Risk-Based Design

By Jon A. Schmidt, P.E., SECB, BSCP

Risk management is a popular topic in structural engineering circles these days — including this magazine — usually in the context of reducing the liability of firms and individuals from a business and professional practice standpoint. However, risk management is also potentially relevant to the technical aspects of structural engineering, especially in an age of terrorism.

For more than a decade now, Sandia National Laboratories has had a program in place called Architectural Surety® that advocates a risk-based approach to building design. Its foundation is the identification of three types of hazards to which a structure may be subjected:

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- Normal hazards are those that occur on a regular or ongoing basis. Examples include dead, live, hydrostatic, snow, rain, and ice loads. Owners generally expect their structures to experience ordinary wear and tear under theseconditions, but to remain reliable.
- Abnormal hazards are those that are unusual but naturally occurring. Examples include wind and earthquake loads. Owners generally expect their structures to experience some or perhaps even considerable damage under these conditions, but to remain safe.
- Malevolent hazards are those that occur only as a result of deliberate human action. Examples include sabotage, crime, terrorism, and war. Owners generally do not expect their structures ever to experience these conditions, but to remain secure.

Building codes traditionally specify the minimum loads due to normal and abnormal hazards for which a structure must be designed. These loads are based on years of successful practice, as well as probabilistic assessments of naturally occurring events that are normalized to a particular recurrence interval, usually 50 years. The designer then accounts for various combinations of loads associated with multiple hazards by applying a factor to each that is grounded in the conditional probabilities of their simultaneous occurrence.

Seismic design has become an exception to this traditional procedure. It is now recognized that a 50-year earthquake is not an appropriate design basis. Instead, a less likely earthquake of higher magnitude is used, but then reduced to provide equivalent static loads, even though the actual structure is expected to experience significant dynamic effects, including permanent deformation. Occupancy dictates whether and how much special detailing is required to ensure such ductile behavior. An irregular or otherwise complex structure requires an analysis that explicitly accounts for dynamic effects and/or ductile behavior.

This method is called "performance-based design" because the code requirements are associated with three specific performance levels: immediate occupancy, life safety, and collapse avoidance. The magnitude of earthquake for which a structure must comply with each of these performance levels is tied to its occupancy; a hospital, for example, is subject to stricter requirements than an office building. Although often touted as superior to prescriptive codes, performance-based design is itself still inherently prescriptive.

The next phase in the evolution of structural engineering could involve the explicit consideration of risk. Loads and damage levels associated with different hazards would be calibrated to provide a relatively uniform level of acceptable risk based on the nature, quantity, function, and importance of the building's occupants and contents. Analysis of structural systems would inform the design of their individual components.

Risk is traditionally defined as the product of an event's probability and its severity, often categorized qualitatively based on orders of magnitude of both likelihood and consequences; for example, very low, low, medium, and high. The result is something called the risk matrix, in which each cell represents a particular combination of probability and severity, and thus a particular level of risk. The amount of risk that is acceptable depends on specific code requirements and the engineer's professional judgment. Structures would be designed such that their performance corresponds to a cell of the matrix that has a risk value less than an appropriate maximum.

Performance-based seismic design is actually grounded in just such a matrix, but the risk levels are hidden within the code provisions, limiting the amount of judgment that the engineer can exercise. In particular, codes provide no mechanism by which the designer can verify that the loads due to all relevant hazards are properly calibrated to provide an approximately uniform level of risk.

Antiterrorism considerations strongly suggest the need for risk-based design in structural engineering. The probability and severity of an intentional attack are not scientifically quantifiable; at best, an educated guess can be made on the basis of appropriate threat, vulnerability, and criticality assessments that establish a reasonable load magnitude and minimum level of protection.

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A prescriptive approach is by no means appropriate for a hazard that has such a low likelihood, even for structures that are considered to be the most attractive targets. Explicit consideration of risk seems to offer the basis for a more rational engineering solution. If this is appropriate for a situation that is inherently unpredictable, would it not also make sense for more commonly encountered conditions?▪

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