Beyond Failure…

A Look at the "How" and the "Why" When Structures Fail

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Many structural engineers never encounter a structural failure in their career. This is probably good! These engineers might logically conclude that "real" failures are limited to major seismic events or the latest round of hurricanes. And thankfully, the performance of engineered buildings in these events has been reasonably good, not withstanding the widespread damage to cladding, windows, roofing systems, and other non-structural components. Generally, building structural systems do not collapse in well-designed buildings.

Building Failures are Common

Yet, building failures are more common than most engineers realize. The authors have had the opportunity to investigate dozens of building failures in their careers. These failures were normally the result of a gravity loading condition, usually a snow event, but also included thunderstorms, fire, and lateral pressures from commodities.

Failed corporate jet hanger

Excluded from this discussion are hurricanes, tornadoes and earthquakes. It is the observation of the authors that failures in hurricanes and tornadoes are often not investigated from a structural perspective. The insurance industry, the media, and the public are often very willing to accept the catastrophic nature of violent storms, despite the fact that many structures should have performed better. Earthquake damage is also not covered in this article, since seismic events represent very unique conditions and are covered in many other sources.

This article covers routine, common structures that are not complex. Yet these simple, common buildings failed catastrophically under storm events and other conditions that were adequately predicted by building code loadings and specifications. *So why did they fail and what went wrong?*

Example cases are limited to those with extensive structural damage and usually complete failure. Specifically excluded from this discussion are structures with serviceability problems. Such issues as vibration, masonry cracking due to lateral drifts, and excessive crane system wear and tear are failures in owners' minds. These are failures to perform their intended function, but they are not collapses.

The Failure Examples

This article is based on a presentation the authors have made for professional groups. The presentation covered seven different building failures in considerable detail. It is impractical in this article to cover each failure in any technical detail, and in some cases legal disclosure agreements prevail. Therefore, only general observations are discussed; but, in no way does this alter the themes and conclusions offered.

What became obvious when developing the presentation was not so much the technical issues with each failure, but the design and construction process problems that came to light. The forensic issues were relatively easy to determine, but *how* and *why* problems occurred were much more difficult to explain.

A brief review of the projects discussed in the presentation shows the following. Six of the seven used pre-engineered metal buildings (PEMB), and one was a concrete tilt-up structure. Some of the structures were quite large, up to 113 feet in height and 100,000 square feet in plan. Fires that occurred during failure heavily damaged two buildings, and it is not uncommon for fire to be a secondary problem. Snow loads were involved in four of the failures, although all loads were within code prescribed limits. Wind was involved in one failure, but the load was also within code limits. One building failed during construction, but the others had been in place for years.

Rigid frames in failed corporate jet hanger

A quick summary of the failure mechanisms and damages on each of the seven buildings shows:

Building One

This large PEMB structure failed due to incorrect application of wind loads. Over $7 million in damages resulted.

Building Two

This small PEMB truck garage failed catastrophically due to incorrect assumptions regarding the stiffness of the column lateral brace. This resulted in $3.5 million of damage.

Truck garage during demolition

Building Three

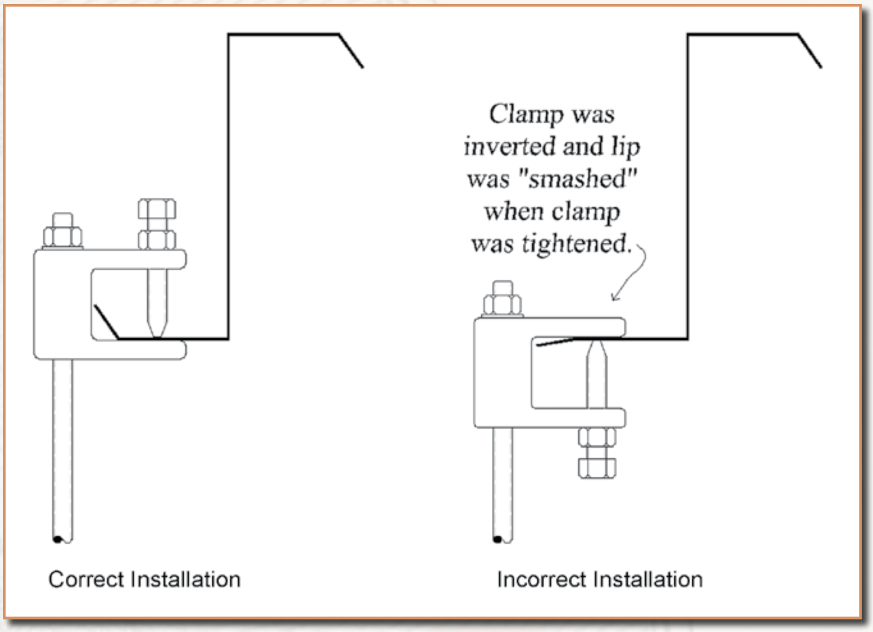
This small PEMB failed catastrophically due to extensive damage to cold-formed purlin stiffening lips caused by incorrect sprinkler clamp installation. This also resulted in $3.5 million of damage.

