Structural Collapses During Construction

Lessons Learned, 1990-2008

By Mohammad Ayub, P.E., S.E.

The Occupational Safety and Health Administration (OSHA) investigated 96 structural collapses during construction involving fatalities and injuries from 1990 to 2008. The most probable causes of these incidents are summarized in *Table 1* (available in the online version of this article; visit **www.STRUCTUREmag.org**). These incidents took the lives of 117 construction employees and caused injuries to another 235. The incidents occurred in a wide range of structures – steel, concrete and timber, high-rises and low-rises. The aggregate number of construction deaths due to all causes is staggering – approximately 1,000 in 2008 alone. *Figures 1* and *2* show the number of deaths and the rate of fatalities in the construction industry. As can be seen, the highest rate of deaths and injuries occurs in construction activities.

Construction errors contributed to 80% of the structural collapses investigated by OSHA. The remaining 20% of the incidents are attributed to structural design flaws on the part of either the structural engineer of record (SER) or a structural engineer retained by a contractor to design specific members. Steel structures, including scaffolds and platforms, were involved in 62% of these incidents.

Discussion

The largest group of structural collapses involved 60 steel structures:

- 14 structural steel frames
- 14 scaffolds
- 18 special steel structures and cranes
- 5 television antenna towers
- 3 cofferdams
- 6 steel roof trusses and joists

The second largest group involved 29 concrete and masonry structures:

- 3 concrete frames
- 12 shorings supporting freshly placed concrete
- 4 demolitions involving concrete structures
- 5 precast concrete structures
- 5 masonry walls

The third group consisted of wood structures:

- 7 wood frames and roof trusses

Construction Errors

1) In 47 cases, contractors did not generally follow the installation procedures prescribed and recommended by the manufacturers and designers, such as providing temporary bracing, lateral bracing, diagonal bracing, bridging and anchoring, guy cables, lateral supports, and proper welded connections.
2) In 15 cases, contractors overloaded certain structural members beyond their ultimate capacities.
3) In 9 cases, contractors did not provide temporary bracing during construction of steel frames, and concrete or masonry walls. As a result, wind pressures caused their collapse.
4) In 7 cases, contractors began to demolish existing structures without regard to structural stability and capacity of existing structural members.

Structural Design Errors

Out of 96 incidents, 19 construction incidents were related to structural design errors. These occurred in 13 steel structures, five concrete structures, and one masonry structure. 17 of these incidents are briefly described below.

Incident No. 4
Precast Concrete Beams

Two critical bottom reinforcing bars of a precast beam were not provided with the required development lengths. This resulted in a significantly reduced flexural strength of the beam, and hence the failure.

Lessons learned: The precast beam designer and detailer must indicate in their detail drawings the required rebar development lengths, including the rebar splice lengths per the ACI code.

Incident No. 6
Soldier Beam and Lagging Cofferdam

The installed outlookers between the soldier beams and walers did not have sufficient strength to resist the unbalanced lateral earth pressure.

Lessons learned: Outlookers that transfer forces from the waler to the soldier beam could be subjected to flexural stresses due to unbalanced earth pressure. Such outlookers must be designed to resist all anticipated forces.

Incident No. 8
Steel Stack

During the design of the steel stack, the SER did not consider vortex shedding under sustained wind speed.

Lessons learned: Uniform winds with little turbulence are known to create vortex shedding, which causes large vibrations in the across-wind direction in tall stacks of circular cross-sections under the condition of resonance. Winds that are not in a steady state do not create vortex shedding. The transverse resonance occurs when the shedding frequency becomes close to the natural frequency of the steel stack. The SER must consider a suitable abatement method.

Incident No. 15
Steel Sheeting Cofferdam

The engineer under-proportioned the depth of embedment of the cofferdam steel sheet piles, resulting in a "quick condition" and subsequent soil failure.

Lessons learned: Appropriate seepage forces at the bottom of the excavation must be considered in determining the depth of sheet piles.

Incident No. 16
Concrete Building

The formwork design engineer under-proportioned the support system for all reasonably anticipated vertical and lateral loads imposed on the formwork.

Lessons learned: The formwork design engineer must consider all anticipated vertical and lateral loads to be imposed on the formwork and proper load transfer to the base, and must provide detail drawings.

Incident No. 22
Steel Canopy Structure

The structural engineer did not properly design the canopy structure for the loads that were placed on it.

