BUILDING WIND DAMAGE PREDICTION AND MITIGATION USING DAMAGE BANDS

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ABSTRACT: The wind damage resistivities of buildings impacted by hurricanes and tornadoes depend primarily upon the strength of the connections between the building components, the nature of the components, the architectural design features, and the nature of the immediate environment. Using previously derived building wind vulnerability relationships based on upper and lower damage probabilities of building components and connections, called damage bands, and building relative wind resistivity indices based on expert experience, this paper presents detailed procedures for predicting wind damage to individual buildings, portfolio analysis, and wind damage mitigation. Building component types and features that furnish specified percent reductions in wind damage degree over those of a conventional building are recommended for implementing a program of wind damage mitigation. The ease of implementation and robustness of these damage prediction methods make them particularly attractive for insurance underwriting and wind damage mitigation.

INTRODUCTION

Wind damage to buildings principally manifests in breach of the roof envelope, the wall envelope, and consequent damage to the building contents. Hence, the vulnerability of buildings in windstorms is a function of the strength of building envelope components and their connections. Also, for a given building impacted by winds of a given intensity, the resulting damage is largely dependent upon the nature of its immediate environment and the architectural design of the building. Prediction of the degree of wind damage suffered by a building or group of buildings has several applications, such as damage mitigation and/or reduction, insurance underwriting, and emergency management planning. The amount (or degree) of damage as used in this paper is defined as the ratio of the replacement cost of damaged building components (due to wind pressures and wind-borne missiles) to the replacement cost of the building.

Previous investigations on wind damage prediction either have developed methods that are applicable only for damage prediction of a group of buildings within given geographic areas or broad building classes (Hart 1976; Boissonnade and Dong 1993; Stubbs and Perry 1996; Sill and Kozlowski 1977), are not robust in their applications (Friedman 1984; Sparks and Bhinderwala 1993; Chiu 1994), or do not give explicit information on the amount of damage suffered by a building or group of buildings (Mehta et al. 1981; Mehta et al. 1993).

It is necessary that a wind damage prediction model satisfy the following criteria: (1) the model should be capable of predicting the actual amount (or degree) of damage to a building or groups of buildings; and (2) there should exist some proportionality relationship between the model predictions of damage degrees to individual buildings, based upon their relative wind performance characteristics. The first criterion is, of course, the desired output, upon which several decisions are ultimately based—for example, setting rates for insurance premiums, recommendations for wind-resistant construction, building selection for wind upgrade purposes, etc. The second criterion enables a check to be made on the precision of the model predictions and, in a way, serves as the single most important check on the predicted values of damage degrees. Based on the above premise, a new procedure was proposed for wind damage prediction to individual buildings and groups of buildings using the concept of wind damage bands and a building relative wind resistivity model (Unanwa and Ihekweazu 1999; Unanwa et al. 2000). The purpose of the present paper is two-fold: (1) to provide a detailed procedure, complemented by use of examples, for implementation of the proposed expressions for wind damage prediction to individual buildings and groups of buildings; and (2) to demonstrate the applicability of the wind damage models to wind damage mitigation.

OVERVIEW OF WIND DAMAGE MODEL

The procedure for wind damage prediction of individual buildings and groups of buildings is based on the concept of wind damage bands for building occupancy classes. Wind damage bands define the damage degree ranges bounded by a lower and upper damage threshold for given intensities of the wind hazard and are obtained using the formulation (Unanwa et al. 2000):

$$DD(l) = \sum_{i=1}^{n} P_{fi}(CCF_i)\alpha_i \tag{1}$$

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where $DD(l)$ = Damage degree at hazard level l; P_{fi} = component conditional probability of failure (or component fragility); CCF_i = component cost factor; α_i = component location parameter; and n = number of components used in the building damage model.