Building Four

This large PEMB stored toxic material. A minor failure occurred, which set off a chain of events that led to a serious fire and major environmental clean-up. The initial failure was an under-designed cold-formed purlin supporting a sprinkler main located in a snow drift area. The collapse of the purlin rendered the sprinkler system non-functional and also simultaneously initiated a fire. Total damages were over $32 million.

Building Five

This moderate size PEMB suffered severe structural damage due to a flash fire in the blanket insulation system. Over $2 million in damage resulted.



Correct versus incorrect hanger clamp installation

Building Six

This small PEMB corporate aircraft hangar failed due to the widespread omission of compression flange bracing by the erector. This resulted in over $12 million of damages.

Building Seven

This small tilt-up concrete structure suddenly failed during construction due to winds from a thunderstorm. Investigations later showed an incorrect temporary wall brace was sent to the jobsite. About $250,000 in damage occurred, but fortunately no one was injured.

Failure Theme One – The SER Problem

For any discussion of failures to be useful to the structural engineering community, some overall sense must be made of the failures. It is not enough just to explain the structural-mechanical events of the failure. It is quite clear to the authors that the common theme of most failures in routine structures is a breakdown in the design and construction process. It is usually due to a decision by an owner, architect, or construction manager to shortcut traditional roles and responsibilities. This has usually meant the omission of the role of the structural engineer of record (SER) and the lack of the "check and balance" role provided by the SER.

The omission of the SER is usually coupled with several other decisions. The most common of these is to use a pre-engineered structure of some type, usually a metal building. Other common pre-engineered components are plated wood trusses and steel joists. Many owners, architects, and construction managers, and perhaps even some structural engineers, seem to think that these industries act as their own "SER". At best, they serve as delegated design professionals acting under the supervision of the SER….or at least in theory!

The reality is that, for most of the failures investigated by these authors, there was *no* SER. Another reality is that the sales forces of the pre-engineered structure companies often sell their wares on the basis of replacing the need for the structural engineer. This has been a very appealing cost reduction for many owners, architects and contractors. The structural engineering community has done very little to counter this trend and explain the value of the SER.

Failure Theme Two – No Quality Control Process

The trend in the authors' structural engineering careers has been for engineers to avoid the jobsite at all costs. This trend is a result of liability concerns to be sure, but in several of the failures even the most basic framing inspection should have revealed the missing components, like flange braces. Please note that of all of the pre-engineered systems mentioned, none of these suppliers will inspect the completed buildings and take responsibility. They do not regularly visit job sites. Only the SER can perform this function.

Another key function not performed by supplier companies is the review of shop drawings. The design community has recognized the coordination of shop drawings as absolutely critical to successful construction, yet on common structures it is routinely omitted. Only the SER can perform this function.

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Building Failure	SER	Site Observation	Special Inspections	Design Review
1	No	No	No	No
2	No	No	No	No
3	No	No	No	No
4	No	No	No	No
5	No	No	No	No
6	No	No	No	No
7	Yes	Yes	Yes	Yes

Quality assurance summary of seven building failures

Failure Theme Three – Lack of Building Code Enforcement

In the heavily developed parts of the United States, building codes are routinely mandated and enforced. In some cases this includes very effective special inspection procedures. However, in many portions of the country, if there is an adopted code at all, it is not rigorously enforced. In the case of all of the failures discussed in this article, building code enforcement was lax.

This leaves the owner in a very dangerous position of "assuming" all is correct with the building. No one is looking after the owner's interests. Only the SER can properly recommend loadings and serviceability criteria, and perform the quality control functions, even if pre-engineered products are used.

Failure Theme Four – The Design-Build Process

The authors are strong proponents of the design-build method of construction delivery. Yet, all of the failures discussed used design-build as the delivery method. Design-build is the preferred method of construction on most private work and some public work. An investigation of this issue leads to a question: Is the problem design-build as some engineers might maintain, or is it the lack of a strong engineer on the design build team? The authors strongly feel it is the latter. *Structural engineers have been minimized in the emergence of design-build, and they must reclaim their proper role in the design-build process.*

Conclusions

This article strongly endorses the role of the SER as the owner's only assurance that the proper structure, both in technical terms and in functional terms, is designed and constructed. Such a role would have prevented most of the failures discussed, and avoided over $55 million of direct economic loss. The structural engineer must be able to justify his or her value to the owner and to the construction team, as well as maintain his or her commitment to public safety.▪

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