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PRIMER

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When an unexpected structural failure occurs, building owners imagine similar catastrophic events happening to their structures

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Reacting Rationally to Unexpected Structural Failures

In the wake of any catastrophic, high-profile structural collapse, we often witness an intense and emotional response by those responsible for other structures to promptly take some action in an attempt to provide reassurance that their structures are reliable.

While this primer is intended primarily to provide an engineering perspective to help building owners and property managers make informed and rational decisions regarding their own structures while under substantial pressures, building officials, government agencies, and legislators may also find it helpful.

When an unexpected structural failure occurs, building owners and property managers often face significant pressure to "do something" as they—along with their clients/tenants—imagine similar catastrophic events happening to their structures. While these pressures may demand a response (and sometimes actions) to address very real emotions, it can be highly advantageous to utilize objective sources of subject matter expertise to facilitate rational responses and actions. Specifically, a decision maker may benefit greatly by learning about structural reliability in general and the extent—if any—to which information gleaned from the recent failure relates to their structure(s). With this background education, decisions will be much more rational, and owners will be less prone to letting emotions lead to costly actions that are potentially ineffective, unnecessary, or overly invasive.

Fundamental Concepts

Understanding these basic concepts should help an owner make an informed decision about what actions, if any, they should take.

Limited Relevance

When the circumstances of a failure have not been identified (i.e., the failure has yet to be explained), the only thing it teaches us is that structures can fail, which we knew before the failure occurred. Even after the factors contributing to a specific failure are understood, the failure often teaches us little to nothing about a different structure.

Safe vs Safe Enough

"Safe" in the popular vernacular is often used as a binary term (i.e., something is either safe or not safe). However, "safe" in the engineering vernacular is only relative (i.e., something poses less risk than some defining benchmark of safety) and a basis of comparison is needed. In other words, "safe" is not like a light switch that is either "on" or "off." Rather, it represents a position on a continuum of relative safety. The word "safe", like the word "cold", represents less of something (i.e., risk and heat, respectively) than some baseline of comparison. For engineering and architectural applications, the basis of comparison for "safe" could be another structure, or an abstract benchmark such as that represented by the provisions contained in a building code. There are an infinite number of possible comparative bases, which means there are an infinite number of possible definitions of "safe." In most cases, when we are asking if a structure is "safe" we are asking if a structure is "safe enough", or in other words, does a structure have the structural reliability we expect of other legally occupied structures in the same locality.

Unfortunately, "safe" is often used by architects and engineers either without a basis of comparison, or with an inappropriate basis. Such misuse often leads to misunderstandings, misdiagnoses, illogical recommendations, and other problems associated with the evaluation and characterization of structures. Therefore, be cautious of uses of the word "safe" that don't have an associated basis of comparison to give it meaning.

Structural Reliability

Designing and constructing an absolutely safe structure would be unattainable, and even getting close would be cost prohibitive. Building codes around the world inherently define what is considered "safe enough" by prescribing minimum requirements that establish threshold levels of acceptable risk that demand will exceed capacity resulting in structural failure. Thus, even code-compliant structures that are inherently defined as "safe" still have some—albeit very small—risk of failure. This approach of using relative reliability to characterize design and construction must also be employed when evaluating an existing building and when considering what, if anything, might be done to make it more reliable (i.e., safer).

As a practical matter, history has proven that only a very small fraction of structural elements fail spontaneously while in use, which means that very few structures contain critical structural problems. So, looking for them in a currently serviceable and reasonably maintained structure would be like looking in a haystack for a needle that probably isn't there. This is an important notion to understand when seeking some level of assurance that a structure is "safe." Evaluating a particular structure for significant unspecified deficiencies is work that involves a wide range of possible scopes and a similarly wide range in confidence in the results. If an owner wishes to pursue such an evaluation, they need to decide what combination of scope and confidence will suffice.

Aspects of Structural Reliability

There are three primary aspects to structural reliability: design, construction, and maintenance. In-service modifications to the usage and loading of the structure that deviate from the original design intent can be categorized in all three aspects. Defective products or materials would be categorized with construction.

Common design, construction, and maintenance practices in the United States and many other countries have resulted in extremely reliable constructed facilities. This is why buildings, bridges, and other structures that have been designed, constructed, and maintained via typical engineering methods so rarely fail, and this rarity contributes significantly to the shock and emotion that occur in the wake of such failures.

Structures in the United States are so reliable that they are typically not given "general" structural check-ups, other than those mandated by applicable authorities (e.g., periodic inspections of many bridges). Further, even when general check-ups are required, the scopes of such check-ups often address only a small fraction of potential structural problems, and yet the reliability of structures remains very high.

