Codes and Standards

updates and discussions related to codes and standards

Changes in Codes, Standards and Practices Following Structural Failures

Part 2: Buildings

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This is Part 2 of a series of articles calling attention to the practice and introducing illustrative examples of changes in structural design and construction codes, standards, regulations and practices that have followed catastrophic structural failures. Part 1, in the December 2010 issue of STRUCTURE, focused on bridges. This Part 2 is devoted to buildings.

It is a credit to our structural engineering profession that failures have been, and continue to be, used to improve design, construction and regulatory practices. We do not just pay up, rebuild and walk away – we delve, we learn, and we improve.

Following a failure, engineers often carry the forensic investigations to great details, so as to have reasonable engineering certainty not only in the cause(s) of the failures but also in the identification of the responsible parties, which is needed for resolution of the frequently inevitable disputes. A valuable peripheral benefit of the laborious search is a clearer understanding of structural behavior and a better appreciation of pitfalls in current practices. These can provide information and material to effect eventual changes in design and/or construction practices, codes, standards, oversight and regulatory procedures, and even in local laws.

While the investigations of the causes of structural failures are performed by engineers, and the subsequent changes in codes, standards and practices are developed by engineers, those changes are often influenced or are even driven by economics and local politics.

The "lessons learned" from failures are interesting but worthless if not heeded and not acted upon to prevent their re-occurrence.

The author's intent with this article is to bring awareness to the fact that changes in design and construction practices, codes, standards, oversight and regulatory procedures have and continue to come about as the result of costly and catastrophic failures, and to urge our fellow professionals to continue that trend.

Illustrative Cases

The following are just a few examples of welcomed changes in design and/or construction codes, standards, regulations and practices that have been initiated in response to structural failures of buildings that were caused by design and/or construction errors, oversight and regulatory practices, as well as by misuse and inadequate maintenance. The author has been an expert consultant/witness in several of the cases cited.

Figure 1: Collapsed space frame roof at Hartford Civic Center.

1) Serious "soul searching", review and debate among architectural and structural design professionals regarding the need for improved control and peer review of the design of long-span structures. An early documentation of a formal effort was the 1981 report, *Towards Safer Long-Span Buildings*, by the Long-Span Building Panel of the American Institute of Architects (AIA). It opined that "independent design reviews should not be mandatory," but suggested that guidelines be created to, among other things, "develop comprehensive, coordinated building code requirements covering long-span design and construction" and to "develop guidelines for design review of the architect's and engineer's structural design and calculations." Related activities of the previous and subsequent years popularized the idea and, on many projects, introduced the practice of peer review. This effort followed the catastrophic collapse of the space-frame roof of the Hartford Civic Center in Hartford, CT on the evening of January 18, 1978 *(Figure 1)*, just hours after the University of Connecticut Men's Basketball team defeated the University of Massachusetts (the author's Alma Mater), and was enhanced by other long-span roof collapses at the C. W. Post Center Auditorium of Long Island University in Greenvale, NY in 1978, the Kemper Memorial Arena in Kansas City, MO in 1979, and the Rosemont Horizon Arena in Rosemont, IL in 1980.
2) Nationwide debate and judicial court proceedings on the matter of delegation of design responsibility by licensed

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Figure 2: Collapsed skyways in Kansas City Hyatt Hotel.

professional engineers to contractors. Part of the early debate was the article, *The Hyatt Regency Decision – One View*, by Robert Rubin and Lisa Banick in the August, 1986 issue of *The Construction Lawyer*. In this article, the authors opined that "The Hyatt collapse should be used as impetus to modify structural engineering practices [related to delegation of design responsibility] in order to avert other potential tragedies – even though it is recognized their implementation might not have averted the Hyatt collapse. It is a good opportunity for re-evaluation and remediation." The issue is still alive today, as discussed in the article, *Structural Design Delegation*, by David Hatem and Matthew Tuller in the November 2009 issue of STRUCTURE. The authors report that "Over the last decade, national groups representing structural engineers have provided guidelines for providing appropriate contract language to outline the design services included in 'normal' structural design, and those that are delegated to third-parties." One of these organizations is the Council of American Structural Engineers (CASE), which developed a series of National Practice Guidelines. This undying attention, debate and re-evaluation was triggered by the catastrophic failure of two suspended walkways in the Hyatt Regency Hotel in Kansas City, MO, on July 17, 1981 *(Figure 2)*, killing 114 and injuring over 216 people; and periodically fueled by catastrophes attributed in part to inappropriate delegation of design responsibilities.