The upper boundary of a damage band for a class of buildings represents the wind damage function of the least wind resistant building in the building class, while the lower boundary represents the damage function of the most wind resistant building in the building class. This implies that the wind damage functions for all other buildings in that occupancy class lie within the damage band. This information presents a powerful tool for determining the damage degree to individual buildings and groups of buildings impacted by high winds.

For an individual building, the damage degree due to wind pressures and wind-borne missiles is given by (Unanwa and Ihekweazu 1999):

$$BDD_i = DD_i^L + RRI(DD_i^U - DD_i^L) \tag{2}$$

where BDD_i = individual building damage degree at hurricane intensity i; DD_i^L and DD_i^U are, respectively, the degrees of damage furnished by the lower and upper damage functions of the damage band for the building class under consideration at hurricane intensity i; and RRI is a relative resistivity index, defined as

$$RRI = \sum_{i=1}^{n} P_i W_i \Big/ \sum_{i=1}^{n} W_i \tag{3}$$

In (3), P_i = quality point associated with each building wind performance parameter; W_i = weight associated with each performance parameter; and n = number of performance parameters.

For a group of buildings, the proposed expression for the probable maximum loss (PML) due to wind pressures and wind-borne missiles is

$$PML(\%) = \frac{\sum_{j=1}^{4} RRI_j^{av}(DD_{ij}^U + DD_{ij}^L)N_j}{\sum_{j=1}^{4} N_j} \tag{4}$$

Alternatively, if the average replacement value for buildings in each occupancy class, BRV_j, is known, the PML for a group of buildings may be obtained in dollar terms, as follows:

$$PML(\$) = \sum_{j=1}^{4} RRI_j^{av}(DD_{ij}^U + DD_{ij}^L)N_j BRV_j \tag{5}$$

In (4) and (5), RRI_j^{av} = average relative resistivity index for buildings of class j; DD_{ij}^U and DD_{ij}^L are, respectively, the damage degrees furnished by the upper and lower damage functions for building class j given hurricane intensity i; and N_j = number of buildings in building class j. The index j denotes different building classes, such as low-rise residential, commercial/industrial, institutional/government, and mid-rise (4–10 story) buildings. In principle, j can be generalized to any number of building classes, provided their damage bands exist.

TABLE 1. Building Performance Parameters

Parameter, P_i (1)	Parameter types, $P_i(\cdot)$ (2)
P1-Roof covering	(1) asphalt shingles; (2) wood shingles; (3) asbestos shingles; (4) slate roof; (5) clay tiles; (6) architectural metal roof; (7) flat concrete tiles; (8) built-up roofs; (9) ballasted single membrane roof; (10) mechanically-attached single membrane roofs
P2-Roof geometry	(1) flat without parapet; (2) flat with parapet; (3) gable; (4) hip; (5) shed; (6) mansard; (7) gambrel; (8) multi-level roof; (9) complex
P3-Roof span	(1) 0-20 ft; (2) 21-40 ft; (3) 41-70 ft; (4) >70 ft
P4-Roof sheathing	(1) reinforced concrete; (2) precast concrete panels; (3) plywood; (4) metal panels; (5) oriented strand board
P5-Roof structure	(1) concrete; (2) steel trusses or joists; (3) steel beams; (4) wood trusses, beams, or joists
P6-Exterior wall system	(1) wood siding-wood frame; (2) brick veneer-wood frame; (3) stucco on wood frame; (4) concrete block (reinforced); (5) stone veneer-wood frame; (6) solid brick; (7) solid stone; (8) precast concrete panels
P7-Exterior door	(1) solid core wood; (2) sliding glass door; (3) aluminum/metal door; (4) flush (hollow core) door
P8-Percent wall occupied by exterior doors & windows	(1) 0–25%; (2) 26–50%; (3) >50%
P9-Partition wall	(1) masonry; (2) wood frame; (3) metal studs
P10-Beam/column system	(1) concrete; (2) steel; (3) laminated wood; (4) none
P11-Floor structure	(1) concrete; (2) wood frame; (3) metal frame
P12-Building code	(1) ANSI/ASCE standard; (2) model building code; (3) customized building code; (4) no code/unknown
P13-Building age	(1) 1–5 yrs; (2) 6–10 yrs; (3) 11–20 yrs; (4) 20–30 yrs; (5) >30 yrs
P14-Building envelope maintenance	(1) 1/yr; (2) 1/5 yrs; (3) 1/10 yrs; (4) 1/20 yrs or greater
P15-Windows glass	(1) annealed (AN); (2) fully tempered (FT); (3) heat strengthened (HS); (4) monolithic insulating (IG-AN/AN); (5) monolithic insulating (IG-FT/FT); (6) monolithic insulating (IG-HS/HS); (7) laminated glass (LG-AN/AN); (8) laminated glass (LG-HS/HS); (9) laminated glass (LG-FT/FT); (10) unknown glass type
P16-Roof overhang	(1) yes; (2) no
P17-Skylights	(1) yes; (2) no
P18-Canopy	(1) yes; (2) no
P19-Overhead doors	(1) yes; (2) no
P20-Gravel or roof mounted equipment on nearby buildings	(1) yes; (2) no
P21-Shutters on exterior doors and windows	(1) yes; (2) no

