmagliul}@unina.it; c.francesco.m@gmail.com*

² *Construction Technologies Institute (ITC), National Research Council (CNR), Naples, Italy*

Keyword(s): rocking; rigid blocks; nonstructural elements; rocking spectra; seismic assessment

Abstract

The dynamics of rocking-dominated elements has been studied for several decades. The first documented studies were carried out at the end of the ninth century [1], and the groundwork of the classical theory has been laid in the seventies/eighties (e.g., [2,3]). The topic is still an object study by several research groups, as it is demonstrated by the copious recent literature [4–6]. Rocking and overturning spectra were developed in the literature [7] to supply applicative tools for expeditious assessment of rocking response, in analogy with the typical approaches based on pseudo-acceleration spectra. However, the potential of the spectral-based assessment approach has not been fully exploited, with regard to seismic inputs and elements housed within buildings.

The present study proposes an innovative approach for developing statistical-based rocking and overturning spectra associated with the response of unanchored components housed in buildings. The spectra are obtained by processing the results of an extended numerical campaign of incremental analyses [4], carried out considering multiple block geometries, representative of a wide range of component scenarios. Real floor motions are considered as loading histories, and dimensionless acceleration-based intensity measures are used. The spectral ordinates are meant as fragility parameters, and they are expressed as a function of multiple damage conditions, based on the dimensionless rocking rotation amplitude. The study provides closed-form equations expressed as a function of intensity measures, damage conditions, and block geometry. These formulations provide useful criteria for expeditious assessment of the seismic response of rocking blocks housed in reinforced concrete buildings.

References

- [1] Milne J, Gray T. On Seismic Experiments. *Philosophical Transactions of the Royal Society of London* 1882;863–83.
- [2] Housner GW. The behavior of inverted pendulum structures during earthquakes. *Bulletin of the Seismological Society of America* 1963;53:403–17.
- [3] Yim C-S, Chopra AK, Penzien J. Rocking response of rigid blocks to earthquakes. *Earthquake Engineering & Structural Dynamics* 1980;8:565–87. <https://doi.org/10.1002/eqe.4290080606>.
- [4] D'Angela D, Magliulo G, Cosenza E. Seismic damage assessment of unanchored nonstructural components taking into account the building response. *Structural Safety* 2021;93:102126. <https://doi.org/10.1016/j.strusafe.2021.102126>.
- [5] Bao Y, Konstantinidis D. Dynamics of a sliding-rocking block considering impact with an adjacent wall. *Earthquake Engng Struct Dyn* 2020;49:498–523. <https://doi.org/10.1002/eqe.3250>.
- [6] Makris N, Kampas G. Size Versus Slenderness: Two Competing Parameters in the Seismic Stability of Free-Standing Rocking Columns. *Bulletin of the Seismological Society of America* 2016;106:104–22. <https://doi.org/10.1785/0120150138>.
- [7] Makris N, Konstantinidis D. The rocking spectrum and the limitations of practical design methodologies. *Earthquake Engineering & Structural Dynamics* 2003;32:265–89. <https://doi.org/10.1002/eqe.223>.

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Title: Visco-elastic coupling of rigid blocks subjected to seismic excitation

Author(s): Alessandro Contento^{*1}, Angelo Di Egidio²

¹ College of Engineering, Fuzhou University, Fuzhou, China, alessandro@fzu.edu.cn

² DICEAA, University of L'Aquila, L'Aquila, Italy, angelo.diegidio@univaq.it

Keyword(s): Coupled rigid blocks; rocking motion; Maxwell visco-elastic device; seismic performances; gain coefficients and maps.

Abstract

In Civil Engineering several structures, or structural elements, have been studied as series or parallel coupling of rigid blocks. Usually, the coupling is intended as either a method to protect noticeable structures that behave as rigid blocks or to use rigid blocks for the improvement of the dynamic behavior of frame structures [1]. For example, some papers studied the behavior of stacked blocks [2] or blocks equipped with mass-damper dynamic absorbers [3]. In relatively recent years, the attention has been partially shifted to the seismic protection of rigid-block-like structures through external devices coupled with the rigid-block-like structure, as in [4], where the authors studied the seismic performances of blocks coupled with a hysteretic mass damper inerter. This study investigates the seismic performance of two rigid blocks coupled in parallel through a Maxwell visco-elastic device. The equations of motion are written by considering the eight different relative configurations that the blocks can assume; the transition relationships between such configurations are explicitly derived. The efficiency of the coupling is evaluated by means of gain coefficients which are defined as the ratio of the maximum rocking angles of one of the coupled blocks and the corresponding stand-alone block. Values of such gain coefficients less than unity highlight a good performance of the coupled system with respect to the stand-alone blocks. Two kinds of seismic analyses are performed using four earthquake records selected by accounting for their different spectral characteristics. The first analysis focuses on the seismic behavior of blocks with similar dimensions. As can be expected, the behavior of the coupled blocks with equal dimensions is close to that of the single stand-alone rigid blocks. However, results showed that small variations in the dimensions of one of the blocks provide a significant improvement in the seismic behavior of the coupled system. A similar dynamic behavior was already found in two equal base-isolated tower buildings connected by a viscous device, where the performance of the coupled system was significantly improved by slightly breaking the symmetry of the system [5]. The second analysis studies the possibility of improving the seismic response of a block by coupling it with another block with smaller dimensions. The coupling with a smaller block is found to be particularly effective for blocks that in the stand-alone configuration would overturn or be close to overturning.

References

- [1] Makris, N., Aghagholizadeh. M., "The dynamics of an elastic structure coupled with a rocking wall," *Earthquake Engineering & Structural Dynamics*, Vol. 46(6), page 945–962, (2017).
- [2] Spanos P.D., Roussis P.C., Politis N.P.A., "Dynamic analysis of stacked rigid blocks," *Soil Dynamics and Earthquake Engineering*, Vol.21(7), page 559-578, (2001).
- [3] Di Egidio A., de Leo A.M., Simoneschi G., "Effectiveness of mass-damper dynamic absorber on rocking block under one-sine pulse ground motion", *Int. Journal of Non-Linear Mechanics*, Vol. 98, page 154-162, (2018).
- [4] Di Egidio A., Contento A., "Improvement of the dynamic and seismic behavior of rigid block-like structures with a hysteretic mass damper coupled with an inerter," *Applied Science*, Vol.12(22), Article Id: 11527, (2022).
- [5] Di Egidio A., Zulli D., "Critical and post-critical galloping behavior of base isolated coupled towers," *Int. Journal of Non-Linear Mechanics*, Vol.134, Article Id: 103728, (2021).

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Title: Demand to capacity seismic assessment of unanchored building contents

Author(s): Gennaro Magliulo^{*1,2}, Danilo D'Angela¹, and Francesco Mario Calenzo¹

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy, {gmagliul,danilo.dangela}@unina.it; c.francesco.m@gmail.com*

² *Construction Technologies Institute (ITC), National Research Council (CNR), Naples, Italy*

Keyword(s): rocking; rigid blocks; nonstructural elements; seismic assessment; building response

Abstract

The seismic response of unanchored/freestanding nonstructural elements housed in buildings is often governed by a rocking-dominated motion. The seismic behaviour of these elements is typically extremely complex due to heavy nonlinearities and major sensitivity to multiple parameters. Rigid block modelling is often implemented to assess the seismic response of these elements, and the classical theory developed by Housner [1] and other early researchers [2,3] is still quite used in the literature after so many decades [4,5]. Despite the topic has been studied for decades, there are still several issues that have not been sufficiently addressed, and further studies should be carried out. Firstly, most studies are focused on seismic response of rocking elements subject to ground motions (e.g., monumental elements), without systematically addressing the case of building contents. Secondly, most studies investigated peculiar block geometries and did not provide results that can be potentially extrapolated or generalized. Lastly, the literature often focused on the assessment of the seismic capacity, without performing seismic safety verifications, which are based on the comparison of demand and capacity.

The present study tries to address the abovementioned limits regarding the seismic response of rocking-dominated elements, with focus on freestanding elements housed within buildings [6]. A seismic safety assessment is carried out by comparing seismic demand measures, estimated according to the latest regulation/code requirements, and seismic capacity measures, derived from incremental numerical analyses of rocking blocks [6]. The influence of the hosting buildings is considered in terms of acceleration amplification and filtering effects, as well as the record-to-record uncertainty is accounted for. The study provides quantitative measures of safety associated with a set of representative building contents, considering representative building scenarios, associated with critical facilities (e.g., healthcare facilities).

References

- [1] Housner GW. The behavior of inverted pendulum structures during earthquakes. *Bulletin of the Seismological Society of America* 1963;53:403–17.
- [2] Ishiyama Y. Motions of rigid bodies and criteria for overturning by earthquake excitations. *Earthquake Engineering & Structural Dynamics* 1982;10:635–50. <https://doi.org/10.1002/eqe.4290100502>.
- [3] Aslam M, Godden WG, Scalise DT. Earthquake Rocking Response of Rigid Bodies. *J Struct Div* 1980;106:377–92. <https://doi.org/10.1061/JSDEAG.0005363>.
- [4] Makris N, Kampas G. Size Versus Slenderness: Two Competing Parameters in the Seismic Stability of Free-Standing Rocking Columns. *Bulletin of the Seismological Society of America* 2016;106:104–22. <https://doi.org/10.1785/0120150138>.
- [5] Giouvanidis AI, Dimitrakopoulos EG. Rocking amplification and strong-motion duration. *Earthquake Engineering & Structural Dynamics* 2018;47:2094–116. <https://doi.org/10.1002/eqe.3058>.
- [6] D'Angela D, Magliulo G, Cosenza E. Seismic damage assessment of unanchored nonstructural components taking into account the building response. *Structural Safety* 2021;93:102126. <https://doi.org/10.1016/j.strusafe.2021.102126>.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Peak rotation hazard-curve comparisons of alternative rocking modelling approaches

Author(s): Christian Málaga-Chuquitaype¹

¹ *Department of Civil and Environmental Engineering, Imperial College, London, UK, c.malaga@imperial.ac.uk*

Keyword(s): rocking, hazard curve, hazard-consistent, numerical procedures)

Abstract

Rocking behaviour due to support motion is experienced by a wide range of structures, from small museum exhibits to large bridge piers. Besides, rocking can also be used as a resilient seismic isolation strategy to reduce the costs of protective systems in conventional structures. Despite their deceptively simple configuration, predicting the response of rigid rocking bodies is a challenging task complicated by an enormous sensitivity to impact and imperfections that have called into question a reliance on wholly deterministic approaches [1]. To overcome these limitations, emphasis is now shifting towards the estimation of statistical descriptors of the rocking response rather than deterministic descriptors of rotational histories. These efforts, however, need to be balanced against practical considerations of time and availability of computational resources and, importantly, have in mind the intended use of these estimations. In this context, one aspect that has been left out from the discussions is the engineering need to establish hazard consistent estimates and the influence of alternative modelling approaches on the values of these predictions. This study aims to introduce this discussion by employing a large number of response history analyses on rigid rocking blocks. Models based on the direct numerical solution of the rotational equation of motion as well as on solutions of the linear complementary problem arising from non-smooth dynamics idealizations are explored. Although the behaviour of the rocking block is known to depend on various ground-motion intensity measures, the peak ground acceleration is selected here as a first attempt to rationalize the influence of the variability of the ground motion. Seismic demands are expressed in the form of hazard curves [2,3]. The results of this study offer an initial point of view on the importance of different modelling strategies within a performance-based rocking response evaluation and the divergence of their estimates at different hazard levels.

References

- [1] Bachmann, J. A., Strand, M., Vassiliou, M.F., Broccardo, M., Stojadinović B. "Is rocking motion predictable?." *Earthquake Engineering & Structural Dynamics* 47.2, 535-552 (2018).
- [2] Arteta, C. A., Norman A. A.. "Conditional scenario spectra (CSS) for hazard-consistent analysis of engineering systems." *Earthquake Spectra* 35.2,737-757 (2019).
- [3] Zahra, F., Macedo, j., Málaga-Chuquitaype, C. "Hybrid data-driven hazard-consistent drift models for SMRF." *Earthquake Engineering & Structural Dynamics* (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: An analytical approach to investigate the dynamics of time-modulated elastic metasurfaces

Author(s): Antonio Palermo^{*1}, Xingbo Pu¹, Alessandro Marzani¹.

¹ *Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, 40033, Italy
antonio.palermo6@unibo.it; xingbo.pu2@unibo.it; alessandro.marzani@unibo.it*

Keyword(s): Elastic Metasurfaces, Time-modulated systems, Non-reciprocal devices

Abstract

Elastic metasurfaces are structured interfaces equipped with mechanical resonators which are able to manipulate the dispersive properties of elastic waves. Their capabilities stem from the coupling between the propagating waves and the localized motion of the resonators which induces peculiar wave phenomena such as mode conversion, rainbow trapping, wave localization and/or rerouting [1]. Of particular interest is the use of such interfaces to control the propagation of surface elastic waves, given their applications in different technological contexts, e.g., from electronic devices and energy harvesters to lab-on-chip devices.

Currently, several analytical formulations are available to predict the dispersive properties and the elastic wavefields along time-invariant metasurfaces. Nonetheless, time-varying metasurfaces, obtained by a time-modulation of the resonator mechanical properties, can further enhance the metasurface manipulation capabilities enabling the propagation of non-reciprocal (e.g. unidirectional) elastic waves. Still, the computation of the dynamic response of a finite-size, non-periodic, time-modulated metasurface requires the use of numerical techniques (e.g. FEM) given the lack of available analytical tools.

Therefore, in this talk, we present and discuss a general analytical framework, based on the multiple scattering technique, to model the dispersive properties and the wave field along finite-size, non-periodic and time-modulated elastic metasurfaces. The method utilizes impedance operators to describe the coupling between the modulated resonators and the elastic waveguide, ad-hoc Green's functions to compute the scattered fields induced by the resonators vibrating on the waveguide, and a multiple scattering scheme to couple the incident and scattered fields and obtain the total wavefield along and outside the metasurface. Using this approach, we discuss the existence of directional band gaps and frequency conversion phenomena induced by the time-modulated metasurface. The proposed analytical framework could pave the way toward the design of microdevices for surface wave manipulation with applications in communication and signal processing technologies.

References

- [1] Yabin, J., et al. "Physics of surface vibrational resonances: Pillared phononic crystals, metamaterials, and metasurfaces." *Reports on Progress in Physics*, 086502, (2021).
- [2] Palermo, A, et al., Surface wave non-reciprocity via time-modulated metamaterials. *Journal of the Mechanics and Physics of Solids*, 145, 104181, 2020.
- [3] Pu, X., Palermo, A., Marzani, A., A multiple scattering formulation for elastic wave propagation in space-time modulated metamaterials, arXiv:2301.00874 (2023)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Out-of plane behavior of single-layer graphene membrane: the interatomic potentials

Author(s): Michele Curatolo^{*1}, Giovanni Formica², Franco Milicchio³, Ginevra Salerno⁴

¹ Department of Architecture, Roma Tre University, michele.curatolo@uniroma3.it

² Department of Architecture, Roma Tre University, giovanni.formica@uniroma3.it

³ Department of Engineering, Roma Tre University, franco.milicchio@uniroma3.it

⁴ Department of Architecture, Roma Tre University, ginevra.salerno@uniroma3.it

Keyword(s): Graphene, nanomaterial, molecular mechanics, interatomic potentials

Abstract

Single-layer graphene is the basic element of several carbon materials such as graphite, fullerenes and carbon nanotubes. The in-plane single-layer graphene behavior has been intensively studied in the past years [1-4]. Indeed, several works, both experimental and theoretical with ab-initio methods, are in agreement about the elastic properties of graphene membranes such as the Young's Modulus, the Poisson's ratio and the stress-strain limit in the uniaxial mechanical test framework.

On the other hand, the out-of-plane behavior has been much less investigated, both experimentally and theoretically. To the best of our knowledge, there are very few works available about out-of-plane experimental tests of graphene membranes [5, 6] and only in [7] we can find an estimation of the out-of-plane bending stiffness given by ab-initio methods.

For this reason, here we investigate the response of graphene membranes in terms of out-of-plane deformability through all the interatomic potentials available in commercial molecular dynamics software such as LAMMPS. Finally, results are compared with the experimental results available in literature and the more appropriate interatomic potential is defined.

References

- [1] Scarpa, F., Adhikari, S., & Phani, A. S., Effective elastic mechanical properties of single layer graphene sheets. *Nanotechnology*, 20, 065709, (2009).
- [2] Genoese, A., Genoese, A., Rizzi, N. L., & Salerno, G., On the derivation of the elastic properties of lattice nanostructures: the case of graphene sheets. *Composites Part B: Engineering*, 115, 316-329, (2017).
- [3] Genoese, A., & Genoese A., Rizzi, N. L., & Salerno, G., On the in-plane failure and post-failure behaviour of pristine and perforated single-layer graphene sheets. *Mathematics and Mechanics of Solids*, 24(11), 3418-3443, (2019).
- [4] Liu, F., Ming, P., & Li, J. (2007). Ab initio calculation of ideal strength and phonon instability of graphene under tension. *Physical Review B*, 76(6), 064120.
- [5] Lee, C., Wei, X., Kysar J.W., Hone J. Measurement of the elastic properties and intrinsic strength of monolayer graphene. *Science*, 321(5887):385-8, (2018).
- [6] Rasuli, R., & Ahadian, M. M. Mechanical properties of graphene cantilever from atomic force microscopy and density functional theory. *Nanotechnology*, 21(18), 185503, (2010).
- [7] Kudin, K.N. Scuseria, G.E., Yakobson, B.I. C2F, BN, and C nanoshell 290 elasticity from ab initio computations, *Phys. Rev. B* 64, 235406, (2001).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Eigenfrequencies of a cantilever nanobeam with a tip point mass partially immersed in fluid

Author(s): Ante Skoblar^{*1}, Goranka Štimac Rončević¹, Marko Čanadija¹, Roberto Žigulić¹,

¹ *Department of Engineering Mechanics, Faculty of Engineering University of Rijeka, 51000 Rijeka, Croatia*

^{*} *Correspondence: ante.skoblar@riteh.hr*

Keyword(s): PurelySDM nonlocal model; fluid-structure interaction; Bernoulli-Euler beam theory; eigenfrequencies;

Abstract

When the vibrating beam with a tip mass is immersed in fluid, the main effect of the tip mass (decrease of the eigenfrequency) is reduced for local and nonlocal elasticity theories [1,2]. This effect can have a crucial impact on the functionality of a mass nanosensor [3]. In this paper, the calculation of eigenfrequencies of a cantilevered nanobeam with a tip point mass partially interacting with a heavy fluid is performed using the Purely nonlocal Stress-Driven integral Model (PurelySDM) [4], a nonlocal approach that leads to well-posed structural problems in nanomechanics, and Bernoulli-Euler beam theory for the kinematics of nanobeam vibrations. The equations defining the system are solved using the method of separation of variables for the beam vibrations and the pressure field in a surrounding fluid. The fields are defined by the superposition of the fields mode shapes. Eigenfrequencies of the beam-fluid system are defined from the homogeneous system of equations with classical and constitutive boundary conditions applied to the general solution of the differential equilibrium. They are compared for local and nonlocal elasticity theories and conclusions are drawn.

References

- [1] Barretta R., Čanadija M., Marotti de Sciarra F., Skoblar A., "Free Vibrations of Bernoulli-Euler Nanobeams with Point Mass Interacting with Heavy Fluid Using Nonlocal Elasticity", *Nanomaterials*, 12, 2676, (2022).
- [2] Xing J.T., Price W.G., Pomfret M.J., Yam L.H., "Natural vibration of a beam-water interaction system," *Journal of Sound and Vibration*, 199, 491-512, (1997).
- [3] Gupta S.V., *Mass Metrology (Chapter 11: Nanotechnology for Detection of Small Mass Difference)*, Springer Series in Materials Science 155, (2019).
- [4] Romano G., Barretta R., Nonlocal elasticity in nanobeams: The stress-driven integral model, *International Journal of Engineering Science*, 115, 14-27, (2017).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Structural Deterioration and Mechanical Degradation of Limestone Calcined Clay Cement (LC3) under Elevated Temperature

Author(s): Kim Meow Liew^{1,2}, Gen Li^{*1}, Binbin Yin^{1,2}, Jinhua Sun³, Venkatesh Kumar R. Kodur⁴

¹ Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon, Hong Kong, China, kmliew@cityu.edu.hk.

² Centre for Nature-Inspired Engineering, City University of Hong Kong, Kowloon, Hong Kong, China

³ Thermal Science and Energy Engineering, The University of Science and Technology of China, Hefei, China

⁴ Department of Civil and Environmental Engineering, Michigan State University, Lansing, Michigan, USA

Keyword(s): Limestone calcium clay cement; Water evaporation; Elevated temperature; Molecular dynamics

Abstract

Cement industry is facing demanding challenges to reduce carbon emissions [1]. The use of limestone calcined clay cement (LC3) has been identified as one of the sustainable ways to reduce the industry's carbon footprint by up to 40% at relatively low costs [2]. However, the recent studies revealed higher strength loss in LC3 composites than ordinary Portland cement composites at the elevated temperatures [3]. Such degradation is mainly induced by water evaporation, which expands micro pores and undermines the microstructures of cement hydrate such as calcium alumina silicate hydrate (C-A-S-H) [4]. Therefore, investigating the intrinsic structural deterioration of LC3 under elevated temperature is urgently required for understanding the mechanisms underlying their poor mechanical performances. In this work, a series of experimental and simulation investigations are conducted to elucidate the fire performance of newly developed LC3 composites. Specifically, experimental results show the effects C-A-S-H composition and water variation on the composites' thermal-mechanical behaviour and post-fire properties. Meanwhile, simulation approaches are employed to reproduce the physical-mechanical behaviours of LC3 at elevated temperatures, in which the water evaporation under the high temperature is illustrated. The evaporation process of pore water, interlayer water and intralayer water is thoroughly described using the molecular simulation methods. Further, the mechanism underlying the poor high temperature resistance of LC3 is uncovered. The evaporation of water leads to the twist of silicate chain in C-A-S-H, which initiates the structural deterioration of LC3. Besides, the inner pore pressure is also extremely increased, resulting in the spalling of LC3 in micro and mesoscale. This work portrays the fire performance of LC3 and provides original insights to understand the mechanisms of their structural and mechanical degradation at elevated temperature.

References

- [1] Akbar A., Liew, K.M., "Assessing recycling potential of carbon fiber reinforced plastic waste in production of eco-efficient cement-based materials". *Journal of Cleaner Production*, 274, 123001 (2020).
- [2] Sharma M, Bishnoi S, Martirena F, Scrivener K. "Limestone calcined clay cement and concrete: A state-of-the-art review". *Cement and Concrete Research*, 149,106564, (2021).
- [3] Cao Y, Wang Y, Zhang Z, Ma Y, Wang H. Thermal stability of limestone calcined clay cement (LC3) at moderate temperatures 100–400°C. *Cement and Concrete Composites*, 135, 104832 (2023).
- [4] AzariJafari H, Amiri MJ, Ashrafi A, Rasekh H, Barforooshi MJ, Berenjian J. Ternary blended cement: An eco-friendly alternative to improve resistivity of high-performance self-consolidating concrete against elevated temperature. *Journal of Cleaner Production*, 223, 575-586 (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Deterioration Detection in tiles focusing on Historical Buildings in Portugal Based on Novel Deep Learning Methods

Author(s): Narges Karimi¹, Mayank Mishra^{*2}, Paulo B. Lourenço³

¹Researcher, Department of Civil Engineering, ISISE, University of Minho, Guimarães, Portugal, n.karimi@ui.ac.ir

² Marie Skłodowska-Curie Individual Fellow (IF), Department of Civil Engineering, ISISE, University of Minho, Guimarães, Portugal, mayank@civil.uminho.pt

³Professor, Department of Civil Engineering, ISISE, University of Minho, Guimarães, Portugal, pbl@civil.uminho.pt

^{*}Corresponding Author: Mayank Mishra, mayank@civil.uminho.pt

Keyword(s): Historical Buildings in Portugal, Deterioration Detection of tiles, Monument Conservation, Machine Learning; Deep Learning, Convolutional Neural Networks (CNN)

Abstract

The most notable characteristic of Portuguese architecture is tiles that cover the constructions with colorful patterns. Buildings covered in tiles have become one of the most recognizable things about Portugal. They have come to represent the culture of the country all over the world. Nowadays, they deteriorate because of masonry materials, the passage of time, and natural and human factors [1]. Detection and assessment of tile damages could be productive for conservation plans for Portugal's heritage. Structural health monitoring (SHM) systems are essential for evaluating and monitoring structural health. Nowadays, deep learning procedures based on image processing techniques are applied to detect structural damages as part of automatic structural health monitoring systems [2-3]. This article has utilized deep learning methods to detect deterioration in tiles, focusing on monuments in Portugal. To achieve initial data, the authors took around 5000 images of damages, including cracking, Crater- Glaze detachment- Tile lacunae- Staining [4]. The performances of the several models of architecture-based convolutional neural networks (CNN) are compared, and based on their Accuracy, precision, and recall criteria the optimal model was selected.

References

- [1] Silva, Teresa P., Maria-Ondina Figueiredo, and Maria-Isabel Prudêncio. "Ascertaining the degradation state of ceramic tiles: a preliminary non-destructive step in view of conservation treatments." *Applied Clay Science* 82 (2013): 101-105.
- [2] Mishra, Mayank. "Machine learning techniques for structural health monitoring of heritage buildings: A state-of-the-art review and case studies." *Journal of Cultural Heritage* 47 (2021): 227-245.
- [3] Mishra, M., Barman, T., & Ramana, G. V. (2022). Artificial intelligence-based visual inspection system for structural health monitoring of cultural heritage. *Journal of Civil Structural Health Monitoring*, 1-18.
- [4] Costa, MCdSRd. "Study of 19th century wall tiles for technical replicas development". Diss. tese de doutoramento, Departamento de Engenharia Civil–Universidade de Aveiro, Aveiro, 2013.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The HBIM process for the management of architectural heritage: geometric and material knowledge to develop an effective conservation and enhancement strategy

Authors: Manuela Aricò^{*1}, Alessandra Ferro¹, Mauro Lo Brutto¹, Antonino Maltese¹, Gaspare Massimo Ventimiglia²

¹ *Department of Engineering, University of Palermo, Palermo, Italy, manuela.arico@unipa.it; alessandra.ferro01@unipa.it; mauro.lobrutto@unipa.it; antonino.maltese@unipa.it*

² *Department of Architecture, University of Palermo, Palermo, Italy, gasparemassimo.ventimiglia@unipa.it*

Keywords: HBIM, 3D survey, parametric model, conservation, preservation

Abstract

The methods of analysis, conservation and enhancement of historic buildings are usually still linked to traditional approaches where data are acquired and processed by multiple experts, resulting in a lack of collaboration and integration of information. The management of historic buildings has found in the process of Heritage Building Information Modelling (HBIM) a collaborative process for creating a digital replica of the building consisting of “intelligent” parametric objects with semantic attributes, representing all the elements of the historic asset. This process can be aimed at heritage management, preventive maintenance, and periodic diagnostic monitoring of the state of conservation too. The most recent tools and methods for the HBIM process are related to the application of the Scan-to-BIM methodology, which, starting from a detailed 3D survey, allows obtaining a very dense point cloud to be used to produce the parametric 3D model [1]. Although several researchers have evaluated the Scan-to-BIM methodology, this approach still has some shortcomings [2]. For example, material decay should be considered, as historic buildings are subjected to progressive deterioration due to exposure to atmospheric agents or traumatic events that worsen their conditions altering the morphology of surfaces. Consequently, the inclusion of information about these aspects can be the basis for increasing knowledge to be used in any conservation/preservation projects or maintenance works.

The paper presents an experimental approach that aims at generating a parametric model in the HBIM environment where the architectural elements are modelled with a greater level of detail, and decay information is integrated by an appropriate workflow. To test this experimental approach the historical building of Villa Castelnuovo in Palermo (Italy) was chosen as a case study.

A 3D data acquisition with laser scanning and photogrammetric techniques was carried out to get a very detailed point cloud of the buildings and to generate high-resolution orthoimages of the facades. The point cloud was employed as the basis for parametric modelling in the HBIM environment while the orthoimages were used to map the decays of the façades. This information was integrated within the HBIM model ensuring also the possibility of combining multitemporal data to compare and monitor the decaying over time. The work lays the basis for further experimentation of data integration within the HBIM environment, to obtain an effective tool capable to support plans for the management and maintenance of monuments.

References

- [1] Rocha G., Mateus L., Fernández J., Ferreira V., “A Scan-to-BIM Methodology Applied to Heritage Buildings” *Heritage*, 3, 47-67, (2020).
- [2] Santoni A., Martín-Talaverano R., Quattrini R., Murillo-Fragero J.I., “HBIM approach to implement the historical and constructive knowledge. The case of the Real Colegiata of San Isidoro (León, Spain)” *Virtual Archaeology Review*, 12(24), 49–65, (2021).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Pickering Emulsions Stabilized by Halloysite Nanotubes: a versatile starting material for geopolymers and coating layers preparation

Author(s): Martina Maria Calvino, Lorenzo Lisuzzo, Giuseppe Cavallaro, Giuseppe Lazzara, Stefana Milioto

¹ *Department of Physics and Chemistry, University of Palermo, Palermo, Italy.*

Keyword(s): Halloysite, Clay, Geopolymer, coating, thermal analysis, hybrid materials, microwax.

Abstract

Nowadays, Pickering emulsions are extensively employed in various applications due to their numerous advantages over surfactant stabilized droplets, such as low or no toxicity, ease of storage, low production costs, etc. In this regard, particles obtained from eco-sustainable sources have been employed for their design in order to satisfy the need for environmentally friendly materials. Among them, halloysite clay nanotubes can act as interfacially active inorganic particles, and we recently proposed a novel protocol for the preparation of wax/halloysite based Pickering emulsions characterizing their stability and structure. Moreover, we designed new green coatings based on biopolymers (chitosan and pectin) [1] and geopolymers filled with wax/halloysite microspheres. Within this, the fillers combined with the aforementioned biopolymers were successfully employed to fabricate composite films with enhanced mechanical properties. A significant hydrophobization of the biopolymeric films was also detected by water contact angle measurements designing novel biocompatible nanocomposite systems that can protect the artwork surface from the aging process caused by environmental conditions. Microwax particles obtained from Pickering emulsions were also embedded in halloysite-based geopolymers developing a new hybrid material with heat storage capacity and enhanced flexural performances [2]. The incorporation of microwax into the geopolymers was confirmed using various techniques, including thermal analyses, spectroscopies, microscopies, and contact angle experiments. The homogeneous dispersion within the geopolymeric network improved again the coating's physico-chemical properties by increasing the hydrophobicity. Furthermore, the Pickering emulsions were employed for the treatment of waterlogged wooden samples [3]. Compared to archaeological woods treated only with wax, the inclusion of nanotubes led to a notable enhancement in mechanical properties such as stiffness and flexural strength, making this method useful for treating larger-sized shipwrecks.

The discussed approaches suggest the development of wax/halloysite Pickering emulsions with versatile functions for both eco-friendly coating and cultural heritage applications.

References

- [1] Caruso M.R., Cavallaro G., Lazzara G., Milioto S. (2023). Pectin/microwax composites for surface coating and protection. *Materials Letters* 333, 133567.
- [2] Calvino M.M., Lisuzzo L., Cavallaro G., Lazzara G., Milioto S. (2022). Halloysite based geopolymers filled with wax microparticles as sustainable building materials with enhanced thermo-mechanical performances. *Journal of Environmental Chemical Engineering* 10, 108594.
- [3] Lisuzzo L., Hueckel T., Cavallaro G., Sacanna S., Lazzara G. (2021). Pickering Emulsions Based on Wax and Halloysite Nanotubes: An Ecofriendly Protocol for the Treatment of Archeological Woods. *ACS Appl. Mater. Interfaces* 13, 1651.

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Palermo, Italy, August 27 - 30, 2023

Title: Methodological approaches for underwater archaeological metals investigation

Author(s): Francesco Armetta^{*1,2}, Maria Luisa Saladino ^{1,2}

¹ *STEBICEF Department, University of Palermo, Viale delle Scienze and INSTM UdR – Palermo, Bld.17, I-90128 Palermo (Italy)*

² *CNR – Istituto per I Processi Chimico-Fisici (IPCF), V.le F. Stagno D'Alcontres, 37, I-98158 Messina, (Italy)*

Keyword(s): Bronze, Orichalcum, non invasive investigation, neutron

Abstract

The investigation of archaeological metals recovered in underwater sometimes is a challenge for a chemist because of the reactions involved in the developing of their corrosion and the lack of information about the environmental conditions. Here, some examples of investigation performed on different underwater archaeological metals is reported: the Montefortino-type helmets and the metals fragments from the Punic Ship exhibited at the Archaeological Park Lylibeum (Marsala-TP, Italy) [1-2], the orichalcum ingots recovered in Gela seabed (Caltanissetta, Italy) [3], the roman and Punic rostrum from the Egadi battles (second Punic war).



Figure 1 Photos of the Montefortino helmets, orichalcum ingots the metals fragments from the Punic Ship.

For each of this case-study, an appropriate set-up of analysis was developed in order to answer to the archaeological questions, and help to reconstruct the history of the objects. In some cases, the main request regards the metal production, while in other cases the interest was mainly devoted to the determination of the processes involved in the deterioration of the metal and to the definition of the conservation state. So that, the used multi-analytical approaches were tailored by the application of

conventional and non-conventional investigation techniques to determine the chemical composition. In detail, X-ray fluorescence and diffraction and neutron investigations have been a powerful micro and non-invasive means of studying the artifacts, by providing information about the nature and the processing of the metals.

The approaches developed for the investigation of the Montefortino helmets and of the metals findings from the Punic Ship will be presented to describe possible available information and at the same time clearly show the strong impact of the chemical-physical investigations to unveil a kind of degradation processes developed in the underwater archaeological metals.

References

- [1] F. Armetta*, M.L. Saladino, A. Scherillo, E. Caponetti, Microstructure and phase composition of bronze Montefortino helmets discovered Mediterranean seabed to explain an unusual corrosion (2021) Scientific Reports, 11 (1), art. no. 23022.
- [2] F. Armetta, R.C. Ponterio, I. Pibiri, M. L. Saladino*, New insight on archaeological metal finds, nails and lead sheathings, of the Punic Ship from Battle of the Egadi Islands (Submitted paper).
- [3] E. Caponetti, F. Armetta*, L. Brusca, D. Chillura Martino, M. L. Saladino, S. Ridolfi, G. Chirco, M. Berrettoni, P. Conti, B. Nicolò, S. Tusa, Microchemical Journal, 2017, 135.