High reliability does not mean zero risk. Even in highly reliable populations of structures, structural elements sometimes fail unexpectedly. In the wake of such a failure, it is wise to learn why it occurred and, if applicable, use this information to better understand other structures. Fortunately, most major structural failures are due to relatively unique combinations of factors/events and, as such, provide little or no basis for questioning the integrities of other structures. For example, if a building failure is due to an error by the design team, the likelihood of any particular structure being similarly affected is not significant unless, perhaps, it was designed by the same entity.

In terms of deterioration, distress, or performance irregularities that contributed to a specific collapse, it is difficult to establish similarities with other structures. Owners of structures should be paying attention to such issues whether or not they learn of recent failures and should understand the significance of damage and performance irregularities in their building whether or not another building recently collapsed.

If a defective product (e.g., standard precast concrete element, manufactured joist, proprietary connection) contributed to a failure, concern about structures with similar elements would usually be justified. Again, this only applies once problems with the product have been identified.

Confidence

An unexplained failure of a structure should not adversely affect people's confidence in other structures. This is why people, including structural engineers, continue to drive over bridges, stay in hotels, and work in office buildings even after such structures sustain yet-to-be-explained failures. However, news of a failure may justifiably cause owners who have not taken reasonable measures to maintain their structures to question their reliabilities and inspire actions to understand and, if necessary, address existing conditions.

Most owners reacting to a recent failure without specific knowledge of any problems would cite a loss of confidence by themselves or others (e.g., tenants, lenders, insurers) as the reason for seeking help. Therefore, let's examine the reasons to have confidence in structures and differentiate between sound and unsound reasons for reduced confidence.

Confidence in Design

Reasons for having confidence in a building's design include the following:		Does a single, unexpected failure of another structure affect these reasons?
Belief that the design team was conscientious and competent	▶	**No;** Provided the design team was not the same
Belief that the design team used appropriate standards	▶	**No;** Unless the standards were the same and history has shown them to promote significant structural problems[1]
Independent review of the design team's work	▶	**No;** Unless the owner relied on a reviewer who also reviewed the failed building
The infrequency of design-related structural failures	▶	**No;** Because one failure does not materially affect the frequency of structural failures

So, unless the owner relied on professionals who may have contributed to or overlooked problems with the failed structure, or the owner learned that their structure may have been adversely affected by problematic standards, the failure should not undermine confidence in the design.

Confidence in Construction

Reasons for having confidence in a building's construction include the following:		Does a single, unexpected failure of another structure affect these reasons?
Belief than the construction team was conscientious and competent in its execution of the design	▶	**No;** Provided the construction team was not the same
Independent review of construction (comparison of as-built conditions to design intent)	▶	**No;** Provided the construction reviewer was not the same
The infrequency of construction-related structural failures	▶	**No;** Because one failure does not materially affect the frequency of structural failures

Barring knowledge that a building was constructed and the construction reviewed by the entities responsible for the failed structure, confidence in its construction should not be affected.

[1] Arguably, these situations are already known but an owner may not learn of them until a particular failure occurs. But, even in such cases, owners are rarely required to evaluate or retrofit their structures.

Confidence in Maintenance

Reasons for having confidence in a building's maintenance include the following:	Does a single, unexpected failure of another structure affect these reasons?
Belief that the responsible parties have been conscientious and competent in their obligation to maintain a properly designed and constructed structure ▶	It may cause the owner to question their approach to maintenance
A lack of detectable evidence of significant structural degradation or performance irregularities ▶	It may make the owner or others more cognizant of and concerned about possible signs of degradation or performance issues (i.e., conditions are noticed that previously went unnoticed)
The infrequency of maintenance-related structural failures ▶	**No;** Because one failure does not materially affect the frequency of structural failures

If an owner has been attentive to maintenance, they should have reasonable knowledge of the condition of their structure, making irrelevant the condition of any other structure.

Barring an intended modification, the only thing about a structure that can change with the passage of time is its condition… the quality of the original design and construction remains constant. Consequently, maintenance is the primary factor that determines the actual extent to which the reliability of a structure changes over time.

The Rational Effect of an Unexpected Structural Failure on Confidence

If an owner knows of no significant structural design or construction deficiencies and is confident that their structure has been reasonably maintained, the fact that another building failed provides no rational basis for losing confidence in their structure, regardless of how catastrophic and/or high profile that collapse was. However, if the investigation of the unexpected failure indicates that there were contributing factors that could affect other structures (e.g., a defective product used in multiple buildings), then owners of buildings with those similarities should investigate the matter.