IMPLEMENTATION OF WIND DAMAGE PREDICTION MODEL

The relative resistivity index, *RRI*, of a building is a measure of the building's wind damage resistance relative to other buildings. *RRI* is determined for a specific building based upon the relative wind damage susceptibilities of the building's components, features, and nature of the building's immediate built environment, called building wind performance characteristics or parameters. The building wind performance characteristics employed for the present purpose are listed in Table 1. The various forms of each performance parameter in Table 1 reflect prevalent U.S. east coast building construction materials, technology, and design.

Before the relative resistivity index of a specific building can be determined by this procedure, it is necessary to have a knowledge base of the relative wind damage performance of the various forms of each building wind performance parameter $P_i(\cdot)$. This information forms the basis upon which the components and features of a specific building can be evaluated to obtain the building's relative resistivity index. An expert-supplied knowledge base given in terms of a (0–1) scale rating of alternative forms of the building performance parameters, $P_i(\cdot)$, and their relative weights, W_i, were obtained via a two-stage Delphi method (Linstone and Turoff 1975) as described in Unanwa et al. (2000). The aggregated results of the expert ratings of the $P_i(\cdot)$ and W_i are shown in Table 2. In addition to incorporating interaction effects of building components' failure in developing building wind damage bands (Unanwa et al. 2000), interaction effects of the performance factors in Table 2 were taken into consideration in the expert-supplied values of P_i's and W_i's in Table 2. It is also to be noted that the effect of selecting either the "yes" or "no" option of performance parameter P21 is to default to use of the related parameters, P7, P8, P15, and P20, in a manner that is consistent with the lower (if yes) or upper (if no) bound damage contributions.

The writers note that the parameters P1–P21 in Table 2 are the same as those listed in Table 1. Once the type of a wind performance parameter for a building is selected from Table 1, the quality point corresponding to that option is readily obtained from Table 2. For example, if the partition wall of a certain building is made of wood frame, i.e., option #2 of parameter P9 [or P9(2)] of Table 1, the corresponding quality point $P_i(\cdot)$ is obtained from Table 2 as follows: (a) enter Table 2 at the row starting with the number P9; (b) move horizontally along the P9 row until you reach the Quality Points column indicated as $P_i(2)$; (c) the number at the intersection of the P9 row and the $P_i(2)$ column is the required quality point. In this example, the quality point = P9(2) = 0.46.

The *RRI* for any building is obtained from (3) once the characteristics of the building, $P_i(\cdot)$, are specified. A *RRI* value close to 1 would indicate a building whose features and components offer very little resistance to wind damage, while a *RRI* value close to 0 represents a building whose features and components offer very high resistance to wind damage.