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Palermo, Italy, August 27 - 30, 2023

Title: Vibration Control and Fatigue Life Enhancement of Horizontal Axis Wind Turbine Blade Using Shape Memory Alloy Tendon

Author(s): M. Mohamed Sajeer^{*1}, A. Chakraborty²

¹ *Department of Civil Engineering, Indian Institute of Technology Kanpur, Uttar Pradesh, India, sajeer@iitk.ac.in.*

² *Department of Civil Engineering, Indian Institute of Technology Guwahati, Assam, India, arunasis@iitg.ac.in.*

Keyword(s): Semi-active tendon, shape memory alloy, smart longitudinal stiffening, wind turbine system, Brinson's constitutive model.

Abstract

Ever-increasing demand for energy pushed the envelopes for power generation on every passing day with the depletion of fossil fuel, the pressure on alternative sources are also mounting. Due to this reason the size of wind turbines has increased exponentially to convert more wind energy. This growth of the turbine blade brings in a large amplitude of vibration when exposed to aerodynamic loads which, in turn, demands a robust control strategy for safe and sustained operation. Therefore, the vibration control of modern wind turbine blades is essential. With this in view, strengthening of the blade using a longitudinal stiffener of shape memory alloy (SMA) is proposed in this paper. A discrete reduced order model of an onshore turbine is developed using NREL 5MW wind turbine data and the performance is investigated the response under the rated wind speed. In this study, wind fields are generated with 15% turbulence using TurbSim wind simulator at hub height on the upwind side and the loads at different points on each blade are evaluated using blade element momentum theory (BEMT). The proposed model is validated using the detailed model in FAST (Fatigue Aerodynamics, Structures, and Turbulence) developed by the NREL. The results obtained in this analysis shows a similar response in comparison with the same obtained using FAST under the same wind flow generated by TurbSim. Brinson's constitutive model of SMA and the thermodynamic principle are used for material characterisation of the stiffener. A voltage switching algorithm is proposed based on the smart properties of SMA (i.e. the shape memory effect and the superelastic effect) to develop the semi-active control strategy. The results obtained from the analysis shows that the peak of blade tip displacement in both out-of-plane and in-plane direction is reduced significantly with a guaranteed reduction during the power failure, if any.

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Title: Flexural-torsional wave bandgaps in locally-resonant thin-walled beams

Author(s): Andrea Burlon^{*1}, Giuseppe Failla²

¹ *Department of Civil, Energy, Environmental and Materials Engineering, University of Reggio Calabria, via Rodolfo Zehender 89122 Reggio Calabria, Italy, andrea.burlon@unirc.it*

² *Department of Civil, Energy, Environmental and Materials Engineering, University of Reggio Calabria, via Rodolfo Zehender 89122 Reggio Calabria, Italy, giuseppe.failla@unirc.it*

Keyword(s): Band gaps; Local resonance; Thin-walled beams; Coupled flexural-torsional waves

Abstract

This work deals with the band gaps formation for coupled flexural-torsional waves propagating in locally-resonant thin-walled beams. A simplified dispersive equation for a beam with monosymmetric and open cross section, hosting a periodic array of translational and torsional resonators, is derived adopting an homogenization approach. This approach allows to easily identify the locations and the amplitudes of the bandgaps and to provide an insight into the band gap formation mechanism [1]. In this regard, this work shows that the band gaps formation is strictly connected to the concept of negative effective inertial properties. Particularly, it is found that the band gaps arise in the frequency regions where the matrix of the homogenized inertial properties is negative definite; the latter matrix is a frequency dependent matrix that allows to rewrite the dispersive equation of the locally-resonant beam under study as the dispersive equation of an equivalent uniform beam, whose inertial properties are substituted by appropriate homogenized quantities. The concept of negative effective inertial properties can be considered as an extension and a generalization of the concept of negative effective mass, usually employed to identify the band gaps for uncoupled flexural waves in locally-resonant Euler-Bernoulli beam [2]. An alternative exact method based on the joint use of the transfer matrix approach and the Bloch theory is employed to validate the proposed approach. As further validation, results for the wave propagation in the infinite beam are finally compared with the transmittance of a corresponding finite beam, computed making use of a generalized function approach.

References

- [1] Burlon A., Failla G., "On the band gap formation in metamaterial locally-resonant thin-walled beams" , European Journal of Mechanics/A Solids, 97 104798 (2023).
- [2] Liu Y., Zhao H., Wen J., Wen X. Design guidelines for flexural wave attenuation of slender beams with local resonators. Phys. Letter. A 362, 334-347 (2007).

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Title: Experimental characterization and modelling of non-conventional TMD utilized for seismic retrofitting of existing structures

Authors: Michela Basili^{*1}, Maurizio De Angelis²

¹ *Department of Economics, Universitas Mercatorum, Rome, Italy, michela.basili@unimercatorum.it*

² *Department of structural and geotechnical engineering, Sapienza University of Rome, Rome, Italy, maurizio.deangelis@uniroma1.it*

Keywords: non-conventional TMD, existing structure, inter-story isolation, vertical extension, experimental characterization, modelling, seismic excitation, nonlinear behavior, seismic retrofitting

Abstract

In the last years it is becoming recognized that isolating a part of the mass of a building and converting it into tuned mass, i.e. implementing inter-story isolation, or adding a vertical extension on the top of it and connecting sub-structure and super-structure with an isolation layer, can be valid techniques for structural retrofitting of existing constructions. In both cases, a non-conventional tuned mass damper (TMD) is realized, known for its superior characteristics with respect to conventional TMDs for its robustness in case of variations of the design parameters and seismic effectiveness especially against events with impulsive character [1]. The strategy, applied to existing buildings, simultaneously and successfully joins seismic retrofitting with sustainable recovery and growth [2].

The paper illustrates the results of a dynamic characterization conducted on a non-conventional TMD, realized with a mass placed on two high damping rubber bearings, to be implemented as retrofitting intervention on an existing frame linear structure. The experimental tests were selected to expressly investigate the dependence of the TMD prototype to the intensity and frequency content of the excitation and to observe how these factors affect the dynamical characterization of the control system. The input signals utilized are: i) white noise at different intensities, ii) continuous sine sweep and blocks sine sweep tests, at increasing and decreasing frequency, iii) harmonic signals at constant deformation varying the frequency and the intensity. Through the tests, the nonlinear behavior of the TMD, induced by the elastomeric isolators, is evidenced. TMD stiffness and damping properties are experimentally identified, and their dependence on the input intensity and frequency is highlighted. Later, based on the experimental results presented in [3], where the TMD is implemented on a three-story steel frame structure, as possible intervention of vertical extension or inter-story isolation, suitable numerical models to represent the experimental results of the structure with non-conventional TMD, are presented and discussed. Investigations on the use of reduced order models or complete multi-degrees-of-freedom models, to catch the dynamic behavior of the substructure with the non-conventional TMD are carried out, and particular emphasis is given to the modelling of the TMD damping behavior related to different mechanisms through the adoption of viscous and non-viscous damping models.

References

- [1] De Angelis M., Perno S., Reggio A., "Dynamic response and optimal design of structure with large mass ratio TMD", *Earthq. Eng. Struct. Dyn.*, 41(1),41-60, 2012.
- [2] Argenziano M., Faiella D., Bruni F., De Angelis C., Fraldi M., Mele E., "Upwards - Vertical Extensions of Masonry Built Heritage for Sustainable and Antifragile Urban Densification", *J. Build. Eng.*, 44, 102885, 2021.
- [3] Basili M., De Angelis M., "Experimental Dynamic Response of a Multi-Story Frame Structure Equipped with Non-Conventional TMD Implemented via Inter-Story Isolation", *Appl.Sci.*, 12, 9153, 2022.

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Title: Cyclic stress effect on the fractional poroviscoelastic model

Author(s): F. Amiri^{*1,2}, E.Bologna^{1,3}, G. Nuzzo¹, M. Zingales^{1,3}

1Università degli studi di Palermo, Dipartimento di Ingegneria, Viale delle Scienze, Palermo, Italy

2 MERLN Institute for Technology Inspired Regenerative Medicine, Complex Tissue Regeneration department, Maastricht University, Maastricht, the Netherlands

3 Bio/NanoMechanics for Medical Sciences Laboratory (BNM 2 -Lab), Advanced Technology Network (ATeN)-Center, CHAB Pole, Viale delle Scienze, Ed.18, 90128, Palermo, Italy

Keyword(s): Poromechanics, Fractional calculus, Fractional-Order Hereditariness, Meniscus

Abstract

Menisci are C-shaped fibrocartilaginous tissues located between femoral condyles and tibia. They play a crucial role in proprioception, joint lubrication, and nutrition of articular cartilage, as well as absorbing shock and distributing loads evenly, cooperating with tendons and protecting knee joint against damage caused by hyperextension and hyperflexion [1]. Obviously, complete or partial loss of a meniscus can have detrimental effects on knee, leading to serious long-term consequences. For this reason, several studies have been conducted to formulate menisci mechanical behavior, but this is extremely challenging due to their complex in-homogeneous micro-structure and lack of complete experimental characterization of material properties [2, 3].

In detail, the menisci's biomechanical function is due to the fact that they are able to compress the synovial fluid in the joint cartilage, reducing friction forces during weight bearing. Thus, diffusion phenomenon explains how interstitial fluid moves through interconnected pores in the solid matrix of the menisci. According to this, a considerable number of studies have been conducted on poromechanical models to describe diffusion phenomenon on meniscus [4, 5, 6]. They usually adopted the classical Theory of Poroelasticity, which combines Hooke's law to describe the linear deformation of porous solid, and Darcy's law to describe flow in a porous medium. Nevertheless, it is ineffective for all materials that exhibit a non-linear elastic behavior, such as biological tissues.

In recent years, the Fick and/or Darcy transport equations were also modified using fractional calculus in order to introduce the memory effect induced by interaction between fluid particles and pore structure of elastic medium [7, 8]. In other studies, a power-law variation of the geometric and physical properties of the porous medium was considered, leading to a fractional-order relationship between incoming flow and pressure applied to the control section [9].

In the previous paper we introduced a viscoelastic porous medium using Caputo's fractional derivative [11, 12] in the constitutive flow-pressure equations, considering confined compression test, as well as fully drained compression test and comparing the constitutive law to the one of classical theory of three-dimensional consolidation process [10]. This relation, along with initial and boundary conditions, leads to the complete solution of diffusion phenomenon in a biological porous medium. Particularly, it was revealed that Fractional Visco-poroelasticity Model is ruled by three parameters, namely the anomalous consolidation coefficients $C\alpha$ and $C\beta$, and the β order of Caputo's derivative. Particularly, we considered a constant load, but it is known that the acting meniscus is generally subjected to a cyclic load during normal journey activity, as walking, cycling, running, etc....

For this reason, in this paper we extend the previous application considering a cyclic load in order to simulate the real condition of diffusion phenomenon within meniscus. This allows to elucidate structure-function relationships and to predict the mechanical response of biological tissue under various loading conditions.

References

- [1] I. D. McDermott, A.A. Amis. "The consequences of meniscectomy", Bone and Joint Journal, 88.12: 1549-1556, 2006.
- [2] O. Barrera, E. Bologna, M. Zingales, and G. Alotta, "Experimental Characterization of the Human Meniscal Tissue," IEEE 4th Int. Forum Res. Technol. Soc. Ind. RTSI 2018 - Proc., 2018.
- [3] Milad Imeni, Behzad Seyfi, Nasser Fatouraei, Abbas Samani. "Constitutive modeling of menisci tissue: a critical review of analytical and numerical approaches". Biomechanics and Modeling in Mechanobiology. 19:1979–1996, 2020.
- [4] M. Caputo, "Models of flux in porous media with memory," Water Resour. Res. - WATER RESOUR RES, vol. 36, pp. 693–706, Mar. 2000.
- [5] M. Caputo and W. Plastino, "Diffusion in porous layers with memory," Geophys. J. Int., vol. 158, no. 1, pp. 385–396, Jul. 2004.
- [6] Sabri Uzuner, LePing Li, Serdar Kucuk, Kaya Memisoglu, "Changes in Knee Joint Mechanics After Medial Meniscectomy Determined With a Poromechanical Model", J Biomech Eng., 142(10): 101006, 2020.
- [7] L. Deseri and M. Zingales, "A mechanical picture of fractional-order Darcy equation," Commun. Nonlinear Sci. Numer. Simul., vol. 20, no. 3, pp. 940–949, 2015.
- [8] G. Alaimo, V. Piccolo, A. Cutolo, L. Deseri, M. Fraldi, M. Zingales, "A fractional order theory of poroelasticity", Mechanics Research Communications, vol. 100, 2019.
- [9] E. Bologna, F. Graziano, L. Deseri, M. Zingales, "Power-Laws hereditary of biomimetic ceramics for cranioplasty", International Journal of Non-Linear Mechanics, vol. 115, pp. 61-67, 2019.
- [10] Maurice A. Biot, "General Theory of Three Dimensional Consolidation", Journal of Applied Physics, vol. 12, 155, 1941, doi: 10.1063/1.1712886.
- [11] Alotta, G. et al. "On the numerical implementation of a 3D fractional viscoelastic constitutive model". 1–13 (2015).
- [12] Di Paola M, Pinnola FP. Calcolo frazionario viscoelasticit`a. Published online 2011

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Title: The free Energy function for non-linear hereditary materials

Author(s): Emanuela Bologna^{1,2}, Gaia Prezioso^{*1}, Massimiliano Zingales^{1,2}

¹ Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali, Viale delle Scienze, ed. 8, I-90100, Palermo, Italy, emanuela.bologna@unipa.it, gaia.prezioso@community.unipa.it

² Bio/NanoMechanics for Medical Sciences Laboratory (BNM²-Lab) Advanced Technology Network (ATeN)-Center, CHAB Pole, Viale delle Scienze, ed. 8, I-90128, Palermo, Italy, massimiliano.zingales@unipa.it

Keyword(s): non-linear hereditariness; fractional calculus; free energy; biological tissues

Abstract

Material hereditariness has been studied since 20th century, in fact the study of the long-term behaviour of different materials, including foams, polymers and concrete, has led to the formulation of mathematical models based on the Boltzmann superposition principle, in order to obtain constitutive equations. Obviously, these formulations concern those materials that present a linear behaviour, and it is proven using Boltzmann superposition principle, that implies a linear relation, in the constitutive equation, between creep and relaxation.

Moreover, remaining in the context of linear hereditariness, it was obtained a formulation of the free energy function which was unique, and which guaranteed the absence of ambiguity in the calculation of maximum recoverable work and dissipation [1,2,3].

However, it was demonstrated that biological fibrous materials, including tendons and ligaments, show a nonlinear behaviour even for low stress-strain levels [4]. Therefore, the fractional calculus was introduced in order to study the long-term behaviour of these materials, also for the non-linear behaviour representation. In this circumstance, the well-known relation between creep and relaxation functions cannot be used [5].

Consequently, the aim of this study is to extend the free energy function, already formulated for those materials that present a linear behaviour, to the context of the non-linear hereditariness. Indeed, starting from the constitutive non-linear relation, between stress and strain, a unique formulation for the free energy is obtained and it is proposed in this study, along with some numerical considerations.

References

- [1] Staverman A., Schwarzl T., "Thermodynamics of viscoelastic behavior", Ver. Akad. Can. Wet. Amsterdam, B55, 474-485, (1952).
- [2] Deseri L., Di Paola M., Zingales M., "Free energy and states of fractional-order hereditariness", International Journal of Solids and Structures, 51, 3156-3167, (2014).
- [3] Colinas-Armijo N., Di Paola M., Pinnola F., "Fractional characteristic times and dissipated energy in fractional linear viscoelasticity", Commun Nonlinear Sci Numer Simulat, 37, 14-30, (2016).
- [4] Provenzano P., Lakes R., Keenan T., Vanderby R., "Nonlinear Ligament Viscoelasticity", Annals of Biomedical Engineering, 29, 908-914, (2001).
- [5] Bologna E., Di Paola M., Dayal K., Deseri L., Zingales M., "Fractional-order nonlinear hereditariness of tendons and ligaments of the human knee", Phil. Trans. R. Soc. A, 378(2172), (2020).

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Title: Fractional equivalent linearization technique

Authors: Chiara Masnta*¹, Antonina Pirrotta¹

¹ *Department of Engineering, University of Palermo, Viale delle Scienze, 90128, Palermo, Italy*

Keywords: Fractional derivative, Linearization, Tuned Liquid Column Damper, Experimental Tests

Abstract

In structural engineering, the behavior of many systems is governed by nonlinear differential equations, with nonlinear damping often being the most influential cause of nonlinearity. In order to reduce computational complexity and calculation time, equivalent linear models are commonly adopted to approximate the actual response of these systems. However, most linearization techniques have been developed for nonlinear systems subjected to stochastic processes, with few existing for deterministic excitations [1]. Therefore, this study proposes a novel equivalent linearization method for determining the response of systems with nonlinear damping, under any kind of input, by resorting to the properties of fractional calculus [2]. The proposed mathematical formulation substitutes the original nonlinear differential equation with a linear differential equation of fractional order. Fractional derivatives may be more appropriate than integer derivatives to capture the frequency-dependence of damping properties, as they can alter both the resonant frequency and degree of damping simultaneously. In this manner, the application of fractional calculus transforms into a linearization technique, valid also for deterministic inputs. The reliability of the proposed linearization is experimentally examined by investigating the dynamic behavior of scale models of two devices commonly used for structural vibration control: the Tuned Liquid Column Damper (TLCD) and its sliding version (STLCD), chosen as typical examples of weakly nonlinear systems. Both devices consist of a U-tube tank partially filled with liquid; in the STLCD, the tank is mounted on a roller support, connected via a spring-dashpot unit to the structure to be controlled, while in the TLCD, it is fixed [3]. The damping effect in both devices is mainly generated by wave breaking and liquid impact on the tank walls, resulting in a complex interaction between the liquid and structure and nonlinear governing equations. Previous works demonstrated that, for U-tube tanks with narrow branches, stochastic equivalent linearization methods can successfully predict the experimental behavior [3]. In this work, the fractional derivative is introduced to model the liquid motion inside the TLCD and STLCD under deterministic and stochastic inputs. The accuracy of the proposed approach is assessed by comparisons with both experimental and numerical results obtained using classical stochastic methods.

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References

- [1] Jalali, H. An alternative linearization approach applicable to hysteretic systems. *Commun. Nonlinear Sci. Numer. Simul.* 19. 245-257 (2014).
- [2] Spanos, P.D., Evangelatos, G.I. Response of a non-linear system with restoring forces governed by fractional derivatives-time domain simulation and statistical linearization solution" *Soil Dynamics and Earthq. Eng.*, 30, 811–821 (2010).
- [3] Di Matteo, A., Lo Iacono, F., Navarra, G. and Pirrotta, A. Innovative modeling of tuned liquid column damper motion, *Commun Nonlinear Sci Numer Simul* 23, pp. 229-244 (2015).

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Title: Towards an ethically safe design of autonomous robots

Author(s): Antonio Chella*¹

¹ *Department of Engineering, Università degli Studi di Palermo, Italy, antonio.chella@unipa.it*

Keyword(s): ethical design, autonomous robots

Abstract

The development of autonomous robots raises several ethical, safety, and mechanical considerations that must be taken into account to ensure that robots are designed and operated in an ethically safe manner. This paper discusses some critical considerations for the development of autonomous robots.

1. Fairness to humans: autonomous robots should be designed to operate by allowing possible human control and human intervention in decision-making. Robot designers must ensure that robots do not harm humans or the environment.

2. Transparency: in developing autonomous robots, attention should be paid to transparency so that people can understand how they work and make informed decisions about their use. This includes ensuring that autonomous robots' programming and decision-making processes are documented and understandable to humans.

3. Safety: ensuring the operational safety of autonomous robots is critical. Robot designers should provide that autonomous robots are designed with robust, fail-safe mechanisms and are programmed to put human safety first.

4. Ethical considerations: autonomous robots must be designed and operated to satisfy ethical principles, including respect for human rights, non-discrimination, and accountability. For example, autonomous robots should not be programmed to discriminate against people based on race, gender, or other factors.

5. Cybersecurity: autonomous robots must be equipped with robust cybersecurity measures to prevent them from being hacked or otherwise compromised. Robot designers must ensure that data transmitted by autonomous robots are secure and not vulnerable to cyberattacks.

6. Environmental impact: the development and operation of autonomous robots should consider their potential effects on the environment, such as their energy consumption or potential for pollution.

In summary, designing and developing autonomous robots that are ethical, safe, and mechanically sound requires careful consideration of many factors, including human oversight, transparency, safety, ethics, cybersecurity, and environmental impact. Only by considering these factors can we ensure that autonomous robots are developed and operated to benefit society while minimizing their potential harm.

Machine Learning Assisted Design of Honeycomb Lattices for Enhanced Energy Absorption and Failure Strength

Bhargav Reddy Isanaka¹, Tanmoy Mukhopadhyay^{2*}, Rajendra Kumar Varma¹, Vinod Kushvaha^{1*}

¹Department of Civil Engineering, Indian Institute of Technology Jammu, Jammu, J&K, India

²Department of Aerospace Engineering, Indian Institute of Technology Kanpur, Kanpur, UP, India

*Email address: i.bhargav@iitjammu.ac.in, tanmoy@iitk.ac.in, rajendra.varma@iitjammu.ac.in, vinod.kushvaha@iitjammu.ac.in

Abstract:

Honeycomb lattice materials have received significant attention in the aerospace, automobile and medical industry due to their unique properties that make them ideal for various applications. These materials are characterised by their exceptional strength-to-weight ratio, thermal stability, and low density. The hexagonal arrangement of the atoms in a honeycomb lattice provides a unique combination of strength and flexibility, making these materials ideal for applications that require high performance and low weight, such as aircraft and spacecraft components, thermal protection systems, energy storage systems etc. Many modern structural applications require structures to absorb energy while maintaining the minimum amount of material added to the structure. To this end, conventional approaches to designing periodic microstructural geometry are probably saturated. Consequently, machine learning and artificial intelligence advances in this field are well suited to enhance the mechanical properties of artificially engineered lattice structures.

This study presents machine-learning models to predict the honeycomb lattice structure's failure band position and stress-strain behaviour under different loading conditions. The Sobol sampling technique is adopted to obtain the input parameters as random combinations of cell regularity (0, 0.3, 0.5, 0.7, 1), relative density (in the range of 3% to 9%), and elastoplastic material property (in the field of $\pm 20\%$). Simultaneously, we also proposed a sequential strengthening for identified failure bands in lattice structures for regular hexagonal lattices and a reinforcement strengthening mechanism for irregular geometries. This results in an increase of up to 30% in the energy absorption and ultimate stress for regular honeycomb lattices.

Keywords: Machine learning in lattice material, failure band, energy absorption, enhancement of failure strength

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Title: Efficient 3D simulation of material microstructures via transfer learning

Author(s): Lori Graham-Brady¹, Ashwini Gupta, Noah Wade

¹ *Civil & Systems Engineering, Johns Hopkins University, Baltimore, MD, USA, lori@jhu.edu*

Keyword(s): Material microstructure; stochastic simulation; Monte Carlo simulation

Abstract

Almost every material exhibits random variations in microstructure that affect the macro-scale performance of the material. Therefore, calculations related to reliability of systems comprised of such materials require stochastic representation of these microstructures. While stochastic finite element analyses provide a direct non-Monte-Carlo based path, these techniques are typically limited to linear systems. The ability to generate sample microstructures is key to Monte Carlo simulation of system response. Aside from very simple microstructures, such as spherical inclusions randomly located in space or Voronoi tessellations, these simulations are not easily achieved using simple statistical approaches. Optimization-based approaches that search for microstructures that match key statistics, such as correlation function, have proven to be accurate but are also extremely slow to converge, even in two dimensions. Such approaches are practically infeasible for generating three-dimensional microstructures. This work discusses a ML-based approach that uses statistical descriptors and feature maps from VGG19, a pre-trained deep neural network, both of which are combined into a differentiable loss function that serves as the basis for rapid generation of two-dimensional microstructures that match the basic features of a given material microstructure [1]. The presentation will also show how two-dimensional microstructures can be stacked in all three directions, to generate three-dimensional microstructures in a way that is much less memory intensive than similar full three-dimensional representations. The approach is applied to an irregular two-phase porous ceramic material and a multi-phase polycrystalline material.

References

[1] Bhaduri, A., Gupta, A., Olivier, A., Graham-Brady, L. "An efficient optimization based microstructure reconstruction approach with multiple loss functions," Computational Materials Science, 199:110709, 2021.

Title: Data-driven AI for the NDE of continuous welded rails

Author(s): Piervincenzo Rizzo^{*1}, Matthew Belding², Alireza Enshaeian¹

¹ *Laboratory for Nondestructive Evaluation and Structural Health Monitoring Studies, Department of Civil and Environmental Engineering, University of Pittsburgh, 3700 O'Hara Street, 729 Benedum Hall, Pittsburgh, PA 15261.*

² *Department of Electrical and Computer Engineering, University of Pittsburgh, 3700 O'Hara Street, 1124 Benedum Hall, Pittsburgh, PA 15261.*

Keyword(s): continuous welded rails, rail neutral temperature, finite element model, machine learning, nondestructive evaluation, structural health monitoring.

Abstract

This paper describes a monitoring/inspection technique for the estimation of longitudinal stress in continuous welded rails (CWR) to infer the rail neutral temperature (RNT), i.e. the temperature at which the net longitudinal force in the rail is zero. The technique is based on the use of vibration measurements and machine learning (ML). A finite element analysis is conducted to model the relationship between the boundary conditions and the longitudinal stress of any given CWR to the vibration characteristics of the rail. The results of the numerical analysis are used to train a ML algorithm that is then tested using field data obtained by an array of accelerometers polled on the track of interest. In the study presented in this article, the proposed technique was tested in the field. A commercial FEM software was used to model the rail track as a short rail segment repeated indefinitely and under varying boundary conditions and stress. Three ML models were developed using hyperparameter search optimization techniques and k-fold cross validation to infer the stress or the RNT the frequencies of vibration extracted from the time waveforms obtained from two accelerometers temporarily attached to the rail. The results of the experiments demonstrated that the success of the technique is dependent on the accuracy of the model and the ability to properly label the modes of the detected frequencies. The ML was also able to learn from the experimental data only and successfully predicted the neutral temperature of the tested rail section.

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Title: Variational formulations in viscoplasticity with computational applications

Author: Fabio De Angelis*¹

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples 80125, Italy, fabio.deangelis@unina.it*

Keyword(s): viscoplasticity, variational formulations, computational applications.

Abstract

In the present analysis a variational formulation for viscoplasticity is considered and applied to problems of solids and structures, see e.g. Perzyna [1], Skrzypek and Hetnarski [2], Oden and Reddy [3]. A strategy is illustrated for the derivation of variational principles by including the nonlinear field equations and the constitutive multivalued equations into a viscoplastic operator governing the structural problem, see e.g. De Angelis [4].

A consistent procedure is illustrated for deriving a multifield potential in all the unknown variables of the viscoplastic structural problem and accordingly the relevant multifield variational principle is presented. The proposed procedure shows to be appropriate for the consistent derivation of variational principles in viscoplasticity suitable to deal with problems characterized by singularities and non-smooth functions, see De Angelis [5]. The presented treatment provides the support for a variationally consistent development of numerical algorithms for finite element applications in the inelastic analysis of solids and structures. An implicit numerical scheme is illustrated by connecting the evolution of the consistency parameter with the flow function of the viscoplastic constitutive model. The adopted procedure has the advantage of being applicable to different viscoplastic constitutive models by suitably specializing the viscoplastic flow function, see De Angelis and Cancellara [6]. The procedure is enhanced by deriving a tangent operator which can be adopted for different viscoplastic constitutive models by suitably specializing the appropriate flow function. A useful property of the derived tangent operator is the possibility to include yield functions of arbitrary type. Computational results and examples are presented in order to illustrate the effects of different constitutive models and the influence of different loading rates on the nonlinear behavior of inelastic solid materials.

References

- [1] Perzyna, P., The constitutive equations for rate sensitive materials, *Quart. Appl. Math.*, Vol. 20, pp. 321-332, (1963).
- [2] Skrzypek, J.J., Hetnarski, R.B., *Plasticity and Creep*, Begell House CRC Press, (1993).
- [3] Oden, J.T., Reddy, J.N., *Variational Methods in Theoretical Mechanics*, Springer, NY, (1983).
- [4] De Angelis, F., An internal variable variational formulation of viscoplasticity, *Comput. Methods Appl. Mech. Engrg.*, Vol. 190, pp. 35-54, (2000).
- [5] De Angelis, F., A multifield variational formulation of viscoplasticity suitable to deal with singularities and non-smooth functions, *Int. Journal of Engineering Science*, Vol. 172, Art. 103616, pp. 1-16, (2022).
- [6] De Angelis, F., Cancellara, D., Multifield variational principles and computational aspects in rate plasticity, *Computers and Structures*, Vol. 180, pp. 27-39, (2017).

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Reissner's plate model by SGBEM indirect approach.

Silvio Salvatore Terravecchia*¹, Marianna Zito

¹ *Dipartimento di Ingegneria, Area Strutture, Università di Palermo, Italia, silviosalvatore.terravecchia@unipa.it*

² *Dipartimento di Ingegneria, Area Strutture, Università di Palermo, Italia, marianna.zito@unipa.it*

Keyword(s): SGBEM, Reissner's plate, shear deformable plate, progenitor matrix, RIM technique.

Abstract

The Symmetric Galerkin Boundary Element Method (SGBEM) is applied to the shear deformable plate model (Reissner's model) whose fundamental solutions are expressed through the Bessel functions of the second kind of n -th order. The symmetric solving system is obtained through an indirect approach, called for "progenitor matrix" [1]. The latter is a matrix of coefficients determined by embedding the plate in an unbounded domain whose complementary boundary Γ^+ must remain unstressed and undeformed when the solution is obtained; this allows writing boundary conditions of the type $\mathbf{u}^+ = \mathbf{0}$; $\mathbf{t}^+ = \mathbf{0}$ verified point by point on Γ^+ . Substituting in the boundary conditions the Somigliana's Identities (S.I.s) of the displacements and tractions and carrying out the weighing process, the "progenitor matrix" is obtained.

The real kinematic and mechanical boundary conditions, through a reordering and partitioning of the "progenitor matrix", allow determining the symmetric matrix of the solving system and the boundary load terms. The "progenitor matrix" coefficients are calculated through the expansion in power series of the Bessel functions present in the fundamental solutions; this makes it possible to isolate a singular part (weak, strong and hypersingular) and a regular part in the coefficients. The coefficient's singular part is treated through the theory of distributions, which allows calculating it in closed form [2]; the regular part is calculated through numerical integration techniques.

A generalized technique, called Radial Integral Method (R.I.M.) [3] is used for transforming the domain integral with body forces into boundary integral for any vertical load variation law. Modified fundamental solutions suitable to be integrated on the boundary are obtained. The RIM technique application depends on the singularities present in the kernel of domain integral. In the displacements S.I., the strong singularity $1/r$ allows the technique to be directly applied; in the tractions S.I., the hypersingularity $1/r^2$ is treated using both regularization techniques and R.I.M. technique. In the latter case, a boundary integral, to which is added a domain vector of free terms called Bui Free Term, is obtained.

The singular coefficients of the "progenitor matrix" calculated in closed form through the theory of distributions and the application of the R.I.M. for the calculation of the domain vertical loads vector, allow obtaining a robust solving system that provides excellent results even in the presence of sparse boundary discretization. Several examples, which take into account different domain load conditions, are provided.

References

- [1] Panzeca T., Cucco F., Terravecchia S. S., "Symmetric boundary element method versus finite element method". *Comput Methods Appl Mech Eng*, 191, 3347-3367, 2002.
- [2] Terravecchia S. S., "Closed form coefficient in the symmetric boundary element approach". *Eng Analysis Boundary Elem*, 30, 479-488, 206.
- [3] Gao X. W., Davies T. G., "An effective boundary element algorithm for 2D and 3D elastoplastic problems". *Int J Solids Struct*, 37, 4987-5008, 2000.

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A manufacturing defects-based finite element modelling of curvilinear fibre composites

Prakash Chettri¹ and Devesh Punera^{*2}

¹ School of Infrastructure, IIT Bhubaneswar, Bhubaneswar, India, 20SE06016@iitbbs.ac.in

² School of Infrastructure, IIT Bhubaneswar, Bhubaneswar, India, devesh@iitbbs.ac.in

Keyword(s): Curvilinear fibre; Variable Stiffness; Manufacturing defects; Higher-order shear deformation.

Abstract

Many current engineering applications require high-performance materials with excellent stiffness, strength, and lightweight characteristic. Composite materials formed through modern manufacturing methods appear much suitable for such applications. Variable stiffness composites formed with curvilinear fibres help to improve the structural performance of the laminates and tailor structural properties. The idea of variable stiffness is inspired by many biological and natural systems [1]. Automated Fiber Placement (AFP) is widely used to produce curvilinear fibre composites with better control and precision. However, AFP induces certain defects in the form of gaps and overlaps, which may adversely affect the structural performance of the laminates [2]. So, determining the actual performance of the laminates considering manufacturing defects is essential. The present work proposes a two-dimensional (2D) higher-order shear and normal deformation kinematic model for variable angle tow (VAT) composites in with manufacturing constraints and defects. Governing equations are evaluated using the variational energy principle, and C0 continuity-based finite element approach is used for numerical solutions. The theoretical formulation is developed to consider the effect of manufacturing constraints; a methodology is designed to locate gaps and overlaps for linearly varying and constant curvature fiber paths. This work uses a multi-field homogenization model to evaluate the effective properties of such variable stiffness composites. Gaps deteriorate the structural performance; maximum plate deflection increases by 4.89% and 4.10% when the gap area is considered for constant curvature and linearly varying fiber paths, respectively.

References

- [1] Punera, D., and Mukherjee, P. "Recent developments in manufacturing, mechanics and design optimization of variable stiffness composites," *Journal of Reinforced Plastics and Composites*, 41, 917-945, (2022).
- [2] Brasington, A., Sacco, C., Halbritter, J., Wehbe, R., and Harik, R. "Automated Fiber Placement: A Review of History, Current Technologies, and Future Paths Forward." *Composites Part C*, Vol. 6, p. 100182, (2021).