3) Temporary ban and tighter design and construction requirements in some states on lift-slab construction. This was the result of the April 23, 1987 collapse during construction of the L'Ambiance Plaza 16-story residential building in Bridgeport, CT *(Figure 3)*, in which 28 workers of the lift-slab construction project were killed. The L'Ambiance Plaza catastrophe also added fuel to the debate on the matter of delegation of design responsibility as a result of the alleged deficiencies in the design of the post-tensioned slabs that had been delegated to the contractor.
4) Requirements for an Independent Structural Engineering Review (ISER), *Connecticut Public Act 88-358 and 89-255*, were adopted by the Connecticut legislature in 1988 and 1989 "to assure the stability and integrity of the primary structural support systems" in structures exceeding certain threshold limits. The most recent documentation of the requirements and explanation of the review process are in the *Recommended Guidelines for Performing an Independent Structural Engineering Review in the State of Connecticut*, Document SEC/CT-301-08, prepared and issued by the Structural Engineers Coalition of Connecticut on 2008/07/08. These acts were in response to the three major structural failures in the State of Connecticut: Hartford Civic Center, Mianus River Bridge, and L'Ambiance Plaza.
5) Requirements by the State of Florida *Building Construction Standard*, Chapter 553, effective May 30, 2005, revised April 28, 2008, of "threshold inspection" of certain construction activities in order to ensure structural

Figure 3: Collapsed lift-slab buildings at L'Ambiance Plaza.

Figure 4: Collapsed Berkman Plaza.

component conformance of large structures. It defines a "threshold" building as: "Any building which is greater than three stories or 50 feet in height, or which has an assembly occupancy classification that exceeds 5,000 square feet in area, and an occupant capacity of greater than 500 persons. " The threshold inspection must also include a final conformance certification by a qualified Special Inspector. The Florida *Statute 553.79* provides that the Board of Architecture and the Board of Engineering certify individuals as Special Inspectors, and that only those individuals with experience in design and construction of buildings of these specific types and sizes of buildings may be licensed as Special Inspectors. This followed a number of collapses, deaths and injuries in the 1970s and 1980s, particularly the Harbour Cay Condominium incident in Cocoa Beach, FL on March 27, 1981, when a five-story flat-plate reinforced concrete building collapsed as concrete was being placed for the roof slab, killing 11 workers and injuring 23 others. A more recent case prior to the 2008 revision of the Standard was that of the multi-level reinforced concrete parking structure at Berkman Plaza in Jacksonville, FL *(Figure 4)*, under construction on December 6, 2007, where 60% of the structure collapsed "like a stack of pancakes", killing one and injuring 23 others. At the time of this writing, this project is still in litigation.

6) *Buildings Bulletin 2009-011*, dated June 30, 2009, issued by the New York City Department of Buildings (which will soon find its way into the NYC Building Code) with "requirements for using existing structures to support the weight of concrete during placement and the inspection procedures and requirements

Figure 5: Collapsed wall adjacent to construction site.

for such concrete placement." These requirements have been generated by the numerous instances of failures of existing old building walls when concrete walls of new buildings were being poured against them *(Figure 5)*. The final trigger for the action was the March 6, 2009 collapse of the wall of a restaurant when workers poured concrete against an exterior side wall at 270 West 123rd Street in New York City, in which eleven restaurant customers and construction workers were injured.

7) *New Steel Erection Final Rule* by the US Department of Labor, Office of Safety and Health Administration (OSHA), issued on January 18, 2001, effective January 18, 2002, mandating the use of four, rather than two, anchor bolts in structural steel column base plates, as well as a minimum design load and eccentricity in Section 1926.755(a) *General requirements for erection stability* of the Construction Industry Standards. This rule was "negotiated" as a result of numerous construction accidents caused by the toppling of unbraced steel columns during erection *(Figure 6)*.
8) New and stricter requirements by the New York City Department of Buildings in Section 3306.5 *Submittal documents for demolition* of the NYC Building Code, introduced in Local

Figure 6: Toppled column during erection.

Figure 7: Collapsed building during demolition.

Law 57 of 2009, effective December 2, 2009. The new requirements include that documents signed and sealed by a registered design professional shall be submitted for the Building Department's review and approval. The documents shall show the extent, sequence, means and methods of demolition, the bracing and shoring necessary to support all demolition operations, as well as the description of mechanical equipment proposed to be used, together with calculations showing the adequacy of the existing structure to support loads imposed by such equipment. This followed the July 14, 2005 complete collapse during demolition of a one-story building at 2633 Broadway in New York City *(Figure 7)*, injuring one person, and the complete or partial collapses of several multi-story buildings during demolition work in New York City.