In the case of a group of buildings, the average relative resistivity index, RRI^{av} [see (4) and (5)], may be obtained by employing the average characteristics of buildings. Using (3) and the average characteristics of the model buildings in *Means* (1995, 1996), suggested values of RRI^{av} for use in (4) and (5) are given in Table 3. The data used for developing the RRI^{av} values in Table 3 are consistent with those previously used in developing building component

TABLE 2. Quality Points for Building Performance Parameters

Performance parameter, P_i (1)	Relative weight, W_i (2)	Quality Points									
		$P_i(1)$ (3)	$P_i(2)$ (4)	$P_i(3)$ (5)	$P_i(4)$ (6)	$P_i(5)$ (7)	$P_i(6)$ (8)	$P_i(7)$ (9)	$P_i(8)$ (10)	$P_i(9)$ (11)	$P_i(10)$ (12)
P1	14	0.98	0.74	0.64	0.51	0.50	0.65	0.07	0.70	0.35	0.34
P2	6	0.70	0.50	0.70	0.40	0.60	0.50	0.40	0.60	1.00	
P3	12	0.40	0.60	0.75	0.98						
P4	11	0.00	0.15	0.80	0.60	1.00					
P5	12	0.00	0.37	0.14	0.50						
P6	9	1.00	0.49	0.60	0.05	0.20	0.10				
P7	7	0.10	0.97	0.35	0.68						
P8	11	0.60	0.80	1.00							
P9	4	0.05	0.46	0.43							
P10	4	0.00	0.09	0.37	1.00						
P11	4	0.00	0.33	0.16							
P12	5	0.04	0.35	0.05	0.70						
P13	5	0.01	0.12	0.37	0.50	0.90					
P14	5	0.00	0.22	0.62	1.00						
P15	14	1.00	0.00	0.50	0.50	0.00	0.00	1.00	0.50	0.00	1.00
P16	12	0.50	0.00								
P17	11	0.75	0.00								
P18	4	0.75	0.00								
P19	11	1.00	0.00								
P20	11	0.75	0.00								
P21	[a]	[a]	[a]								

[a] Effect of quality points and weights for two options (i.e., yes or no) of this performance parameter is to default to use of related parameters, P7, P8, P15, and P20, in a manner consistent with lower (if yes) or upper (if no) bound damage contributions.

TABLE 3. Average Relative Resistivity Indices for Buildings

Building (1)	Average relative resistivity index, RRI^{av} (2)
1-story	0.61
2–3 story low-rise	0.53
4–10 story mid-rise	0.34