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Title: Applicability of self-sensing capacity to the detection and evaluation of cracks on bio-mineralized-mediated self-healing cementitious composites

Authors: Naru Kim^{*1}, Daeik Jang², H.K. Lee³

¹ Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea, nalu4859@kaist.ac.kr

² Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea, svs2002@kaist.ac.kr

³ Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea, haengki@kaist.ac.kr

Keywords: Self-healing; Self-sensing; Bio-mineralization; Carbon-based materials

Abstract

Studies on bio-mineralization-mediated self-healing cementitious composites have recently been spotlighted as eco-friendly and sustainable technology to mitigate cracks in the composites [1]. The self-healing capacity of cementitious composites with a variety of dosages or species of incorporated microbes is a primary focus of researchers [1,2]. Meanwhile, in order to properly activate the dormant microbes for self-healing, the detection of cracks need to be preceded [3]. In addition, it has been reported that the self-healing capacity decreases as the crack opening commences, signifying that the instant detection and evaluation of cracks are essential [4]. Thus, the development of self-healing and self-sensing cementitious composites have become a promising strategy to ensure the durability and structural integrity of the cementitious composites [5]. In this regard, earlier works on the self-healing and self-sensing cementitious composites will be summarized, and an initial work on the assessment of self-healing and self-sensing capacity of cementitious composites incorporating microbes and carbon-based materials will be presented [6].

References

- [1] Kim H., Son H.M., Seo J., Lee H.K. "Recent advances in microbial viability and self-healing performance in bacterial-based cementitious materials: A review," *Construction and Building Materials*, 274, 122094, (2021).
- [2] Ganendra G., De Muynck W., Ho A., Arvaniti E.C., Hosseinkhani B., Ramos J.A., Boon N. "Formate oxidation-driven calcium carbonate precipitation by *Methylocystis parvus* OBBP," *Applied and Environmental Microbiology*, 80(15), 4659-4667, (2014).
- [3] Wang J.Y., Soens H., Verstraete W., De Belie N. "Self-healing concrete by use of microencapsulated bacterial spores," *Cement and Concrete Research*, 56, 139-152, (2014).
- [4] Luo M., Qian C.X., Li R.Y. "Factors affecting crack repairing capacity of bacteria-based self-healing concrete," *Construction and Building Materials*, 87, 1-7, (2015).
- [5] Jin X., Haider M.Z., Cui Y., Jang J.G., Kim Y.J., Fang G., Hu J.W. "Development of nanomodified self-healing mortar and a U-Net model based on semantic segmentation for crack detection and evaluation," *Construction and Building Materials*, 365, 129985, (2023).
- [6] Kim N., Jang D., Lee H.K. "Development of self-healing and self-sensing engineered cementitious composites," In preparation.

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Title: How hole chamfer can affect perforated plates' fluid dynamic performance

Author(s): Giacomo Ferrarese^{*1}, Stefano Benzi², Marco Maria Agostino Rossi³, Stefano Malavasi⁴

¹ Civil and Environmental Department, Politecnico di Milano, Milano, Italy, giacomo.ferrarese@polimi.it

² Civil and Environmental Department, Politecnico di Milano, Milano, Italy, stefano.benzi@polimi.it

³ Civil and Environmental Department, Politecnico di Milano, Milano, Italy, marcomaria.rossi@polimi.it

⁴ Civil and Environmental Department, Politecnico di Milano, Milano, Italy, stefano.malavasi@polimi.it

Keyword(s): perforated plates, hole chamfer, chamfered holes, pressure dissipation, cavitation performance

Abstract

The production of perforated plates (PF) consists of puncturing a flat metal sheet in order to create a desired arrangement of the holes designed to achieve a certain performance goal. Machining can cause unexpected chamfering on holes that can change their hydraulic performance if not taken into consideration. PF are commonly used in a variety of industrial applications, including filtration, ventilation, and flow control.

This study investigates the effect of a very small chamfer (hardly visible to the naked eye) on the performance of perforated plates in terms of pressure dissipation and of resistance to cavitation. The parameters influencing performance of PF are largely discussed in literature [1,2]. However, the effect of chamfering has been discussed very little. A previous study by Barros et al [3] numerically investigated pressure dissipation as a function of the hole chamfer, but only in hydraulic conditions related to a particular application and without considering cavitation resistance. In the present study, experimental tests were conducted on different geometries of perforated plates, investigating three configurations: one with the hole chamfer upstream, a second one with the hole chamfer downstream, and a third one with the hole chamfer on both sides of the plate. The perforated plates were tested under different operating conditions of flow and pressure.

Experimental tests have shown that PF with the chamfered holes placed upstream dissipate less pressure, limiting flow detachment at the hole entrance. From the cavitation point of view the chamfer placed upstream increase the device resistance.

The findings of this study highlight the importance of a proper positioning of the perforated plates, i.e. the upstream or downstream position of the hole chamfer (even if geometrically small) can significantly impact the performance of the designed perforated plate.

References

- [1] Maynes, D., Holt, G.J., Blotter, J., "Cavitation Inception and head loss due to liquid flow through perforated plates of varying thickness," Journal of Fluids Engineering, 135(3), p 031302, (2013) (<https://doi.org/10.1115/1.4023407>)
- [2] Dabiri, S., Sirignano, W.A., Joseph, D.D., "Cavitation in orifice flow," Phys. Fluids 19(7), pp. 72-112, (2007) (<https://doi.org/10.1063/1.2750655>)
- [3] Barros Filho J.A., Santos, A.A., Navarro, M.A., Jordão, E., "Effect of chamfer geometry on the pressure drop of perforated plates with thin orifices", Nucl. Eng. Des., 284, pp. 74–79, (2015) (<https://doi.org/10.1016/j.nucengdes.2014.12.009>)

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Title: Analysis and measurement of pressure and velocity in intermittent water distribution networks: a comparison between laboratory and numerical experiments.

Author(s): Fabrizio Traina^{*1}, Mauro De Marchis¹ Fulvio Lo Valvo², Alberto Vella² and Giuseppe Costantino Giaconia²

¹*Facoltà di Ingegneria e Architettura, University of Enna Kore, Enna, Italy, fabrizio.traina@unikorestudent.it*

²*Dipartimento di Ingegneria, University of Palermo, Palermo, Italy*

Keyword(s): information and communication technologies (ICT); water distribution network; experimental pipe network, intermittent water distribution.

Abstract

Efficient management of water distribution networks (WDNs) is currently a focal point, especially in countries where water scarcity conditions are amplified by frequent drought periods. In these cases, in fact, pressure and flow rate become the fundamental variables of WDNs' management. Similarly, WDNs are often obsolete and affected by several points of water losses. Leakages are mainly affected by pressure; hence water utilities usually exploit pressure management aiming to reduce physical losses. It is clear how pressure plays a fundamental role in WDNs management and, more generally, in water safety. Even though the technologies are quite mature, these systems are often expensive, especially if a capillary monitoring system is required; thus, water managers apply the measurement of the flow rate and pressure at very few points. Today, the implementation of the Internet of things (IoT) can be considered a key strategy for monitoring water distribution systems. Once the sensors are installed, in fact, it is relatively easy to build a communication system able to collect and send data from the network. In the proposed study, a smart pressure and flow rate monitoring system was developed starting from a low-cost hardware solution and by also exploiting some open-source software packages. The prototype system is composed of a cheap microcontroller based embedded system and a software GUI performing human interactions. The efficiency of the proposed tool was compared with a SCADA monitoring system.

To investigate on the efficiency of the proposed measurement system, an experimental campaign was carried out at the Environmental Hydraulic Laboratory of the University of Enna (Italy), and hydrostatic as well as hydrodynamic tests were performed. The results showed the ability of the proposed tool to have accurate knowledge of pressure and flow rate in a WDN with a simple, scalable, and economic system.

One of the main innovative goals of the proposed measurement system is the ability to collect a large amount of data also covering Intermittent Water Supply (IWS) use cases helping Water Utilities to optimally perform network management, thus reducing the access inequity of water resources among several users. IWS is, in fact, a solution developed to cope with unexpected water shortages caused by various reasons such as network maintenance and climatic change. Many researchers have developed different models to study the processes of WDN pipes' filling and emptying. Many of these models use different approaches to cover the same phenomenon. In the proposed research the experimental data have been used to calibrate a new numerical model, written in python language, able to simulate the behaviour of intermittent supply, resolving the governing equation using the Method of Characteristics (MOC).

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Title: Hydraulic transients induced by Pressure Reduction Valves – simulation and validation

Author(s): Alessandro Siviero¹, Riccardo Vesipa^{*2}

¹M.Sc. Student at Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Torino, Italy, alessandro.siviero@studenti.polito.it

² Assistant Professor at Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Torino, Italy, Riccardo.vesipa@polito.it

Keyword(s): water hammer, pressure reduction valves, mathematical model, PID algorithm, MOC, Python, total head

Abstract

In this paper we discuss a classical problem of hydraulic engineering: the flow transients occurring in the water main of an aqueduct. More in details, we discuss the development and validation of a numerical model for estimating the flow transients resulting from on the hydraulic system in the particular case of a motor that changes the opening percentage abruptly, thus resulting in a strong water hammer generation along the conduit. The problem is novel and deserves attention and dissemination because it encompasses the interaction between hydraulics (the water main) and controls (the valve used to regulate the flow in the conduit).

The system taken as example for the study has been modeled as a water main that connects an upstream tank and a downstream tank. It is characterized by high elevation gradients (hundreds of meters) and significant lengths (tens of km). The water main has at its end a pressure reduction valve (PRV) installed, equipped with a PID algorithm aimed at keeping the level of the US tank at a set level. The PRV is characterized by a complex relationship between the actuator position (regulating the opening) and the corresponding discharge coefficient. Along the water main have been considered, in the simulation, a series of points of interest, from which retrieving additional data about pressure and flow rate, that could be easily setup in a real environment via sensors and monitoring systems. To simulate the flow transients induced by the PRV maneuvers, the method of the characteristics (MOC)^[1] is used to solve the classical water hammer equations. The MOC is implemented in a Python code as an open source able to perform theoretical simulations as well as to validate real scenarios.

The numerical model can therefore act in different modes and has been tested in different ways. More in detail: (i) A repeating and abrupt open cycle has been done, ranging from a full opening to a full closure and vice versa, noticing a clear presence (and measuring the effects) of the water hammer phenomenon and the friction losses with time, in terms of flow and total head. (ii) A series of tests done by feeding the algorithm with a progressive multi-step maneuver, with time-spaced values between the different steps in terms of nominal opening. This highlighted the most critical instants for the system in terms of total head, which were those near the final maneuvers (bringing to a full closure of the valve). (iii) A test, conducted by feeding in a time series of the opening values of the valve, was given as input to the Python code, with the change happening at the fixed motor speed. (iv) The Python code simulated the flow transients induced by such opening time-series, in terms of pressure and flow time-series. (v) The final calibration only required a minor (5%) on the pressure surge celerity and led to an almost perfect match^[2] (in terms of time of occurrence and magnitude) with sufficient robustness.

The developed numerical model is capable to provide very precise simulations for big aqueducts and to test PID algorithms governing the PRV and to test emergency maneuvers with high accuracy and reliable for long simulation time spans (days) in relatively small running times (minutes).

References

[1][2] Chaudhry M.H., Applied Hydraulic Transients, New York, Van Nostrand Reinhold Co., pgs 34/99-103, 1987

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Title: A reference digital replica of an urban tree based on ambient vibration tests

Author(s): Michele Betti¹, Nicola Cavalagli², Francesco Clementi^{*3}, Ersilia Giordano³, Ernesto Grande⁴, Gianluca Standoli³

¹ *Dep. of Civil and Environmental Engineering, University of Florence, Firenze, Italy, michele.betti@unifi.it*

² *Dep. of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, nicola.cavalagli@unipg.it*

³ *Dep. of Civil and Building Engineering and Architecture, Polytechnic University of Marche, Ancona, Italy, francesco.clementi@univpm.it, e.giordano@pm.univpm.it, g.standoli@pm.univpm.it*

⁴ *Dep. of Engineering Science, University Guglielmo Marconi, Roma, Italy, e.grande@unimarconi.it*

Keyword(s): Ambient Vibration Tests (AVTs), Tree Dynamics, Finite Element Model, Laser Scanner

Abstract

In urban areas, trees play a crucial role in enhancing the quality of life of residents. However, concerns about their potential to compromise safety, structures, and routine activities due to the occurrence of tree falls have highlighted the need for research to develop engineering-efficient methods and models to identify potential hazards to humans [1].

Recent efforts have focused on developing new technologies, instruments, and testing methodologies to measure and monitor trees, as well as investigating the effects of diseases and fungi on tree integrity. Although Operational Modal Analysis (OMA) and other engineering techniques [2] have advanced our understanding of tree dynamics, generating numerical models that enable accurate interpretation of experimental data and provide additional insights beyond experimentation remains challenging [3].

In this paper, we present a novel parametric Scan-to-FEM approach that utilizes a Generative Programming paradigm and a visual programming environment to create a highly detailed Finite Element Model (FEM) of a tree. The process begins with a 3D laser scanner survey of the tree and culminates in the creation of a digital twin of the tree structure. The parametric model is imported into a FE environment and calibrated via an inverse dynamic problem using modal properties identified from ambient vibration tests conducted in February 2023. This approach successfully estimates the uncertain parameters of the tree, allowing for the creation of a reference digital replica of the current structural condition of the tree and setting performance standards to optimize the control of the tree's structural integrity over time.

References

- [1] Baker, C. J., and H. J. Bell. 1992. "The aerodynamics of urban trees." *Journal of Wind Engineering and Industrial Aerodynamics*, 44 (1–3): 2655–2666. [https://doi.org/10.1016/0167-6105\(92\)90057-H](https://doi.org/10.1016/0167-6105(92)90057-H).
- [2] James, K. 2014. "A Study of Branch Dynamics on an Open-Grown Tree." *Arboriculture & Urban Forestry*, 40 (3). <https://doi.org/10.48044/jauf.2014.014>.
- [3] Bergeron, C., J.-C. Ruel, J.-G. Elie, and S. J. Mitchell. 2009. "Root anchorage and stem strength of black spruce (*Picea mariana*) trees in regular and irregular stands." *Forestry*, 82 (1): 29–41. <https://doi.org/10.1093/forestry/cpn035>.

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Title: Reconstruction of concrete internal defects based on unsupervised domain adaptation algorithm for impact vibration signals

Author(s): Gao Shang¹, Jun Chen^{*1}

¹ *Department of Civil Engineering, School of Transportation Science and Engineering, Beihang University, Beijing, China, junchen@buaa.edu.cn*

Keyword(s): Unsupervised domain adaptation, Defect reconstruction, Deep learning, Wavelet transform, Impact vibration

Abstract

Due to the corrosion of steel bars and the action of external loads, hidden internal defects such as delamination and voids easily occur in concrete slabs during the service [1]. The detection of internal defects of concrete slabs is a challenging task, and the early use of non-destructive evaluation (NDE) methods to accurately locate internal defects provides a basis for concrete repair and avoids traffic accidents and property losses. The traditional method based on the artificial selection of the damage sensitive index of the structural response signal is very susceptible to interference, which limits its application in engineering practice.

The rise of deep learning has attracted researchers explore the possibility its combination with traditional detection methods to detect internal defects in concrete. Dorafshan and Azari proposed to detect internal defects in concrete based on deep learning analysis of vibration signal time-frequency images [2], but two problems still exist: 1) Traditional time-frequency analysis (TFA) method cannot correctly reflect the data-sensitive damage characteristics due to the uncertainty principle. 2) There is not a large amount of labeled data from real structures available for network training.

To address these issues, we propose an unsupervised domain adaptation algorithm for impact echo signals to detect internal defects in concrete slabs. Impact vibration signals acquired from both experiments and numerical simulations are used for the training and testing of deep learning network. The wavelet transform based synchrosqueezing transform (WT-SST) method is first developed to perform time-frequency conversion on vibration signals, which provides a basis for effective feature extraction of the network. The unsupervised domain adaptation (DA) network is then proposed to transfer training on labeled numerical simulation data (original domain) and unlabeled real structural data (target domain). The DA network extracts and learns domain-invariant features of two-domain two-dimension (2D) time-frequency images by maximizing the domain recognition error and minimizing the probability distribution distance. Finally, the damage probability predicted by the trained model is used as an index to image the 2D defect cloud image of the concrete slab.

References

- [1] Zhang G., Harichandran R.S., Ramuhalli P., "An automatic impact-based delamination detection system for concrete bridge decks," *NDT E Int.* 45(1), 120-127, (2012).
- [2] Dorafshan S., Azari H., "Deep learning models for bridge deck evaluation using impact echo," *Constr. Build. Mater.* 263, (2020).

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Title: EMI instrumented wearable piezoelectric ring for bolted connection monitoring

Author(s): Jianchao Wu¹, Weijie Li^{*2}.

¹ Hubei Key Laboratory of Earthquake Early Warning, Institute of Seismology, China Earthquake Administration, Wuhan, China, Email address: jianchaowu85@gmail.com

² School of Civil Engineering, Dalian University of Technology, Dalian, China, Email address: liweijie@dlut.edu.cn

Keyword(s): Lead zirconate titanate (PZT), electromechanical impedance (EMI), wearable piezoelectric ring (WPR), bolted connection monitoring

Abstract

Due to loss of preload, structural failure caused by bolt loosening is a common occurrence in engineering structures. Effective monitoring on bolted connection is of great importance to provide early warning to the structural maintenance department. In this study, a novel and reusable electromechanical impedance (EMI) instrumented wearable piezoelectric ring (WPR) was proposed to detect the bolted connection loosening. In the experimental investigation, the EMI spectra of three identical WPRs during the bolt loosening process were acquired and analyzed. It was concluded that the changes in bolt looseness could be qualitatively and quantitatively characterized by the conductance spectra. Specifically, the resonance frequency and amplitude at certain frequencies were reduced correspondingly as the bolts loosen. Moreover, two statistical metrics including mean absolute percentage deviation (MAPD) and root mean square deviation (RMSD) were adopted to evaluate different degrees of bolted connections quantitatively. Both metrics showed an increasing tendency during the bolt loosening process in three different frequency bands. It was found that both metrics demonstrated a good linear correlation with the bolt torque variations. Both of them serve as reliable indicators to detect the looseness status in the bolted connection. To gain deeper insight into the correlation of the change of peak frequency with the bolt loosening process, a preliminary finite element simulation was performed. The EMI simulation was achieved by the harmonic analysis in finite element model (FEM) software ANSYS. The simulation result is in agreement with the experimental studies. Therefore, during the bolt loosening process, the loading conditions and boundary conditions are changed, and can be interrogated and quantify by the change of frequency in the conductance of the WPR. The present work verify the feasibility and applicability of using EMI instrumented WPR for bolted connection monitoring.

References

- [1] Nikraves SMY, Goudarzi M. "A review paper on looseness detection methods in bolted structures", Latin American Journal of Solids and Structures, Vol 14, page2153-76, (2017).
- [2] Li, Weijie, Jianjun Wang, Tiejun Liu, and Mingzhang Luo. "Electromechanical impedance instrumented circular piezoelectric-metal transducer for corrosion monitoring: modeling and validation." Smart Materials and Structures, Vol 29, page 035008, (2020).
- [3] Chalioris CE, Voutetaki ME, Liolios AA. "Structural health monitoring of seismically vulnerable RC frames under lateral cyclic loading", Earthquakes and Structures, Vol 19,page 29-44 (2020).
- [4] Chen, Dongdong, Linsheng Huo, and Gangbing Song. "EMI based multi-bolt looseness detection using series/parallel multi-sensing technique." Smart Structures and Systems, Vol 25, page 423-432, (2020).
- [5] Wu, Jianchao, Qingzhao Kong, Weijie Li, and Gangbing Song. "Interlayer slide detection using piezoceramic smart aggregates based on active sensing approach." IEEE Sensors Journal, Vol 17, page 19, (2017).

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Title: POST-EARTHQUAKE RAPID SEISMIC DEMAND ESTIMATION AT UNMONITORED LOCATIONS VIA BAYESIAN NETWORKS

Author(s): Pooria Mesbahi^{*1}, Enrique García-Macías², Marco Breccolotti³, Filippo Ubertini⁴

¹ *Department of Civil and Environmental Engineering, University of Perugia, Ph.D. Student, Perugia, Italy, pooria.mesbahi@studenti.unipg.it*

² *Department of Structural Mechanics and Hydraulic Engineering, University of Granada, Assistance Professor, Granada, Spain, enriquegm@ugr.es*

³ *Department of Civil and Environmental Engineering, University of Perugia, Associate Professor, Perugia, Italy, marco.breccolotti@unipg.it*

⁴ *Department of Civil and Environmental Engineering, University of Perugia, Full Professor, Perugia, Italy, filippo.ubertini@unipg.it*

Keyword(s): Bayesian Networks; Seismic hazard analysis; Ground motion prediction equation (GMPE); Bayesian model updating; Machine learning; Seismic demand model

Abstract

Rapid safety estimation of buildings and infrastructural systems after an earthquake is a common, yet difficult, challenge that typically relies upon time consuming visual inspections. A more rigorous seismic analysis defines safety criteria based on a demand-capacity model. To apply a similar approach in a rapid assessment framework, however, engineers require accurate estimations of intensity measures (IMs) at the site location to estimate the seismic demand and evaluate the health status of the structure using fragility curves. Unfortunately, however, IM values are only available at monitored locations, for instance where a sensor of a strong motion network is available or where a structure equipped with a monitoring system is located. Although using spatial interpolation methods can provide estimation of IMs, they cannot consider the uncertainties inherent in a seismic event nor incorporate decisive factors such as local characteristics (e.g. soil type) of the site directly in this estimation. Furthermore, traditional use of an attenuation relationship lacks the capability to update the model after a new event. To address these issues, we propose using Bayesian Networks (BN), which are directed acyclic graphs (DAG) including a set of probabilistic variables and their conditional dependencies that can provide an algorithm for inference and prediction under uncertainty. Not only can BNs incorporate complex probabilistic relationships between variables but also, they have the capability to systematically update the model as soon as new data are observed by the monitoring system. In the proposed BN approach, an attenuation model is employed for the estimation, and the probabilistic variables of the model are updated after any new information arrives to the strong motion network. This evidence is subsequently used to estimate the IMs at the unmonitored locations in probabilistic terms. The proposed method is benchmarked against a simple kriging interpolator considering some recent earthquake shocks in central Italy. Overall, the proposed method is especially suited for bridge networks located in the far-field from the epicenter, where accurate estimations of the local seismic demand suffered by each bridge during the shock may allow to speed up the process of taking an informed decision about keeping the bridge open to traffic or closing it until a detailed inspection is carried out.

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Title: Stochastic Response Analysis of Multi-Dimensional Nonlinear Systems via GE-GDEE with Enhanced Tail Accuracy

Author(s): Yi Luo^{*1}, Chao Dang², Matteo Broggi³, Michael Beer^{4 5 6}

¹ Institute for Risk and Reliability, Leibniz University Hannover, Hannover, Germany, yi.luo@irz.uni-hannover.de

² Institute for Risk and Reliability, Leibniz University Hannover, Hannover, Germany,

chao.dang@irz.uni-hannover.de

³ Institute for Risk and Reliability, Leibniz University Hannover, Hannover, Germany, broggi@irz.uni-hannover.de

⁴ Institute for Risk and Reliability, Leibniz University Hannover, Hannover, Germany, beer@irz.uni-hannover.de

⁵ Institute for Risk and Uncertainty, University of Liverpool, Liverpool, United Kingdom

⁶ International Joint Research Center for Resilient Infrastructure & International Joint Research Center for Engineering Reliability and Stochastic Mechanics, Tongji University, Shanghai, PR China

Keyword(s): globally-evolving based generalized density evolution equation (GE-GDEE), effective drift coefficients (EDC)

Abstract

Stochastic response analysis of multi-dimensional nonlinear systems has been a significant challenge in engineering fields for decades. However, a recently developed globally-evolving based generalized density evolution equation (GE-GDEE) technique has shown great promise in efficiently handling various high-dimensional nonlinear systems, with robust performance and high accuracy [1][2]. The accuracy of GE-GDEE highly depends on the estimation accuracy of the effective drift coefficients (EDC) of the equation [3]. However, capturing the tail characteristics of the EDC from a limited number of Monte Carlo samples is challenging, as usually there are no samples in the tail range. In this work, inspired by the importance sampling concept, a scheme to settle this problem is proposed by simply magnifying the drift coefficients to obtained samples in the marginal zone. This enables better estimation of the EDC, especially in the tail. As a result, a higher accuracy in the probability density tail can be achieved. A numerical example with an analytical solution is studied to illustrate the effectiveness of the proposed scheme.

References

- [1] Lyu M.Z., Chen J.B., "A unified formalism of the GE-GDEE for generic continuous responses and first-passage reliability analysis of multi-dimensional nonlinear systems subjected to non-white-noise excitations", *Structural Safety*, 98: 102233. (2022).
- [2] Luo Y., Spanos P.D., Chen J.B., "Stochastic response determination of multi-dimensional nonlinear systems endowed with fractional derivative elements by the GE-GDEE", *International Journal of Non-Linear Mechanics*, 147: 104247. (2022).
- [3] Sun T.T., Chen J.B., "Physically driven exact dimension-reduction of a class of nonlinear multi-dimensional systems subjected to additive white noise", *Journal of Risk & Uncertainty in Engineering Systems - A*, 8 (2): 04022012. (2022).

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Title: An effective procedure for the full probabilistic characterization of the structural response of large DOF systems subjected to seismic actions

Author(s): Giacomo Navarra^{*1}, Francesco Lo Iacono¹, Maria Oliva¹

¹ Faculty of Engineering and Architecture, Kore University of Enna, Enna, Italy

Emails: giacomo.navarra@unikore.it, francesco.loiacono@unikore.it, maria.oliva@unikore.it.

Keyword(s): Response spectrum; Spectrum-consistent PSD; Stochastic analysis; large system; seismic engineering; Random vibration

Abstract

Most building codes typically define the design value of earthquake loads at a given site by means of the pseudo-acceleration Response Spectra (RS), which depend on the seismicity of the site, the soil conditions, the importance of the structure, the assumed ductility of the structure and the limit state under consideration. However, this approach is strictly valid only for Single degrees-of-freedom (DOF) systems, as the evaluation of the response for Multi DOF structures implies approximations in the determination of the modal response correlation coefficients. Despite this limitation, the use of the RS method to predict the peak values of structural displacements and internal forces has the significant advantage to avoid the direct integration of the equations of motion, gaining in the last decades great popularity among structural engineers. On the other hand, in several design scenarios earthquakes can be modelled as stationary zero-mean Gaussian processes, thus the seismic input is fully defined in probabilistic sense by its Power Spectral Density (PSD) function. This approach, at least for linear structural systems, implies that the full characterization of the response process can be obtained by random vibration theory. In the case of weak nonlinearities, Statistical Linearization (SL) techniques lead to very refined solutions and, for nonlinear systems, it allows for the artificial generation of ground motion time-history samples, matching the design RS, in order to perform Monte-Carlo simulations (MCS). However, for structural problems concerning a large number of DOF as well as for those problems that make intensive use of SL technique (e.g. optimal design procedures) the computational burden required is still huge to make the PSD approach convenient with respect to the classical RS method. Recently, an analytical model for the PSD functions consistent with most seismic RS has been proposed [1] and closed-form approximate expressions of the spectral moments have been derived and numerically validated for the seismic response of single- and multi-degree of freedom systems [2], so that a complete procedure to analyze the response statistics of structural system subjected to seismic load has been set up. In this work, the proposed procedure is used to evaluate the probabilistic distribution of the response maxima for large DOF systems in computationally efficient way, by avoiding or strongly reducing numerical evaluations of response statistics.

References

- [1] Barone G., Lo Iacono F., Navarra G., Palmeri A., "A novel analytic model of power spectral density function coherent with earthquake response spectra", in: Proc. of the 1st International Conference on uncertainty quantification in computational sciences and engineering (UNCECOMP), 25-27 May 2015, Crete Island (Greece), p. 394–406, (2015).
- [2] Barone G., Lo Iacono F., Navarra G., Palmeri A., "Closed-form stochastic response of linear building structures to spectrum-consistent seismic excitations", Soil Dynamics and Earthquake Engineering, 125, 105724, (2019).
- [3] Navarra G., Lo Iacono F., Oliva M., "An Efficient Stochastic Linearisation Procedure for the Seismic Optimal Design of Passive Control Devices", Frontiers in Built Environment, 6, 32, (2020).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The Durability and Self-Healing performance of Ultra-High Performance Concrete in Aggressive Chloride-rich Environments.

Author: Ruben Paul Borg^{*1}

¹ Faculty for the Built Environment, University of Malta, Msida, Malta, ruben.p.borg@um.edu.mt

Keyword(s): Ultra- High-Performance Concrete; Durability; Self-Healing; Chloride Penetration; Crystalline Admixtures; Nano-Additives

Abstract

Ultra-High performance concrete (UHPC) with improved functional performance characteristics is developed for structures in extremely aggressive exposure conditions to improve their durability performance in extreme environments. UHPC can be used and exploited in aggressive coastal environment in XS exposure conditions in order to enhance to service life of structures throughout their life cycle [1]. In this study, the durability performance of self-healing ultra-high performance concrete based on crystalline admixtures and three different types of nano-additives was assessed with respect to different environmental exposure conditions. The UHPC durability performance was enhanced through the exploitation of crystalline admixtures which promote self-healing and nano-additives [2]. Three different types of nano-additives were assessed in the research: Nano Alumina, Nano Cellulose and Nano Cellulose Fibres. The different UHDC mixes developed were exposed to different environmental conditions including water and a chloride-rich environment in order to assess the performance of the material over time. Furthermore, both cracked and un-cracked UHPC samples were assessed to determine the self-healing capabilities of the concrete. The fresh properties of the self-healing fibre-reinforced UHPC were determined with respect to empirical tests for self-compacting concrete. The mechanical properties including the compressive and flexural strength and the Ultrasonic Pulse Velocity were defined over the curing period. Durability properties of the UHPC were determined over time, with respect to direct and indirect durability tests, including chloride-ion penetration, chloride migration, water sorptivity, water permeability, Vacuum saturation porosity and concrete resistivity. The crack-healing capability of cracked UHPC was assessed through microscopy. Results confirmed that all the nano-additives used in the production of UHPC, led to an enhancement of both the mechanical and durability performance over time. All the UHPC samples indicated a very good performance when cured in aggressive environment, with even an improvement in durability performance for UHPC mixes exposed to a chloride-rich environment. The research confirmed the improved performance of UHPC based on crystalline admixture and nano-additives, mechanical and durability properties as well as their ability to self-heal in a chloride rich environment.

References

- [1] Serna, P., Lo Monte, F., Mezquida-Alcaraz, E.J., Cuenca. E., Mechtcherine, V., Reichardt, M., Peled, A., Regev, O., Borg, R.P., Tretjakov, A., Lizunov, D., Sobolev, K., Sideri, S., Nelson, K., Gastaldo Brac, E.M., Ferrara, L., "Upgrading the concept of UHPFRC for High Durability in the cracked state: The concept of Ultra High Durability Concrete (UHDC) in the Approach of the H2020 Project ReSHEALience", Sustainable Materials Systems and Structures SMSS 2019, RILEM Publications SARL Volume 128, pp 764-771. (2019)
- [2] Borg, R.P., Vassallo, C., "Investigation of the Durability and Self-Healing properties of Ultra-High Performance Concrete based on Crystalline Admixtures and Nano-Additives, exposed to a Chloride-rich Aggressive Environment", 8th International Conference on Self-Healing Materials ICSHM-Milano 2022, (2022)

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Palermo, Italy, August 27 - 30, 2023

Title: Refined numerical analysis of the seismic response of masonry building aggregates

Author(s): Sofia Villar^{*1}, Fabio Di Trapani², Marilisa Di Benedetto³, Massimo Petracca⁴, Guido Camata⁵

¹ *Dipartimento di ingegneria Strutturale Edile e Geotecnica, Politecnico di Torino, Turin, Italy, villar.sofia.97@gmail.com*

² *Dipartimento di ingegneria Strutturale Edile e Geotecnica, Politecnico di Torino, Turin, Italy, fabio.ditrapani@polito.it*

³ *Dipartimento di ingegneria Strutturale Edile e Geotecnica, Politecnico di Torino, Turin, Italy, marilisa.dibenedetto@polito.it*

⁴ *ASDEA Software, Pescara, Italy, m.petracca@asdea.net*

⁵ *Dipartimento di Ingegneria e Geologia, Università degli studi "G. D'Annunzio" di Chieti-Pescara, Pescara, Italy, g.camata@unich.it*

Keyword(s): Building aggregates, Masonry, Homogenized masonry, Finite element modelling, STKO, OpenSees

Abstract

This study aims to investigate the behavior of unreinforced masonry aggregate buildings, which are part of the Italian historical building heritage. These structures are composed of multiple structural units that have been added over time. The seismic response of these structural systems is quite complex to be interpreted, mainly because the contribution of each unit may depend on the so-called "aggregate effect". The study provides a detailed numerical investigation of a reference three-unit building aggregate by varying different boundary conditions, e.g. the degree of connection between the walls and the flexibility of the floors. The masonry homogenization was carried out using layered 2D shell elements with an advanced material damage model available in STKO software platform for OpenSees. The case study models were tested with nonlinear static and dynamic analyses, assessing the influence of the parameters mentioned above on the overall and the individual structural unit response. The findings indicate that the aggregate effect may be fundamental to the seismic performance of building aggregates although this beneficial contribution is significantly affected by the boundary conditions.

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Palermo, Italy, August 27 - 30, 2023

Title: Refined assessment of the internal forces of infilled frames due to frame-infill interaction under seismic loads

Authors: Marilisa Di Benedetto^{*1}, Fabio Di Trapani², Massimo Petracca³, Guido Camata⁴

¹ *Dipartimento di Ingegneria Strutturale Edile e Geotecnica, Politecnico di Torino, Turin, Italy, marilisa.dibenedetto@polito.it*

² *Dipartimento di Ingegneria Strutturale Edile e Geotecnica, Politecnico di Torino, Turin, Italy, fabio.ditrapani@polito.it*

³ *ASDEA Software, Pescara, Italy, m.petracca@asdea.net*

⁴ *Dipartimento di Ingegneria e Geologia, Università degli studi "G. D'Annunzio" di Chieti-Pescara, Pescara, Italy, g.camata@unich.it*

Keywords: Infilled frames, Masonry, Reinforced concrete, Shear, Micro-modelling, STKO, OpenSees

Abstract

Infill-frame interaction significantly alters the internal forces acting on the surrounding concrete frame members and conditions the evolution of the damage under seismic loads. The assessment of this complex interaction is still a challenge as it is influenced by several geometrical and mechanical parameters characterizing the infilled frame. In the current study, a refined numerical micro-modelling approach is proposed to accurately reproduce the infilled frame, especially focusing on the contact interaction between the masonry and the reinforced concrete members. The micro-model was realized with the STKO software platform for OpenSees. The latter provides explicit modelling of the masonry units and the mortar layers with 2D quadrilateral elements and a nonlinear material constitutive law, while the interface interaction was modelled by using frictional interface contact elements. The internal forces on the frame members were evaluated by integrating the nodal forces at specific cross-sections of the RC members. Results show that the distribution of the internal force strictly depends on the possible failure modes of an infilled frame, which in turn depends on the mechanical coupling between the masonry units and the mortar. A parametric investigation is finally carried out revealing the parameters playing the major role and their possible use for an engineered design.

