Acceptable Risk for Progressive Collapse

How Safe Is Safe Enough?

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Though engineers recognize that there is nothing like perfect safety, stipulating risk criteria has often prompted controversy. This is not surprising, since the specification of acceptable risk requires crossing the boundary between the elegant technical world of risk assessment into the far rougher realm of subjective value judgments.

Such discord was evident when members voted down the proposed progressive collapse (PC) resistance provisions in recent International Code Council (ICC) meetings. The changes were vigorously opposed by building owners, architects and many professional organizations, including NCSEA and SEI. The ICC members were concerned about the ambiguous definition of PC, the amorphous nature of the threat to be protected against and inadequate guidance for acceptable performance. Specifically, the requirements for enhanced structural integrity reignited an old debate about cost-effectiveness, with the inevitable follow-up question, "*How safe is safe enough?*" A strategy to resolve this dilemma is proposed here.

The Nature of the Threat

The specification of PC risk criteria faces significant challenges stemming from a hazy understanding of the phenomenon, muddled nomenclature in current usage and the lack of an acceptable performance measure for structural integrity. To begin with, describing any building collapse with the prefix *progressive* seems superfluous, since most structural failures do occur in stages and are progressive to some degree; the effects of earlier stages are necessary to make subsequent stages possible. A perusal of various structural codes and design guidelines shows that there is no unique and commonly accepted definition of what PC really represents.

In fact, the term seems to have been used interchangeably to represent two very distinct failure types. After the Ronan Point incident, PC was coined to represent a domino-style disproportionate failure from a propagating chain reaction, starting with minor initial damage. The phenomenon attracted outsized attention due to the apprehension of lurking danger in existing structures designed by member-based codes and trepidation that the rules for structural system assembly may not be properly understood. Such failures (Type I PC) are a consequence of inadequate system capacity due to deficiency in robustness; i.e., the poor quality of the structural configuration.

More recent usage for dramatic collapses from substantive malevolent intentional acts, such as the Murrah Federal Building or the World Trade Center, has created ambiguity. These failures (Type II PC) resulted from the catastrophic nature of the threat magnitude, simultaneously imposing loads on more than one structural member substantially larger than assumed in their design. Thus the consequences were certainly not disproportionate to the applied abnormal loads.

Even though the structural system consequences may be similar, grouping these different failure types under the generic rubric of PC is clearly not in consonance with the original definition. However, irrespective of the PC type, it remains clear that the causative agent will always remain a "black swan" and can include all types of potential triggering circumstances.

Designing For Black Swans

Black swans are unexpected and unlikely, but not impossible, events that can lead to serious safety consequences for structures. Because the exact nature of an event that might impair a structural system is unknown, specifying a particular threat or designing structures for arbitrary abnormal loads adds cost without addressing the real issue. The problem is not one of inadequate system reliability but of deficient system robustness, which modern codes do not consider in structural design. For PC, the focus needs to shift from extreme loading scenarios to coping with unexpected demands. The consequence-based structural design (CBSD) approach for black swan events provides a capacity-oriented design strategy that leverages system characteristics to optimize robustness and structural integrity.

In the primary stage, the structure is designed as usual in accordance with the current probabilistic member-based code provisions for normal loads, providing appropriate minimum joint resistance, continuity and inter-member ties. Thereafter, a numerical performance measure for structural integrity is used to develop consequence factors that determine the member contributions towards system response. Applying CBSD, structural members are designed with due accounting of their contribution to adverse system response. The aim is to achieve high structural system integrity, whatever the unforeseen causal event.

Risk Acceptance Philosophy

A complete lack of event, likelihood and demand data makes it infeasible to assign absolute risk criteria for PC failures, and it is prudent to desist from prescribing arbitrary requirements for the unknowable. As design for black swans is only a secondary step, a possible alternative is moving system risk acceptability towards the common law approach of demonstrating due diligence using the concept of "as low as reasonably practicable" (ALARP). ALARP represents the "best practice" engineering judgment that provides a reasonable balance between risk and benefit, given prevailing constraints. ALARP means that the cost involved in further reducing the risk would be grossly disproportionate to the benefit.

This philosophy is in line with common sense engineering practice that has worked successfully throughout history. One does not have to know the absolute risk, but can still be confident that the design is as safe as can be. The concept is flexible enough to accommodate individual or societal risk. At most, structural codes could specify domains of "definitely acceptable" and "definitely not acceptable" risk regions and let the designer choose the appropriate ALARP point between these boundaries.

The CBSD approach is ideally suited for the application of the ALARP principle. The member-based structural design provides buildings with some level of inherent structural integrity which CBSD augments by selectively upgrading vulnerable members or sequences of members to prevent PC. Following ALARP, how far down the chain of members to upgrade is solely at the discretion of designer. Code provisions for PC should only provide safety guidance; how much risk to accept in a structural system design should be the exclusive prerogative of the designer.▪

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Further Reading

Nafday, Avinash M. "Consequence Based Structural Design Approach for Black Swan Events." *Structural Safety*, Vol. 33, Issue 1, January 2011.