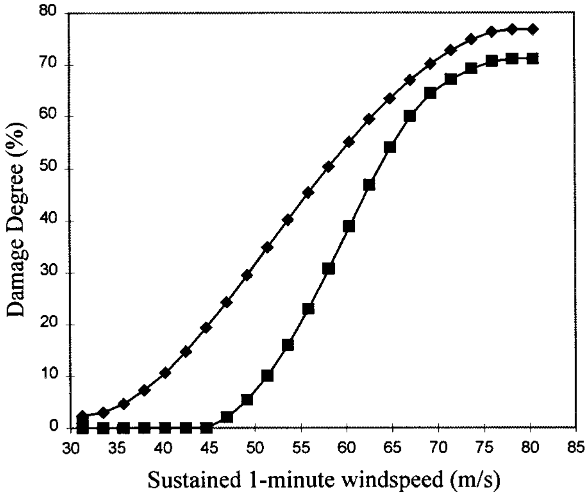

FIG. 1. Wind Damage Band for 1–3 Story Residential Buildings

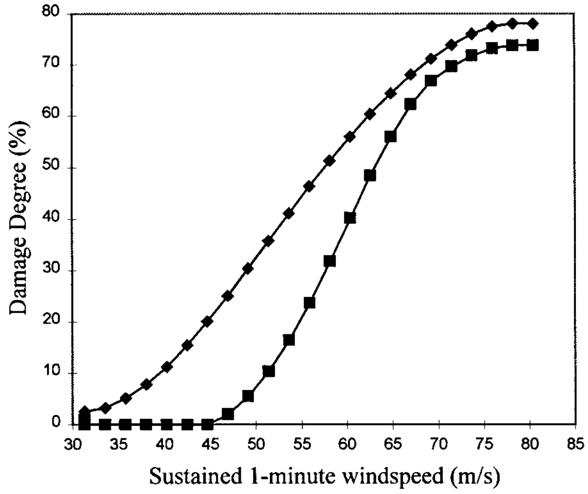

FIG. 2. Wind Damage Band for 1–3 Story Commercial/Industrial Buildings

cost factors for the building damage bands (Unanwa et al. 2000). Although the building damage bands for low-rise buildings shown in Figs. 1–4 are for 1–3 story buildings, the RRI^{av} values in Table 3 have been given in terms of two categories of low-rise buildings, namely, 1 story buildings, and 2–3 story buildings. This separation was done purely as a refinement to the damage prediction for a portfolio of buildings, since the characteristics $P_i(\cdot)$ of 2 story and 3 story buildings are similar but somewhat different from those of 1 story buildings (*Means* 1995, 1996).

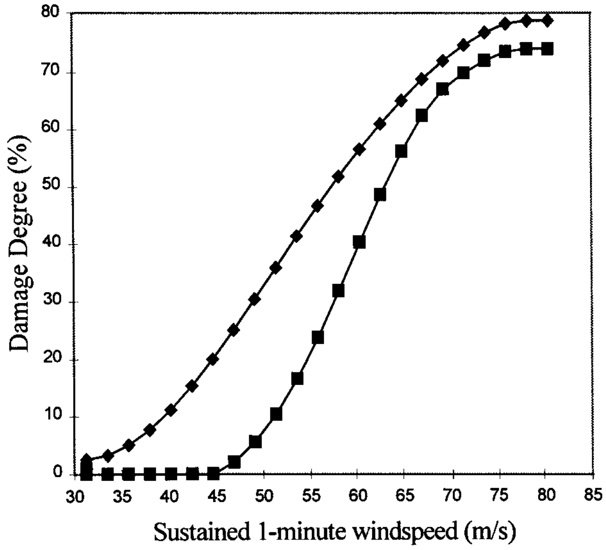

FIG. 3. Wind Damage Band for 1–3 Story Institutional Buildings

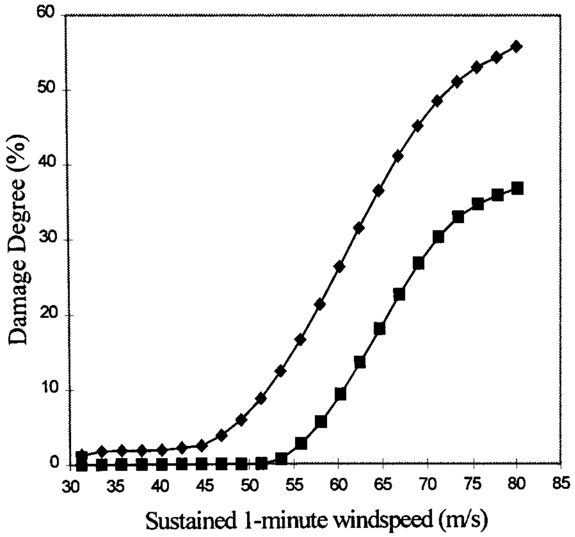

FIG. 4. Wind Damage Band for 4–10 Story Mid-Rise Buildings

EXAMPLE OF INDIVIDUAL BUILDING DAMAGE DEGREE DETERMINATION

To illustrate the implementation of the methodology described above for an individual building, let us determine the degree of damage to a low-rise apartment building impacted by a hurricane with a sustained one-minute wind intensity of 58.1 m/s (130 mph). We assume the wind performance characteristics $P_i(\cdot)$, of the apartment as shown in Table 4.