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Title: Simulation of the hysteretic behavior of timber connections by the Vaiana-Rosati model: parameters identification based on energy dissipation

Author(s): Agnese Spedicato^{*1}, Nicolò Vaiana¹, Stefania Lo Feudo², Jean-Luc Dion², Luciano Rosati¹

¹ Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy, agnese.spedicato@unina.it, agnese.spedicato@isae-supmeca.fr

² Quartz (EA7393), VAST-FM, ISAE-Supméca, Saint-Ouen-sur-Seine, France, stefania.lofeudo@isae-supmeca.fr, jean-luc.dion@isae-supmeca.fr

Keyword(s): hysteresis loop, timber connection, Vaiana-Rosati model

Abstract

Timber buildings are increasingly used in seismic geographic areas due to their lightweight and ductile behavior, which is influenced by several factors, including building geometry, connection design and the properties of the wood materials used. Being the new architectural frontier to incentive the design of tall timber buildings [1], and to achieve well performance, it is necessary to consider how those structures may react during dynamic events, such as earthquakes or wind loads.

Commonly, connections are designed to be strong enough to withstand the forces generated during a dynamic excitation, but also ductile enough to allow some deformation without causing damage. Depending on the type of connection chosen, including single fasteners, angle brackets and hold-downs, timber buildings exhibit complex force-displacement hysteresis loops, indicative of energy dissipation. Moreover, the characteristic hysteretic behavior of timber structures is much more complex than those of other materials. Specifically, the typical hysteresis loop shapes are affected by two different phenomena: pinching as well as force and/or stiffness deterioration.

Due to the lack of knowledge of the seismic behavior of timber structures, researchers have developed several phenomenological models to simulate it. This paper will aim to simulate the experimental hysteresis loops of timber connections, using the Vaiana-Rosati model, recently formulated in [2]. The model permits the simulation of very complex loop shapes, using parameters with a specific physical meaning. In addition, the model parameters identification will take into account the energy dissipation during the load time history [3], in order to reduce the analysis effort in the model calibration and make the procedure more accurate.

References

- [1] Follesa M., Fragiaco M., Casagrande D., Tomasi R., Piazza M., Vassallo D., Canetti D., Rossi S., "The new provisions for the seismic design of timber buildings in Europe", *Engineering Structures*, 168, 736-747, (2018).
- [2] Vaiana N., Rosati L., "Classification and unified phenomenological modeling of complex uniaxial rate-independent hysteretic responses", *Mechanical Systems and Signal Processing*, 182: 109539 (2023).
- [3] Vaiana N., Capuano R., Rosati L., "Evaluation of path-dependent work and internal energy change for hysteretic mechanical systems", *Mechanical Systems and Signal Processing*, 186: 109862 (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Parametric identification of frictional joints in structures

Author(s): Jean-Luc Dion^{*1}, Antonio Baldassarre¹, Stefania Lo Feudo¹, Franck Renaud¹

¹ VAST-FM, QUARTZ Laboratory EA7393, ISAE-Supméca 93400 SAINT OUEEN SUR SEINE, France,
jean-luc.dion@isae-supmecca.fr

Keyword(s): Dynamic friction, Non-linear system identification, Kalman filters

Abstract

The work developed in this paper aims to produce identified reduced order model for joints in structures for dynamics simulations under transient or random excitations. The parametric identification of proposed friction model is based on nonlinear model dynamics and measurement setup [1,3] with three orthogonal symmetry-planes and four contact areas. A measurement example is presented for a contact pair of aluminum alloys starting from sticking limit until complete sliding. Physics and tribologic phenomena are depicted and analysed. In order to use experimental results in vibration models, a method is proposed to identify a reduced order model with steady state models [2] from these measurements. The identified model is used for a joint in a larger structure in order to analyze and assess its efficiency in dynamics simulations. The induced nonlinear normal modes are tracked with Kalman filters [3] and allow to link global measurements to local nonlinear model in joints. A discussion on the observability of local model in global measurement is proposed.

References

- [1] M.Eriten, C.-H.Lee, A.Polycarpou, Measurements of tangential stiffness and damping of mechanical joints: Direct versus indirect contact resonance methods, *Tribology International* 50(2012) 35–44.
- [2] P.Dahl, A solid Friction Model, The Aerospace Corporation, El Segundo, CA,1968, TOR-0158H3107–18I-1.
- [3] J. Dion, G. Chevallier, O. Penas, and F. Renaud, "A new multicontact tribometer for deterministic dynamic friction identification," *Wear*, vol. 300, no. 1-2, pp. 126 – 135, 2013.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Optimization strategy for the calibration of a generalized hysteretic model.

Author(s): Salvatore Sessa^{*1}, Nicolo Vaiana²

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy, salvatore.sessa2@unina.it*

² *Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy, nicolo.vaiana@unina.it*

Keyword(s): Asymmetric hysteresis, Inverse identification, Generalized Bouc-Wen

Abstract

Within the context of nonlinear analysis of structural systems presenting hysteretic phenomena, a class of phenomenological constitutive models has been recently presented [1] and extended to asymmetric loops with softening and hardening behaviour [2].

Compared to models having similar behaviours, such classes are significantly more efficient being capable of providing closed form responses without using iterative procedures nor differential relationships. Nevertheless, because of their phenomenological characterization, their parameters need to be properly calibrated by matching experimental hysteresis loops. Parameter identification turns out to be particularly complex in the case of the asymmetric case [2] since they cannot be directly related to physical properties of the experimental response.

The present research investigates an identification procedure based on the optimization of least-square residuals defined in terms of response amplitude and stiffness. In particular, because of the presence of hardening and softening phenomena, simplex- and gradient-based optimization procedures need a robust calibration of their first trials.

The proposed procedure consists of three subsequent optimization phases of which the first two perform preliminary and separate identifications of two sets of the constitutive parameters. Such pre-processed results are then adopted as first trials of a conclusive global optimization adopting a weighted residual involving response amplitude and stiffness.

Numerical applications are provided in order to show the robustness of the proposed procedure as well as its sensitivity with respect to the weights adopted for the residual. Moreover, comparisons with the Generalized Bouc-Wen model [3], providing similar hysteresis loops, proves the advantages of the investigated class of asymmetric materials.

References

- [1] Vaiana N., Sessa S., Marmo F., Rosati L., "A class of uniaxial phenomenological models for simulating hysteretic phenomena in rate-independent mechanical systems and materials," *Nonlinear Dynamics*, 93(3), 1647-1669, (2018).
- [2] Vaiana N., Sessa S., Rosati L., "A generalized class of uniaxial rate-independent models for simulating asymmetric mechanical hysteresis phenomena," *Mechanical Systems and Signal Processing*, 146, 106984 (2021).
- [3] Song J., Der Kiureghian A., "Generalized Bouc-Wen model for highly asymmetric hysteresis," *Journal of Engineering Mechanics*, 132(6), 610-618, (2006).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A new numerical one-domain approach solver for the interaction of free fluid and porous medium at the mesoscale

Author(s): Costanza Aricò¹, Martin Schneider², Daniele Puleo¹, Rainer Helmig²

¹ Department of Engineering, University of Palermo, Palermo, Italy, costanza.arico@unipa.it, daniele.puleo02@unipa.it

² Institute for Modelling Hydraulic and Environmental Systems (IWS), Universitaet Stuttgart, Germany, martin.schneider@iws.uni-stuttgart.de, rainer.helmig@iws.uni-stuttgart.de

Keyword(s): free fluid, porous medium, coupling, continuum medium, anisotropy, numerical scheme

Abstract

Momentum transfer at the interface between free fluid and porous media deserves significant investigation. Interface transport phenomena are involved in different environmental, industrial and biomedical applications (e.g., filtration and drying processes, groundwater flow, passive control devices using porous coating, heat exchangers, fuel cells, flows in biological tissues) [1].

A new numerical continuum *one-domain approach* (ODA) solver is presented for the simulation of the transfer processes between a free fluid and a porous medium. The solver is developed in the framework of the *mesoscopic scale* approach, assuming a continuous variation of the porosity and permeability of the porous medium within a transition zone close to the interface between the clear fluid region and the bulk porous matrix. The governing equations are the Navier-Stokes-Brinkman equations and the continuity equation. We assume a Newtonian and incompressible fluid inside and around a saturated and anisotropic porous medium, with the solid particles fixed in space. We discretize the computational domain using unstructured meshes. A fractional time step procedure is applied, where one predictor and two corrector problems are sequentially solved within each time step (PP, CP1 and CP2, respectively). The PP is solved in the framework of a marching in space and time procedure, which present some important numerical advantages. The CP1 and CP2 require the solution of large linear systems, whose matrices are sparse, symmetric and positive definite. A fast and efficient solution is obtained using a preconditioned conjugate gradient method. The numerical discretization strategy adopted for CP1 and CP2 can be regarded as a Two-Point-Flux-Approximation (TPFA) scheme, which, unlike the standard TPFA schemes, does not require the grid mesh to be $\mathbf{K}$ -orthogonal, ($\mathbf{K}$ is the anisotropy tensor), as shown in the provided tests. In some of the presented applications, we compare the solution of the present algorithm with the one provided by a continuum one-domain approach developed in the *macroscopic scale* framework, where a *penalized* Navier-Stokes set of governing equations is solved. An extra penalizing Darcy term in the momentum equation accounts for the drag force of the solid particles of the porous medium over the fluid [2]. Porosity and permeability undergo discontinuous change between the values in the bulk porous region and those in the clear fluid region. Compared with the reference solutions, the results of the *macroscale* approach show significant differences throughout the domain.

References

- [1] M. Chandesris, D. Jamet, "Boundary conditions at a fluid-porous interface: An *a priori* estimation of the stress jump coefficients", *Int. J. Heat Mass Transf.*, vol. 50, 3422–3436 (2007)
- [2] C.-H. Bruneau, I. Mortazavi, "Numerical modelling and passive flow control using porous media", *Computers & Fluids*, vol. 37, 488.498 (2008)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Numerical investigation of the flat plate solar collector (FPSC) at the mesoscale and macroscale. Preliminary results

Author(s): Memoona*, Daniele Puleo, Antonina Pirrotta, Costanza Aricò

Department of Engineering, University of Palermo, Palermo, Italy, xxx.memoona@unipa.it, daniele.puleo02@unipa.it, antonina.pirrotta@unipa.it, costanza.arico@unipa.it

Keyword(s): Flat plate solar collector, porous media, mesoscale approach, macroscale approach, numerical analysis

Abstract

Solar thermal systems have been one of the most exciting technologies of interests for engineers. One of the oldest solar thermal systems, the flat-plate solar collectors (FPSC), which is also the most applied one, exhibits a high amount of heat loss and minor thermal efficiency. Porous materials, in particular porous metal foams, can be effectively used as a *passive* way of improving heat transfer of FPSC. Due to the presence of voids, porous materials are used to store thermal energy and enhance thermal mixing, promoting thermal conductivity of the fluid [1, 2].

The problem of heat and mass transfers at the fluid–porous interface can be investigated at different scales [3]. At the microscopic pore-scale, each pore of the porous media is described and the direct numerical simulation gives the exact description of the transport processes. Such an approach presents two drawbacks, namely 1) the high computational effort, due to the exact discretization of the geometries within the porous matrix and 2) the lack of an exact knowledge of the entire porous geometry [3]. For these reasons it is necessary to “lower down” the precision of the porous region by using descriptions at the *mesoscopic* or *macroscopic* scales. At the mesoscopic level, a fictitious continuum medium replaces the fluid and solid phases, and the transition from the bulk fluid to the bulk porous region is obtained by a continuous variation of the porosity and permeability, as well as the thermal conductivity properties within a transition zone (or transition layer, TL), located in between the two bulk regions. In the *macroscopic* approach, the so-called penalized-Navier-Stokes and transport equations has been widely applied. Porosity, permeability and conductivity undergo discontinuous change between the values in the bulk porous region and those in the clear fluid region. In the present work we first derive from pore-scale simulations the porosity, permeability and thermal conductivity profiles in the TL. Then we compare the results obtained applying a mesoscale and a macroscale numerical approach to simulate the flow and heat transport process within and around a theoretical FPSC. Important decision strategies are derived.

References

- [1] S. Saedodina, S.A.H. Zamzamian, M. Eshagh Nimvari, S. Wongwises, H. Javaniyan Jouybari, “Performance evaluation of a flat-plate solar collector filled with porous metal foam: Experimental and numerical analysis”, *Energy Conversion and Management* vol. 153 278–287 (2017)
- [2] K. Anirudh, S. Dhinakaran, “Performance improvement of a flat-plate solar collector by inserting intermittent porous blocks”, *Renewable Energy*, vol. 145 428-441, (2020)
- [3] A. d’Hueppe, M. Chandesis, D. Jamet, B. Goyeau, “Boundary conditions at a fluid–porous interface for a convective heat transfer problem: Analysis of the jump relations”, *International Journal of Heat and Mass Transfer*, vol. 54 3683–3693 (2011).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Intelligent Automatic Operational Modal Analysis

Authors: Marco Martino Rosso^{*1}, Angelo Aloisio², Giuseppe Carlo Marano^{1,4}, Giuseppe Quaranta³,

¹ DISEG, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy, marco.rosso@polito.it , marilisa.dibenedetto@polito.it , fabio.ditrapani@polito.it , giuseppe.marano@polito.it

² Civil, Environmental and Architectural Engineering Department, Universita' degli Studi dell'Aquila, Via Giovanni Gronchi 18, 67100 L'Aquila, Italy

³ Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

⁴ College of Civil Engineering, Fuzhou University, Fuzhou, Fujian 350108, China.

Keywords: machine learning, operational modal analysis, random forest, stabilization diagram, stochastic subspace identification, tall building, uncertainty propagation

Abstract

Within the structural health monitoring (SHM) field, consistent research efforts have been invested in developing automatic vibration-based indirect methodologies for inspecting existing heritage conditions. Current trends are mainly focused on output-only automatic operational modal analysis (AOMA), specifically throughout the stochastic subspace identification (SSI) technique among others. In the literature, a widespread workflow is implemented in a four-step solution: choice of the SSI control input parameters, computation of stabilization diagrams, stable poles' alignments detection, and their final clustering. However, the so far proposed solutions have not provided yet complete answers to some challenging and still open questions. For instance, an arbitrarily poor initial choice of the SSI control parameters may jeopardize the entire procedure. Therefore, in the current study, the authors present a novel intelligent-based AOMA framework in a machine learning perspective. Specifically, random forest-driven Monte Carlo sampling of control parameters represents a promising intelligent way to automatically choose the proper SSI control parameters. Furthermore, the recurrent stable physical poles in the stabilization diagram among the Monte Carlo simulations deliver some special insights about mode shape confidence intervals. A numerical benchmark is herein analyzed illustrating some preliminary results and potentials of the proposed methodology.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Influence of noise on First Passage Time maps and their use for early damage detection

Author(s): Kevin Theunissen*¹, Vincent Denoël²

¹ *Structural & Stochastic Dynamics, University of Liège, Liège, Belgium, kevin.theunissen@uliege.be*

² *Structural & Stochastic Dynamics, University of Liège, Liège, Belgium, v.denoel@uliege.be*

Keyword(s): Structural health monitoring, Change detection, Signal processing

Abstract

In structural health monitoring, First Passage Time (FPT) is defined as the random time spent by a stochastic system to evolve from an initial to a terminal energy level. By pairing various values of the initial and terminal energy levels, statistics of the FPT (such as average or standard deviation) can be represented in so-called FPT maps. Besides, histograms of the FPT for some specific combinations of initial and terminal energy levels provide additional information about the system dynamics. This way to process time series collected on real structures under unmeasured environmental loading has been made possible thanks to the development of efficient algorithms.

Previous works have revealed that FPT maps and histograms have a great potential to detect slight damage [1,2]. In-lab demonstrators on a steel strip have been used as prototypes to develop a proof-of-concept. However, in real-life applications, the level of ambient noise might be higher than what has been considered in the lab experiments. Also, the type of noise (white, brown, pink, band-limited or non, etc.) is expected to make the detection procedure more difficult. It is indeed known that the effect of noise can complicate damage detection, especially when the input is unknown and under changing environmental conditions [3].

In order to evaluate the sensitivity of the damage detection technique based on FPT maps and histograms to noise, an exhaustive study has been carried out. It is based on numerical simulations of a simple LTI system mimicking the experimental setup of the steel strip previously used by the authors. On one hand, this system has been subjected to unmeasured noises of various types as exogenous loading. On the other hand, the measured output has been also corrupted by various types of noise, pretending that the measurement was imperfect. The influence of several combinations of such modifications of the input and output of the model has been studied carefully. The proposed exposé will deliver the major outcomes of this study in terms of statistical descriptions and fault detectability conditions.

References

- [1] Theunissen K., Verstraelen E., Golinval J.-C., Denoël V., "Influence of structural damages on first passage time maps" in ISMA-USD Noise and Vibration Engineering Conference 2022, Louvain, Belgium, 2022.
- [2] Theunissen K., Verstraelen E., Golinval J.-C., Denoël V., "Localization of structural damage based on First Passage Times for a pre-stressed steel strip" in IMAC-XLI, Austin, USA, 2023.
- [3] Deraemaeker A., Reynders E., De Roeck G., Kullaa J., "Vibration-based structural health monitoring using output-only measurements under changing environment", *Mechanical Systems and Signal Processing*, 22, 34-56, (2008).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Characterization of the dynamic response of a curved nine-spans post-tensioned concrete box girder highway bridge with half-joints

Author(s): Elisa Tomassini^{*1}, Enrique García-Macías², Francesco Mariani³, Ilaria Venanzi⁴ and Filippo Ubertini⁵

¹ Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 - 06125 Perugia, Italy, elisa.tomassini1@studenti.unipg.it

² Department of Structural Mechanics and Hydraulic Engineering, University of Granada, Av. Fuentenueva sn, 18002 Granada, Spain, enriquegm@ugr.es

³ Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 - 06125 Perugia, Italy, francesco.mariani6@studenti.unipg.it

³ Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 - 06125 Perugia, Italy, ilaria.venanzi@unipg.it

⁴ Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 - 06125 Perugia, Italy, filippo.ubertini@unipg.it

Keyword(s): Structural Health Monitoring, Operational Modal Analysis, Multi-span bridge, Vibration-based SHM, Half-joints.

Abstract

In recent years, one of the most investigated topics in road infrastructure engineering is finding new effective ways to improve the safety of bridge networks. Indeed, the worldwide failure of a large number of bridges has pressed governments to increase investments and to enact new monitoring regulations in the global context [1-4]. In this field, Structural Health Monitoring (SHM) plays a key role and effectively complements traditional visual inspection techniques in the field of low intrusive non-destructive analysis. Among the wide world of SHM techniques, Operational Modal Analysis (OMA) is a vibration-based method that consists in analysing the ambient accelerations recorded at strategic locations on the structure in order to extract and track its modal features (frequencies, mode-shapes and damping ratios). On this basis, damage detection can be conducted in data-drive fashion through statistical pattern recognition approaches [5-8]. Indeed, a statistically meaningful change in the distribution of tracked modal features, after proper compensation of environmental and operational effects, can reveal variations in the stiffness properties of the structure and therefore the onset of certain types of damage. Therefore, one of the most recent advances in OMA algorithms is related to the development of continuous Automated OMA embedded in complex and high-potential software [9-10]. Thanks to new regulations and increasing awareness of SHM potential, these powerful technologies are currently being transferred to real-world applications to enable an effective large-scale monitoring method for infrastructure network management authorities. Since multi-span bridges are often monitored using a large number of sensors, the continuous modal identification with such big data challenge results in: (i) a high computational burden and (ii) necessity for high-performance hardware to perform the analyses in a short timeframe. Moreover, sometimes the periodicity of structural bridge components (e.g. equal length of the spans, cross section, connections) makes the global assessment particularly challenging [11]. In fact, in periodic structures, the modal properties of spans typically appear as dense clusters of poles with closely spaced frequencies and mode shapes with similar wavelengths. To avoid these bottlenecks, the analysis is often performed

through span-wise identification of the bridge. While this approach is effective from the computational point of view, it may lose the ability to perform a global assessment of the entire structure. This approach also produces a replication of the same global modes in different subgroups that may be wrongly interpreted as local modes. Thus, the main purpose of this work is to perform a critical analysis by comparing the results of a global analysis with those of an analysis by subgroups of channels. Quality of the identified modes, correlations with operational and environmental conditions, as well as quality of typical statistical control charts used for novelty detection are considered in the analysis. The choice of subgroups of channels is guided by the static scheme and the characteristics of the cross-section of the deck, as well as the geometrical layout of the channels. The investigated case study is a curved nine-spans post-tensioned concrete box girder bridge characterized by 10 half-joints and continuously monitored with more than 50 sensors.

References

- [1] Federal Highway Administration (FHWA) of U.S. Department of Transportation, Apportionment of Highway Infrastructure Program Funds Pursuant to the Department of Transportation Appropriations Act, 2022 (May 5, 2022).
- [2] American Society of Civil Engineers ASCE, 2021 Report Card for America's Infrastructures (2021).
- [3] Zhang G., Liu Y., Liu J., Lan S., Yang J., Causes and statistical characteristics of bridge failures: A review, *Journal of Traffic and Transportation Engineering (English Edition)* 9 (3), 388–406 (2022).
- [4] Italian Ministry of Infrastructure and Transport, Guidelines on Risk Classification and Management, Safety Assessment and Monitoring of Existing Bridges (July 1, 2022).
- [5] Magalhães F., Cunha Á., Explaining operational modal analysis with data from an arch bridge, *Mechanical systems and signal processing* 25 (5), 1431–1450, (2011).
- [6] An Y., Chatzi E., Sim S., Laflamme S., Blachowski B., Ou J., Recent progress and future trends on damage identification methods for bridge structures, *Structural Control Health Monitoring* 26, e2416, (2019).
- [7] Maes K., VanMeerbeek L., Reynders E., Lombaert G., Validation of vibration-based structural healthmonitoring on retrofitted railway bridge KW51, *Mechanical Systems and Signal Processing* 165 (2022).
- [8] Hou R., Xia Y., Review on the new development of vibration-based damage identification for civil engineering structures: 2010–2019, *Journal of Sound and Vibration* 491, 115741, (2021).
- [9] García-Macías E., Ruccolo A., Zanini M. A., Pellegrino C., Gentile C., Ubertini F., Mannella P., P3P: a software suite for autonomous SHM of bridge networks, *Journal of Civil Structural Health Monitoring*, 1–18, (2022).
- [10] García-Macías E., Ubertini F., MOVA/MOSS: Two integrated software solutions for comprehensive Structural Health Monitoring of structures, *Mechanical Systems and Signal Processing* 143, 106830, (2020).
- [11] J. Zhang, E. Reynders, G. De Roeck, G. Lombaert, Model updating of periodic structures based on free wave characteristics, *Journal of Sound and Vibration* 442 (2019) 281–307.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A mechanical model of exudative macular oedema

Author(s): Alessia Ruffini¹, Maria Dvoriashyna², Rodolfo Repetto^{*1}

¹*Department of Civil, Chemical and Environmental Engineering, University of Genoa, Italy, alessia.ruffini@edu.unige.it, rodolfo.repetto@unige.it*

²*Mathematical Institute, University of Oxford, United Kingdom, dvoriashyna@maths.ox.ac.uk*

Keyword(s): Exudative macular oedema, fluid flow in the retina

Abstract

Exudative macular oedema consists of accumulation of fluid in the intra- or sub-retinal space, in a specific zone of the retina called macula, due to fluid leakage from blood vessels. Clinical observations show that fluid accumulation typically occurs in the fovea, although there are no retinal blood vessels there. We propose an explanation of this finding, based on the use of a mechanical model of fluid and solute transport in the retina. Müller cells (MC) are cells that span the thickness of the retina and are responsible for its mechanical behaviour. MCs density varies along the retina, being very low in the fovea and much larger in the parafovea. Moreover, MCs are orthogonal to the retinal surface at their extremities and inclined in the middle layer. Inclined cells are packed much more closely, reducing tissue permeability.

This is confirmed by our calculation of tissue permeability, according to which the middle layer is approximately 10 times less permeable, in agreement with Antcliff's experimental work [1], which shows the presence of a middle layer of the retina, characterised by a higher resistance to fluid flow. We study flow motion in the retina due to leakage or impairment of blood vessels in the retina, modelling the tissue as a non-homogeneous, anisotropic, poroelastic medium. The overall hydraulic conductivity of the retinal tissue predicted by our model is in good agreement with the value measured by Fatt et al. [2]. The fluid circulation model predicts that fluid accumulates in the fovea as observed clinically. Fluid accumulates in the foveal region because this region is more compliant than the rest of the retina, owing to a much lower density of MCs, and the foveal pressure there is high. The model also suggests that the density and conformation of MCs have a significant impact on fluid motion in the retina during macular oedema and that fluid can move a relatively long distance from the exudation region along the retina because the middle layer of the retina has a lower hydraulic conductivity.

References

- [1] Antcliff, R. J., Hussain, A. A., & Marshall, J. (2001). Hydraulic conductivity of fixed retinal tissue after sequential excimer laser ablation: barriers limiting fluid distribution and implications for cystoid macular edema. *Archives of ophthalmology*, 119(4), 539-544.
- [2] Fatt, I., & Shantinath, K. (1971). Flow conductivity of retina and its role in retinal adhesion. *Experimental eye research*, 12(2), 218-226.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Hemodynamics in patients supported on VA-ECMO: a preliminary 0D model.

Authors: Caterina Cara^{*1}, Paolo Peruzzo¹, Laura Besola², Nicola Nencioni², Andrea Colli² and Francesca M. Susin¹

¹ *Department of Civil, Environmental and Architectural Engineering, Padova, Italy, caterina.cara@phd.unipd.it*

² *Department of Surgical, Medical and Molecular Pathology and Critical Care, University of Pisa, Pisa, Italy*

Keyword(s): VA-ECMO, Lumped Models, Hemodynamics, Cardiogenic shock treatment

Abstract

Cardiogenic shock (CS) is a severe cardiac condition characterised by highly depressed ventricular contractility and insufficient oxygenation of organs and tissues. When it is refractory to conventional treatments, the VA-ECMO (*Veno Arterial- Extracorporeal Membrane Oxygenation*) can be adopted to (partly) compensate both the oxygenation and circulation function. The use of VA-ECMO is still controversial. Mortality for CS patients on VA-ECMO remains high and its variability with the etiology of CS is unclear [1]. Important side effects such as worsening of the gas exchange through lungs in treated patients are reported [2] and patient selection and management remain challenging. On the other side, there is increasing evidence that VA-ECMO can not only support patients but also favour their cardiac function recovery. However, the engineering literature focused on these issues is still very limited.

In the above panorama, we propose a simple lumped parameters model as a preliminary predictive tool of hemodynamics in subjects supported on ECMO. The model couples the complete circulation of [3] and a VA-ECMO parallel circuit that drains/delivers blood at the level of the right atrium/aortic valve, respectively. The only functional element of the ECMO included in the model so far is the mechanical pump, which can supply either a given constant flow rate or pressure head. The mechanical energy conservation equation is solved between the drainage and the delivery sites to calculate the unknown between the pressure head and the flow rate. Viscous friction losses along the ECMO cannulae are taken into account, while temporal inertia of the blood flow is neglected.

A series of preliminary runs were carried out to test the potential of the model to shed light on clinical observations and to serve as a practical tool for the improvement of the device management. To that aim, the model was run to calculate the VA-ECMO pump pressure head that guarantees the flow rate and mean arterial pressure met in the clinical practice to set the device. The clinical setting is usually performed according to a trial-and-error procedure. Coupling model predictions and the pumping performance curves of the device could hence allow the automatic setting of the device itself and save precious time in the initiation of the treatment. Model results also suggest a possible reason for the ventricular function recovery, quite often observed in treated patients. For a given contractility impairment grade the model shows that the left ventricle stroke work is lower in the supported than in the non-supported VA-ECMO patient, i.e., the mechanical circulatory support helps the left ventricle work unloading. For what VA-ECMO side effects are concerned, model predictions show that the pulmonary capillary pressure is higher in treated than in non-treated subjects, almost independently on the contractility impairment level. The above occurrence might be among the factors driving the observed worsening of spontaneous oxygenation in patients on VA-ECMO.

The presented model has more than one limitation (e.g., organs are modelled as one single element apart from lungs and parameters are calibrated on a reference rather than on a specific patient) but confirms the appropriateness of 0D modelling as a strategy to effectively investigate both the positive

and negative effects of treating CS by VA-ECMO. The automation of the current ECMO devices management seems also a possible outcome.

References

- [1] Alba AC, Foroutan F, Buchan TA, Alvarez J, Kinsella A, Clark K, Zhu A, Lau K, McGuinty C, Aleksova N, Francis T, Stanimirovic A, Vishram-Nielsen J, Malik A, Ross HJ, Fan E, Rac VE, Rao V, Billia F. "Mortality in patients with cardiogenic shock supported with VA ECMO: A systematic review and meta-analysis evaluating the impact of etiology on 29,289 patients." *J Heart Lung Transplant*. 2021 Apr;40(4):260-268. doi: 10.1016/j.healun.2021.01.009. Epub 2021 Jan 19. PMID: 33551227.
- [2] Tsangaris A, Alexy T, Kalra R, Kosmopoulos M, Elliott A, Bartos JÁ and Yannopoulos D "Overview of Veno-Arterial Extracorporeal Membrane Oxygenation (VA-ECMO) Support for the Management of Cardiogenic Shock." *Front. Cardiovasc. (2021) Med.* 8:686558. doi: 10.3389/fcvm.2021.686558
- [3] Comunale G, Peruzzo P, Castaldi B, Razzolini R, Di Salvo G, Padalino MA, Susin FM. "Understanding and recognition of the right ventricular function and dysfunction via a numerical study". *Sci Rep*. 2021 Feb 12;11(1):3709. doi: 10.1038/s41598-021-82567-9. PMID: 33580128; PMCID: PMC7881145.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Anchoring and Migration of Balloon in REBOA

Author(s): Chiang Mei¹, Yile Li², Simone Michele³, Paolo Sammarco^{*4}, Paul McBeth⁵

¹ Dept. of Civil and Environmental Engineering, Massachusetts Institute of Technology, USA, ccmei@mit.edu

² Katy, Texas, USA, yile.li@gmail.com

³ School of Engineering, Computing and Mathematics, University of Plymouth, Drake Circus, Plymouth, UK, simone.michele@plymouth.ac.uk

⁴ Dept. of Civil Engineering and Computer Science, Università degli Studi di Roma 'Tor Vergata', Roma, Italy, sammarco@ing.uniroma2.it

⁵ Trauma and Acute Care Surgery, Cumming School of Medicine, University of Calgary, Canada, City, Country, Paul.McBeth@albertahealthservices.ca

Keywords: Blood flow, Biological Fluid Dynamics, Flow-vessel interactions

Abstract

A mechanical theory is described for a phenomenon in the surgical procedure of *Resuscitative Endovascular Balloon Occlusion of the Aorta* (REBOA) [1]. In this procedure a balloon is pushed into the aorta by a catheter and then inflated in order to stop haemorrhage. One of the hazards of this procedure is the tendency for the balloon to migrate away from its intended position. This work examines the mechanics of balloon anchoring and migration by analyzing the effects of pressure waves, the sheet flow and solid friction in the thin gap between the walls of the aorta and balloon. A viscoelastic model is adopted for the aorta wall for pressure waves between the left ventricle and the balloon. The lubrication approximation is used for blood flow in the thin gap between the walls of balloon and aorta. Samples of quantitative predictions are discussed on how the inflation pressure and balloon characteristics affect the balloon anchoring and migration. The crucial roles of solid friction and balloon placement are pointed out, which should help in guiding the manufacturing of balloons and their usage in the field.

References

[1] Mei, C.C., Li, Y.L., Michele, S., Sammarco, P., Mcbeth, P.B. Anchoring and Migration of Balloon in REBOA. *Journal of Fluid Mechanics*, 2021, 927, A20

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Parameter estimation of stochastic fractional dynamic systems using recursive nonlinear filtering system identification methods

Author(s): Alberto Di Matteo^{*1}, Kalil Erazo², Pol D. Spanos³

¹ *Department of Engineering, University of Palermo, Italy*

² *Department of Civil and Environmental Engineering, Rice University, USA*

³ *L. B. Ryon Chair in Engineering, Rice University, 6100 Main Street, Houston, TX 77005-1827, USA*

Keyword(s): Fractional derivative systems; Parameters identification; Kalman filters; Particle filters.

Abstract

In this paper, various nonlinear filtering system identification methods [1, 2] are extended and applied to estimate the parameters of stochastic dynamic systems comprising fractional derivatives terms [3]. Specifically, time domain recursive filtering-based identification procedures are considered. In this regard, three methods are studied: the unscented Kalman filter, the ensemble Kalman filter, and the particle filter [4]. Further, the effectiveness and accuracy of these methods are assessed considering different operating conditions including measured forcing inputs (input-output identification), stationary and non-stationary excitations (output-only identification), various kinds of measurements and of measurement noise levels. In this context, several baseline results are provided that can be used in the modeling and identification of structural and mechanical systems whose behavior can be modelled by fractional derivative elements. It is shown that nonlinear filtering methods have the capability to estimate the parameters of linear and nonlinear fractional systems, and that the order of the fractional derivative elements can be identified from the response measurements.

References

- [1] Erazo K., Nagarajaiah S., "An offline approach for output-only Bayesian identification of stochastic nonlinear systems using unscented Kalman filtering", *Journal of Sound and Vibration*, 397, 222-240, 2017.
- [2] Kerschen G., Worden K., Vakakis A.F., Golinval J.C., "Past, present and future of nonlinear system identification in structural dynamics", *Mechanical systems and signal processing*, 20, 505-592, 2006.
- [3] Spanos P.D., Zhang W., "Nonstationary stochastic response determination of nonlinear oscillators endowed with fractional derivatives", *International Journal of Non-Linear Mechanics*, 146, 104170, 2022.
- [4] Khalil M., Sarkar A., Adhikari S., Poirel D., "The estimation of time-invariant parameters of noisy nonlinear oscillatory systems", *Journal of Sound and Vibration*, 344, 81-100, 2015.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Novel bridge damping identification procedure through vehicle-bridge interaction

Author(s): Matteo Mazzeo¹, Roberta Santoro^{*1}, Alberto Di Matteo²

¹ *Department of Engineering, University of Messina, Messina, Italy, {matteo.mazzeo, roberta.santoro}@unime.it*

² *Department of Engineering, University of Palermo, Palermo, Italy, alberto.dimatteo@unipa.it*

Keyword(s): vehicle-bridge system, modal parameters, variational mode decomposition (VMD), Natural Excitation Technique.

