Prevention and Response to Infrastructure Disasters: A Civil Engineer's Duty

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Introduction

A civil engineer's primary duty is to design, build, and maintain the nation's core infrastructure, which serves as a foundation to society [1]. The American Society of Civil Engineers (ASCE) Code of Ethics states that practicing engineers have an ethical responsibility to contribute safe designs that "protect and advance the health, safety, and welfare of the public" [2]. While it is important to advance infrastructure and develop innovative solutions, protecting the public from infrastructure disasters is a greater and more immediate responsibility. From the destruction of Pompeii from Mount Vesuvius in 79 AD to the southeastern states affected by Hurricane Helene in 2024, well-designed infrastructure has proven to fail in natural disasters throughout history. The threat of natural disasters is inescapable, and their frequency and severity will only increase with climate change. Additionally, man-made disasters are also out of a civil engineer's control, such as building fires and vehicle accidents. Both causes of disaster have a degree of inevitability, but this does not dismiss an engineer's obligation to mitigate their impacts and avoid future occurrences. Civil engineers hold the primary responsibility to protect the economic well-being and physical safety of the population from the risk of catastrophic damage caused by natural and man-made disasters. Patterns of infrastructure disaster alongside inherent ethical responsibility should undeniably rouse engineers to engage in preventative design, effectively respond to accidents, and examine the impacts of their decisions.

Prevention

One aspect of the protection of the public clause in the Code of Ethics is preventing infrastructure failures, loss of lives and resources. Ideally, innovation in preventative design would be prioritized over improving response efforts, as successful prevention would require less resources for disaster response. Recent infrastructure failures and their wide array of consequences should motivate engineers to avert the problem before it occurs, by implementing frequent maintenance, detailed assessments, as well as appropriate protections that anticipate natural and man-made disasters.

The first step to prevention is to assess the state of infrastructure and develop awareness of potential dangers. Prioritization is key given the sheer amount of built infrastructure. For instance, there are over 600,000 bridges in the US alone, so a prioritization system must be established for effective risk prevention. Additionally, assessment must consider not only the isolated condition of the infrastructure, but also its potential performance under expected and unexpected conditions. For example, the US Army Corp of Engineers regularly allocates risk allocations for their bridge portfolio and in 2019 they changed their risk categorization of the Mojave River Dam based on its expected need to perform in extreme flood events [3]. A timely assessment indicated that changes could be made to prevent catastrophic flooding in downstream communities. Assessment has limited value unless paired with repair, which is exactly what the Army Corp of Engineers plans to do. In January of 2023, they released a statement revising their master plan for the bridge to protect "natural and cultural resources…[and] the public" [4]. Assessment, maintenance, and redesign are difficult given our ever-changing understanding of natural disasters and those caused by climate change but are crucial for prevention.

Infrastructure disasters can also be avoided by implementing protections in the design process that account for weather events and accidents. This can be complex since there are numerous disaster causes, each with their own prevention needs, requiring a cost benefit tradeoff. It also becomes difficult when the probability of occurrences is low, so it is questionable if they necessitate preventive design. For example, three percent of bridge failures were caused by fire from 1980 to 2012 [5]. The recent I-95 bridge collapse, the result of a gasoline tanker truck crashing and catching fire, was a rare bridge fire disaster and caused significant costs for repair and traffic management. While events such as this are generally unlikely, they still create an ethical responsibility for engineers to prevent, especially if they have generally been ignored in the past. The Nature Communications Journal published a paper in 2024 that details strategies for analyzing fire damage and incorporating its risk into structural design, which is a step in the right direction of preventing accidents like the I-95 collapse [6]. Similarly, preventive design could have lessened the tragedy of the Francis Scott Key Bridge collapse, when six construction workers were killed after a massive ship container crashed into a pier. It was known that this bridge was susceptible to progressive collapse, meaning the failure of one element will likely result in failure of the structure [7]. A basic preventative measure in this situation could have been to retrofit the bridge's design, as it cannot perform safely under rare, yet catastrophic accidents. Furthermore, bridge protection redundancies, which have become more standard, such as dolphins and artificial islands protect piers and dissipate collision energy. Acknowledging the possibility of disaster and incorporating design redundancies would be an ethical decision that may reduce damage and save lives.

The other side of preventative design is focusing on climate resilient infrastructure which includes "projects to adapt traditional infrastructure systems assets to a changing climate" [8]. Given the effects of human-induced climate change that are already in action, civil engineers have a duty to account for inevitable weather events in their designs and construction. The country of Georgia, for instance, established a flood protection program in 2023 that produces hazard maps and plans for advanced drainage systems and flood defenses in anticipation of increased flooding [9]. This future oriented design essentially increases the safety factor to prevent rare, yet catastrophic failures. Similarly, the Resilient Florida Program, developed in 2021 to protect inland waterways and coastlines aims to design infrastructure with the key purpose of protecting coastal Florida communities from impending sea level rise [10]. Both comprehensive approaches are key examples of engineers above and beyond to design protections for critical infrastructure.