1. Using the above building information and the data from Tables 1 and 2, values of the performance parameters for the building characterized in Table 4 are given by the vector:

TABLE 4. Data for Individual Building Damage Degree Determination

Parameter, P_i (1)	Parameter type, $P_i(\cdot)$ (2)
P1-Roof covering	Asphalt shingles
P2-Roof geometry	Gable
P3-Roof span	25 ft
P4-Roof sheathing	Plywood
P5-Roof structure	Wood trusses
P6-Exterior wall system	Brick veneer-wood frame
P7-Exterior door	Flush (hollow core) door
P8-Percent wall occupied by exterior doors & windows	15%
P9-Partition wall	Wood frame
P10-Beam/column system	None
P11-Floor structure	Wood frame
P12-Building code	Model building code
P13-Building age	12 years
P14-Building envelope maintenance	Once in 10 years
P15-Windows glass	Regular (annealed)
P16-Roof overhang	Yes
P17-Skylights	No
P18-Canopy	No
P19-Overhead doors	Yes
P20-Gravel or roof mounted equipment on nearby buildings	Yes
P21-Shutters on exterior doors and windows	No

$$P_i = [0.98, 0.70, 0.60, 0.80, 0.50, 0.49, 0.68, 0.60, 0.46, 1.0, 0.33, 0.35, 0.37, 0.62, 1.0, 0.50, 0, 0, 1.0, 0.75]^T \tag{6}$$

2. Employing (6) and the weight factors in Table 2, the relative resistivity index, *RRI*, for the building is obtained from (3) as $RRI = 0.633$.
3. From the damage band data for residential buildings (Fig. 1), the threshold damage percentages for the 58.1 m/s (130 mph) windspeed are $DD_i^L = 30.7$ and $DD_i^U = 50.3$.
4. Using (2), the building damage degree, BDD_i, is obtained as

$$BDD_i = 30.7 + 0.633(50.3 - 30.7) = 43\%.$$

This result implies that 43% of the replacement value of the apartment building will be damaged by the hurricane. The results of the above procedure for individual buildings have also been verified against the actual damage suffered by three different buildings in Hurricane Fran and the actual damage degrees were found to be within 95% of the model prediction intervals.

Implementation of (2) to determine the degree of damage to any given low-rise (1–3 story) or mid-rise (4–10 story) building may also be easily accomplished by programming the damage band data (i.e., the damage functions in Figs. 1–4), the wind performance parameter data from Tables 1 and 2, (2) and (3), and interactively inputting the wind performance characteristics $P_i(\cdot)$ for the building in question.

EXAMPLE CALCULATION OF DAMAGE DEGREE TO A GROUP OF BUILDINGS

Eq. (4) can readily be applied to determine the damage degree to a portfolio of buildings, for example, the group of buildings in one or more coastal locations, with insurance coverage underwritten by a particular insurance company. As an example, let us assume that two neighboring towns with a total of 75 buildings in the portfolio of an insurance company were impacted by a hurricane. The distribution of buildings in the two towns and windspeed data at landfall of the hurricane are as shown in Table 5.

Using the information in Tables 3 and 5, and the damage band data for the four building classes (Figs. 1–4), (4) is implemented as shown in Table 6. It is to be noted that the RRI^{av} values used for the low-rise buildings are the weighted mean values of the 1 story and 2–3 story RRI^{av} values, i.e., $RRI^{av} = 0.61(0.2) + 0.53(0.8) = 0.55$ for low-rise residential buildings; $RRI^{av} = 0.61(0.8) + 0.53(0.2) = 0.59$ for low-rise commercial buildings; and $RRI^{av} = 0.61(0.5) + 0.53(0.5) = 0.57$ for low-rise institutional buildings. The probable maximum loss to the group of buildings = (sum of column 6)/(sum of column 3) = 2,163/75 = 29%. This result means that the probable maximum loss to the insured buildings equals 29% of the replacement values of the buildings.