Abstract

Dynamic identification is a consolidated approach in structural health monitoring to assess the health status of structures such as bridges. Conventional monitoring strategies involves direct installation of a network of sensors on the structure for a fixed time span. However, economic constraints make direct monitoring feasible only for a limited number of important bridges. To overcome this limitation, bridges indirect dynamic identification methods have been proposed, in which an instrumented moving vehicle is used as a moving sensor [1].

In this contribution a novel procedure for the extraction of modal parameters of bridge structures crossed by a vehicle is presented. The vehicle is assumed as a single-degree-of-freedom oscillator, whereas the bridge is modelled as a simply supported Euler-Bernoulli beam.

Novel approximate closed-form expressions are presented for the vertical responses of the system considering both the effect of damping and road roughness.

The proposed method exploits as input signal the acceleration at the vehicle-bridge contact point: Variational Mode Decomposition [2] is used to retrieve both modal frequencies and uni-modal signal components. Further, the Natural Excitation Technique (NExT) [3] is then used to convert the uni-modal components to free vibration-like signals. In this manner, the modal damping ratios are obtained from the converted free vibration components using a novel area-based approach. Results have shown that the proposed approach significantly limits the effect of noise on the damping estimates, thus leading to a higher degree of accuracy with respect to other comparable procedure in the literature [4].

References

- [1] Yang Y.B., Lin C.W., Yau J.D., "Extracting bridge frequencies from the dynamic response of a passing vehicle", *Journal of Sound and Vibrations*, 272(3–5), 471–493, (2004).
- [2] Dragomiretskiy K., Zosso D., "Variational mode decomposition", *IEEE Transactions on Signal Processing*, 62(3), 531–44, (2013).
- [3] James III G.H., Carne T.G., Lauffer J.P., "The natural excitation technique (NExT) for modal parameter extraction from operating wind turbines", *Tech. rep. Sandia National Labs., NM (United States)*, (1993).
- [4] Yang Y.B., Shi K., Wang Z.L., Xu H., Zhang B., Wu Y. T., "Using a single-DOF test vehicle to simultaneously retrieve the first few frequencies and damping ratios of the bridge", *International Journal of Structural Stability and Dynamics*, 21(08), 2150108, (2021).

Fisher Information based Optimal Sensor Locations for Structural Identification: Non-Stationary Inputs and Non-Classically Damped Systems

Dhiraj Ghosh^{*1}, Suparno Mukhopadhyay²

¹*Civil Engineering Department, Indian Institute of Technology Kanpur, Kanpur, India, dghosh@iitk.ac.in*

²*Civil Engineering Department, Indian Institute of Technology Kanpur, Kanpur, India, suparno@iitk.ac.in*

Keywords: modal identification, stiffness identification, optimal sensor locations, Fisher information, minimum uncertainty, non-stationary inputs, non-classically damped systems, damage detection

Abstract:

In vibration-based structural identification, the determination of optimal sensor locations has been predominantly attempted for problems with known or stationary inputs, and for classically damped systems. However, in many cases, the input excitation may not be measured and may be nonstationary. Similarly, many systems, such as primary-secondary systems, may not be classically damped. In this study, we consider two such cases. The optimal sensor locations, for identifying different parameters (modal as well as stiffness) are obtained by maximizing the associated Fisher information, such that the optimally located sensors contain the maximum information about the parameters of interest. First, we consider the case of unmeasured non-stationary base excitation, modelled as a uniformly (amplitude) modulated random process. Under such motions, it is shown that the sum of eigenvalues of the output power spectrum, considered as measurement parameter, follows an exponential distribution. The Fisher information is then shown to comprise of the sum of these eigenvalues, along with the sensitivities of the output power spectrum to the parameters of interest. Next, we consider primary-secondary systems, which can be non-classically damped, and formulate the approach in the state-space framework to deal with the mode shapes being inherently complex. The methodology is illustrated through numerical simulations as well as experimental data from shake table tests. The effect of unobserved modes is also studied. It is shown that, while stiffness depending on unobservable modes are not identified or have high estimation uncertainty, the optimal sensor set-ups for identifying a stiffness and for identifying the modes most sensitive to that stiffness are not necessarily the same. Finally, the importance of optimal sensor locations in damage detection is highlighted through the shake table tests. It is shown that the estimation uncertainties in structural parameters and damage severities are least for optimally located sensors.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Asymptotic Homogenization for determining the effective mechanical response of a composite material exhibiting fractional viscoelastic behavior at the microstructural scale

Author(s): Alfio Grillo^{*1}, Raimondo Penta², Ariel Ramírez-Torres²

¹ *Dipartimento di Scienze Matematiche (DISMA) "G.L. Lagrange", Politecnico di Torino, Torino, Italy, alfio.grillo@polito.it*

² *School of Mathematics & Statistics, University of Glasgow, Glasgow, UK, Ariel.RamirezTorres@glasgow.ac.uk; Raimondo.Penta@glasgow.ac.uk*

Keyword(s): Asymptotic Homogenization; Multiscale Modeling; Fractional Viscoelasticity;

Abstract

In this contribution, we summarize the results of a recent study [1] that addresses the determination of the effective mechanical response of a biphasic composite material, whose phases are characterized by viscoelastic behavior of fractional type.

We call "micro-scale" the scale of the composite at which the two phases are resolved distinctly, and, for our purposes, we assume that at this scale the composite admits periodic structure, obtained by repeating a characteristic elementary cell. Moreover, we invoke scale separation.

We begin our study with a geometric and topological description of the composite's internal structure, and with the consideration, at the scale of the elementary cell, of the linear momentum balance laws applying to each phase of the composite, of the interface boundary conditions, and of the stress-strain constitutive laws. The constitutive laws are taken viscoelastic and written in the form provided by Eringen [2], but with the hypothesis their material properties exhibit two-scale space dependence and fractional viscoelastic behavior, as described e.g. by the fractional Kelvin-Voigt model.

To account for the two-scale nature of the problem, we solve the so-called "cell problem", and perform asymptotic homogenization to obtain the effective viscoelastic model of the homogenized composite. To this end, we apply the Laplace-Carson transform to the microscale, determine the composite's effective viscoelastic coefficients in the Laplace-Carson domain, and compute their inverse transform.

As an example, we consider the case in which the two phases are an elastic material and a Kelvin-Voigt fractional viscoelastic material. This choice is due to the fact that the fractional Kelvin-Voigt constitutive law is often employed to describe the mechanical behavior of human breast and prostate cells [3]. For decreasing values of the fractional parameter, we observe a transition in the trend of the decay of the effective properties, which passes from the exponential decay of the classical Kelvin-Voigt model to an oscillatory decay, as predicted by the Mittag-Leffler function, which arises in the fractional Kelvin-Voigt model.

References

- [1] Ramírez-Torres A., Penta R., Grillo A., "Effective properties of fractional viscoelastic composites via two-scale asymptotic homogenisation," *Mathematical Methods in the Applied Sciences*, Accepted (2023).
- [2] Eringen A.C., *Mechanics of Continua*, R. E. Krieger Publishing Company, New York (1980).
- [3] Bonfanti A., Kaplan J.L., Charras G., Kabla A., "Fractional viscoelastic models for power-law materials." *Soft Matter*, **16(26)** 6002-6020 (2020)

Challamel N., Atanacković T.M., Zhang Y.P. and Wang C.M., On the wave propagation in fractional nonlocal elastic rods, beams and plates, ASCE-EMI 2023, 27-30 August 2023, Palermo, Italy.

Abstract

This paper showcases the capability of fractional nonlocal elastic structural models to capture specific wave dispersive properties of lattice structural mechanics, or paradigmatic discrete structural models. More specifically, it is shown herein that lattice rods (or Lagrange lattice), lattice beams (or Hencky bar-chain model) and lattice plates (or Hencky net model) closely behave as fractional nonlocal elastic structural models for wave propagation. The fractional nonlocal elastic model considered is the fractional generalization of Eringen's differential model introduced by Eringen in 1983. Challamel et al. (2013) showed that this fractional generalization of Eringen's nonlocal differential model was able to capture the scale effects of the wave dispersive properties of one-dimensional axial lattice. The optimal fractional (non-integer) derivative lies between 2 and 3 for the axial lattice (and 2D or 3D elastic lattices as shown by Challamel et al, 2022), and it can be calibrated along the first Brillouin zone via a hypergeometric transcendental equation. Lattice beams and plates (one-dimensional or two-dimensional Hencky-type models) can also be efficiently approximated by the fractional nonlocal elastic Euler-Bernoulli beam or Kirchhoff-Love plate model. However, their optimal fractional derivatives lie between 3 and 4 and they can be calibrated along the first Brillouin zone via another hypergeometric transcendental equation. When introducing the fractional Laplacian for the fractional nonlocal plate model, it is shown that the fractional nonlocal plate exhibits an isotropic response in the low frequency regimes and a cubic symmetry in the high frequency regimes (anisotropic nonlocal response in the high frequency regime). A similar response is observed for the Hencky plate response which behaves as an isotropic Kirchhoff-Love continuum plate model in the low frequency regime, with some anisotropic properties in the high frequency regime.

Keywords: Wave propagation; Scale effects; Nanostructures; Nonlocal elasticity; Eringen model; Fractional derivative; Born-Kármán model; Hencky bar-chain; Hencky net; Nonlocal beam; Nonlocal plate; Fractional nonlocality

References:

Challamel N., Zorica D., Atanacković T.M. and Spasić D.T., On the fractional generalization of Eringen's nonlocal elasticity for wave propagation, *C. Rendus Mécanique*, 341, 298-303, 2013.

Challamel N., Atanacković T., Zhang Y.P. and Wang C.M., A fractional nonlocal elastic model for lattice wave analysis, *Mech. Res. Comm.*, 126, 103999, 1-9, 2022.

Eringen A.C., On differential equations of nonlocal elasticity and solutions of screw dislocation and surface waves, *J. Appl. Phys.*, 54, 4703-4710, 1983.

EMI 2023 International Conference

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Title: Random vibrations in Earthquake engineering: state of the art and future perspectives

Author(s): Giuseppe Carlo MARANO*¹

¹ *Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, Italy, giuseppe.marano@polito.it*

Keyword(s): Random vibration, seismic engineering, uncertainty in dynamical systems

Abstract

The main focus in structural engineering is accurately predicting seismic actions induced on real structures by earthquakes. However, due to large uncertainties associated with different aspects of earthquakes, only partial information is available for predicting future real seismic events. This makes using conventional assumptions necessary for predicting such events. To describe possible earthquakes that will occur during structures' lifetime, indirect and concise indexes are used. Design response spectra are widely used by practitioners in structural engineering to predict structural response under future possible seismic events. Housner was the first to average and smooth the response spectra of three strong-motion records and then proposed the use of his average spectrum in seismic design. However, this theory cannot predict the response characteristics of the whole ensemble of records considered at a given site, and therefore a stochastic-based approach must be employed to predict the structural response to future earthquake ground motions. The random vibration theory, which widely considers dynamic loads with intrinsic random nature, can be applied for predicting a wide range of possible dynamic problems in various engineering applications. Therefore, applying probabilistic theory concepts to structural response estimation is theoretically more correct because it is closer to the real random nature of earthquake load and corresponding structural responses. The approach involves modelling both the excitation and response as "stochastic" or "random processes" and can be specified in terms of statistical parameters such as the mean and the variance or functions such as the power spectrum. While research on the probabilistic approach to seismic design of structures is becoming increasingly important in improving earthquake response prediction and reliability assessment of structures, only limited investigations of stochastic modelling of system response to random excitation consider this approach. This work presents the main researches in this field, discussing the advantages and limitations of future applications of random vibration theory in seismic engineering.

References

- [1] G. C. Marano, G. Acciani, A. Fiore, A. Abrescia, Integration algorithm for covariance non-stationary dynamic analysis of SDOF systems using equivalent stochastic linearization, *International Journal of Structural Stability and Dynamics* **15**(2) (2015) 1450044.
- [2] G. C. Marano, R. Greco, Efficiency of base isolation systems in structural seismic protection and energetic assessment, *Earthquake Engineering & Structural Dynamics* **32**(10) (2003) 1505-1531.
- [3] R. Greco, G. C. Marano, Site based stochastic seismic spectra, *Soil Dynamics and Earthquake Engineering* **55** (2013) 288-295.
- [4] G. C. Marano, F. Trentadue, R. Greco, Optimum design criteria for elastic structures subject to random dynamic loads, *Engineering Optimization* **38**(7) (2006) 853-871.
- [5] G. C. Marano, F. Trentadue, R. Greco, Stochastic optimum design criterion for linear damper devices for seismic protection of buildings, *Structural and Multidisciplinary Optimization* **33**(6) (2007) 441-455.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Boundary value problems for fractional stochastic differential equations under white noise process

Author(s): Andrea Burlon^{*1}, Mario Di Paola², Giuseppe Failla³, Pol D. Spanos⁴

¹ Department of Civil, Energy, Environmental and Materials Engineering, University of Reggio Calabria, via Rodolfo Zehender 89122 Reggio Calabria, Italy, andrea.burlon@unirc.it

² Department of Civil, Energy, Environmental and Materials Engineering, University of Reggio Calabria, via Rodolfo Zehender 89122 Reggio Calabria, Italy, giuseppe.failla@unirc.it

³ Department of Engineering, University of Palermo, Viale delle Scienze 90128 Palermo, Italy, mario.dipaola@unipa.it

⁴ Department of Mechanical Engineering and Materials Science, Rice University, 6100 Main, Houston, Texas, USA, spanos@rice.edu

Keyword(s): Boundary value problems; Fractional derivatives; White noise; Fractals.

Abstract

This work pertains to boundary value problems involving fractional stochastic differential equations under white noise process. These problems are of relevant interest both because they govern a large amount of probabilistic mechanical problems and because they find applications in the context of the Wiener path integral approach, a technique employed in stochastic engineering dynamics for determining the stochastic response of structural and mechanical systems [1,2,3]. Here, a technique is proposed to determine the exact solution of some fractional stochastic boundary value problems under a Gaussian white noise process, for any involved fractional order. The proposed technique relies on a specific discretization of the white noise process and makes use of a pertinent conditioning of a set of random variables, the latter deriving from the adopted white noise discretization. In this manner, the mean and the variance of the response process, solution of the boundary value problems under study, are readily computed. As a relevant issue, the proposed technique highlights the fractal nature of both the white noise process and the response process. The case of a boundary value problem involving the fractional Brownian motion is first presented in order to elucidate the problem at hand. Juxtapositions with Monte Carlo simulations demonstrate the correctness of the proposed technique.

References

- [1] Kougiumtzoglou I.A., Spanos P.D., "An analytical Wiener path integral technique for non-stationary response determination of nonlinear oscillators", Probabilistic Engineering Mechanics, Vol 28, pages 125-131, (2012).
- [2] Kougiumtzoglou I.A., Spanos P.D. Nonstationary stochastic response determination of nonlinear systems: a Wiener path integral formalism, Journal of Engineering Mechanics, Vol 140, 9, (2014).
- [3] Di Matteo A., Kougiumtzoglou I.A., Pirrotta A., Spanos P.D., Di Paola M. Stochastic response determination of nonlinear oscillators with fractional derivatives Elements via the Wiener path integral, Probabilistic Engineering Mechanics, Vol 38, pages 127-135, (2014).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Fractional differential equations forced by α -stable white noise

Author(s): Gioacchino Alotta*¹

¹ *Department of Civil, Energy, Environment and Materials Engineering (DICEAM), University "Mediterranea" of Reggio Calabria, 89124, Reggio Calabria, Italy*

Keyword(s): fractional differential equation, α -stable white noise, probabilistic solution

Abstract

This work deals with the probabilistic characterization of the response of systems governed by fractional differential equations forced by α -stable noise. In this context, the main difficulty is that, since the response of a fractional differential equation depends upon all the past history of the input, the Markovianity of the system increases of one unity at each time step. This makes the classical methods of integration, such as path integral solution, very computationally demanding, hence impossible to apply. In this work it is shown that, as the input white noise is stationary, the Markovianity of the system remains one also in presence of a system governed by a fractional differential equation. It follows that computationally efficient solutions may be built in terms of characteristic function of the response. Further, the developed numerical scheme is proved to be useful also in the case of fractional differential equations forced by non-stationary α -stable white noise input. Some interesting observations are derived by analysing the developed numerical scheme. Extensive numerical simulations are performed to assess the proposed methodology and particular focus is devoted to the case $\alpha=2$, i.e. in presence of normal white noise input, which is of major interest in engineering.

References

- [1] Samorodnitsky, G., and Taqqu, M. Stable Non-Gaussian Random Processes: Stochastic Models with Infinite Variance. Stochastic Modeling Series. Taylor & Francis, (1994).
- [2] Di Paola M., Alotta G., Path integral methods for the probabilistic analysis of nonlinear systems under a white-noise process, ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering, 6(4), 040801 (2020).
- [3] Alotta G., Di Paola M. Probabilistic characterization of nonlinear systems under α -stable white noise via complex fractional moments. Physica A, 420: 265-276, (2015).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A performance-based hurricane engineering methodology to quantify the effects of climate change and structural aging for single-family wooden houses

Author: Michele Barbato*¹

¹ *Civil and Environmental Engineering, University of California-Davis, Davis, CA, mbarbato@ucdavis.edu*

Keyword(s): Performance-based engineering, hurricane losses, climate change, structural aging, single-family houses

Abstract

Hurricanes are a major source of economic and life losses every year, particularly in the US Gulf and Atlantic coasts. Climate change and structural aging effects are expected to further exacerbate the hurricane risk in this region. Light-frame wooden single-family homes are particularly vulnerable to hurricane hazard. Therefore, a methodology is needed to assess and mitigate hurricane hazard under changing climate conditions and aging of existing and new structures. This paper illustrates a novel extended version of the performance-based hurricane engineering (PBHE) framework [1,2], which is employed here to assess the combined effects of hazard and vulnerability nonstationarity introduced by climate change and structural aging, respectively. This framework is used in conjunction with a recently-developed predictive model for hurricane wind speed distributions under changing climate conditions [3]. A multi-layer Monte Carlo simulation approach is used for probabilistic damage, loss, and cost-benefit analysis [4]. This investigation compares the effects of different nonstationarity assumptions, i.e., climate change only, structural aging only, and combined climate change and structural aging. The proposed methodology is demonstrated through the hurricane loss analysis of a wooden single-family house located in Pinellas Park, FL. For this specific application example, both climate change effects and structural aging effects are significant when considered independently. In addition, the combined effects of climate change and structural aging can almost double the expected total losses during a 50-year service design life when compared to the benchmark case in which the effects of climate change and structural aging are neglected.

References

- [1] M. Esmaeili, M. Barbato, "Performance-Based Hurricane Engineering under Changing Climate Conditions: General Framework and Performance of Single-Family Houses in the US", *J. Struct. Eng.* 148 (2022). [https://doi.org/10.1061/\(asce\)st.1943-541x.0003447](https://doi.org/10.1061/(asce)st.1943-541x.0003447).
- [2] M. Barbato, F. Petrini, V.U. Unnikrishnan, M. Ciampoli, "Performance-Based Hurricane Engineering (PBHE) framework", *Struct. Saf.* 45 (2013). <https://doi.org/10.1016/j.strusafe.2013.07.002>.
- [3] M. Esmaeili, M. Barbato, "Predictive Model for Hurricane Wind Hazard under Changing Climate Conditions", *Nat. Hazards Rev.* 22 (2021) 04021011. [https://doi.org/10.1061/\(asce\)nh.1527-6996.0000458](https://doi.org/10.1061/(asce)nh.1527-6996.0000458).
- [4] V.U. Unnikrishnan, M. Barbato, "Performance-Based Comparison of Different Storm Mitigation Techniques for Residential Buildings", *J. Struct. Eng.* 142 (2016) 04016011. [https://doi.org/10.1061/\(asce\)st.1943-541x.0001469](https://doi.org/10.1061/(asce)st.1943-541x.0001469).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Mechanical insights on energy dissipating devices behaviour

Authors: Francesco Pimpinella^{*1}, Maddalena Marchelli², Valerio De Biagi¹

¹ *Dipartimento di Ingegneria Strutturale, Edile e Geotecnica (DISEG), Politecnico di Torino, Torino, Italy, email: francesco.pimpinella@polito.it; valerio.debiagi@polito.it*

² *Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture (DIATI), Politecnico di Torino, Torino, Italy, email: maddalena.marchelli@polito.it*

Keywords: energy dissipating devices, mechanical behaviour, natural hazards, analytical model

Abstract

Whenever a structure or a system are subjected to dynamic loads, energy dissipation happens. If the energy incoming to the system is significant, it would be non-feasible to only rely on the system damping to dissipate energy and, for this reason, plastic properties of materials are exploited. However, some phenomena imply an incoming energy so high that dissipation needs to be assigned to specific components, appropriately designed for this purpose. With reference to rockfall protecting flexible barriers, these components are located along the ropes that connect the structure with the foundation system (anchors). Investigating their mechanical behaviour is fundamental to develop more performant and efficient brakes and to monitor the systems in which these components are already applied.

In this work, two energy dissipating devices commonly used in the field of rockfall protection have been analyzed: the dissipation mechanism in these braking devices is based on friction and plastic deformation. The first brake is constituted by a hollow slender square pipe in compression with an internal transversal restrain provided by the connecting rope. The second is a steel ribbon bended around a fixed roller. The mechanical behaviour of the devices was investigated thanks to the limited literature on the topic [1-3] to provide an analytical solution of the dissipating mechanism. Static tests were conducted on small scale devices in order to calibrate the model. The analytical model can be used to quantify the properties of aged devices by adjusting the mechanical and geometrical properties of the brakes.

References

- [1] Wang M., Shi S.-Q., Cui L.-M., Yang Y.-K., "Mechanical performance analysis on U-brake energy dissipator used in passive protection nets", *Engineering Mechanics*, 33, 114-120 (2016) (in Chinese)
- [2] Wierzbicki T., Abramowicz W., "On the crushing mechanics of thin-walled structures", *Journal of Applied Mechanics*, 50, 727-34 (1983)
- [3] Abramowicz W., Jones N., "Dynamic progressive buckling of circular and square tubes", *International Journal of Impact Engineering*, 2, 179-208 (1986)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The probabilistic response of masonry structures under Tsunami

Author(s): Panagiotis G. Asteris¹, Liborio Cavaleri^{*2}

¹ School of Pedagogical and Technological Education, Athens, Greece, panagiotisasteris@gmail.com

² Department of Engineering, University of Palermo, Italy, liborio.cavaleri@unipa.it

Keyword(s): Tsunami loads, vulnerability, fragility curves, tsunami fragility functions, masonry structures

Abstract

Evaluation of tsunami vulnerability of coastal buildings is gaining high interest in the last years in the areas with high tsunami hazard. Fragility evaluation is a fundamental step to obtain a quantitative estimation of the probability of building damage and in order to define possible strategies for risk mitigation. Several empirical fragility curves are available for masonry structures. However, an empirical fragility curve is generally based on field surveys after tsunami events, not always available. Conversely, analytical fragility curves are based on prediction approaches. In this paper, first time, a proposal for the evaluation of analytical fragility curves for masonry structures typical of the Mediterranean coasts based on simplified structural analyses and damage indexes is presented. The proposal considers the uncertainties in the demand by the definition of the probability distribution of the inundation scenarios. Further, the uncertainties in the structural capacity are considered. Several Monte Carlo simulations on some masonry structure types have been carried out to evaluate the fragility related to each fixed damage state assuming the inundation depth as intensity measure.

References

- [1] Alam, M.S., Barbosa, A.R., Scott, M.H., Cox, D.T., van de Lindt, J.W. "Development of Physics-Based Tsunami Fragility Functions Considering Structural Member Failures", *Journal of Structural Engineering*, 144(3), 04017221-1-17 (2018).
- [2] ASCE/SEI 7-16 (American Society of Civil Engineers). Minimum Design Loads for Buildings and Other Structures, Reston, Virginia. (2017).
- [3] Asteris, P.G., Moropoulou, A. Skentou, A.D., Apostolopoulou, M., Mohebkah, A., Cavaleri, L., Rodrigues, H. Varum, H. "Stochastic Vulnerability Assessment of Masonry Structures: Concepts, Modeling and Restoration Aspects", *Appl. Sci.*, 9(2), 243 (2019).
- [4] Benfratello, S., Cavaleri, L., Papia, M. "Identification of stiffness, dissipation and input parameters of multi degree of freedom civil systems under unmeasured base excitations", *Probabilistic Engineering Mechanics*, 24, 190-198 (2009).
- [5] Cavaleri, L., Di Trapani, F. & Ferrotto, M.F. "A new hybrid procedure for the definition of seismic vulnerability in Mediterranean cross-border urban areas", *Nat Hazards*, 86, 517–541 (2017).
- [6] Cavaleri, L., Papia, M. "An output-only stochastic parametric approach for the identification of linear and nonlinear structures under random base excitations: Advances and comparisons", *Probabilistic Engineering Mechanics*, 35, 11-21 (2014).
- [7] Charvet I., Macabuag, J., Rossetto, T. "Estimating Tsunami-Induced Building Damage through Fragility Functions: Critical Review and Research Needs", *Front. Built Environ*, 3:36 (2017).
- [8] Foster A.S.J., Rossetto T., Allsop W. "An experimentally validated approach for evaluating tsunami inundation forces on rectangular buildings", *Coastal Engineering*, 128, 44–57 (2017).

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EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Hysteretic cycles via thermodynamic and variational approaches

Authors: Luca Placidi^{*1}, Francesco D'Annibale²,

¹ *Università Telematica Internazionale Uninettuno, Facoltà di Ingegneria, Roma, Italy. E-mail: luca.placidi@uninettunouniversity.net*

² *Università degli studi dell'Aquila, Dipartimento di Ingegneria Civile, Edile - Architettura, Ambientale, L'Aquila, Italy. E-mail: francesco.dannibale@univaq.it*

Keywords: Hysteretic cycles, hemivariational approach, thermodynamics

Abstract

Modelling of hysteretic phenomena is a challenge from a mechanical and engineering points of view. The reason is that structures, systems, materials, and devices are ruled by complex hysteretic behaviour.

In the first part of the talk we will present the theoretical framework for modelling an hysteretic spring from two points of view: the thermodynamic and the hemivariational ones [3,4,5]. In particular, we will propose how to derive kinematic and isotropic hardening hysteretic behaviour with and without the related flow rules assumption.

In the second part of the talk we will show how it is possible to adjust the hysteretic shape of the force-displacement diagram by changing the functional shape of the dissipation energy. Thus, we will show how the coupling, in the dissipation energy, between damage and plasticity induces fatigue and therefore the change of the hysteretic cycle along the time evolution. Thus, we will show the derivation of the S-N curve (or Whöler diagram).

Finally, we will show how the use of granular micromechanics (in the same form Navier [1] and Cauchy [2] used almost two hundred years ago to derive linear elasticity constitutive equations) yields an immediate generalization of the spring's behaviour to that of a 3D continuum.

References

- [1] Navier C.L., “Sur les lois de l'équilibre et du mouvement des corps solides elastiques”, Memoires de l'Academie Royale de Sciences de l'Institut de France, 7, 375–393, (1827)
- [2] Cauchy A-L., “Sur l'équilibre et le mouvement d'un systeme de points materiels sollicités par des forces d'attraction ou de repulsion mutuelle”. Exercices de Mathematiques, 3, 188–212 (1828)
- [3] Placidi L., Barchiesi E., Misra A., Timofeev D. “Micromechanics-based elasto-plastic–damage energy formulation for strain gradient solids with granular microstructure”. CONTINUUM MECHANICS AND THERMODYNAMICS, vol. 33, p. 2213-2241, (2021)
- [4] Placidi L., Barchiesi E., dell'Isola F., Maksimov V., Misra A., Rezaei N., Scrofani A., Timofeev D. “On a hemi-variational formulation for a 2D elasto-plastic-damage strain gradient solid with granular microstructure”. MATHEMATICS IN ENGINEERING, vol. 5, p. 1-24, (2022)
- [5] Placidi L., Timofeev D., Maksimov V., Barchiesi E., Ciallella A., Misra A., dell'Isola F., Micro-mechano-morphology-informed continuum damage modeling with intrinsic 2nd gradient (pantographic) grain-grain interactions. INTERNATIONAL JOURNAL OF SOLIDS AND STRUCTURES, vol. 254-255, (2022)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Modeling of hysteretic systems using physics-guided universal ordinary differential equations

Authors: Sebastián Delgado-Trujillo¹, Diego A. Alvarez², Daniel Bedoya-Ruiz³, Michael Heredia-Pérez^{*4}.

¹*Department of Civil Engineering, Universidad Nacional de Colombia - Sede Manizales, MSc. Graduate, Manizales, Colombia, jsdelgadot@unal.edu.co*

²*Department of Civil Engineering, Universidad Nacional de Colombia - Sede Manizales, Associate Professor, Manizales, Colombia, daalvarez@unal.edu.co*

³*Department of Civil Engineering, Universidad Nacional de Colombia - Sede Manizales, Full Professor, Manizales, Colombia, dabedoyar@unal.edu.co*

⁴*Department of Civil Engineering, Universidad Nacional de Colombia - Sede Manizales, MSc. Student, Manizales, Colombia, mherdiap@unal.edu.co*

Keywords: Hysteresis modeling, Nonlinear structural identification, Physical consistency, Bouc-Wen hysteretic model, Scientific machine learning, Universal ordinary differential equations, Physics-guided neural networks.

Abstract

This work introduces a framework for modeling and identifying hysteretic structural systems using multilayer perceptrons and physical principles. The framework models hysteresis based on universal ordinary differential equations (UODEs) [1] and physics-guided neural networks (PGNNs) [2], two machine learning models that combine data with scientific knowledge. The proposed models are UODEs that approximate equations of motion with system state dynamics, using multilayer perceptrons to represent the unknown components. The training of the models follows the theory of PGNNs and incorporates data and physics to avoid the physical violations. The framework is validated with experimental data from ferrocement and recycled plastic lumber walls, showing good accuracy, generalization, and physical consistency. These results may suggest that the proposed hysteretic model could be an alternative to the Bouc-Wen model because they meet its accuracy and versatility while avoiding some of its physical inconsistencies, such as the lack of an elastic range and the violations of the plasticity postulates [3].

References

- [1] Rackauckas C., Ma Y., Martensen J., Warner C., Zubov K., Supekar R., Skinner D., Ali R., Edelman A., "Universal differential equations for scientific machine learning," arXiv preprint arXiv:2001.04385, (2020).
- [2] Arka D., Karpatsch A., Watkins W., Read J., Kumar V., "Physics-guided neural networks (PGNN): An application in lake temperature modeling," arXiv preprint arXiv:1710.11431v3, (2021).
- [3] Charalampakis A., "The response and dissipated energy of Bouc-Wen hysteretic model revisited," Archive of Applied Mechanics, 85, 1209-1223, (2015).

Title: Real-time Structural Health Monitoring and vibration-based damage identification of laboratory scale structure Using Internet of Things enabled Technology: A cantilever beam and fixed beam as a case study

Author(s): Abhishek Dilip Aherwar¹, T. Jothi Saravanan², Mayank Mishra^{*3}, Paulo B. Lourenço⁴

¹ M.Tech Student, School of Infrastructure, Indian Institute of Technology Bhubaneswar, Argul, Khordha 752050, Odisha, India 21se06012@iitbbs.ac.in

² Assistant Professor, School of Infrastructure, Indian Institute of Technology Bhubaneswar, Argul, Khordha 752050, Odisha, India, tjs@iitbbs.ac.in

³ Marie Skłodowska-Curie Individual Fellow (IF), University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal, mayank@civil.uminho.pt

⁴ Professor, University of Minho, ISISE, ARISE, Department of Civil Engineering, Guimarães, Portugal pbl@civil.uminho.pt

*Corresponding Author: Mayank Mishra, mayank@civil.uminho.pt

Keyword(s): IoT; SHM; non-destructive; Intelligent sensors; Frequency response function

Abstract

The internet-of-things (IoT)-based technologies are becoming increasingly important for the operational maintenance, security, and structural health monitoring (SHM) of civil engineering infrastructures in real-time. Accurate vibration data obtained from accelerometers is crucial for SHM of essential infrastructure and construction, and IoT allows for the collection of operationally relevant data [1]. IoT improves situational awareness at a fundamental level by detecting important field metrics that might be related to the health of the structure, such as vibration, strain, stress, and other physical occurrences, reactions, and conditions. Structural health monitoring (SHM) is the technique used to evaluate the health status of a structure and determine its present health state without causing intrinsic damage to the structure. The purpose of SHM is to support non-destructive analyses that can determine the location and extent of damage, predict impending accidents in advance, and forecast the remaining life of the infrastructure [2-5]. In this paper, the focus is on predicting damage in a cantilever and fixed beam laboratory structure using IoT devices equipped with sensors, which can provide the real-time natural frequency of the structure. The results obtained from the IoT devices were compared to traditional benchmark industry-standard accelerometers. The comparison with traditional expensive accelerometers shows promising results with <8% difference between them. This research on two case study structure shows that IoT devices can provide a economical substitute for vibration-based SHM by using intelligent sensors that are cheap and frequency response function can give the operating frequencies of the structure.

References

- [1] Mishra, M., Lourenço, P. B., & Ramana, G. V. (2022). Structural health monitoring of civil engineering structures by using the internet of things: A review. *Journal of Building Engineering*, 48, 103954.
- [2] Khurshid, K., Danish, A., Salim, M. U., Bayram, M., Ozbakkaloglu, T., & Mosaberpanah, M. A. (2023). An In-Depth Survey Demystifying the Internet of Things (IoT) in the Construction Industry: Unfolding New Dimensions. *Sustainability*, 15(2), 1275.
- [3] Kamal, M., & Mansoor, A. (2022, August). Structural Health Monitoring and IoT: Opportunities and Challenges. In *Intelligence of Things: Technologies and Applications: The First International Conference on Intelligence of Things (IC IoT 2022)*, Hanoi, Vietnam, August 17–19, 2022, Proceedings (pp. 3-15). Cham: Springer International Publishing.
- [4] Scuro, C., Lamonaca, F., Porzio, S., Milani, G., & Olivito, R. S. (2021). Internet of Things (IoT) for masonry structural health monitoring (SHM): Overview and examples of innovative systems. *Construction and Building Materials*, 290, 123092.
- [5] Cao, Y., Miraba, S., Rafiei, S., Ghabussi, A., Bokaei, F., Baharom, S., ... & Assilzadeh, H. (2020). Economic

application of structural health monitoring and internet of things in efficiency of building information modeling.
Smart Struct Syst, 26(5), 559-573.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Multi-class and Unknown Damage Detection under Varying Environmental Conditions via Open Set Domain Adaptation

Author(s): Mingyuan Zhou^{*1}, Zhilu Lai^{1,2}

¹ *The Internet of Things Thrust, The Hong Kong University of Science and Technology (Guangzhou), Guangzhou, China*

² *Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, China*

Emails: mzhou151@connect.hkust-gz.edu.cn; zhilulai@ust.hk

Keyword(s): Damage detection, Wind turbine blade, Domain adaptation, Open-set

Abstract

Data-driven Structural health monitoring (SHM) has been extensively studied in the past few years and yet remains an active research field. The success of many proposed data-driven SHM methods relies on the assumption that the training and testing data are closely distributed. However, in real engineering practice, the encountered damaged scenarios have high possibilities of being unseen before, which may not be fully covered by the training data set. Conventional SHM approaches often have difficulties in accurately detecting and characterizing unseen damage categories. Meanwhile, environmental and operational variabilities (EOVs) readily influence the performance of damage detection. To address the problem due to unseen damage classes and EOVs, we proposed a deep learning-based domain adaptation methodology. We investigated the dataset of an experimental small-scale wind turbine blade [1], and validated the proposed method. The results demonstrated that our model can detect unknown structural damages under temperature variations.

