Risk and Reliability in Building Engineering and Design

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On June 24, 2021, the south portion of the Champlain Towers condominium building in Surfside, Florida, collapsed, killing 98 people. Following a 10-day rescue operation, the remainder of the building was demolished. In the months since this catastrophic failure, investigations into the cause of the collapse raised questions regarding multiple structural design deficiencies and long-term maintenance problems at the building. Several buildings of similar construction and vintage in the Miami area have been identified as being at risk of some structural failure.

Almost exactly four years prior to the Champlain Towers collapse—June 14, 2017—a fire at the Grenfell Tower in North Kensington, West London, resulted in the deaths of 72 people. More than 70 people were injured. As in the case of Champlain Towers, forensic analysis of the causative factors of the failure identified features of construction that are common to many similar structures. While the design flaws at Grenfell are generally prohibited under US codes, we are not immune in this country to large-scale fatal fires.

Building failures and the resultant loss of life have prompted changes in building construction regulations since the very first codes were written. The Code of Hammurabi, from 1,700 B.C.E., contained provisions for punishment of, or reparations by, a builder of a structure that fails. The Triangle Shirtwaist fire, which killed 146 textile workers in one of the worst loss-of-life incidents in the United States, led, in part, to the development of the Building Exits Code, a predecessor of the Life Safety Code. Building and fire codes are historically reactive documents. The cited failures are extreme cases, but less-catastrophic failures come at a cost as well.

As professional engineers, our highest responsibility is to uphold the public safety, health, and welfare. A clear expectation in meeting this responsibility is that we learn the lessons of past failures and avoid similar mistakes in our own area of expertise. But is learning the lesson and reactively changing our standard details or specifications to close technical gaps sufficient? What are our responsibilities beyond meeting the base technical requirements of a building code or design standard? When and how should we focus on the question of risk, and how can we incorporate into our daily practice a way of thinking that produces better outcomes? What are our ethical obligations in this area?

These are difficult questions to answer in an environment where many decisions are influenced by capital investment and return on such investment. While some building owners are forward-thinking and interested in achieving best-value, others may be skeptical and resistant to incurring additional expense even if it mitigates some risk to their operations. If we want to make a case for a higher level of performance, how best can we do this? There are many analytical tools at our disposal that can aid us in establishing a framework for discussion with owners and other stakeholders when we seek to go beyond mere code compliance. One such method can be found in performance-based design.

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In the discipline of fire protection engineering, performance-based approaches are often implemented when there are scenarios that prescriptive codes do not adequately address. At the beginning of the analysis/design process, we seek to establish fire safety goals and objectives that reflect an owner's values and risk tolerance. These goals and objectives are often couched in terms of life safety, property protection, and continuity of operations. The goals are high level statements, e.g., "The maximum allowable downtime for this data center is 24 hours." Objectives are more measurable and can be translated to performance metrics, e.g., "A fire in a data rack must be limited to the rack of origin."

Inevitably, the discussion comes around to issues of uncertainty and risk. A basic definition of risk is provided by William D. Rowe in *An Anatomy of Risk*: "Risk is the potential for realization of unwanted, negative consequences of an event." In purely mathematical terms, risk is often defined as the product of an event probability and its consequences. That is,

RISK = Probability of (Event) x Consequences of (Event).

As engineers, dealing with uncertainty is a daily occurrence. We must often make decisions without all of the pertinent information or without solid data on probabilities of equipment failure. In fact, due to the lack of reliable data of event probabilities, pure risk calculations are seldom carried out in routine building design. Such analyses are generally limited to areas of engineering analysis and systems design where such data is essential and has been collected for this purpose. Predicting the severity of consequences of an event is equally challenging.

This does not mean that we cannot or should not apply the concepts of risk and risk mitigation in a qualitative way. A risk matrix, like the one below, is one tool that we can use to frame the discussion. There are variations of this matrix that can be used, including in the International Code Council's Performance Code for Buildings and Facilities. Depending on the stated goals and objectives, the risk matrix may be used to organize the analysis to focus on events or scenarios that are most likely to threaten our goals.

In the data center example, due to the current material supply environment, it may be the case that a much lower level of potential damage can be tolerated because the lead time on replacement circuit boards is too long. This means that we need to detect potential problems when they are much smaller but might also lead an owner to seek other risk mitigation measures to protect data.

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Risk Value Matrix

CONSEQUENCES

PROBABILITY OF EVENT P(1)

	LOW DAMAGE OR LOSS	LOW MODERATE DAMAGE OR LOSS	MODERATE DAMAGE OR LOSS	HIGH DAMAGE OR LOSS	VERY HIGH DAMAGE OR LOSS
VERY HIGH	4	3	1	1	1
HIGH	4	3	2	1	1
MODERATE	4	4	2	2	1
LOW	5	4	3	3	3
VERY LOW	5	5	4	4	4

As engineers, our focus will be on control of risk through design; however, we must always be mindful when dealing with complex, integrated systems that inspection, testing, and maintenance, and regulatory control will affect the reliability of a system over time. In environments where regulatory control is lax or where it is known that ITM is substandard, a more complex solution may not be the best approach. For this reason, a full understanding of the system components, their interconnectedness, and the ways in which these contribute to the system's success or failure is necessary.

Other analytical tools such as fault trees, success trees, and what-if analyses are available to assist us in structuring our thought process and fully describing the necessary components to achieve a reliable solution to meeting goals. An example is the Fire Safety Concepts Tree (National Fire Protection Association Guide 550), which is a structured way of understanding the various mitigation methods that can be used to achieve stated fire safety objectives. Similar tools are available for other disciplines.

Engineers are creative, and creativity involves failure. Catastrophic events aside, there are risks of negative outcomes in every engineering endeavor. Rare would be the engineer who never experiences failure of some magnitude in a building or system of their design. Mitigating the risks in meeting our professional obligations to society should be a part of our daily practice. By developing a mindset that routinely considers issues of risk and reliability in achieving our clients' goals, perhaps we can increase the probability of long-term success.

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