TABLE 5. Data for Damage Degree Calculation of Group of Buildings

Parameter (1)	Town #1 (2)	Town #2 (3)
Sustained 1-minute windspeed in m/s (mph)	58.1 (130)	40.2 (90)
Number of low-rise residential buildings insured (20% are 1 story high)	25	10
Number of low-rise commercial/industrial buildings insured (80% are 1 story high)	12	8
Number of low-rise institutional/government buildings insured (50% are 1 story high)	6	4
Number of insured mid-rise buildings (4–10 story high)	4	6
Total number of insured buildings	47	28

TABLE 6. Example Calculation of Wind Damage Degree to Group of Buildings

Index j (1)	Building type (2)	Number of buildings, N_j (3)	Town (4)	RRI_j^{av} (5)	$RRI_j^{av}(DD_{ij}^U + DD_{ij}^L)N_j$ (6)
1	Low-rise residential	25	1	0.55	1,114
		10	2	0.55	59
2	Low-rise commercial	12	1	0.59	588
		8	2	0.59	53
3	Low-rise institutional	6	1	0.57	285
		4	2	0.57	25
4	Mid-rise	4	1	0.34	36
		6	2	0.34	3
Total		75			2,163

TABLE 7. Characteristics of Basic Building

Parameter (1)	Type (2)
Roof covering	Asphalt shingles
Roof geometry	Gable
Roof span	21–40 ft
Roof shealthing	Plywood
Roof structure	Wood trusses
Exterior wall system	Wood siding-wood frame
Exterior door	Flush (hollow-core) door
Percent wall occupied by exterior doors and windows	0–25%
Partition wall	Wood frame
Beam/column system	None
Floor structure	Wood frame
Building code	Model Building code
Building age	6–10 years
Building envelope maintenance	Once in 5 years
Windows glass	Regular (Annealed glass)
Roof overhand	Yes
Skylights	No
Canopy	No
Overhead doors	Yes
Gravel or roof-mounted equipment on nearby buildings	Yes
Shutters on exterior doors and windows	No

APPLICATION TO WIND DAMAGE MITIGATION

The procedure for predicting the degree of wind damage to individual buildings can also be applied to determine the relative significance or effect of each of the wind performance characteristics shown in Table 1 on building damage degree. For this purpose, a reference (or basic) building configuration is defined so as to approximate the characteristics of buildings that are routinely damaged in hurricanes. The characteristics of the basic building are listed in Table 7. The damage function of the basic building, BDD_i (basic), is then determined as previously outlined for an individual building. In determining the damage function for this purpose, the component cost factors, CCF_i [(1)] used were based on the average values of CCF_i for the 1–3 story low-rise buildings used in developing the building damage bands, as opposed to use of CCF_i for a particular building class.

The effect of each form of a wind performance parameter $P_i(\cdot)$ in Table 1 was then investigated by successively substituting each $P_i(\cdot)$ of Table 1 for the corresponding basic building parameter while leaving the other parameters of the basic building unchanged, and then determining the damage degree for the resulting configuration. For example, to investigate the effect of use of flat concrete tiles for roof covering, the only change to be made to the characteristics of the basic building in Table 7 is simply to replace asphalt shingles with flat concrete tiles. This procedure results in nine building configurations for the P1(·) alternatives, 8 for P2(·), 3 for P3(·), etc., for a total of 71 configurations. Comparison of the percent damage for each of the resulting configurations, BDD_i(configuration), with that furnished by the basic building, BDD_i(basic), enables the most significant wind performance parameters that affect building damage degree to be identified. The results are expressed in terms of maximum percent decrease in damage degree over the basic building maximum damage degree, i.e.