References

[1] Ou Y., Tatis K., Dertimanis V., Spiridonakos M., Chatzi E., "Vibration-based monitoring of a small-scale wind turbine blade under varying climate conditions. Part I: An experimental benchmark," Structural Control and Health Monitoring, 2020.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Identification of strain influence lines of railway bridges from the structural response at train passage

Authors: Said Quqa¹, Antonio Palermo^{*1}, Alessandro Marzani¹

¹ *Department of Civil, Chemical, Environmental, and Materials Engineering, University of Bologna, Bologna, Italy, said.quqa2@unibo.it, antonio.palermo6@unibo.it, alessandro.marzani@unibo.it*

Keywords: train, bridge, influence line, structural health monitoring, damage identification.

Abstract

Modern societies heavily depend on railway infrastructure. Bridges are needed to cross roads, rivers and/or valleys, and are pivotal for the transportation system due to the limited redundancy of the railway network. However, their aging is a growing global concern as many have already exceeded their design life. As such, structural health monitoring (SHM) systems have been implemented to assess the state of health of these structures and ensure safe operation.

Among the available SHM systems, those based on strain measurements are largely used mainly due to the low cost of strain gauges. Still, standard strain gauges are sensitive to environmental conditions [1], capable of recording data only at low frequencies, and are characterized by a limited sensitivity suitable for monitoring strains induced by a high level of loads. Therefore, strain sensors in bridge SHM systems are typically used to measure the strain at vehicle passage.

Recently, researchers have exploited the load of passing vehicles to estimate the influence lines of bridges [2,3] and use them as a tool for damage identification. For such estimation, one single load at a time is considered so that each point of the influence line corresponds to a point of the bridge, thus enabling damage detection and localization. Railway bridges pose a challenge to these approaches due to the simultaneous presence of multiple forces on the structure.

To tackle this challenge, in this study, the strain time history collected during the passage of a train (i.e., multiple wheel forces) is first deconvoluted using a unitary-amplitude load function derived from the rectangular impulse function measured by laser barriers placed at the wheels level. Basically, each impulse corresponds to a wheel of the train crossing the laser beam. A linear least squares problem is solved to estimate the quasi-static strain response at the passage of a single force, i.e., the strain influence line of the bridge. With this rationale, the strain influence line is exploited to build a damage index for damage detection and localization under passing trains. Promising results show the potential of this method to identify damage indicators for SHM using sparse low-cost sensor networks.

References

- [1] Farrar CR, Worden K. Structural Health Monitoring: A Machine Learning Perspective. John Wiley and Sons, Ltd; 2012.
- [2] Alamdari MM, Kildashti K, Samali B, Goudarzi HV. Damage diagnosis in bridge structures using rotation influence line: Validation on a cable-stayed bridge. Eng Struct 2019;185:1–14.
- [3] Wang N-B, He L-X, Ren W-X, Huang T-L. Extraction of influence line through a fitting method from bridge dynamic response induced by a passing vehicle. Eng Struct 2017;151:648–64.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Debonding sawtooth analytical model for SRG-strengthened joints subjected to direct shear and experimentally tested

Authors: Natalia Pingaro^{*1}, Angelo Savio Calabrese², Gabriele Milani³, Carlo Poggi⁴

¹ Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, natalia.pingaro@polimi.it

² Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, angelosavio.calabrese@polimi.it

³ Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, gabriele.milani@polimi.it

⁴ Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, carlo.poggi@polimi.it

Abstract

This paper presents a new and simple analytical debonding model for Steel Reinforce Grout (SRG)-strengthened specimens subjected to direct shear tests. The non-linearity is concentrated at the interface between mortar and textile supposed linear elastic, assuming a perfect bond between the support – infinitely rigid and resistant – and mortar. The behavior at the interface, assumed discontinuous and multilinear, is characterized by a tangential stress-slip relationship consisting of four phases: three elastic perfectly brittle and one elastic perfectly ductile [1]. Experimentally, in the load-displacement curves, when the debonding starts, a pseudo-linear hardening is observed [2] [3] and, consequently, it is essential to assume a non-zero residual tangential resistance at the interface. Admitting such hypotheses, a second order differential field equation which describes the slippage of the reinforcement on the support admits closed form solutions, suitably derived. This paper also proposes an implementation in a commercial finite element (FE) code, which discretizes the interface between mortar and steel cords by means of three in parallel cutoff bars, two of which are elastic perfectly brittle and one elastic perfectly ductile, using rigid beams for the connections and modelling SRG with elastic quadrilateral elements. Finally, the reliability of the proposed procedure and model is validated against experimental tests carried out by the authors using five SRG-reinforced concrete specimens subjected to a standard shear test.

References

- [1] Pingaro N., Calabrese A. S., Milani G., Poggi C., Debonding sawtooth analytical model for SRG-strengthened joints subjected to direct shear and experimentally tested. Submitted
- [2] De Santis S., Ceroni F., de Felice G., Fagone M., Ghiassi B., Kwiecien A., et al. Round Robin Test on tensile and bond behavior of Steel Reinforced Grout systems. Composites Part B, 127, 100-120, (2017).
- [3] Malena M., de Felice G., Debonding of composites on a curved masonry substrate: Experimental results and analytical formulation. Composite Structures, 112, 194-206, (2014).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A Genetic Algorithm approach for the calibration of a numerical model for the simulation of the FRCM-to-masonry bond

Author(s): Giovanni Minafò^{*1}, Gaetano Camarda², Marielisa Di Leto³, Lidia La Mendola⁴

¹ Department of Engineering, University of Palermo, Palermo, Italy, giovanni.minafo@unipa.it

² Department of Engineering, University of Palermo, Palermo, Italy, gaetano.camarda@unipa.it

³ Department of Engineering, University of Palermo, Palermo, Italy, marielisa.dileto@unipa.it

⁴ Department of Engineering, University of Palermo, Palermo, Italy, lidia.lamendola@unipa.it

Keyword(s): optimization; genetic algorithm; FRCM; bond

Abstract

The use of Fabric Reinforced Cementitious Matrix (FRCM) composites for structural upgrading applications of existing masonry buildings is a well-established practice. The spreading use of inorganic matrix-based composites is knowing an increasing interest in the scientific community, especially for their mechanical characterization and for the assessment of the actual load-carrying capacity of this class of composites. In this context, a variety of numerical approaches was proposed in the literature with the target of predicting the debonding load and bond length, and each approach corresponds to different model parameters and uncertainties. These last refer especially to the constitutive law of the fabric-to-matrix and matrix-to-support interfaces, depending on several mechanical and geometrical features and mechanisms.

This work presents a possible approach for the estimation of the unknown parameters characterizing a finite element (FE) model for the simulation of shear bond tests between FRCM and masonry or stone supports. The FE model is developed under simplified assumptions and adopting simple truss elements and zero-length discrete shear links for modelling the interface. A simplified shape of the constitutive law is assumed for the interfaces, with unknown parameters and a Genetic Algorithm (GA) framework is settled for their estimation. The GA is adopted for optimizing the match between the numerical simulations and the experimental results collected from the literature. The wide experimental database allows to draw some general conclusions on the dependence of the interface parameters and the mechanical features of the FRCM.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Advanced numerical modelling of masonry arches reinforced with SRG

Authors: Natalia Pingaro^{*1}, Gabriele Milani²

¹ Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, natalia.pingaro@polimi.it

² Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, gabriele.milani@polimi.it

Abstract

An efficient and simple numerical strategy for the study of masonry arches reinforced with SRG, that can be adopted in common practice, is presented. Non-linearities are concentrated in the mortar joint and at the interface between substrate and reinforcement package, both modeled with either elastic perfectly brittle or elastic perfectly ductile cutoff bars; bricks and reinforcement are meshed with elastic quadrilateral elements [1]. The aim is to simulate the possible SRG debonding and the non-linear behavior of the joints both in bending and in shear (mode 1 and 2 respectively). The behavior at the interface between substrate and reinforcement is simulated using three different non-linear models: the first with a single elastic perfectly brittle cutoff bar, the second with two in parallel elastic perfectly brittle cutoff bars and the third with three in parallel cutoff bars, two of which elastic perfectly brittle and one elastic perfectly ductile [2]. The cutoff bars are placed between the substrate and the reinforcement. For mortar joints, the ultimate tangential strength is evaluated considering both the hypothesis of elastic perfectly brittle behavior in tension and infinitely elastic in compression, and the Mohr Coulomb failure criterion assuming a realistic friction angle which remains constant during the deformation process. The numerical strategy is tested on a masonry arch reinforced with SRG. The validation is carried out against both some experimental results obtained in situ [3] and existing numerical models [4] available in the literature for the same arch. From a careful analysis of the results obtained in terms of global load-displacement curves and from a detailed observation of the non-linearities that develop in the model, the simplicity and consistency of the method proposed are assessed.

References

- [1] Pingaro N., Milani G., Simple non-linear numerical modelling of masonry arches reinforced with SRG using elasto-fragile and elasto-ductile truss Finite Elements. Submitted
- [2] Pingaro N., Calabrese A. S., Milani G., Poggi C., Debonding sawtooth analytical model for SRG-strengthened joints subjected to direct shear and experimentally tested. Submitted
- [3] Carozzi F.G., Poggi C., Bertolesi E., Milani G., Ancient masonry arches and vaults strengthened with TRM, SRG and FRP composites. *Composite Structures*, 187, 466-480, (2018).
- [4] Bertolesi E., Milani G., Carozzi F. G., Poggi C., Ancient masonry arches and vaults strengthened with TRM, SRG and FRP composites: Numerical analyses. *Composite Structures*, 187, 385-402, (2018).

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Title: A simple micro-mechanically based constitutive model for the analysis of masonry structures

Author(s): Gregorio Bertani^{*1}, Luca Patruno¹, Antonio Maria D'Altri^{1,2}, Giovanni Castellazzi¹, Stefano de Miranda¹

¹ Department of Civil, Chemical, Environmental and Materials Engineering, Bologna, Italy, gregorio.bertani2@unibo.it, luca.patruno@unibo.it, am.daltri@unibo.it, giovanni.castellazzi@unibo.it, stefano.demiranda@unibo.it

² Department of Civil and Environmental Engineering, Princeton, USA, am.daltri@princeton.edu

Keyword(s): Masonry, Continuum model, Block-based model, Failure mechanism, Homogenization

Abstract

Due to the inherent nonlinearity and complex interactions between the constituents, masonry structures are usually analysed by means of numerical models. Particularly, in order to accurately reproduce the masonry failure mechanisms, the mortar-blocks arrangement has to be taken into account. For this aim, block-based models are the natural choice, since they allow the geometry of masonry to be explicitly represented. However, their use for large scale structures is still computationally expensive and their application thus limited to the analysis of simple masonry structures. Conversely, continuum models are usually computationally cheaper and suitable for the analysis large-scale structures, although their accuracy strongly depends on the adopted constitutive law.

In this contribution, we propose a continuum model for regular periodic masonry aimed at combining the accuracy of block-based models and the computational cost of continuum models. The model is based on a multisurface strength domain for masonry, obtained through homogenization of a block-based model with finite strength blocks and frictional-cohesive zero-thickness interfaces. Each failure surface that contributes to the strength domain represents a failure mechanism, so allowing to explicitly distinguish the failure typology taking place in the material. Non-associated behaviour of interfaces is considered. The damaging behaviour for block cracking/masonry crushing is also discussed.

The proposed model is validated against a finite element block-based model and its performance evaluated for some simple structural examples.

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Title: A three-dimensional interface for the nonlinear axial-flexural behavior of masonry macroelements subjected to biaxial bending

Author(s): Christian Salvatori^{*1}, Gabriele Guerrini², Andrea Penna³

¹ Dept. of Civil Engineering and Architecture, University of Pavia, Italy, christian.salvatori01@universitadipavia.it

² Dept. of Civil Engineering and Architecture, University of Pavia, Italy, gabriele.guerrini@unipv.it

³ Dept. of Civil Engineering and Architecture, University of Pavia, Italy, andrea.penna@unipv.it

Keyword(s): biaxial bending, equivalent-frame modelling, masonry structures, nonlinear macroelement, tensile strength, three-dimensional axial-flexural interface

Abstract

Among all the modelling strategies aimed at assessing the seismic performance of masonry structures, the equivalent-frame approach with nonlinear macroelements is one of the most popular. However, this modelling strategy commonly neglects the out-of-plane stiffness and strength of walls, relying on their in-plane contributions only. Moreover, the tensile strength of masonry is usually ignored, due to its low magnitude compared to the compressive one.

This paper presents an advanced three-dimensional interface meant to incorporate the biaxial bending response into the current axial-flexural behavior of the macroelement [1] implemented in the TREMURI software [2]. The novel interface is able to capture the coupled in-plane/out-of-plane behavior of masonry piers with a reasonably low computational effort, through the combination of multiple layers with in-plane force-deformation formulations analytically integrated over the cross-section depth. The contribution of the masonry tensile strength can be also introduced in the integral formulation of the layers.

The paper briefly outlines the theoretical formulation and discusses numerical examples, referring to fiber models of the same interfaces as exact solutions, due to their versatility and straightforward implementation. The proposed interface showed satisfactory agreement with the results of the reference models, while reducing the computational time by at least one order of magnitude.

References

- [1] Penna A., Lagomarsino S., Galasco A., "A nonlinear macroelement model for the seismic analysis of masonry buildings", *Earthquake Engineering & Structural Dynamics*, 43(2), 159-179, 2014, DOI: 10.1002/eqe.2335
- [2] Lagomarsino S., Penna A., Galasco A., Cattari S., "TREMURI program: an equivalent frame model for the nonlinear seismic analysis of masonry buildings", *Engineering Structures* 56, 1787-1799, 2014, DOI: 10.1016/j.engstruct.2013.08.002

EMI 2023 International Conference

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Title: Finite Element Micro-Modelling of Masonry Structures: Calibration and Analysis Challenges

Author(s): Amirhossein Ghezelbash^{*1}, Francesco Messali², Jan G. Rots³

¹ Civil Engineering and geosciences, Delft University of Technology, Delft, Netherlands, A.Ghezelbash@tudelft.nl

² Civil Engineering and geosciences, Delft University of Technology, Delft, Netherlands, F.Messali@tudelft.nl

³ Civil Engineering and geosciences, Delft University of Technology, Delft, Netherlands, J.G.Rots@tudelft.nl

Keyword(s): Finite Element Analysis, Masonry, Calibration, Implicit, Explicit

Abstract

Numerical simulations are commonly considered an efficient and reliable supplement to experimental campaigns to predict the behaviour of masonry structures. They are fundamental especially when testing and damaging real-world structures, such as historical monuments and under-use residential and commercial buildings, is impossible. Various computational approaches are proposed to represent the response of masonry at different scales. Each strategy is developed with a certain level of idealization of structure and materials, and considers different assumptions to capture the correct response of the cases under study. In addition, each technique uses a unique set of input parameters that are identified through calibration methods. In engineering practice, the absence of robust calibration could result in incorrect design or assessment and unpredicted structural damages. This study investigates the challenges in the computational simulation of masonry structures using two simplified 3D micro finite element models, proposing a step-by-step calibration procedure. The outcomes of a Delft University of Technology experimental campaign on quasi-static loading of in-plane and out-of-plane calcium silicate brick masonry walls [1] and of few other experiments are simulated using the dynamic damage-plasticity-based models of Aref and Dolatshahi [2] and D'Altri et al. [3]. The former model uses an explicit-based solver, while the solver of the latter is implicit-based. The proposed calibration procedure uses the results of a selection of small-scale component tests to extract material constitutive model inputs that can be directly used in models of large-scale walls. Input parameters that are not direct outcomes of the small-scale experiments are identified and calculated through additional calibration steps. Findings show that the results of small- and large-scale simulations are sensitive to the employed mesh properties, boundary conditions, and load application methods. While both approaches use similar constitutive material models, the different solver and implementation choices yield different outcomes in the prediction of out-of-plane flexural bending of wallets and walls. High time consumption of the implicit model and the pronounced fluctuations in the force response of the explicit model are identified as the current shortcomings that limit their application to building-level studies, especially in case of quasi-static cyclic and dynamic analyses.

References

- [1] Messali F, Ravenshorst G, Esposito R, Rots J.G. "Large-Scale Testing Program for the Seismic Characterization of Dutch Masonry Walls" in 16th World Conference on Earthquake, Chile, January 2017.
- [2] Aref A.J., Dolatshahi K.M., "A three-dimensional cyclic meso-scale numerical procedure for simulation of unreinforced masonry structures," Computers and Structures, Vol. 120, pp. 9-23, 2013.
- [3] D'Altri A.M., Messali F., Rots J.G., Castellazzi G. de Miranda S., "A damaging block-based model for the analysis of the cyclic behavior of full-scale masonry structures," Engineering Fracture Mechanics, Vol. 209, pp. 423-448, 2019.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Stochastic response determination of nonlinear systems with fractional derivative elements via path integral approach using Laplace's method

Author(s): Alberto Di Matteo^{*1}, Antonia Pirrotta²

¹ *Department of Engineering, University of Palermo, Palermo, Italy, alberto.dimatteo@unipa.it*

² *Department of Engineering, University of Palermo, Palermo, Italy, antonina.pirrotta@unipa.it*

Keyword(s): Path Integral, Laplace's method of integration, Fractional derivative

Abstract

In this paper the nonstationary response of nonlinear single-degree-of-freedom systems, comprising fractional derivative elements, under broad-band stochastic excitations is studied. A version of the Path Integral (PI) approach is developed for determining the evolution of the response probability density function (PDF). Specifically, the PI approach is generally employed for evaluating the response PDF in short time steps, based on a discretized version of the Chapman–Kolmogorov equation [1]. Here the procedure is extended to nonlinear oscillators with fractional derivative elements, resorting to an approximate modeling of the amplitude of the system response as a one-dimensional Markovian process [2]. Further, the proposed PI approach is here employed in conjunction with the so-called Laplace's method of integration, which yields an approximate analytical solution of the involved integrals [3]. In this manner, the repetitive integrations generally required in the conventional numerical implementation of the procedure are circumvented. Various nonlinear systems are considered in the numerical applications, and appropriate comparisons with Monte Carlo simulation data are presented, demonstrating the reliability of the proposed approach.

References

- [1] Pirrotta A., Santoro R., "Probabilistic response of nonlinear systems under combined normal and Poisson white noise via path integral method", *Probabilistic Engineering Mechanics*, 26, 26-32, (2011).
- [2] Di Matteo A., Spanos P.D., Pirrotta A., "Approximate survival probability determination of hysteretic systems with fractional derivative elements", *Probabilistic Engineering Mechanics*, 54, 138-146, (2018).
- [3] Di Matteo A., "Path integral approach via Laplace's method of integration for nonstationary response of nonlinear systems", *Meccanica*, 54, 1351-1363, (2019).

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Title: A possible description of random variables in quantum computing.

Author(s): Salvatore Sessa*¹

¹ *Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy,*
salvatore.sessa2@unina.it

Keyword(s): Quantum computing, Random Variables, Probability analysis.

Abstract

Quantum computing has recently emerged from its prototypal stage and is becoming a promising technology capable of addressing common computational problems achieving significant advantages in terms of treatment and performance [1]. Differently from classic informatics, where the basic logic information has Boolean and deterministic nature, quantum computing is based on *Qubits* described by one or more quanta excited in superposition states. For this reason, qubits interactions involve typical quantic phenomena such as entanglement, coherence, and decoherence [2].

An essential aspect concerns the indetermination of measurements due to the Uncertainty and Observer Principles. Specifically, the outcome of quantic measurements, although binary, present a probabilistic characterization. Moreover, measurements irremediably adulterate the superposition states of the measured qubits since the relevant quantic transistor collapses because of decoherence; hence, qubits' cloning is generally forbidden.

Such peculiarities make this technology significantly different than its classical counterpart: use of quantum computers does not merely consists in running old-fashioned algorithms on more powerful machines but in developing new implementation strategies capable of taking advantages of the benefits granted by quantum phenomena, possibly overcoming their drawbacks.

Concerning the probabilistic nature of the qubit superposition states, while it can represent a critical problem that needs to be addressed for deterministic computations, still it may be an essential advantage in probabilistic analyses thus capable of achieving *quantum advantage*.

In this sense, the present research exploits a possible representation of the statistics of arbitrary integer-positive random variables by means of qubit strings according to the traditional binary representation of integers. Initial quantum states of the involved qubits are initialized consistently with the chosen probability mass function.

Such a representation aims to permit the use of random variables in arithmetic logic units thus permitting direct computations as for the case of scalar variables, thus avoiding complex computational strategies such as Monte Carlo simulations or numerical approaches.

Moreover, it will be shown that, in order to correctly represent the statistics of the variables, it is necessary to properly take into account the statistical dependence between the qubits that arises because of the string representation. In this sense, the initialization process involves a circuit of logic quantum gates calibrated on the original probability mass function of the variable.

Although the investigated examples are very simple because of the limited availability and capacity of quantum processors, so that the presented research has not an immediate advantage in common practice, it aims to discuss new perspectives in probabilistic and reliability computations.

References

- [1] Arute F., Arya K., Babbush R., "Quantum supremacy using a programmable superconducting processor," *Nature*, 574, 505-510, (2019).
- [2] Park J., "The concept of transition in quantum mechanics," *Foundations of Physics*, 1(1), 23-33, (1970).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Diffusive term of the Fractional Fokker Planck equation handled by self-similarity theory

Authors: Salvatore Russotto*¹, Mario Di Paola¹, Antonina Pirrotta¹

¹ Department of Engineering, University of Palermo, Palermo, Italy, salvatore.russotto01@unipa.it

Keywords: Fractional Fokker Planck equation; Self-similarity; Fractional Brownian motion; Nonstationary processes; Characteristic function.

Abstract

Fractional Differential Equations (FDE) are nowadays largely used to model real-life phenomena such as viscoelasticity [1-3], heat transportation [4-5], nonlocal continuum [6] and so on. In case of a one-term FDE enforced by a white noise, the response process is the so-called fractional Brownian motion (fBm) which is self-similar [7]. In a recent paper [8], the self-similarity was used to find the evolutionary equation of the fBm's variance, showing that the order of the fractional derivative, is linked to the Hurst index of the process.

On the basis of the aforementioned work [8], in this paper the concept of self-similarity is extended for the first time from the statistics of the process to the statistical descriptors showing that the extension in terms of Probability Density Function (PDF) is not possible, while the self-similarity property can be easily extended to the characteristic function. By using this extension, the diffusive term of the Fractional Fokker Planck (FFPK) equation is found in terms of characteristic function (CF) for both stationary and nonstationary white noise input process. Unlike other papers [9], the diffusive term of the proposed FFPK equation is linked to a one-term FDE enforced by white noise. Particularly, first of all the diffusive term of the FFPK is found for the case of stationary white noise input and then the solution obtained is used as the kernel of the Boltzmann superposition in order to find the solution also for the case of nonstationary white noise input. Since the inverse Fourier transform of the CF exactly matches the response process in terms of PDF, the proposed FFPK in terms of CF can be considered reliable.

References

- [1] Di Paola M., Pirrotta A., Valenza A., "Viscoelastic behavior through fractional calculus: an easier method for best fitting experimental results", *Mech. Mater.*, 43, 799–806, (2011).
- [2] Di Paola M., Failla G., Pirrotta A., "Stationary and non-stationary stochastic response of linear fractional viscoelastic systems", *Probab. Eng. Mech.*, 28, 85–90, (2012).
- [3] Di Paola M., Russotto S., Pirrotta A., "Self-similarity and response of fractional differential equations under white noise input", *Prob. Eng. Mech.*, 70, 103327, (2022).
- [4] Nuzzo G., Amiri F., Russotto S., Bologna E., Zingales, M., "A fractional-order theory of phase transformation in presence of anomalous heat transfer", *Materials Research Proceedings*, 26, 77-82, (2023).
- [5] Zingales M., "Fractional-order theory of heat transport in rigid bodies", *Commun. Nonlinear Sci. Numer. Simul.*, 19 (11), 3938–3953, (2014).
- [6] Alotta G., Di Paola M., Pinnola F.P., Zingales M., "A fractional nonlocal approach to nonlinear blood flow in small-lumen arterial vessels", *Meccanica*, 55, 891–906, (2020).
- [7] Mandelbrot B.B., Van Ness J.V., "Fractional Brownian motions, fractional noises and application", *SIAM review*, 10, 422-437, (1968).
- [8] Di Paola M., Pirrotta A., "Fokker–Planck equation of the fractional brownian motion", *International Journal of Non-Linear Mechanics*, 147, 104224, (2022).
- [9] West B.J., Grigolini P., "Fractional differences derivatives and fractal time series", Chapter IV of *Applications of Fractional Calculus in Physics*, World Scientific, 171–201, (2000).

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Title: Reliability bounds for structures controlled by external fractional viscoelastic dampers

Authors: Alba Sofi^{*1}, Giuseppe Muscolino², Mario Di Paola³

¹ *Department of Architecture and Territory, University "Mediterranea" of Reggio Calabria, Reggio Calabria, Italy, alba.sofi@unirc.it*

² *Department of Engineering, University of Messina, Messina, Italy, gmuscolino@unime.it*

³ *Department of Engineering, University of Palermo, Italy, mario.dipaola@unipa.it*

Keywords: viscoelastic dampers, fractional calculus, interval analysis, stochastic processes

Abstract

Over the last decades, different types of energy dissipation devices and various innovative design approaches have been proposed for seismic retrofitting. A promising strategy to improve the seismic performance of frame structures consists in employing external structural control systems, like reinforced concrete walls, which are often referred to in the literature as exoskeleton structures (see e.g., [1,2]).

The present study addresses seismic safety assessment of a frame structure connected to a much more rigid wall (the exoskeleton) by means of a set of viscoelastic dampers whose behaviour is described by a fractional constitutive law [3]. To obtain a reliable prediction of the seismic performance of the controlled structure, uncertainties affecting the mechanical properties of materials are taken into account. Since available experimental data are often insufficient to obtain an accurate probabilistic characterization, in the present study, uncertainties are described as interval variables with assigned lower bound and upper bound according to the interval model [4]. Ground motion acceleration is modelled as a zero-mean stationary Gaussian random process. Reliability analysis is carried out by interval extension of the classical first-passage problem [5]. The bounds of the interval-valued reliability function are computed by an efficient approximate procedure. A frame structure controlled by external fractional viscoelastic devices with interval properties defined based on experimental results available in the literature [6] is selected as case-study.

References

- [1] Mazza F., "Dissipative steel exoskeletons for the seismic control of reinforced concrete framed buildings," *Structural Control Health Monitoring*, 28, e2683 (2021).
- [2] Di Lorenzo G., Tartaglia R., Prota A., Landolfo R., "Design procedure for orthogonal steel exoskeleton structures for seismic strengthening," *Engineering Structures*, 275, Part A, 115252, (2023).
- [3] Podlubny I., "Fractional Differential Equations," 198, *Mathematics in Science and Engineering*. Academic Press, San Diego (1999).
- [4] Moore R.E., Kearfott R.B., Cloud M.J., *Introduction to Interval Analysis*, SIAM, Philadelphia PA (2009).
- [5] Sofi A., Giunta F., Muscolino G., "Reliability Analysis of Randomly Excited FE Modelled Structures with Interval Mass and Stiffness via Sensitivity Analysis," *Mechanical Systems and Signal Processing*, 163, 107990 (2022).
- [6] Montgomery M., Christopoulos C., "Experimental Validation of Viscoelastic Coupling Dampers for Enhanced Dynamic Performance of High-Rise Buildings," *Journal of Structural Engineering (ASCE)* 141, 4014145 (2015).

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Title: A proposal for the probabilistic distribution of highly-non-Gaussian peak factors for the wind pressure acting on hyperbolic paraboloid roofs

Author: Michele Barbato*¹

¹ *Civil and Environmental Engineering, University of California-Davis, Davis, CA, mbarbato@ucdavis.edu*

Keyword(s): Wind pressure, peak factor, stochastic process, hyperbolic paraboloid roof

Abstract

The probabilistic description of wind pressure peak factor is a complex problem with important design applications. Recent studies on hyperbolic paraboloid roofs have shown that the wind pressure peak factors can be significantly higher than those estimated using a Gaussian approximation [1,2]. However, the wind pressure peak factors are typically described using a Gumbel distribution [3] or a type III extreme value distribution [4]. In this paper, a new type II extreme value distribution is proposed to probabilistically describe the peak factors of wind pressure processes acting on hyperbolic paraboloid roofs when the underlying process is highly non-Gaussian. The assumed distribution is validated using existing wind pressure time histories that were experimentally recorded in wind tunnel tests [5]. It is found that, whereas the Gumbel distribution assumption is sufficiently accurate when the underlying stochastic process is approximately Gaussian, the type II extreme value distribution provides a better fit to the experimental results corresponding to highly-non-Gaussian processes. Further investigation is needed to determine the distributions corresponding to intermediate situation of mildly-non-Gaussian processes.

References

- [1] F. Rizzo, M. Barbato, V. Sepe, Peak factor statistics of wind effects for hyperbolic paraboloid roofs, *Eng. Struct.* 173 (2018). <https://doi.org/10.1016/j.engstruct.2018.06.106>.
- [2] F. Rizzo, M. Barbato, V. Sepe, Shape dependence of wind pressure peak factor statistics in hyperbolic paraboloid roofs, *J. Build. Eng.* 44 (2021). <https://doi.org/10.1016/j.jobbe.2021.103203>.
- [3] M.F. Huang, W. Lou, C.M. Chan, N. Lin, X. Pan, Peak Distributions and Peak Factors of Wind-Induced Pressure Processes on Tall Buildings, *J. Eng. Mech.* 139 (2013) 1744–1756. [https://doi.org/10.1061/\(asce\)em.1943-7889.0000616](https://doi.org/10.1061/(asce)em.1943-7889.0000616).
- [4] J.D. Holmes, L.S. Cochran, Probability distributions of extreme pressure coefficients, *J. Wind Eng. Ind. Aerodyn.* 91 (2003) 893–901. [https://doi.org/10.1016/S0167-6105\(03\)00019-9](https://doi.org/10.1016/S0167-6105(03)00019-9).
- [5] F. Rizzo, P. D’Asdia Piero, M. Lazzari, L. Procino, Wind action evaluation on tension roofs of hyperbolic paraboloid shape, *Eng. Struct.* 33 (2011) 445–461. <https://doi.org/10.1016/j.engstruct.2010.11.001>.

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Palermo, Italy, August 27 - 30, 2023

Title: Experimental analysis of hemp-matrix biocomposite material for masonry structural strengthening

Author(s): Roberta Scungio¹, Chiara Pepi^{*1}, Pier Francesco Greco¹, Michele Arturo Caponero², Massimiliano Giofrè¹.

¹ Department of Civil and Environmental Engineering, University of Perugia, Italy, roberta.scungio@studenti.unipg.it, chiara.pepi@unipg.it, pierfrancesco.greco@unipg.it, massimiliano.gioffre@unipg.it

² Photonics Micro-and Nanostructures Laboratory, ENEA Research Center of Frascati, Italy, michele.caponero@enea.it

Keyword(s): Bio composite strengthening; hemp ropes; experimental test; bond; fiber Bragg Grating sensors.

Abstract

Historic masonry constructions may require strengthening interventions to improve their structural performance towards static and dynamic loads. In the last decade, Fiber Reinforced Polymers (FRP) and Fiber Reinforced Cementitious Matrix (FRCM) composites have been used for structural applications. In these composite materials, synthetic fibers arranged in a unidirectional or bidirectional grid are embedded in a polymeric or cementitious matrix. However, the growing environmental sustainability issues have encouraged the investigation on the effectiveness of bio composite materials made of natural fibers embedded in a natural matrix.[1-2-3].

In this paper, the interfacial behavior of a novel hemp based bio composite material bonded to masonry blocks is investigated. Single lap shear tests were carried out on samples made of unidirectional hemp ropes embedded in two different natural matrices (i.e. organic binder based and mortar based)[4-5].

Innovative Fiber Bragg Grating (FBG) sensors were used in order to measure the strain transfer mechanism at the hemp ropes - matrix interfaces.

References

- [1] Codispoti R., Oliveira D. V., Olivito R. S., Lourenço P. B., Figueiro R. "Mechanical performance of natural fiber-reinforced composites for the strengthening of masonry". Composites Part B: Engineering, 77, 74-83. (2015).
- [2] Giofrè M., Vincenzini A., Cavalagli N., Gusella V., Caponero M. A., Terenzi A., Pepi C. "A novel hemp-fiber bio-composite material for strengthening of arched structures: Experimental investigation." Construction and Building Materials, 308, 124969. (2021).
- [3] Giofrè M., Navarra G., Cavalagli N., Iacono F. L., Gusella V., Pepi C. "Effect of hemp bio composite strengthening on masonry barrel vaults damage". Construction and Building Materials, 367, 130100. (2023).
- [4] D'Antino T., Carloni C., Sneed L. H., Pellegrino C. "Matrix-fiber bond behavior in PBO FRCM composites: A fracture mechanics approach." Engineering Fracture Mechanics, 117, 94-111. (2014).
- [5] Saidi M., Reboul N., & Gabor A. "Analysis of bond behaviour of textile-reinforced cement (TRC) applied to masonry using distributed fibre optic sensors and acoustic emission." Composites Part B: Engineering, 247, 110327. (2022).