9) Executive Order 12699 – *Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction*, dated January 5, 1990, was issued by the President of the United States with design requirements for earthquake safety of new federal buildings, mandating that "Each Federal agency responsible for the design and construction of each new Federal building shall ensure that the building is designed and constructed in accord with appropriate seismic design and construction standards." "The purposes of these requirements are to reduce risks to the lives of occupants of buildings owned by the Federal Government and to persons who would be affected by the failures of Federal buildings in earthquakes, to improve the

Figure 8: Collapsed wood frame buildings following the Loma Prieta earthquake.

capability of essential Federal buildings to function during or after an earthquake, and to reduce earthquake losses of public buildings, all in a cost-effective manner." The Order followed the moderately large (7.1 on the Richter Scale) October 17, 1989, Loma Prieta, CA earthquake.

10) Addition of provisions for improved seismic resistance requirements for precast concrete structures, in particular in tilt-up construction, with the inclusion of Section 21.13.5 in ACI 318-08; improvements of connection details in steel moment-frame structures in the 1997 AISC *Seismic Specifications*; and stricter requirements for wood framed shear walls in the 2006 IBC. These provisions were the result of the observed and much-studied damages suffered by buildings in the 1989 Loma Prieta, CA and the 1994 Northridge, CA earthquakes *(Figure 8)*. It is mentioned here that the evaluations of damage after nearly all significant earthquakes in the United States are followed by re-evaluation of seismic design code provisions, and often result in the evolution of improved practices.
11) Stricter and additional requirements to improve the progressive collapse resistance of cast-in-place reinforced concrete structures by providing continuity of reinforcement, first in the ACI 318-02 by the addition of Section 21.2.6.1(b) for mechanical or welded butt splices, and later in the ACI 318-02 and -08 by increasingly stricter and more detailed minimum requirements in Section 7.13.2 for continuity of reinforcement. The intent of the changes was, as stated in the ACI 318-08 *Commentary* Section R7.13, to "improve the ductility and redundancy of structures so that in the event of damage to a major supporting element or an abnormal loading event, the resulting damage may be confined to a relatively small area and the structure will have a better chance to maintain overall stability." These actions were precipitated by the April 19, 1995 bombing of the Murrah Federal Office Building in Oklahoma City, OK, which resulted in heavy damage and collapse of a large part of the building *(Figure 9)*.
12) Rules, regulations, local laws, façade ordinances in a number of cities – including Boston, Chicago, Columbus, Detroit, Milwaukee, Philadelphia, Pittsburgh, New York, and St. Louis – to assure public safety against crumbling façades , falling appendages and other hazards by requiring and strongly enforcing periodic inspection, maintenance and repair of building façades. Their developments were influenced by local politics, economics and engineering practice. (It is noted that façade failures are often the results of inadequate maintenance or repair rather than of design and/or construction defects.) The façade ordinances are mostly in response to incidents of falling materials from buildings onto sidewalks that had caused damage, disruption of traffic and serious injury *(Figure 10)*. In particular, some of the much-publicized incidents that triggered the responses included those of the 1974 falling of a façade tile and the 1999 falling of a piece of wind-propelled glass in Chicago that struck and killed two people; the 1979 falling of a stone appendage that struck and killed a college student in New York; and the 1997 bulging and subsequent partial collapse of the brick veneer on a wall high above Madison Avenue in New York, raining bricks down onto the adjacent building and onto Madison Avenue.

Figure 9: Heavily damaged Murrah Federal Office Building following its bombing.

Figure 10: Decorative pediment fallen from a building façade in Brooklyn, NY.

13) Publication of the ASCE/SEI standard ASCE 37-02 *Design Loads for Structures During Construction* specifying design loads on temporary structures that provide support and access in the construction process and for permanent structures during their construction phases. The standard was developed starting in 1987, first published in 2002, and is now being revised in response to the findings that many construction failures are the result of improper design considerations.

More to Come

At the time of this writing, a number of failures that occurred in the past few years have been or are being investigated, several of which, in the author's opinion, will precipitate changes in codes, standards and practices. Among them are the August 1, 2007 collapse of the I-35W highway bridge at Minneapolis, MN, allegedly caused by the defective design of a steel gusset plate coupled with stockpiling construction material on the structure; the July 10, 2006 collapse of the ceiling support structure in one of the tunnels of the Central Artery/Tunnel in Boston, MA, allegedly caused by a questionable design concept, defective construction, and unsuitable epoxy materials; and a rash of damages in New York City resulting from the construction of underpinning of existing buildings in order to accommodate deeper basements of new buildings on adjacent lots.▪

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