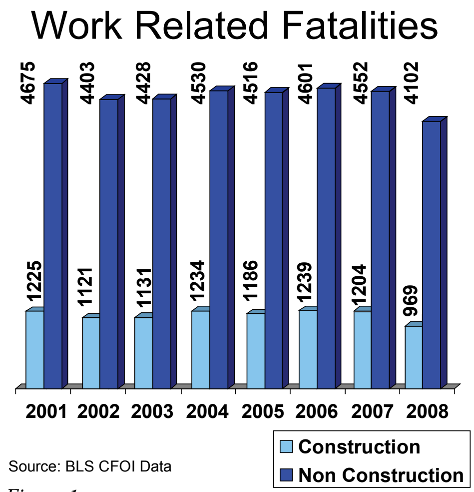

Figure 1.

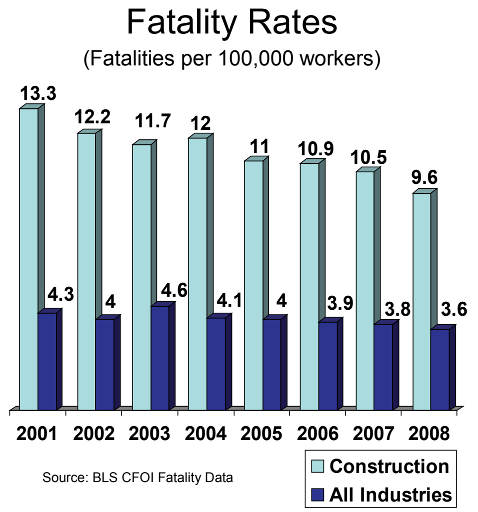

Figure 2.

Lessons learned: Final design should not be based on preliminary loads assumed during the initial design. Final design should be based on the anticipated final loads.

Incident No. 27
Masonry Foundation Wall

The structural engineer did not design a braced masonry foundation wall, and did not provide vertical reinforcement to resist the lateral loads.

Lessons learned: Unreinforced masonry walls are highly susceptible to overturning, especially during construction, unless they are braced. Bracing must stay in place until floor or roof framing installation is completed.

Incident No. 33
Bridge

The structural engineer under-proportioned the steel bracket supporting the steel beams of the catching platform under the center span of the bridge where the deck was being demolished. Also, the epoxy anchors used to support the brackets were improperly designed.

Lessons learned: Compression members must be checked against buckling. Confirmation of the strength of the existing concrete must be verified in designing epoxy anchors.

Incident No. 36
Elevated Structural Steel Platform

The structural engineer arbitrarily selected a single angle as a knee brace to support the platform.

Lessons learned: AISC has a special provision to determine the axial capacity of a single angle. If not followed, it could result in buckling and catastrophic failure.

Incident No. 56
Structural Steel Billboard

This incident occurred the day after the ironworkers completed the framing of a 60-foot-high billboard and its walkway. It resulted in three fatalities. The structure was meant to display advertisements along an interstate highway. The framing consisted of a hollow tube section cantilevered from a tall hollow tube column. At the end of the cantilever member, another long cantilever member was framed over a stub leg welded to the cantilevered beam. The failure occurred at the junction of the round stub leg and the long cantilevered beam.

An investigation revealed that the structural design was flawed in that it did not meet the AISC design specifications for hollow structural sections. The requirement to address chord wall plastification at the junction of the stub pipe and the cantilevered beam was not met. Also, the weld between the stub column and the cantilevered pipe was improperly performed.

Lessons learned: Differences between the design of rolled W shapes and HSS must be recognized, and the appropriate AISC provisions must be followed. Field testing of critical welds must be specified.

Incident No. 60
Scaffold Tower inside a Boiler

The structural engineer under-proportioned the steel beams supporting the 180-foot high scaffold tower inside a boiler.

Lessons learned: Light structural beams, when unbraced, are highly susceptible to lateral-torsional buckling. Proper design must evaluate the unbraced compression flange length.

Incident No. 61
Pedestrian Bridge

A long steel box girder spanning approximately 170 feet collapsed as the top concrete deck was being poured. At the time of the collapse, the concrete pour was almost halfway complete. Under the weight of the concrete, men and equipment, the girder twisted and collapsed. Though cross frames were provided between the girder top and bottom flanges, lateral bracing of the girder itself, when considered as a single longitudinal member, was not provided. As a result, the entire girder twisted in a torsional mode and fell.

Lessons learned: To prevent torsional buckling, long-span steel girders for bridges must have sufficient torsional rigidity in accordance with all applicable codes.