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Title: Analytical modelling of the bond behavior of carbon FRCM-masonry joints exposed to high temperature

Author(s): Veronica Bertolli¹, Cesare Signorini², Andrea Nobili³, Tommaso D'Antino^{*4}

¹ Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, veronica.bertolli@polimi.it

² Institute for Construction Materials, Technische Universität Dresden, Dresden, Germany, cesare.signorini@tu-dresden.de

³ Department of Engineering Enzo Ferrari, University of Modena and Reggio Emilia, Modena, Italy, andrea.nobili@unimore.it

² Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy, tommaso.dantino@polimi.it

Keyword(s): fiber-reinforced cementitious matrix (FRCM), cohesive material law (CML), analytical modelling, direct shear test, temperature conditioning, masonry

Abstract

Fiber-reinforced composites are frequently employed as externally bonded reinforcement of existing masonry members. Among them, fiber-reinforced polymer (FRP) and fiber-reinforced cementitious matrix (FRCM) composites are largely diffused. Although FRPs generally provide higher strength contributions compared to corresponding (i.e., same fiber cross-sectional area) FRCMs, the use of an organic resin matrix is responsible for the poor compatibility between the composite and the substrate and for the low resistance to high temperatures. The use of an organic mortar matrix may overcome these issues, making externally bonded FRCMs an ideal solution for strengthening masonry members. Since failure of FRCM-strengthened members usually occurs due to debonding at the matrix-fiber interface, in some cases followed by fiber rupture, studying the bond behavior of FRCM composites is fundamental to properly design these reinforcements. In this paper, the bond behavior of a carbon FRCM applied onto a masonry substrate and exposed to high temperatures is investigated. Namely, single-lap direct shear tests are performed. Four carbon FRCM-masonry joints are used as control specimens, whereas four specimens are conditioned according to a heating procedure 250-minute long up to 300 °C to study the effect of the temperature exposure. The load responses obtained are modelled using an analytical procedure that defines the interface cohesive material law (CML) of control and conditioned specimens, which is then employed to solve the bond differential equation and obtain the full range behavior of the joints. The results obtained shed light on the effect of temperature exposure on the bond behavior of FRCM-masonry joints.

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Title: Probabilistic models for hemp fibers and yarns mechanical properties to use as bio composite reinforcing material

Author(s): Massimiliano Giofrè¹, Maria Eleonora Pipistrelli¹, Chiara Pepi^{*1}

¹ Department of Civil and Environmental Engineering, University of Perugia, Perugia, Italy, massimiliano.gioffre@unipg.it, mariaeleonora.pipistrelli@studenti.unipg.it, chiara.pepi@unipg.it

Keyword(s): Natural fibers, hemp fibers, mechanical properties, mechanical testing, random modelling.

Abstract

In the last decades, scientific research in building industry has led to impactful results on the development of sustainable composite materials for strengthening interventions. Among these systematic investigations, natural fibers are emerging as suitable replacement for synthetic fibers based composite materials due to their many advantages [1-2]. In particular, bast fibres are widely used in this kind of applications [3-4]. This group includes hemp fibers, that are quickly gaining importance thanks to their high strength, resistance, and elastic properties [5-6].

Despite this, a complete mechanical characterization of natural fibers based ropes and yarns is a difficult task since mechanical and physical properties are strictly related to growth conditions, harvesting procedure and possible treatments [7]. Moreover, manufacture processes require fibers to be twisted and merged in yarns, increasing mechanical properties variability due to sliding issues and similar side effects. Therefore, a statistical analysis is needed in order to obtain consistent information about vegetal fibers properties.

In this study, hemp fibers, yarns and ropes are characterized by performing tensile tests on several samples of different lengths: 120 fibres with four different lengths, 55 yarns, 33 strands and 64 ropes. Testing procedures follow ASTM standards. The study aims especially at filling the gap in literature related to an in-depth assessment of the uncertainties related to the variability of tensile strength and elastic modulus. Therefore, tensile strength and elastic modulus are determined for each sample and the results are analyzed in a probabilistic setting selecting Normal and Weibull probability distribution functions to describe properties' random distributions. Finally, a relationship between tensile properties and hemp fibres, yarns, strands and ropes morphologic characteristics is proposed and discussed.

References

- [1] Pandey J., Nagarajan V., Monhanty A., Misra M., "Commercial potential and competitiveness of natural fiber composites", *Biocomposites*, 1-15, (2015).
- [2] Codispoti R., Oliveira D. V., Olivito R. S., Lourenco P. B., Figueiro R., "Mechanical performance of natural fiber-reinforced composites for the strengthening of masonry", *Composite Part B: Engineering*, 77, (2015).
- [3] Peças P., Carvalho H., Salman H., Leite M., "Natural fibre composites and their applications: a review", *Journal of composites science* 2, 66, (2018).
- [4] Fagone M., Loccarini F., Ranocchiai G., "Strength evaluation of jute fabric for the reinforcement of rammed earth structures", *Composites Part B: Engineering*, 113, 1-13, (2017).
- [5] Manaia J. P., Manaia A. T., Rodrigues L., "Industrial hemp fibers: an overview", *Fibers*, 7, (2019).
- [6] Baysal A., Yayla P., Turkmen H. S., "Static and dynamic behavior of hemp natural fiber felt biocomposites", *Journal of Natural Fibers*, 20, (2023).
- [7] Ho M.-p., Wang H., Lee J.-H., Ho C.-k., Lau K.-t., Leng J., Hui D., "Critical factors on manufacturing processes of natural fibre composites", *Composite Part B: Engineering*, 43, (2012).

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Influence of glass-fibre epoxy coating on bond and tensile behaviour of FRCM systems: an experimental and analytical investigation

Rebecca Grazzini¹, Giulia Misseri¹, Luisa Rovero^{*1}

¹ *Dipartimento di Architettura – Sezione Materiali e Strutture, Università di Firenze, Italy, (*luisa.rovero@unifi.it)*

Keyword(s): FRCM, TRM, glass-fibre textile, epoxy coating, exponential CML, elastic-brittle mortar

Abstract

Fibre Reinforced Cementitious Matrix composite systems display outstanding capabilities for the reinforcement of existing structures. Their modelling is challenging for the numerous damage scenarios, and tests methods for mechanical characterisation are still debated, [1, 2, 3]. An open issue concerns the improvement of textile-matrix bonding due to the low capacity of matrix particles to imbue all textile filaments, [4, 5]. In this study, the influence of epoxy coating of glass-fibre textile on bond and tensile behaviour of FRCM system are addressed through an experimental and an analytical investigation. Six different FRCM systems were considered by combining the same glass-fibre textile, dry or epoxy-coated, and three different matrices based on cement, lime, and gypsum binders. The experimental campaign comprises Direct Tensile Tests (DTT) and textile pull out (TPT) as proposed in [3]. The results highlighted the beneficial effect of the epoxy resin coating that modifies the fibre-matrix adhesion mechanism. An analytical investigation was then conducted to verify the results obtained experimentally. In particular, the analysis concerned analytical modelling of tensile behaviour of FRCM systems through integration of the nonlinear differential problem and assuming an exponential Cohesive Material Law (CML). Assumptions also include, linear elastic behaviour of the textile with limited tensile strength, elastic-brittle matrix, random distribution of mortar strength, [6, 7, 8]. Cracks can open in any position free from the grips, and the global load-slip diagram is built as a composition of partial global-load slip diagrams of the crack-separated sub-portions. For the calibration of the CLMs of the six FRCM systems, the experimental results of TPT were used, considering this test comparable to an adhesion test, as suggested, and verified in [3].

References

- [1] Carloni, C., Verre, S., Sneed, L. H., & Ombres, L. "Open issues on the investigation of PBO FRCM-Concrete debonding," *Composite Structures*, 299, 116062 (2022).
- [2] Focacci, F., D'Antino, T., & Carloni, C. "Tensile testing of FRCM coupons for material characterization: discussion of critical aspects," *Journal of Composites for Construction*, 26(4), 04022039 (2022).
- [3] D'Antino, T., Carozzi, F. G., Colombi, P., Poggi, C. "A new pull-out test to study the bond behavior of fiber reinforced cementitious composites", *Engineering Materials*, 747, 258-265 (2017).
- [4] Donnini, J., Corinaldesi, V., Nanni, A. "Mechanical properties of FRCM using carbon fabrics with different coating treatments", *Composites Part B: Engineering*, 88, 220-228 (2016).
- [5] Bompadre, F., Donnini, J. "Surface modification of glass textile for the reinforcement of a cement-based composite: A review", *Applied Sciences*, 11(5), 2028 (2021).
- [6] Focacci, F., D'Antino, T., & Carloni, C. "The role of the fiber-matrix interfacial properties on the tensile behavior of FRCM coupons," *Construction and Building Materials*, 265, 120263 (2020).
- [7] Fazzi, E., Misseri, G., Rovero, L., & Stipo, G. "Finite difference model for the bond behaviour of poly(paraphenylene benzobisoxazole) (PBO) fibre-reinforced composite system for retrofitting masonry," *Key Engineering Materials*, 916, 425-432 (2022).
- [8] Fazzi, E., Misseri, G., & Rovero, L. "Experimental, analytical, and numerical investigations on bond behaviour of basalt TRM systems," *International Journal of Masonry Research and Innovation*, 8(2-3), 333-354 (2023).

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Title: Rock blocks impacts on masonry walls: modelling for vulnerability evaluation

Authors: Maddalena Marchelli^{*1}, Valerio De Biagi²

¹ *Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Turin, Italy, email: maddalena.marchelli@polito.it*

² *Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Turin, Italy, email: , valerio.debiagi@polito.it*

Keywords: Rockfall impact, kinetic energy, masonry wall, experimental modelling

Abstract

Rockfalls are frequent and widespread phenomena in mountain environments. The hazard can endanger people, structures, infrastructure, environmental features and economic activities. To mitigate the risk, several solutions have been developed, from active measures that prevent the occurrence of the phenomenon, to passive structures that intercept and stop the falling boulders. The kinetic energies range between few kJ to tens of thousands of kJ, depending on the size of the falling boulder and the morphology of the slope along which the phenomenon propagates [1].

The effects of rockfall on constructions can lead to local damages, which can propagate to complete collapses [2]. To quantify the vulnerability of buildings it is necessary to evaluate the local response, i.e. the occurrence of a damage and its size, and the global effects, i.e. how the damage affects the whole building. The present work focuses on the local response of masonry walls to rockfall impacts. The impacting block is modelled as a lumped mass and the wall is considered with its equivalent mass and configuration. For the interaction between the bodies, a one-sided nonlinear element is inserted. The mechanical properties of the element are derived from an experimental campaign on small scale specimen of similar material couples. The results plotted in a kinetic energy-radius of the equivalent sphere chart indicate that there are wall configurations that presuppose large damages when impacted. A simple reliability analysis to produce fragility curves is then proposed [3].

References

- [1] Volkwein A., Schellenberg K., Labiouse V., Agliardi F., Berger F., Bourrier F., Dorren L. K., Gerber W., Jaboyedoff, M. Rockfall characterisation and structural protection—a review. *Natural Hazards and Earth System Sciences*, 11(9), 2617-2651, (2011)
- [2] Vallero G., De Biagi V., Barbero M., Castelli M, Napoli M.L., “A method to quantitatively assess the vulnerability of masonry structures subjected to rockfalls,” *Natural Hazards*, 103, 1307-1325, (2020).
- [3] Marchelli M., De Biagi V., Peila D., “Reliability-based design of rockfall passive systems height,” *International Journal of Rock Mechanics and Mining Sciences*, 139, 104664, (2021)

EMI 2023 International Conference

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Title: Environmental Durability of Externally Bonded FRP-Repaired Concrete

Author(s): Ruben Paul Borg*¹, Fabio Spiteri¹

¹ Faculty for the Built Environment, University of Malta, Msida, Malta, ruben.p.borg@um.edu.mt

Keyword(s): Fibre-Reinforced Polymer, Reinforced Concrete repair, Environmental Exposure, Bond, Chloride-ion penetration, Temperature.

Abstract

Fibre reinforced polymers (FRP) are used in a wide variety of applications in the construction industry. The durability performance of externally bonded fibre reinforced polymer (FRP) concrete was assessed through an experimental investigation of concrete reinforced with one-directional FRP laminate strips, subjected to various environmental exposure conditions. Crushed coralline-limestone aggregate, C30/37 concrete was considered as the base material. Various environmental exposure conditions related to a marine environment were simulated in a laboratory and external environment, mainly to study the effect of chloride ion penetration and temperature variation. The behaviour of the FRP-concrete system was examined after exposed to aggressive environmental conditions through numerous parameters and failure criteria including single-lap shear, pull-pull off and 3-point bending tests. An experimental programme was prepared to investigate the behaviour of the FRP systems subjected to seven different environmental exposure conditions. FRP-concrete samples were conditioned to environments of 20°C and 50°C, with 0%, 50%, and 100% relative humidity levels. Furthermore, the FRP-concrete samples were exposed to wet-dry cycles, and immersed in water with a 3% by weight Sodium chloride solution. The single-lap shear test, pull-off test and the three-point bending test were used as standard test methods, to assess the FRP-concrete bond performance in shear, tension and flexure respectively. The behaviour and the mode of failure of FRP-concrete assemblies when exposed to chloride ion penetration and temperature variations, in a conditioned laboratory and an external environment, could be assessed. In general, higher temperatures were found to have a greater impact on the degradation of the FRP-concrete bond. Wet-dry cycles affected significantly the performance of ultimate bond strength as was also reported in previous studies [1, 2]. Exposure to water and NaCl solution respectively improved the bond between the composite materials in the initial stages of conditioning, while longer exposure periods resulted in a reduction in bond strength, as also reported in literature [3, 4]. From all environmental exposure conditions, the hydrothermal effects of high temperatures and water immersions were found to be the most detrimental, in all three types of tests. The research presents the performance of FRP-crushed coralline-limestone based concrete for different experimental parameters failure criteria, when exposed to aggressive environmental conditions.

References

- [1] Chajes, M. J., Thomson, T. A., & Farschman, C. A., "Durability of concrete beams externally reinforced with composite fabrics" *Construction and Building Materials*, 9 (3), 141-148. (1995)
- [2] Dai, J.-G., Yokota, H., Iwanami, M., & Kato, E., "Experimental investigation of the influence of moisture on the bond behavior of FRP to concrete interfaces" *Journal of composites for Construction*, 14 (6). (2010)
- [3] Kabir, M. I., Shrestha, R., & Samali, B., "Effects of applied environmental conditions on the pull-out strengths of CFRP-concrete bond". *Construction and Building Materials*, 817-830. (2016)
- [4] Toutanji, H. A., & Gómez, W., "Durability characteristics of concrete beams externally bonded with FRP composite sheets". *Cement and Concrete Composites*, 19 (4), 351-358. (1997)

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Title: A strategy to improve the effectiveness of friction dampers for seismic protection

Author(s): Liborio Cavaleri

Department of Engineering, University of Palermo, Italy, liborio.cavaleri@unipa.it

Keyword(s): Dissipative systems, Variable friction dissipative device, Structural dynamics, Seismic energy dissipation

Abstract

A new approach for the energy dissipation is proposed based on the use of a Friction Damper (VFDs). able to vary its capability of dissipation depending on structure displacement demand thanks to its geometry. The characteristics and the efficiency of the damping system in terms of reduction of the displacements and the restoring forces is described under seismic excitations and compared with the performances achievable by classic constant friction dampers (CFDs). The effectiveness of the new damper is shown through a statistical assessment of the dynamic response of SDOF models subjected to natural accelerograms. The possibility to obtain a design criterium is also discussed.

References

- [1] Braga, F., Laterza, M., "Field testing of low-rise base isolated building", *Engineering Structures*, 26 1599–1610, (2004).
- [2] Castaldo, P., Palazzo, B., Ferrentino, T., Petrone, G., "Influence of the strength reduction factor on the seismic reliability of structures with FPS considering intermediate PGA/PGV ratios", *Composites B*, 115, 308–315, (2017).
- [3] Ferrotto, M.F., Cavaleri, L., Di Trapani, F., Castaldo, P., "Full scale tests of the base-isolation system for an emergency hospital" in: 7th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering Methods in Structural Dynamics and Earthquake Engineering, 24–26 June 2019, COMPDYN 2019, Crete, Greece, (2019).
- [4] Ferrotto, M.F., Asteris, P.G., Cavaleri, L., "Strategies of identification of a base isolated hospital building by coupled quasi-static and snap-back tests", *Journal of Earthquake Engineering*, 26(8), 4172-4200, (2022).
- [5] Teruna, D.R., Majid, T.A., Budiono, B., "Experimental study of hysteretic steel damper for energy dissipation capacity", *Advances in Civil Engineering*, 2015, Article ID 631726, (2015).
- [6] Gong, S., Zhou, Y., Ge, P., "Seismic analysis for tall and irregular temple buildings: A case study of strong nonlinear viscoelastic dampers", *The Structural Design of Tall and Special Buildings*, 26(7), (2016).
- [7] Alotta, G., Cavaleri, L., Di Paola, M., Ferrotto, M.F., "Solution for the design and increasing of efficiency of viscous dampers", *Open Constr. Buil. Tech. J.* 10 (Suppl 1: M6) 106–121, (2016).

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Title: Joint Effects of Thermal Stresses and Corrosion on Integral Abutment Bridges

Author(s): Alessandro Contento^{*1}, Angelo Aloisio², Junqing Xue¹, Giuseppe Quaranta, Bruno Briseghella¹, Paolo Gardoni

¹ College of Engineering, Fuzhou University, Fuzhou, China, alessandro@fzu.edu.cn

² DICEAA, University of L'Aquila, L'Aquila, Italy, angelo.aloisio1@univaq.it

¹ College of Engineering, Fuzhou University, Fuzhou, China, junqing.xue@foxmail.com

³ Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy, giuseppe.quaranta@uniroma1.it

¹ College of Engineering, Fuzhou University, Fuzhou, China, bruno@fzu.edu.cn

⁴ Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, USA, gardoni@illinois.edu

Keyword(s): Coupled rigid blocks; rocking motion; Maxwell visco-elastic device; seismic performances; gain coefficients and maps.

Abstract

The corrosion of reinforced concrete structures highly depends on local environmental exposure conditions. For reinforced concrete structures in coastal areas, such deterioration phenomenon turns out to be very severe and can extend significantly in windy zones, since higher wind speeds allow the deposition of a larger concentration of chlorides further inland. And the larger concentration of chlorides, the larger the steel corrosion rate. The connection between chloride deposition rate and steel corrosion rate has been proved in several studies. Additionally, frequent temperature changes and, above all, exposure to extreme temperatures might induce wider cracks and micro-cracks in concrete structures which, in turn, might accelerate the diffusion of corrosive agents. In the case of integral abutment bridges, even before compromising structural safety, the combination of corrosion and extreme temperature variations may lead to the exceedance of some serviceability limit states and to cascading negative effects on the proper operation of the road infrastructure. Motivated by this evidence, the present study aims at verifying the sensitivity of integral abutment bridges to the combined effect of thermal stresses and corrosion. The final goal is to quantify the risk of exceedance of relevant serviceability limit states. For this purpose, the structural model of an existing integral abutment bridge located in Shenzhen (Guangdong, China) has been developed. The model is then used as a case study to quantify the effect of chloride-induced corrosion under different environmental conditions. Particularly, the estimation of the thermal stresses is based on temperature measurements referred to bridges in the Guangdong province. Preliminary results show that high thermal stress may largely amplify the negative effects of corrosion and can anticipate the exceedance of the considered serviceability limit states.

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Title: Enhancing Resilience of Circular RC Bridge Piers with CFRP Seismic Retrofitting: Performance Under Vehicular Lateral Impact Loading

Author(s): Cristoforo Demartino¹ and Sicheng Zhou²

¹ Zhejiang University - University of Illinois at Urbana Champaign Institute, 718 East Haizhou Road, Haining, 314400 Zhejiang, PR China

² Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 31, 20133 Milano, Italy

Keyword(s): Bridge RC piers; Retrofit strategies; CFRP wrapping; Impact response; Static behavior.

Abstract

This study investigates the effectiveness of Carbon Fiber Reinforced Polymer (CFRP) seismic retrofitting on circular Reinforced Concrete (RC) bridge piers under vehicular lateral impact loading through experimental tests [1]. Sixteen 1/3 scale RC bridge piers, featuring three different reinforcement configurations, were tested with and without CFRP retrofit. The first group represents shear-deficient RC bridge piers designed using outdated practices or for non-seismic areas, while the second group has CFRP wrapping applied according to common seismic retrofit practices to enhance shear capacity and ductility.

The experimental tests were conducted under static and lateral impact loading in a propped cantilever setup, simulating a typical short-span viaduct bridge pier configuration. Static tests applied lateral loads monotonically using a hydraulic jacket, while impact tests involved a colliding truck equipped with a rigid hammer at two different impact velocities (3 and 4.5 m/s). The study critically examines transient dynamic characteristics, damage evolution, and post-impact damage by comparing results with and without CFRP retrofit, and under static and dynamic loading conditions.

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References

[1] Zhou, S. C., et al. "Effectiveness of CFRP seismic-retrofit of circular RC bridge piers under vehicular lateral impact loading." *Engineering Structures* 243 (2021): 112602.

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Title: A tropical cyclone intensity model using the conditional generative adversarial network

Author(s): Tianle Chen^{*1}, Xu Hong², Liang Hu³ and Fan Kong⁴.

¹ School of Civil Engineering, Hefei University of Technology, Hefei, China, 2022110580@mail.hfut.edu.cn

² School of Civil Engineering, Hefei University of Technology, Hefei, China, xhong@hfut.edu.cn

³ Nathaz Modeling Laboratory, University of Notre Dame, South Bend, peettr@gmail.com

⁴ School of Civil Engineering, Hefei University of Technology, Hefei, China, kongfan@hfut.edu.cn

Keyword(s): Tropical cyclone intensity, conditional Wasserstein generative adversarial network

Abstract

Tropical cyclones are known to be one of the most destructive natural disasters. In order to assess the reliability of engineering systems and estimate the economic loss caused by these cyclones, it is important to have a probability distribution of the maximum surface wind that they can produce. Predicting the intensity of tropical cyclones is a crucial component of modelling the probability distribution. Statistical approaches are commonly used to relate the change in intensity to environmental variables for engineering applications ^[1,2]. However, these statistical models may not be optimal in representing the complex nonlinear features of tropical cyclones. On the other hand, deep learning methods have been applied in the operational forecast of tropical cyclone intensity, which is recognized as a useful tool to represent nonlinearity ^[3]. The current deep learning methods used in real-time forecasting mainly focus on representing the deterministic relationship between input variables (environmental variables) and the output (TC intensity). However, in order to fully assess the risk of tropical cyclones, it is imperative to incorporate uncertainty and its propagation with the deep learning approach. This study proposes a TC intensity model using conditional Wasserstein generative adversarial network with the gradient penalty (CWGAN-GP) ^[4,5] to train a multilayer perceptron generator that can represent the probability distribution of TC intensity change based on the environmental variables. The proposed model is advantageous as it can accurately represent the non-Gaussian probability distribution of TC intensity change, which is a strong feature of these storms. Numerical results from the proposed CWGAN-GP model demonstrate its effectiveness in accurately predicting the intensity of tropical cyclones.

References

- [1] Jing R.Z., Lin N., "Tropical Cyclone Intensity Evolution Modeled as a Dependent Hidden Markov Process," *Journal of Climate*, 32, 7837–7855, (2019).
- [2] Vickery P.J., Skerlj P.F., Twisdale L.A., "Simulation of Hurricane Risk in the U.S. Using Empirical Track Model," *Journal of Structural Engineering*, 126, 1222–1237, (2000).
- [3] Kozar M.E., Misra V., Powell M.D., "Hindcasts of Integrated Kinetic Energy in Atlantic Tropical Cyclones: A Neural Network Prediction Scheme," *Monthly Weather Review*, 144, 4591–4603, (2016).
- [4] Gulrajani I., Ahmed F., Arjovsky M., Dumoulin V., Courville A.C., "Improved Training of Wasserstein GANs," presented at the 31st Annual Conference on Neural Information Processing Systems (NIPS), Long Beach, CA, (2017).
- [5] Mirza M., Osindero S., "Conditional Generative Adversarial Nets," arXiv:1411.1784 [cs, stat], (2014).

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Title: Masonry differential settlements analysis including the soil

Author(s): Vincenzo Mallardo^{*1}, Antonino Iannuzzo²

¹ *Department of Architecture, University of Ferrara, Ferrara, Italy, mlv@unife.it*

² *Department of Engineering, University of Sannio, Benevento, Italy, aniannuzzo@unisannio.it*

Keyword(s): no tension material, integral equations, energy criteria

Abstract

Most effort in structural analysis of historical masonry structures is devoted to setting up and testing theoretical and numerical models capable to predict the actual behaviour under given loading and displacement conditions (or boundary conditions). Special attention is paid to its brittle behaviour and the coupling between brick and mortar.

On the other hand, in the last decades, monitoring procedures have drawn more and more attention along with the growing need to recover and reuse historical buildings all over the world.

One of the main sources of damage in masonry structures is related to differential settlements. Such settlements need to be located, and also a correct measure of their influence on the structural behaviour of the building is to be computed.

Most of the work on the topic [1-3] has been developed by uncoupling the soil from the structure, without taking directly into account the soil behaviour's influence on the building. Furthermore, rarely the real no-tension property is fully considered in the model.

In the present paper, a novel approach is proposed to investigate the effects of differential settlements on masonry structures modelling the construction as a no-tension material, and, more importantly, directly considering the soil-structure interaction with an explicit modelling of the unilateral contact between soil and structure. The soil behaviour is included by a boundary integral approach, thus avoiding mesh discretisation issues. Some numerical examples will be shown to demonstrate the efficiency of the procedure

References

- [1] R. Gagliardo, F.P.A. Portioli, L. Cascini, R. Landolfo, P.B. Lourenço., A rigid block model with no-tension elastic contacts for displacement-based assessment of historic masonry structures subjected to settlements, *Engineering Structures* 2021, vol. 229, 111609.
- [2] A. Tralli, A. Chiozzi, N. Grillanda, G. Milani, Masonry structures in the presence of foundation settlements and unilateral contact problems, *International Journal of Solids and Structures* 2020, vol. 191-192, p. 187-200.
- [3] A. B. Padura, J. B. Sevilla, J. G. Navarro, Settlement predictions, bearing capacity and safety factor of subsoil of Seville's Giralda, *International Journal of Architectural Heritage* 2012, vol. 6, p. 626-647.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: An iterative linear programming procedure for non-associative kinematic limit analysis of masonry blocks

Author(s): Mariaceleste Lasorella^{*1}, Aguinardo Fraddosio¹, Elio Sacco², Mario Daniele Piccioni¹

¹ *Dipartimento di Architettura, Costruzione e Design, Politecnico di Bari, Bari, mariaceleste.lasorella@poliba.it, aguinardo.fraddosio@poliba.it, mario.daniele.piccioni@poliba.it*

² *Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, elio.sacco@unina.it*

Keyword(s): Limit analysis, dry masonry

Abstract

A simplified approach for numerically solving the kinematic limit analysis problem with a non-associative flow rule is proposed for the assessment of the structural safety level of dry masonry structures.

Masonry is discretized in two-dimensional rigid blocks mutually connected through rough and unilateral contact interfaces, ruled by suitable constitutive laws. The possibility of mechanisms involving both rocking behavior and sliding displacements at the interfaces is considered. This requires the implementation of non-associative flow rules, making more complex and nonlinear the optimization problem related to the search of the collapse load multiplier.

The numerical solution of kinematic limit analysis problems with non-associative flow rules has been the subject of a relatively broad literature and has been solved by employing different optimization procedures [1], [2].

Here, since the determination of the solution for nonlinear programming problems (NLP) is significantly more complex than for the linear programming ones (LP), the NLP is transformed into a sequence of LP, and the collapse multiplier is found as the minimum value for the load multiplier for this sequence. The discussion of some applicative examples allows for illustrating the potentialities of the proposed approach, and the effectiveness of the proposed optimization algorithm.

References

- [1] Gilbert M., Casapulla C., Ahmed H.M., "Limit analysis of masonry block structures with non-associative frictional joints using linear programming", *Computers & Structures*, vol. 84, pp. 873-887, 2006.
- [2] Nodargi N. A., Intrigila C., Bisegna P., "Limit analysis of dry masonry block assemblages with non-associative frictional joints", *AIP Conference Proceedings* 2239, 020033, 2020.

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Title: Limit analysis of non-periodic masonry by means of Discontinuity Layout Optimization

Author(s): Mattia Schiantella^{*1}, Federico Cluni¹

¹ *Department of civil and environmental engineering, University of Perugia, Italy,
mattia.schiantella@unipg.it, federico.cluni@unipg.it*

Keyword(s): Limit analysis, Non-periodic masonry, Discontinuity Layout Optimization

Abstract

It is very common to find irregular bonding patterns in historical masonry, the so called non-periodic textures. Among them we can define a quasi-periodic texture if the masonry courses are horizontal and well defined, otherwise the texture may be called chaotic.

Unlike periodic texture for which several analysis methods have been developed in the past (see [1] for an overview) the determination of structural and mechanical properties of non-periodic textures is more complex. In [2], Discontinuity Layout Optimization procedure has been used for assessment of the influence of such textures on the failure multiplier for a rigid block analysis.

This method was developed for the first time in [3] and it was expanded in [4] and it consists in a limit analysis that identifies the failure mechanism among a large set of potential ones by means of Linear Programming techniques minimizing the energy required.

In [5] a parametric analysis has been addressed, and many aspects such as the effect of the variation of three different textures, the variation of the size of the panel and the mechanical properties of masonry. In a recent work by the authors [6] a further classification for quasi-periodic texture has been provided and the textures have been analysed using both a discrete and a smeared continuum DLO approach. The latter individuates the variation of the aspect ratio of the blocks throughout the wall to build an equivalent homogenized model.

In the present work, the results of an extensive parametric analysis on several wall configurations are presented. In particular, we considered the presence and position of openings, different type of textures, mechanical characteristics, different types of loading and their mutual interactions. Moreover, results obtained by means of DLO are compared to FEM/DEM methods in order to show the accuracy and to highlight the computational advantages and drawbacks.

References

- [1] Sacco, E., Addessi, D., Sab, K., "New trends in mechanics of masonry," *Meccanica*, 53, 1565–1569, 2018.
- [2] Cluni, F., Gusella, V., Schiantella, M., "Upper bound limit analysis of quasi-periodic masonry by means of discontinuity layout optimization (DLO)," in *Proceedings of XXIV AIMETA Conference 2019, Rome (IT)*, 15-19 September 2019, 2124-2133, 2020.
- [3] Smith, C.C., Gilbert, M., "Application of discontinuity layout optimization to plane plasticity problems," *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 463, 2461–2484, 2007.
- [4] Gilbert, M., Smith, C.C., Pritchard, T.J., "Masonry arch analysis using discontinuity layout optimisation," *Proceeding of the Institution of Civil Engineers*, 163, 155-166, 2010.
- [5] Schiantella, M., Cluni, F., and Gusella, V., "Parametric Analysis of Failure Loads of Masonry Textures by Means of Discontinuity Layout Optimization (DLO)," *Materials* 15 (10), 3691, 2022.
- [6] Schiantella, M., Gilbert, M., Smith, C.C., He, L., Cluni, F., "Limit analysis of quasi-periodic masonry walls" (in review)

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Macro-mechanical models for the assessment of tunnelling induced damage on masonry structures

Authors: Marialuigia Sangirardi¹, Cristina Gatta², Daniela Addessi^{2*}, Angelo Amorosi²

¹*Department of Engineering Science, University of Oxford, Oxford, United Kingdom, marialuigia.sangirardi@eng.ox.ac.uk.*

²*Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy. cristina.gatta@uniroma1.it, daniela.addessi@uniroma1.it, angelo.amorosi@uniroma1.it*

Keywords: Masonry, Damage, Settlements.

Abstract

Settlements induced by tunnelling activities in urban environments can cause damage to surface structures. This is evaluated at different levels. Large scale assessments are routinely conducted by applying analytically predicted surface displacements to equivalent elastic beams representing buildings in the affected area. Damage is then typically quantified referring to differential settlements and related distortions [1]. For those structures recognized to be “at risk”, more accurate numerical analyses are needed, possibly resorting to partly or fully coupled soil-structure interaction models. In this context, structural damage is evaluated through tensile strain distributions. Their concentration is considered as an indicator of possible damage location and their magnitude assimilated to damage categories ranging from “negligible” to “very severe”. Although a quantitative measure of strain intensity is referred to, this definition of tunnelling-induced damage is still rather qualitative.

The objective of this work is to propose a more insightful interpretation of the damage phenomena caused by tunnelling-induced settlements. In the framework of finite elements simulations based on the macro-mechanical approach, this is pursued adopting two newly formulated nonlinear constitutive models for masonry [2,3]. These are based on different internal variables to describe failure and degrading mechanisms of the material. Hence, the structural response, in terms of damaging paths, can be critically compared to frame their outputs in the context of classical damage metrics proposed in literature. Uncoupled numerical analyses are performed, subjecting a plain masonry façade to Gaussian settlement profiles in order to reproduce typical configurations, considering different positions of the structure with respect to the tunnel axis.

References

- [1] Burland, J.B., Wroth, C. P., "Settlement of buildings and associated damage", in Proceedings of Conference on Settlement of Structures, Pentech Press, London, England, 611-651, (1974).
- [2] Gatta, C., Addessi, D., Vestroni, F., "Static and dynamic nonlinear response of masonry walls", International Journal of Solids and Structures, 155, 291-303 (2018).
- [3] Lasciarrea, W.G., Amorosi, A., Boldini, D., de Felice, G., Malena, M., "Jointed Masonry Model: A constitutive law for 3D soil-structure interaction analysis", Engineering Structures, 201, 109803 (2019).

Title: Novel numerical approaches for the modelling of axial-symmetric masonry domes

Authors: Francesca Roscini*¹ and Francesca Nerilli*²

¹ *Department of Engineering, Niccolò Cusano University, Rome, Italy, francesca.roscini@unicusano.it*

² *Department of Engineering, Niccolò Cusano University, Rome, Italy, francesca.nerilli@unicusano.it*

Keywords: Finite element, Isogeometric analysis, Masonry dome.

Abstract

The majority of the masonry existing buildings are characterized by curved members. In particular, they could be reckoned in the most significant ancient masonry structures, also largely used. Their structural assessment has been even more considering to guarantee their historical and artistic preservation over time. Therefore, the mechanical behaviour prediction of the mechanical response of curved masonry members as vaults and domes is necessary. Indeed, there has been evidence in the close dependence among their response, their geometry and the intrinsic characteristics of the masonry material, not reacting in tension.

Recently, different computational procedures have been suggested thanks to a large amount of scientific studies [1-3]. In particular, the Limit Analysis has appeared as a reliable and suitable approach for the prediction of the load-carrying capacity of masonry curved members. Likewise, the development of Finite Element modelling (FE) and Discrete Macro-Element Methods (DMEM) have revealed their efficiency in the simulation of the complex structural response of masonry [4-5].