Percent reduction in damage degree =

$$\left[\frac{BDD_i(\text{basic}) - BDD_i(\text{configuration})}{BDD_i(\text{basic})}\right]100 \tag{7}$$

The more significant performance parameters based on a damage degree reduction due to a single performance parameter of at least 2% for performance parameters P1–P15, and 4% for parameters P16–P21, relative to that of the unmodified basic building are shown in Table 8. The higher cut-off value of 4% reduction in damage degree used for significance of the parameters P16–P21 was to compensate for the fact that the knowledge base associated with these parameters is not likely to be as reliable as those for P1–P15, and also to compensate for the ‘‘coarseness’’ of the alternatives of these parameters (these

TABLE 8. Significant Building Wind Performance Parameters

Parameter type $P_i(\cdot)$ (1)	Maximum percent reduction in damage degree (2)
P1-Roof covering	
Asbestos shingles, architectural metal roof	2.3
Slate roof, Clay tiles	3.2
Mechanically-attached single membrane roof	4.4
Ballasted single membrane roof	3.7
Flat concrete tiles	6.2
P3-Roof span	
>70 ft	−2.2[a]
P4-Roof sheathing	
Reinforced concrete	4.3
Precast concrete panels	3.5
P5-Roof structure	
Concrete	2.9
Steel beams	2.1
P6-Exterior wall system	
Brick veneer-wood frame	2.2
Stone veneer-wood frame	3.1
Solid brick	3.5
Reinforced Concrete block, solid Stone, and precast concrete panels	4.0
P7-Exterior door	
Solid-core wod	2.0
P8-Percent wall occupied by exterior doors and windows	
>50%	−2.2[a]
P15-Windows glass	
Fully tempered (FT), monolithic insulating (IG-FT/FT), monolithic (IG-HS/HS), and laminated glass (LG-FT/FT)	6.8
Heat strengthened, monolithic insulating (IG-AN/AN), and laminated glass (LG-HS/HS)	3.4
P17-Presence of skylight	−4.0[a]
P19-Absence of overhead door	5.4
P20-Absence of gravel or roof-mounted equipment on nearby buildings	4.0
P21-Presence of shutters on exterior doors and windows	15.8

[a] Negative values indicate options that contribute to an increase in damage relative to basic building.

parameters simply involve the presence or absence of a building feature).

The maximum change in damage degree was found to occur at a windspeed of about 51.4 m/s (115 mph), corresponding to the windspeed at which the difference in the damage degree of the upper and lower damage function is a maximum (Unanwa et al. 2000). The most significant wind performance parameters are summarized as follows: roof covering, roof sheathing, roof span, roof structure, exterior wall system, exterior door, percent wall occupied by exterior doors and windows, window glass type, presence of skylights and shutters on exterior doors and windows, and absence of overhead doors, and nearby debris sources such as gravel or roof-mounted equipment on nearby buildings. It is to be noted that parameters P3, P8, and P17 in Table 8 result in an increase in wind damage. For these parameters, wind damage reduction is effected by designing buildings with roof spans less than about 70 ft (P3), having no more than 50% of the wall envelope occupied by exterior doors and windows unless the doors and windows are adequately shuttered or otherwise sheltered (P8), and by not providing skylights in the roof envelopes of buildings. It is also seen from Table 8 that the single most significant performance parameter is provision of shutters to exterior doors and windows. The building components and features identified above can be used in desired combinations for wind damage reduction for new constructions and building upgrade purposes.

CONCLUSIONS

This paper has proposed a practical methodology within the existing wind damage database, for implementing wind damage prediction models for individual buildings and groups of buildings, using the damage band technique. A major advantage of the damage band concept is its ease of applicability to wind damage prediction of individual buildings, as illustrated by the example problem given in the paper. The damage prediction procedure is also quite robust, as it can be used to predict damage to any given building, provided the damage band for that type of building exists. While being useful in itself for setting insurance premiums and building selection for retrofitting, the individual building damage prediction capability provides an important tool for wind damage mitigation and also provides useful information for building design. Several building component types and features are identified for use in implementing a wind damage reduction program for new constructions and building selection for upgrade against wind damage.

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