Incident No. 64
Custom Cantilever Finishing Platform

Loads considered in the design of the platform proved to be much lower than the actual loads placed on the platform.

Lessons learned: The engineer must consider realistic and verifiable loads while designing structural framing systems.

Incident No. 66
Parking Garage

A concrete structure under construction collapsed during placement of wet concrete on the 8th level, killing four construction employees and injuring scores of others. Five levels of exterior bays of the structure collapsed, with a complete separation from the exterior columns, while still being connected to the first row of interior columns. An investigation revealed that the exterior beam-column joints were improperly designed. Lack of sufficient reinforcement between the wide perimeter beams and the slender exterior leg contributed to the collapse.

Lessons learned: Exterior slender columns supporting wider beams must be avoided; otherwise, proper beam-column joint connections must be designed and detailed.

Incident No. 68
Gantry Crane

The structural design of the gantry crane was flawed in that it lacked a proper lateral-load-resisting system in one direction. During sudden braking of the crane, a large inertia force developed, and that force toppled the crane.

Lessons learned: Lateral-load-resisting systems must be provided in both directions. Lateral loads could arise from wind, seismic or inertia forces.

Incident No. 81
Stripping Platform

The structural design of the stripping platform was flawed. The temporary shoring frame of the platform was not properly supported, and the outer brace was incorrectly proportioned.

Lessons learned: Load paths and supports of platforms must be evaluated properly. Long compression members are highly susceptible to failure.

Incident No. 90
Post-tensioned Concrete Parking Garage

The structural design undersized the columns and under-proportioned the post-tensioned beam. A number of construction defects also existed.

Lessons learned: Exterior, as well as interior, slender columns supporting wider beams must be avoided; otherwise, proper beam-column joint connections must be designed and detailed.

Conclusion

To prevent structural collapses during construction due to design errors, the SER should:

- Design the entire structure, including components, using the latest applicable industry standards.
- Provide drawings with details or notes such as:
  - For concrete buildings, rebar development and splice lengths and placing details at congested areas; e.g., beam-column and beam-beam connections.
  - For steel buildings, steel yield strengths and welded connections, indicating length, size and type of welds.
  - For timber structures, lumber material with sizes and connection design requirements.
- Consider construction loads during design.
- Avoid exterior slender columns supporting wider perimeter beams.
- Ask for field testing of critical welds.
- Provide stability checks against lateral-torsional buckling.
- Evaluate vortex shedding for tall stacks.
- Check against seepage forces during sheet piling embedment design.
- Verify loads during final design.
- Caution the contractor to provide temporary bracing for unreinforced masonry walls, joists and roof trusses.
- Verify existing concrete strength, rather than making an assumption.
- Determine proper load paths during design.
- Follow AISC specification for single angle design.
- Provide proper bracing or rigid connections to resist lateral loads in both directions.▪

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Table 1: Summary Of Structural Failure Incidents