Determining a Rational Structural Evaluation Scope for My Building

For decision makers looking to determine what action should be taken regarding their structure(s) in the wake of an unexpected structural failure, the answer of what to do is an unsatisfying "it depends." As discussed above, an uninvestigated structural failure will tell us nothing about another structure, and in most cases, a fully investigated failure will identify nothing substantially relevant to the majority of other facilities. Accordingly, in most situations a rational reaction would be to take no action and do nothing beyond continuing to maintain one's structure(s). Despite this, owners and decision makers often still wish to perform some form of structural evaluation of their building(s) as a mechanism to restore their lost confidence in their structure's reliability, often accompanied by an emotional sense of urgency.

When considering voluntary courses of action, an owner needs to weigh the costs and benefits of various scopes of evaluation and decide which works best for them. Just as a doctor should inform a patient as to available treatment options (including doing nothing), their relative medical pros and cons, and then let the informed patient decide what is best for them (rather than dictating a specific approach), a structural engineer should inform an owner as to the range of available evaluation scopes, their costs and relative engineering pros and cons, so that the owner can make an informed decision as to what is best for them. While engineers can advise the owner on engineering-related costs and benefits, the owner must also consider a variety of non-engineering factors (e.g., other potential uses of limited funds, effects of disruptions, public relations) that influence the selection process.

Evaluations of specific factors that contributed to another collapse can be relatively focused, defined by the nature of the contributing factor. However, when the owner's concern is general and unspecified, the breadth, depth, and combinations of available scopes of evaluation is infinite. The degree of certainty to which an engineer has confirmed the structural reliability of an existing structure depends on the depth and invasiveness (cost) of the evaluation being performed. In most cases, there are diminishing margins of return with respect to increased confidence relative to cost. In other words, at some point, it takes substantial additional effort and cost to become only slightly more confident in the reliability of the structure.

Evaluating General Design Concerns

The scope of a design review can vary from a simple check of the applicable codes and standards to a detailed review of every structural element.

- Confirming that the appropriate codes and standards were utilized would be relatively inexpensive and would reveal information about the type and vintage of construction.
- Checking the design of every structural element would provide high confidence that significant design deficiencies, if any, were identified. However, the cost of such an effort would be comparable to the original design cost.
- Between the extremes is a continuum of possible scopes involving evaluation of "selected" items, with the cost and confidence in the results commensurate to the extent of the items selected.

Evaluating General Construction Concerns

The scope of a construction review can vary from a simple check of some readily accessible features (e.g., locations and dimensions of exposed and readily accessible structural elements) to exposure and documentation of every detail, including elements embedded in concrete or buried in soil.

- Checking a few readily accessible elements would provide data—with reasonable engineering certainty—on the conformance of those few elements with the design intent and, possibly, allow reasonable inferences about as-built conditions in other locations.
- Conducting a truly comprehensive assessment would require wholesale dismantling of the entire structure. The resulting reconstruction of the structure would then be subject to construction conformance concerns, requiring either meticulous documentation during reconstruction or wholesale dismantling again.
- Between the extremes is a continuum of possible scopes involving evaluation (by analysis or load testing) of "selected" items, with the cost and confidence in the results commensurate to the extent of the items selected.

Evaluating General Maintenance Concerns

The scope of a maintenance review (i.e., a relative condition assessment) can vary from a simple check of some exposed and readily accessible structural elements to uncovering, examining, and documenting the condition of every structural element, including elements embedded in concrete or buried in soil.

- Checking a few readily accessible elements would provide data—with reasonable engineering certainty—on their condition and, possibly, allow reasonable inferences about conditions in other locations.
- Similar to a comprehensive construction conformance assessment, a truly comprehensive condition assessment would be prohibitively expensive and disruptive.
- Between the extremes is a continuum of possible scopes involving evaluation of "selected" items and use of various condition assessment methods to mitigate the need for destructive measures, with the cost and confidence in the results commensurate to the nature and extent of evaluation.

One Common Approach

Even though a structural evaluation may not be needed at all from a purely rational standpoint, if one is performed, the scope of such an evaluation should be selected by a well-informed owner/decision maker (as discussed above). One approach that is commonly selected by building owners and decision makers to address general concerns is a phased approach. This allows an owner to take small steps until they are satisfied, while it also allows the work from one phase to inform the development of the next. Examining specific tasks that might comprise these phases is beyond the scope of this document, but a skilled and experienced professional can help a building owner determine what scope of evaluation—if any—is most appropriate.

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