The purpose of this research is to present a numerical approach, based on the first-order shear deformation shell theory, able at assessing the mechanical response of masonry domes, modelled as shells of revolution. The theoretical model is implemented via two numerical procedures based on *i*) finite element (FE) formulation and *ii*) iso-geometrical analysis (IGA) [6-9]. The FE procedure is defined by a classical formulation based on the introduction of Lagrangian shape functions and a curved element is modelled able to reproduce also non-constant curvatures. Likewise, the IGA procedure is employed in order to suggest a powerful approach for reproducing the response of masonry domes of complex geometry with low computational cost.

The theoretical model and the adopted numerical procedures are illustrated and then discussed, along with the outcomes display, sensitivity analyses and comparisons between the two numerical suggested approaches.

References

- [1] Tralli, A., Alessandri, C. and Milani, G., "Computational methods for masonry vaults: a review of recent results", *Open Civil Engineering Journal*, 8.1, 272-287 (2014).
- [2] Addessi, D., Marfia, S., Sacco, E., and Toti, J., "Modeling Approaches for Masonry Structures", *Open Civil Engineering Journal*, 8, 288-300 (2014).
- [3] D'Altri, A.M., et al., "Modeling strategies for the computational analysis of unreinforced masonry structures: review and classification", *Archives of Computational Methods in Engineering*, 27.4, 1153-1185 (2020).
- [4] Marfia, S., Ricamato, M., and Sacco, E., "Stress analysis of reinforced masonry arches", *International Journal for Computational Methods in Engineering Science and Mechanics*, 9.2 77-90, (2008).
- [5] Cannizzaro, F., et al., "A Discrete Macro-Element Method (DMEM) for the nonlinear structural assessment of masonry arches", *Engineering Structures*, 168, 243-256, (2018).
- [6] Chiozzi, A., et al., "ArchNURBS: NURBS-based tool for the structural safety assessment of masonry arches in MATLAB", *Journal of Computing in Civil Engineering*, 30.2, 04015010, (2016).
- [7] Hughes, T.J.R., Cottrell, J.A., and Bazilevs, Y., "Isogeometric analysis: CAD, Finite elements, NURBS, exact geometry and mesh refinement", *Computer Methods in Applied Mechanics and Engineering*, 194(39-41):4135_4195, (2005).
- [8] Auricchio, F., et al., "Locking-free isogeometric collocation methods for spatial Timoshenko rods", *Computer Methods in Applied Mechanics and Engineering*, 263, 113-126, (2013).
- [9] Nerilli, F., "Novel FE and IGA approaches for no-tension curved masonry arch model". (Under review)

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Palermo, Italy, August 27 - 30, 2023

Title: Modelling of Masonry with Microporomechanics

Author(s): Pedro Henrique Rios Silveira^{*1}, Rita Esposito¹

¹ Faculty Of Civil Engineering and Geosciences, Delft University of Technology, The Netherlands

^{*} P.H.RiosSilveira@tudelft.nl, R.Esposito@tudelft.nl

Keyword(s): non-destructive testing, cohesion-friction, anisotropic-damage, analytical homogenization

Abstract

It is often a problem in masonry mechanics to obtain formulations that can capture anisotropic effects while still being possible to fit with a small number of simple tests. Despite a wide range of strategies available, models frequently require many non-linear parameters to be determined. In applications where characterization is limited to experiments that can be performed non-destructively in situ or with locally extracted small specimens, it can become impossible to define these parameters. One example where this plays a role is in the assessment of existing masonry construction.

Beyond just calibration, another issue is the computational cost of nonlinear structural analyses. This is particularly the case for the so-called 'brick-to-brick' formulations, which discretize the model with elements at the size of the blocks or smaller. These strategies can be less constraining in terms of calibration than continuum-based ones. However, using them in FEM models might be prohibitively expensive, especially for large structures.

An interesting alternative to these issues is to employ microporomechanical models [1-2]. This class of formulations, based on analytical homogenization of elliptical cracks, has several advantages. They are continuous and therefore computationally cheaper. Anisotropic effects can be directly incorporated either by the distribution of cracks or by having the surrounding material be anisotropic. Damage initiation and evolution are also directional, since cracks of different orientations can grow independently. Lastly, they are based on physical properties, like the size and orientations of defects, meaning they can be calibrated from direct microstructure observation or by simple, non-destructive tests.

Given these advantages, this work discusses the use of microporomechanical formulations for the analysis of masonry. Then, it examines the coupling between cohesion and friction in crack-propagation and global material response. Lastly, a model is used to analyze both isotropic and anisotropic materials, and some of its advantages and limitations are discussed.

References

- [1] Dormieux L., Kondo D., Ulm, F.-J., "Microporomechanics", John Wiley & Sons, Chichester, United kingdom, (2006).
- [2] Zhou Y., Sluijs L. J., Esposito R., "A microporomechanical model to predict nonlinear material behavior of masonry", Computational modelling of concrete and concrete structures, CRC Press, pp. 363–372, (2022).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Revisiting the rocking overturning spectrum of free-standing blocks via shaking table tests

Author(s): Carla Colombo^{*1}, Georgios Vlachakis¹, Nuno Mendes¹, Anastasios I. Giouvanidis², Nathanaël Savalle³, Paulo B. Lourenço¹

¹ *Department of Civil Engineering, University of Minho, ISISE, ARISE, 4800-058 Guimarães, Portugal, e-mail: carla.colombo95@gmail.com, giorgovlachaki@gmail.com, nunomendes@civil.uminho.pt, pbl@civil.uminho.pt*

² *Department of Civil Engineering, University of Nottingham, University Park, NG7 2RD Nottingham, United Kingdom, e-mail: anastasios.giouvanidis@nottingham.ac.uk*

³ *Université Clermont Auvergne, Clermont Auvergne INP, CNRS, Institut Pascal F-63000 Clermont-Ferrand, France, e-mail: nathanael.savalle@uca.fr*

Keyword(s): Rocking motion, overturning maps, shaking table tests, sine pulse, masonry structures, digital image correlation

Abstract

Several earthquake reconnaissances have indicated that masonry structures suffer from failure mechanisms which experience rocking motion [1]. The occurrence of such mechanisms might involve either non-structural elements, such as parapets, pinnacles or artistic features, or more importantly, whole façades, whose weakness can jeopardise the overall stability. In fact, structural components often lack adequate connections, which result in the formation of local out-of-plane collapse mechanisms. These mechanisms form macro-blocks that detach from the rest of the structure and experience out-of-plane rocking motion. As a matter of fact, the rocking problem still constitutes a challenging topic in earthquake engineering and keeps attracting the attention of numerous researchers since the pioneering study of Housner [2]. More specifically, a large number of analytical and numerical studies have focused on the prediction of rocking motion in correlation with the ground excitation and the estimation of overturning criteria. However, experimental campaigns on the topic are scarce, despite their crucial role related to the validation of the proposed models or their shortcomings.

In this work, the dynamic response of a free-standing block subjected to sine-pulse-like excitations is investigated. More specifically, a dimensionless rocking overturning spectrum is experimentally derived by means of more than a hundred shaking table tests. The seismic inputs consist of sinusoidal pulses featured by a wide variation of acceleration amplitudes and frequencies. The dynamic response of the rocking block is recorded via a digital image correlation system, which consists of a contactless measuring technique that permits highly accurate measurements without interfering with the tested specimen. Finally, the experimental investigation includes remarks on the repeatability of the rocking response and the comparison with analytical closed-form expressions that describe the overturning areas [3].

References

- [1] Vlachakis G., Vlachaki E., Lourenço P. B., “Learning from failure: Damage and failure of masonry structures, after the 2017 Lesvos earthquake (Greece)”, *Engineering Failure Analysis*, 117, (2020).
- [2] Housner G. W., “The behavior of inverted pendulum structures during earthquakes”, *Bulletin of the seismological society of America*, 53, 403-417, (1963).
- [3] Dimitrakopoulos E. G., DeJong M. J., “Revisiting the rocking block: closed-form solutions and similarity laws”, *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 468, 2294–2318, (2012).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Rocking analysis of masonry bell towers

Author(s): Luciana Di Gennaro^{*1}, Mariateresa Guadagnuolo¹, Michela Monaco²

¹ Department of Architecture and Industrial Design, University of Campania "Luigi Vanvitelli", Aversa, Italy, luciana.digennaro@unicampania.it

² DING–Department of Engineering, University of Sannio, Piazza Roma 21, 82100 Benevento, Italy, monaco@unisannio.it

Keyword(s): masonry; tower; rocking; double-block model; dynamic analysis; vulnerability

Abstract

The most recent earthquakes that hit Italy, including L'Aquila (2009), Emilia-Romagna (2012), Central Italy (2016), and Ischia (2017), have highlighted the high seismic susceptibility of ecclesiastical masonry complexes. Bell towers are slender masonry structures that frequently belong to ecclesiastical structures. Their presence represents a point of vulnerability as they could cause partial collapse; their loss of capacity is often caused by aging and neglect. In fact, bell towers require preliminary analysis to assess their vulnerability. The assessment of their structural behaviour is crucial when considering the masonry aggregate as a whole [1,2], especially when retrofit interventions are involved.

Accurate analysis and modelling of ecclesiastical structures and aggregate buildings generally are challenging [3]. They comprise different structural parts, determining a complex global behaviour that is not always easy to understand and describe.

Different methodologies to analyse the dynamic response of bell towers exist and generally require knowledge of a significant number of parameters.

This work considers several approaches to analyse the dynamic behaviour of the bell tower emerging from a masonry building. The goal is to provide a preliminary stability estimation, furnishing a risk index evaluation with a quick procedure before more accurate ones.

The proposed method is block-based and combines the rocking of the bell tower [4] with the sliding motion of the underlying building by applying different friction coefficients. The result is a double-block analysis compared with a single-block model subjected to the floor spectrum.

The influence of the masonry complex being calculated using only its total mass and soil friction coefficients has demonstrated that the proposed quick method is suitable for a preliminary evaluation of the bell tower's stability without requiring a strong computational effort, unlike a FEM modelisation of the whole complex.

References

- [1] Gesualdo, A.; Monaco, M. "Seismic Vulnerability Reduction of Existing Masonry Buildings. Modelling of Retrofitting Techniques." In Proceedings of the Final Conference COST ACTION C26: Urban Habitat Constructions under Catastrophic Events, Naples, 16-18 September 2010, pages 853 – 858, (2010).
- [2] Valente, M. "Seismic Vulnerability Assessment and Earthquake Response of Slender Historical Masonry Bell Towers in South-East Lombardia". Engineering Failure Analysis, 129, 105656, (2021).
- [3] Montabert, A.; Mercerat, E.D.; Clément, J.; Langlaude, P.; Lyon-Caen, H.; Lancieri, M. "High Resolution Operational Modal Analysis of Sant' Agata Del Mugello in Light of Its Building History", Engineering Structures, 254, 113767 (2022).
- [4] Housner, G.W. "The Behavior of Inverted Pendulum Structures during Earthquakes". Bulletin Seismological Society of America, 53, pages 403 - 417 (1963).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: An experimental study on the effects of friction variability.

Authors: Michela Monaco¹, Ester Sallicandro¹, Roberto Serpieri²

¹DING - Department of Engineering, University of Sannio, Benevento, Italy, {monaco, aniannuzzo}@unisannio.it, ester.sallicandro@studenti.unisannio.it

²DADI – Department of Architecture and Industrial Design, University of Campania “Luigi Vanvitelli”, Aversa, Italia, roberto.serpieri@unicampania.it

Keyword(s): rocking motion, sliding motion, friction coefficient, experimental tests

Abstract

Predicting motion exhibited by a rigid block freestanding over a macroscopically flat surface subjected to a predetermined sliding ground motion is of considerable interest in theoretical and applied mechanics as it covers relevant applications in seismic engineering, particularly regarding the preservation of historic built heritage. A main engineering issue is whether, for an assigned ground motion, the mechanical response of a rigid body with an interface model describing the contact mechanics of the supporting surface can be accurately predicted looking at the activation of possible sliding or rocking motions. Several authors have tackled the stability of systems composed of single or multiple blocks with possible overturning and sliding [1-3] when the supporting surface is a natural or artificial rock joint. Thus, although the rational foundations of the problem are well established [4,5], no research has been focused on the small-scale features of the contacting surface and the innate coupling among normal and friction forces due to the intrinsic nature of the asperities that unavoidably affect a rock surface [6]. Such a feature adds an important complexity factor to the problem. Although modelling this coupling can be theoretically approached by multiplane Cohesive-Zone Models [7], achieving some predictivity for controlled static cyclic loading, its characterization is eminently a dynamic problem. It can be evaluated only experimentally, as several authors have pointed out [8]. Herein, a contribution to the experimental knowledge of friction and its influence on rocking motion is presented, following preliminary studies by the authors [9]. The experimental campaign has been performed at Unisannio lab, using a motorized plane with a variable inclination angle to determine the static and kinematic friction coefficient between different contact surfaces. The influence of the friction coefficient on the dynamic behaviour of the specimens has been examined using dynamic tests with a unidirectional shaking table.

References

- [1] Housner W.G., "The behaviour of inverted pendulum structures during earthquakes", *Bull. Seism. Soc. Am.*, 53, (1963).
- [2] Franciosi V., Sinopoli A., "The stability degree of masonry structures: The earthquake as collapse parameter", *Mech. Res. Commun.*, 13(4), (1986).
- [3] Shenton, H. W., "Criteria for initiation of slide, rock, and slide-rock rigid-body modes", *J. Eng. Mech.*, 122(7), 690-693, (1996).
- [4] Hertz, H., "Über die Berührung fester elastischer Körper", *J. für die Reine und Angew. Math.* 92, 156-171, (1881)
- [5] Levi-Civita, T., A maldi, U., *Lezioni di meccanica razionale*, 1-2, Zanichelli, Bologna, Italy, (1923).
- [6] Lee, H.S., Park, Y.J., Cho, T.F., You, K.H., "Influence of asperity degradation on the mechanical behavior of rough rock joints under cyclic shear loading", *Int. J. Rock Mech. Min. Sci.*, 38(7), 967-980, (2001).
- [7] Serpieri, R., Alfano, G., Sacco, E., "A mixed-mode cohesive-zone model accounting for finite dilation and asperity degradation". *Int. J. Solids Struct.*, 67, 102-115, (2015).
- [8] Kounadis, A.N., "The effect of sliding on the rocking instability of multi-rigid block assemblies under ground motion", *Soil Dyn. Earthq. Eng.* 104, 1-14, (2018).
- [9] Monaco, M., Guadagnuolo, M., Gesualdo, A., "The role of friction in the seismic risk mitigation of freestanding art objects". *Nat. Hazards*, 73, 389-402, (2014).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: A modified Drucker Prager numerical approach for the analysis of the San Francesco di Paola dome in Naples

Author(s): Claudia Cennamo^{*1}, Concetta Cusano¹, Arsenio Cutolo², Federico Guarracino², Ida Mascolo²

¹ *Department of Architecture and Industrial Design, University of Campania Luigi Vanvitelli, Aversa (CE), Italy, claudia.cennamo@unicampania.it*

² *Department of Structures for Engineering and Architecture, University of Naples "Federico II", Naples, Italy, arsenio.cutolo@unina.it, fquarrac@unina.it, ida.mascolo@unina.it*

Keyword(s): domes, no tension material, masonry, crack pattern analysis, assessment evaluation

Abstract

Building on previous works "[1,2]", which compared the results obtained from an analytical approach based on a simplified membrane theory with a graphical method based on a sliding block technique, here the case study such of the Basilica of San Francesco di Paola in Naples is analysed also by means of a refined numerical approach.

In fact, a number of approaches to the analysis of masonry structures have been proposed by several authors over the years "[3]", but in order to account for the actual building technique, for the masonry texture, for the presence of openings and for many other characteristics, recourse to numerical approaches remains the only viable strategy.

In particular, accounting for all the above mentioned aspects, the present study proposes a FE analysis of the San Francesco di Paola dome with an evaluation of the crack evolution. Reference is made to a specially modified Drucker Prager material model in order to simulate a No Tension material.

Results are discussed in detail and compared to outcomes from membrane and sliding block analyses.

References

- [1] Cennamo C., Cusano C., Fortunato A., Angelillo M., A study on form and seismic vulnerability of the dome of San Francesco di Paola in Naples, *Ingegneria Sismica*, 35(1):88-108, 2018.
- [2] Cusano C., Cennamo C., The gothic arcade of Santa Maria Incoronata in Naples. Equilibrium of gothic arches. *International Journal of Masonry Research and Innovation (IJMRI)*, 3(2): 92-107, 2018.
- [3] Cutolo, A., Guarracino, F., Olivieri, C., Mascolo, I. Nonlinear FE Analysis of a Masonry Spiral Staircase in Nisida: a Refined Numerical Case Study. *International Journal for Multiscale Computational Engineering*, 20(5): 105-114, 2022.

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: The intrados strengthening of masonry arches with FRCM. The three-centred arch

Author(s): Luciana Di Gennaro*¹

¹ *Department of Architecture and Industrial Design, University of Campania "Luigi Vanvitelli", Aversa, Italy, luciana.digennaro@unicampania.it*

Keyword(s): keywords list (Arial font – 11 point size)

Abstract

The reinforcement of masonry arches with the FRCM (Fiber Reinforced Cementitious Matrix) technique is an increasingly used solution to improve the structural strength of masonry arches and vaults[1] . In some cases where it is not possible to intervene on the extrados, such as for cultural heritage and monumental buildings where it is necessary to reduce the impact of the interventions by preserving the shape of the arches and vaults, reinforcement with FRCM is applied to the intrados [2]. In this case, the composite tensile strength compensates for the lack in the masonry apparatus of it by counteracting the opening of cracks and plastic hinges.

This work focuses on the FRCM strengthening performed with PBO (Polyparafenilenbenzobisoxazole) textile applied on three-centred arches. This type of arches can present greater structural vulnerability due to its particular shape. The presence of different curvatures leads to a non-uniform distribution of stresses. In the central part of the arc with a higher radius, the vertical components of the actions are, in fact, more significant than the rest of the structure.

This work aims to assess the effectiveness of FRCM with PBO textiles, strengthening by comparing the results of several numerical modelling with a load test performed on a three-centred arc.

The load test has been performed on an arc of the historical complex of "Santa Maria delle Grazie" church sited in Barano on the isle of Ischia, where restoration works are still ongoing.

Moreover, the historical site hosts an experimental campaign for structural monitoring with innovative techniques. In detail, the load test has been performed with traditional instruments, a fibre optic transducer [3] installed on the tested arc and acoustic sensors for acoustic emission monitoring.

References

- [1] E. Grande, G. Milani, Modeling of FRCM strengthening systems externally applied on curved masonry substrates, *Eng Struct.* 233 (2021). <https://doi.org/10.1016/j.engstruct.2021.111895>.
- [2] A. Borri, G. Castori, M. Corradi, Intrados strengthening of brick masonry arches with composite materials, *Compos B Eng.* 42 (2011). <https://doi.org/10.1016/j.compositesb.2011.03.005>.
- [3] L. Di Gennaro, E. Damiano, M. De Cristofaro, N. Netti, L. Olivares, R. Zona, L. Iavazzo, A. Coscetta, M. Mirabile, G.A. Giarrusso, A. D'Ettore, V. Minutolo, An innovative geotechnical and structural monitoring system based on the use of NSHT, *Smart Mater Struct.* 31 (2022). <https://doi.org/10.1088/1361-665X/ac5fc6>.

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Palermo, Italy, August 27 - 30, 2023

Title: An adaptive Scan-to-BIM workflow for the Dynamic Simulation of Architectural Heritage

Authors: Manuela Aricò^{*1}, Calogero Cucchiara¹, Alessandra Ferro¹, Mauro Lo Brutto¹, Antonino Maltese¹, Calogero Vinci²

¹ *Department of Engineering, University of Palermo, Palermo, Italy, manuela.arico@unipa.it; calogero.cucchiara@unipa.it; alessandra.ferro01@unipa.it; mauro.lobrutto@unipa.it; antonino.maltese@unipa.it*

² *Department of Architecture, University of Palermo, Palermo, Italy, calogero.vinci@unipa.it*

Keywords: 3D survey, Cultural Heritage, Scan-to-BIM, point cloud, FEM, Dynamic Simulations

Abstract

Preserving Cultural Heritage (CH) implies keeping it safe from being damaged or destroyed, for lack of maintenance or exposure to exceptional natural phenomena; the increased awareness on this topic resulted in a demand for up-to-date information to manage the documentation and knowledge of existing historical buildings. In the Architecture, Engineering and Construction (AEC) field, digitisation of CH assets has been encouraged by the development of reality-capture 3D surveys with innovative methodologies such as i.e. Terrestrial Laser Scanning (TLS), Mobile Mapping System (MMS), terrestrial and Unmanned Aerial Vehicle (UAV) photogrammetry. The data acquired on-site are later processed into point clouds which provide - with very high geometric accuracy - consistent support for every application in the CH domain, from preservation to dynamic simulations, including the Finite Element Analysis (FEA) [1]. Point clouds constitute the most reliable reference basis for the proper modelling phase to be performed through the so-called Scan-to-BIM approach, which strictly regulates every single step from processing the acquired data to the final delivery of an object-oriented smart model, more advantageous from a computational point of view, especially for non-linear analyses [2]. However, for this particular purpose, the use of the parametric model is not always simple and the use of the point cloud as starting data for the analysis is still necessary. In these cases, the point cloud need to be manipulated in order to be simplified, reduced and discretised according to regular planes and surfaces.

This paper aims at establishing a proven workflow for obtaining optimised models from a Scan-to-BIM process useful also for dynamic simulation through the Finite Elements Method (FEM); the workflow was applied to two case studies belonging to the Arab-Norman CH in Palermo [3]. In particular, this research focuses on addressing the typical issues of the Scan-to-BIM process applied to seismic assessment, such as the interoperability between software enabling conversion and exchange of information, the modelling of irregular geometries and the identification of a Morphological Quality Index (MQI) for the masonry load-supporting walls aimed at calculating the seismic vulnerability of these case studies.

References

- [1] Lucidi A., Giordano E., Clementi F., Quattrini R. "Point cloud exploitation for structural modeling and analysis", ISPRS Archives, Volume XLIII-B2-2021, pp. 891-898, (2021).
- [2] Ursini A., Grazzini A., Matrone F., Zerbinetti, M. "From Scan-to-BIM to a structural finite elements model of built heritage for dynamic simulation". Automation in Construction, 142, 104518, (2022).
- [3] Aricò M., Lo Brutto M., Maltese A. "A Scan-to-BIM approach for the management of two Arab-Norman churches in Palermo (Italy)", Heritage, 6, pp. 1622-1644, (2023).

EMI 2023 International Conference

Palermo, Italy, August 27 - 30, 2023

Title: Form 'in falso' to masonry wall beam

Author(s): Riccardo Liberotti^{*1}, Federico Cluni², Francesco Faralli³, Vittorio Gusella⁴

Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti 93, 06125 Perugia, Italy

^{*1} riccardo.liberotti@unipg.it

² federico.cluni@unipg.it

³ francesco.faralli@studenti.unipg.it

⁴ vittorio.gusella@unipg.it

Keyword(s): Heritage, composites, FRCM, FEM, sustainability

Abstract

The contribution focuses on what in jargon are defined 'in falso' masonries: load-bearing elements built without a direct load path to foundations, resting directly on vaults [1]. The goal is to broaden the knowledge about their peculiar structural behaviour; a topic insufficiently debated in the literature also in terms of safety and robustness implications [2]. Indeed, the underlying masonry vaults can easily be damaged during earthquakes causing the collapse of 'in falso' walls and leading to progressive collapses that could involve large portions of historical buildings. At this juncture, in order to effectively function as 'wall beams' consolidation interventions are necessary which unfortunately, to date, result in projects non-conservative over precious elements like pavings, frescoes and vaults. The contribution explores the opportunities offered by natural composite materials addressing the actual design criteria of Fiber Reinforced Cementitious Matrix (FRCM) composites. So, an innovative intervention is designed to be a solution more 'sustainable', using less composites than in traditional applications that are usually widespread all over the masonry surface. Then, to make a comparative assessment about the influence of the new intervention – made of composite tapes – an unprecedented experimental campaign started, involving as built and reinforced full-size walls tested in conditions similar to the vaults' damage scenario [3]. In the meantime, based on the promising experimental outcomes, finite element formulations are introduced both for masonry and composite. A description of the modelling approach used, that is still in development, is provided taking into account the issues concerning the complex interaction between these multi-phase materials [4]. In this terms, numerical modelling is refined to be a tool that allows design decisions based on quantitative criteria and engineering design principles.

References

- [1] Liberotti R., Architectural and environmental sustainability of restoration interventions: innovative strategies using FRCM composites for cultural heritage safeguard. Doctoral thesis, University of Perugia (2023).
- [2] Hendry A. W., Sinha, P. B., Davies S. R., Design of Masonry Structures. CRC Press: United States (1997).
- [3] Liberotti R., Cluni F., Faralli F., Gusella V., "Natural FRCM and Heritage Buildings: Experimental Approach to Innovative Interventions on "Wall Beams". Buildings, 12, 1076, (2022).
- [4] Lourenço P. B., Gaetani A., Finite Element Analysis for Building Assessment: Advanced Use and Practical Recommendations, Routledge, London, (2022).

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Title: A Genetic Algorithm approach for the calibration of a numerical model for the simulation of the FRCM-to-masonry bond

Author(s): Giovanni Minafò^{*1}, Gaetano Camarda², Marielisa Di Leto³, Lidia La Mendola⁴

¹ Department of Engineering, University of Palermo, Palermo, Italy, giovanni.minafo@unipa.it

² Department of Engineering, University of Palermo, Palermo, Italy, gaetano.camarda@unipa.it

³ Department of Engineering, University of Palermo, Palermo, Italy, marielisa.dileto@unipa.it

⁴ Department of Engineering, University of Palermo, Palermo, Italy, lidia.lamendola@unipa.it

Keyword(s): optimization; genetic algorithm; FRCM; bond

Abstract

The use of Fabric Reinforced Cementitious Matrix (FRCM) composites for structural upgrading applications of existing masonry buildings is a well-established practice. The spreading use of inorganic matrix-based composites is knowing an increasing interest in the scientific community, especially for their mechanical characterization and for the assessment of the actual load-carrying capacity of this class of composites. In this context, a variety of numerical approaches was proposed in the literature with the target of predicting the debonding load and bond length, and each approach corresponds to different model parameters and uncertainties. These last refer especially to the constitutive law of the fabric-to-matrix and matrix-to-support interfaces, depending on several mechanical and geometrical features and mechanisms.

This work presents a possible approach for the estimation of the unknown parameters characterizing a finite element (FE) model for the simulation of shear bond tests between FRCM and masonry or stone supports. The FE model is developed under simplified assumptions and adopting simple truss elements and zero-length discrete shear links for modelling the interface. A simplified shape of the constitutive law is assumed for the interfaces, with unknown parameters and a Genetic Algorithm (GA) framework is settled for their estimation. The GA is adopted for optimizing the match between the numerical simulations and the experimental results collected from the literature. The wide experimental database allows to draw some general conclusions on the dependence of the interface parameters and the mechanical features of the FRCM.

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Title: Crack width prediction and investigation for flexural reinforced concrete members

Author(s): Zhi Zhang^{*1}, Fangyin Zhang¹, Liling Cao¹, Alaukik Singh².

¹ Forensics, Thornton Tomasetti Inc., New York City, USA, zzhang@thorntontomasetti.com

² Structural Engineering, Thornton Tomasetti Inc., San Francisco, USA

Keyword(s): Crack Width, Reinforced Concrete, Finite Element Modelling

Abstract

Cracks are often developed in flexural reinforced concrete (RC) members, such as beams, slabs, columns because of low concrete tensile strength. The appearance of cracks not only affects the aesthetics of the structure, but impacts the concrete durability and capacity depending on exposure conditions. Therefore, crack control is considered as one of the governing limit states of serviceability during the design of RC structure. In new construction, crack control is achieved by limiting the maximum reinforcement spacing and the size of reinforcement according to current design standards and codes [1-3], under such condition, crack width generally does not exceed 0.012 in (0.3 mm) for RC members [3]. Existing research show that reinforced concrete members may experience faster chloride invasion after getting cracked [4-6]. As such, an appropriate approach to evaluate crack width becomes critical at the phase of condition assessment for existing RC structures. This abstract reviews the crack width prediction equations which were published in research literatures and design codes [2-3, 7-8]. Principles of crack width prediction are reviewed and summarized. A finite element analysis (FEA) is used to predict the crack width and compared to both equation predictions and lab-experiment results. In addition, a field measurement is compared to and validates the equations. Based on our studies of cracks among equations, lab test results, field measurement, and FEA, an appropriate analytical approach to predict the RC member crack width is recommended for future engineering practice to evaluate cracks in existing RC structures.

References

- [1] ACI 318, Building code requirements for structural concrete (ACI 318-14). American Concrete Institute, Farmington Hills, MI, 2014.
- [2] EN 1992-1-1, Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, Management Centre, Avenue Marnix 17, B-1000 Brussels, 2004.
- [3] CEB-FIP, Model Code 1990, Thomas Telford Services Ltd, Thomas Telford House, Heron Quay, London E14 4JD, 1993.
- [4] Djerbi, Bonnet, Khelidj, Baroghel-bouny, Influence of traversing crack on chloride diffusion into concrete, Cement and Concrete Research, Vol. 38, 877-883, 2007.
- [5] Jacobsen, Marchand, Boisvert, Effect of cracking and healing on chloride transport in OPC concrete, Cement and Concrete Research, Vol. 26, No. 6, 869-881, 1996.
- [6] Fan, Adams, Bandelt, Finite element simulation of mechanical-electrochemical coupling effects of steel corrosion in ECC structures, fib Symposium, Lisbon, Portugal, 2021.
- [7] BS 8110-2:1985, Structural use of concrete – Part2: Code of practice for special circumstances, Board of BSI, 1985.
- [8] Balazs G, Cracking analysis based on slip and bond stresses, ACI Material Journal, Vol. 90, Issue 4, 340-348, 1993.

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Title: Effects of post-tension on the structural capacity of masonry bridges

Authors: Laura Niero^{*1}, Riccardo Piazzon², Paolo Zampieri³, Carlo Pellegrino⁴

¹ Department of Civil, Environmental and Architecture Engineering, University of Padova, 35122 Padova, Italy, laura.niero.2@phd.unipd.it

² Department of Civil, Environmental and Architecture Engineering, University of Padova, 35122 Padova, Italy, riccardo.piazzon@phd.unipd.it

³ Department of Civil, Environmental and Architecture Engineering, University of Padova, 35122 Padova, Italy, paolo.zampieri@unipd.it

⁴ Department of Civil, Environmental and Architecture Engineering, University of Padova, 35122 Padova, Italy, carlo.pellegrino@unipd.it

Keywords: Masonry Arch Bridges, Post-tension, Rigid-block analysis

Abstract

Structural strengthening interventions of masonry arch bridges is a current issue for the Italian infrastructure administrations. In road and rail networks there are many masonry bridges built at the end of the 19th century, which requires repair and/or retrofit interventions to guarantee the minimum safety requirements of current standards. In fact, the evolution in modes and means of transportation has led to an increase of traffic loads. For these reasons, repair interventions and structural strengthening are necessary [1]. In addition to externally bonded composites strengthening systems (FRP and FRCM), which collaborate with the masonry structure when the construction is cracked, external post-tensioning systems can be used to increase the shear and the flexural capacity of the masonry bridges. This solution involves the use of noncontinuous strengthening made by tensioned cables that transfer actions to masonry by contact (strengthening at the extrados) or by anchors (strengthening at the intrados of the arch) [2-3]. This provides an increase in the flexural and shear strength of the masonry structure without making substantial changes in the distribution of masses and stiffnesses.

In this paper, a bidimensional rigid-block analysis has been developed, discretizing the structural elements of the masonry arch bridge as an assembly of rigid blocks, which interact via contact surface with Coulomb friction. The effect of post-tension has been considered by applying equivalent external forces to the structure. This approach allows to evaluate the increase in strength of the masonry bridge in terms of ultimate loads.

References

- [1] Jurina L., Mazzoleni M., "Ponti in muratura: verifiche statiche ed interventi di consolidamento con la tecnica dell'arco armato" in Atti del seminario C.I.A.S. "Ponti e viadotti: ispezioni visive e tecniche di risanamento", Bolzano, 1-3 Dicembre 2004.
- [2] Jurina L., "Una tecnica di consolidamento attivo per archi e volte in muratura" in Int. Symp. On Seismic Performance of Built Heritage in Small Historic Centres, Assisi, Aprile 1999.
- [3] Zampieri P., Piazzon R., Ferroni R., Pellegrino C., "The application of external post-tensioning system to a damage masonry arch" in XIX ANIDIS Conference, Seismic Engineering in Italy, Assisi, 11-15 Settembre 2022, 605-609, (2023).

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Title: Seismic Performance Enhancement of Unreinforced Brick Masonry Buildings by Retrofitting with Reinforced Concrete Bands: Full Scale Experiments

Author(s): Lakshmi Latha¹, Samit Ray-Chaudhuri², Suparno Mukhopadhyay^{*3}, Kunwar K. Bajpai⁴

¹ Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, lakshmia@iitk.ac.in

² Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, samitrc@iitk.ac.in

³ Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, suparno@iitk.ac.in

⁴ Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India, kunwar@iitk.ac.in

Keyword(s): unreinforced brick masonry, seismic band, full scale tests, ductility enhancement, energy dissipation

Abstract

This study was aimed to conduct a thorough experimental investigation on the seismic performance of semi-confined unreinforced brick masonry (SC-URBM) building as a structural topology. Experiments were conducted on two identical full-scale single-story brick masonry buildings: one is completely unreinforced (URBM), and the other is retrofitted with semi-confining horizontal and vertical reinforced concrete (RC) elements (SC-URBM). Both buildings were subjected to FEMA 461 [1] specified reverse slow-cyclic quasi-static loading protocol to quantify the improved seismic performance of the SC-URBM building compared to the URBM building. From the experimental results, ductility capacity, load carrying capacity, and energy dissipation capacity were evaluated, along with important observations such as failure mechanisms from pre-peak to post-peak regimes. The results and observation from the experiments demonstrate that the semi-confining elements significantly enhance the energy dissipation capacity and ductility of the retrofitted SC-URBM building without compromising its strength, thereby implying the superior performance of such buildings in comparison to URBM buildings.

References

[1] FEMA. 2007. Interim testing protocols for determining the seismic performance characteristics of structural and nonstructural components. FEMA 461. Washington, DC: FEMA