Type of Collapsed Structure & Incident number (X)	Most probable Cause/causes of the Collapse	Caused by construction or design flaws
Masonry Wall **(1)**	The CMU wall during construction was out of plumb, was not laterally braced, and was overloaded and overstressed.	Construction. 2 Killed, 16 Injured.
Structural Steel Building **(2)**	No temporary bracing. 32 mph wind pressure created overturning moments in excess of the flexural capacity of the column bases.	Construction. 1 Killed.
Steel Beams of a Steel Framed Building **(3)**	Incorrect steel erection procedure. ⅞" diameter high-strength bolts on a roof cantilever beam were overstressed.	Construction. 3 Killed.
Precast Concrete Beams **(4)**	Inadequate development length of #7 bottom rebars.	Design. 1 Killed, 1 Injured.
Precast Concrete Wall Panels **(5)**	Four precast concrete wall panels were not adequately braced to resist the lateral wind pressure.	Construction. 1 Killed, 2 Injured.
Soldier Beam and Lagging Cofferdam **(6)**	Spacer connecting the wale and soldier beam was not adequately designed to resist the expected earth pressures.	Design. 0 Injured.
Masonry Wall **(7)**	No temporary bracing. A gust of wind of 41 mph precipitated the failure.	Construction. 1 Killed, 8 Injured.
Steel Stack **(8)**	Vortex shedding was not considered in the design. It caused the fracture of the field fillet welds at the second splice from the top.	Design. 1 Killed, 6 Injured.
Concrete Shoring System **(9)**	Erected shoring system did not conform to the design drawings and was inadequate for carrying the imposed load during the placement of the concrete at the 4th level.	Construction. 3 Injured.
Roof Cable Structure **(10)**	Eccentrically applied tensioning force at the temporary jacking strands overloaded the gusset plate.	Construction. 1 Killed, 2 Injured.
Steel Erection Towers **(11)**	Inability to resist the forces imposed on the steel towers due to the movement of the west barge.	Construction. 1 Injured.
Structural Steel Framing **(12)**	Inadequate temporary connection of the members and placement of construction materials over the roof members.	Construction. 1 Killed, 1 Injured.
Structural Steel Column **(13)**	Lateral load applied at the top of the column overstressed the welds at the column base.	Construction. 2 Killed.
Overturning of Beams during the Cambering Operation **(14)**	Inadequate lateral torsional buckling strength of the beams, and a reduced modulus of elasticity during heat application.	Construction. 1 Killed.
Steel Sheeting Cofferdam **(15)**	Steel sheeting of the cofferdam did not have sufficient penetration to prevent soil failure.	Design. 2 Killed, 2 Injured.
Concrete Shoring System **(16)**	Formwork support system was undeproportioned for both vertical and horizontal loads.	Design. 18 Injured.
Precast Concrete Single and Double Tees **(17)**	Unplanned additional dead load placed over the single and double tees caused the collapse.	Construction. 6 Injured.
Scaffold Frame **(18)**	Placement of brick at various tiers of the scaffold frame overstressed the frame.	Construction. 1 Killed, 4 Injured.
Movable Winch for Concrete Shaft Forms **(19)**	Winch unit was not fully assembled to its supporting beams with four hold-down rods, as required, before tensioning the wire rope of the winch.	Construction. 1 Killed, 4 Injured.

350' high Radio Transmission Tower **(20)**	Extensive use of corroded tower sections salvaged from older towers. Snatch block at 22 feet above base created lateral loads overstressing the tower.	Construction. 1 Killed, 1 Injured.
Mast Climbing Work Platform **(21)**	The scaffold platform structure, as it was configured and erected in the field, was not designed for the loads imposed upon it.	Construction. 3 Killed. 2 Injured.
Steel Canopy Structure **(22)**	The canopy cantilever trusses and the back-up frames were not properly designed for the imposed loads.	Design. 1 Killed, 1 Injured.
Precast Concrete Parking Garage **(23)**	The shoring towers were neither diagonally braced nor plumbed. The shore frames were overloaded and overstressed.	Construction. 0 Injured.
Pre-engineered Metal Building **(24)**	Intermediate roof bent collapsed due to the lateral force created by a forklift to facilitate connections.	Construction. 2 Injured.
Structural Steel Joists **(25)**	The unbraced top chords of the joists caused the collapse. Though the joists were provided with 8 rows of diagonal bridging, the bridging lines were not anchored and were thus rendered ineffective.	Construction. 0 Injured.
1500-foot- high Antenna Tower **(26)**	Higher forces and moments were developed when the assembly of "track and gin pole" reached a higher elevation. Under this condition, the center of gravity of the assembly above the track underwent large rotations creating undue forces on the system as the bottom of the track was not anchored to the tower.	Construction. 3 Killed.
Masonry Foundation Wall **(27)**	The design of the concrete masonry wall was inadequate for both construction and permanent loads.	Design. 1 Killed.
Concrete Framed Building with Masonry Walls (Demolition) **(28)**	The shoring towers used for demolition had no diagonal bracings and were overloaded and overstressed.	Construction. 3 Killed
Wood Roof Light Gage Metal Building **(29)**	The timber roof trusses collapsed because they were not adequately braced.	Construction. 1 Killed, 1 Injured.
Escalator Truss **(30)**	Bolts connecting two escalator truss segments were overstressed. A number of bolts were only partially engaged.	Construction. 1 Killed.
Pre-engineered Metal Building **(31)**	Lack of adequate temporary bracing of the structural steel frames.	Construction. 1 Killed.
Steel Framed Parking Garage **(32)**	The steel erector did not comply with the sequence of erection and procedures recommended by his consultant. The steel erector failed to provide temporary bracing and guy wires.	Construction. 3 Killed.
Bridge Road **(33)**	The north steel brackets on the piers of the center span of the bridge were improperly designed to support the intended loads.	Design. 1 Killed, 1 Injured.
Grain Elevator **(34)**	The steel erector did not follow proper erection procedures from the manufacturer. Guy cables or temporary supports were not provided during the erection of the elevator.	Construction. 1 Killed.
1,889' high TV Antenna Tower **(35)**	A diagonal member of the tower was removed by the contractor without using any come-a-longs. This resulted in overstressing of the tower members and buckling of tower legs.	Construction. 3 Killed.
Elevated Structural Steel Platform **(36)**	The platform failure was caused by the inadequate temporary knee bracing to support the loads on the platform.	Design. 1 Killed, 4 Injured.
Reinforced Concrete Building (Demolition) **(37)**	Engineering survey was not performed to determine the height of the elevator shaft and the weight of two steel drums over the elevator. The elevator shaft fell onto the excavator cab and killed the operator.	Construction. 1 Killed.
Steel Bridge Girder **(38)**	The C-clamps used to temporarily hold the cross frames to the steel girder were not adequate. The 4x6 temporary strut and come-a-long wire to support the collapsed girder were also inadequate.	Construction 2 Injured.

