Failure Trends

Studying Typical Patterns in Building Failures

By M. Kevin Parfitt, P.E.

Most structural engineers have investigated or designed a fix for at least one structural failure during their careers. Others who work for firms specializing in forensics are exposed to failure issues on a more regular basis, as they assist their clients in restoring damaged or deficient structures. All engineers, from the novice to the experienced, can learn from the study of building failures.

Some would argue that structural failures are rare and happen very infrequently. If we are considering severe or total collapse as the definition of failure, then fortunately the total number of structural failures is small, at least when compared to the total number of buildings and related structures constructed each year. In reality, however, structural-related failure is much more common than many individuals realize. During the time period that the preparation of this article was taking place, it was reported that as of the one year anniversary of Hurricane Katrina, thousands of residential and commercial buildings were not yet rebuilt or restored in the gulf coast area; the National Institute of Standards and Technology (NIST) recently completed and released a report on the Elks Lodge Building collapse in Clinton, Missouri; a wrongful death suit had just been filed related to the collapse of a concrete ceiling tile onto a motorist in one of the Boston Big Dig tunnels; a nine story building in Pakistan damaged from an earthquake last year collapsed, trapping fifteen people; and a partial roof collapse occurred at a grocery store in Colorado due to a severe thunderstorm.

If you include the broader definition of failure as "any system or component that does not perform as intended," the number of failures quickly multiplies in performance-related categories such as floor vibration, excessive deflections, water penetration issues related to building facades and roofs, improper bracing and shoring during construction, and building damage and deterioration from age and lack of maintenance in both newer and historic buildings.

Identifying Failure Patterns and Trends

The advantage of going beyond a simple exposure to failures by making an effort to study them in detail, or to assemble a mental set of case histories, is that categories and trends of failures can be identified. A good background or knowledge of failures not only provides the engineer with a resource for investigation, but more importantly, the knowledge to prevent failures by becoming a better designer in the first place. Along those same lines, the key to preventing failures is education and awareness not only for the structural engineer, but also for the entire project team… from owner to design professionals to building operators.

Major high-profile structural collapses — such as the Hartford Civic Center space frame roof in 1978, the Kansas City Hyatt Regency Hotel walkways in 1981, lift slab construction of the L'Ambiance Plaza in 1987, and the attack on the Murrah Federal Building in Oklahoma City in 1995 — have led to lessons learned, code revisions, and even changes in the way structural professionals operate their businesses. Formal research and study of failures, and a scientific review of case histories in a broader context, has led to changes in industry standards and codes, including design load values for wind and snow that have increased over the years.

Figure 1: This building roof collapse resulted from a procedural failure in the construction and inspection of permanent bracing, despite the presence of manufacturer-installed red tags shown in the photograph on the right.

Figure 2: Comparison of original truss connection to improperly modified truss bottom chord and splice that utilized drywall screws.

Exposure to failure case histories and studies helps to identify failure trends related to different building materials, structural systems, and sometimes even occupancy types. A comprehensive discussion of building failure trends is beyond the scope of this article; however, some of the examples and failure case histories published previously in STRUCTURE® are excellent resources on this topic. Structural engineers and other design professionals are encouraged to use this type of information to create better projects.

Technical and Procedural Errors in Wood Truss Construction

It is important to note that many failures are not the result of design errors, but rather procedural errors related to incomplete documentation, poor communication, and problems in the execution of the design and construction process. As an example of a failure trend, consider the case of metal plate connected wood trusses, which are prevalent on many low-rise non-residential buildings.

Many collapses related to this type of truss system are not from improper design, but from a lack of recognition and understanding concerning the importance of both permanent and erection bracing. Errors in the type, installation, and location of erection bracing, particularly for longer spans, is one of the most frequent causes of wood truss failures. One example is the collapse of a warehouse/manufacturing facility after a modest snow event in the northeast United States. As can be seen in the photograph in *Figure 1*, even though factory-installed red tags were attached to the metal plate wood trusses at the required permanent bracing locations, most of the bracing was never installed or was discontinuous.