Response

While disaster prevention should be the primary focus, engineering response to infrastructure failure cannot be ignored given that catastrophes will still occur despite preventative design. Response efforts are especially critical for minimizing the economic impact of disasters, as the cost of planning and reconstruction time can be significant. Accelerated re-construction techniques are a key response, as seen in the 18-day overpass repair on I-580 in San Francisco following a gasoline tanker fire in 2022. Through the mobilization of 300 people, simultaneously designing and constructing as well as utilizing readily available materials, the contracting team was able to complete their job a month before the deadline, which accelerated economic recovery [11]. However, accelerated construction must be done without cutting corners. In San Franciso, although the design review process was sped up from weeks to 24 hours, thorough review still occurred and exhaustive tests were conducted to ensure the safety of the new concrete bridge deck [11]. Another aspect of response is to devote time and research to analyzing why disasters occur and safety measures forgotten in the design process. This includes forensic engineering, where an "accident investigation" and "failure analysis" are conducted to reveal the cause and mode of failure [12]. While a forensic engineer is typically involved in a failure site investigation, a research and development team are also necessary to fix the problem and complete an effective response. The International Association for Bridge and Structural Engineering, for instance, has a task group dedicated to furthering awareness of bridge fire consequences and plans to hold global educational webinars and publish a set of fire prevention guidelines for bridges [13]. These are a few examples of effective response, actions that fall under the ethical requirement of engineers. By accepting their ethical responsibility to uncover and fix the mistakes in structures, a civil engineer is able to uphold the code of ethics and protect the welfare of the public.

Additional Responsibilities

In addition to specific design efforts to prevent and respond to infrastructure disasters, there are other duties that a civil engineer holds when protecting the public from catastrophe. For instance, public sector investment is needed to improve the quality of prevention and response. Civil engineers must advocate for programs that maintain infrastructure and promote effective disaster response, as well as provide technical knowledge when necessary to support lawmakers. For example, ASCE advocated for and played a large role in the passing of the 2021 Bipartisan Infrastructure Law. [14]. This historic piece of legislation plans to repair infrastructure marked as "poor condition" and invest in protection against climate change across all 50 states over the next five years. This series of projects organized by the federal government with support from civil engineers has a unified front and will have a widespread positive impact, which demonstrates the effectiveness of civil engineers working alongside policy makers. Furthermore, preventive design includes sustainable design that attempts to minimize environmental impact during construction, in addition to increasing resiliency in response to climate change. One way engineers can act on this responsibility is by reducing construction and demolition waste which ends up in landfills. The solution is to adopt a circular economy, which optimizes the use of natural resources and prioritizes reusing construction materials [15]. Another possibility is utilizing materials that have low emissions, require less energy, and are durable, such as insulating smart-windows and self-healing concrete.

The corresponding impacts of options previously discussed must be considered, since civil engineers are responsible for equitable designs and providing safe construction environments. Designers must be cognizant of social inequalities created by selective green infrastructure implementation, which cause a divide between communities prepared for climate adaptation and those that will suffer extreme effects of the climate [16]. To put an end to green gentrification, engineers must include minority communities and, in some cases, even prioritize them over others when addressing infrastructure disaster. Another concern is the safety of the workers on construction sites, especially those involved in the maintenance or demolition of a structure. In October of 2024, a bridge in Mississippi unexpectantly collapsed while in the process of demolition, resulting in three deaths and four critical injuries [17]. This project was intended to improve public safety for those driving in the area, yet it caused harm during execution. Project leaders on site have an ethical duty to account for past, present, and future hazards, as to not ignore the protection of minority communities and employees.

Conclusion

A civil engineer should be compelled to advocate for and implement disaster resilient infrastructure under the code of ethics they agreed to, independent of past or recent accidents. While recent patterns of catastrophe draw attention to this responsibility, civil engineers must proactively make decisions to reduce injuries, death, and economic loss. Engineers do not operate in a vacuum, though, and external factors and mistakes can result in disaster. Many of the examples previously discussed illustrate how engineers can assume their ethical duty by designing preventive measures, efficiently responding to accidents, and practicing equitable and safe execution. While these ideas exemplify exceptional engineering and ethical behavior, they should become standard for every civil engineer. A highly ethical engineer isn't an exception and should not prompt a news article; it is the norm and sets the bar for future engineers to go above and beyond to serve and protect the public.

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