Another common failure category of metal plate connected wood truss systems is improper modification of the individ-

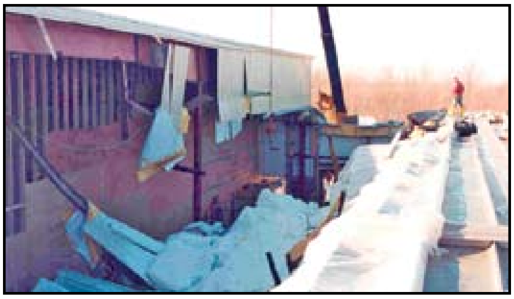

Figure 3: Overview of "link" bay section intended to support drifted snow at the junction of high- and low-roof building areas.

ual trusses to accommodate space changes to the building due to the operational and occupancy needs of the owner. An example of this is shown in *Figure 2*, where an older truss had the bottom chord cut out and later spliced in order to accommodate what was believed to be the installation of some manufacturing equipment or a change in ceiling configuration. Note that the modified truss chord shown in the bottom of the photograph was improperly repaired using only short drywall screws and a plywood gusset plate. Compare the plywood connection to the much more robust original split-ring connector shown at the top of the photograph.

Pattern Identified in Snow Collapses of Metal Building Additions

Another pattern of failure that is often easy to identify is the construction of a high-roof building addition or expansion adjacent to an existing lower roof. This is very common for low-rise industrial or warehouse buildings, often constructed using engineered metal buildings. Most building codes and standards, such as ASCE 7, clearly identify this condition as one that requires a snow drift loading. And, it is most often properly designed accordingly by the metal building manufacturer.

Unfortunately, if the low-roof building is the existing structure, reinforcement of the existing framing is almost always necessary. Not only must the low-roof reinforcing be carefully designed, but it must be properly constructed and integrated with the existing framing. In metal buildings, this is often accomplished by adding intermediate cold-formed Z purlins between the existing roof purlins. This solution is difficult to implement economically, since the Z purlins are highly dependent on the roof decking for proper bracing in order to develop the intended capacity. A typical condition of this type, which resulted in a partial roof collapse, consisted of purlins that were sized smaller in depth than the original ones in order to make it easier to install the new purlins between the existing support framing and the existing roof decking and insulation blanket; however, these same purlins were not attached to the roof decking and were only nominally braced to the original purlins.

Figure 4: Rows of closely spaced Z purlins intended to carry the roof snow drift load rolled and buckled due to a lack of proper bracing as a result of a substantial number of missing purlin-to-roof connector clips

Figure 3 shows a similar framing situation, which also resulted in the failure of a Z purlin roof system from snow loading. In this particular case, the low roof was constructed after the high roof, and the first bay of the lower structure adjacent to the existing building was intended to be the transition section. The lower roof was designed using a triangular-shaped roof snow load intended to account for drifting. On this structure, a standing seam metal roof incorporating sliding deck-to-purlin clips was the diaphragm intended to provide the primary top flange bracing for the Z purlins. Due to difficulties in aligning and installing the clips in such a closely-spaced pattern, the erector left them out entirely on many purlins, resulting in an irregular pattern of bracing every second or third purlin or intermittent bracing along the length of the purlin, depending on the location. This condition was the primary contributor to the roof collapse, which is shown in *Figure 4*.

Becoming Better Designers

Accurate formal statistics on the number of building failures and their specific causes are difficult to obtain, due to the lack of a centralized collection source and because many details are not released by owners and insurance companies as the result of legal issues and concerns over negative publicity. This article presented a fraction of the lessons, trends, and patterns that can be identified from the study of failures. Design professionals in all fields are encouraged to expand their study of building failures so that they can recognize common patterns, and use the resulting lessons learned to serve our industry better.▪

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