Scaffold Tower **(39)**	The scaffold tower was erected without any diagonal bracing at some locations. Also, the K-braces and X-braces were removed at a few locations. In addition, the lateral bracings were temporarily removed at certain levels.	Design and Construction. 1 Killed.
Guardrail System **(40)**	Guardrail system was not properly designed and installed to withstand a 200-pound load.	Construction. 1 Killed.
Reinforcing Steel Cage **(41)**	The erector did not provide adequate lateral support to the 44-foot-high reinforcing steel cage.	Construction. 1 Killed.
Structural Steel Framed Building **(42)**	The contractor removed the temporary bracings of the building frame prematurely. The contractor did not follow the written instructions from the design engineers.	Construction. 2 Killed, 2 Injured.
Floor Beams of a Structural Steel Framed Building **(43)**	Due to the lack of welding between the metal deck and steel beams, one of the interior steel beams was overstressed and collapsed during the concrete pour operation.	Construction. 4 Injured.
Scaffold Towers **(44)**	Lateral braces were not provided between the putlogs. Scaffold towers were erected with components from different manufacturers. The contractor did not perform any structural analyses.	Construction. 3 Injured.
Reinforced Concrete Building (Demolition) **(45)**	The contractor imposed loads on the fourth floor in excess of its ultimate capacity by placing an excavator over 2-foot-deep debris.	Construction. 1 Injured.
Wood Framed Apartment Building **(46)**	Washer plates on top of the sill plate were not provided. The exterior sheathing was not nailed to the bottom sill plate. The building collapsed during a windstorm.	Construction. 1 Killed, 4 Injured.
Bridge Paint Containment Structure **(47)**	The fabricator of the containment structure did not install the proper size U-bolts as per contract documents ,and did not perform the welding using certified welders.	Construction. 1 Killed, 2 Injured.
Longspan Steel Roof Joists **(48)**	The bridging lines of four roof joists were not properly anchored to transfer the lateral loads.	Construction. 1 Killed.
Steel Roof Trusses **(49)**	The steel erector did not provide adequate temporary bracing to the roof trusses. The bridging lines of trusses were not continuous and were not properly anchored.	Construction. 0 Injured.
Masonry Wall and Wood Floor Framing Apartments **(50)**	The mason contractor overloaded the second floor beyond its capacity by placing masonry blocks.	Construction. 5 Injured.
Steel Sheeting Cofferdam **(51)**	The contractor arbitrarily eliminated and changed sizes of a number of main structural members without informing the engineer of record. It resulted in a deficient and unstable structure.	Construction. 0 Injured.
Mast Climbing Platform **(52)**	The overloading of the scaffold platform caused the collapse. The four sections of the platform were loaded well in excess of their safe capacities.	Construction. 3 Injured.
Scaffold Towers **(53)**	The scaffold towers were overloaded and overstressed beyond their ultimate capacity.	Construction. 5 Killed, 10 Injured.
Wood Roof Trusses **(54)**	Inadequate lateral and diagonal bracings were provided at the top chords of the failed trusses. There were no lateral and diagonal bracings at the bottom chord.	Construction. 5 Injured.
Steel Joists Floor Framing **(55)**	The steel joists were not laterally braced and failed under lateral torsional buckling.	Construction. 1 Killed, 4 Injured.
Structural Steel Framed Billboard **(56)**	The structural design of the steel framing did not follow the requirements of AISC's *Hollow Structural Sections*. The weld at the junction of the stub pipe and cantilever beam was not properly performed.	Design & Construction. 3 Killed.
Tilt-up Precast Concrete Wall Panel **(57)**	The failure occurred because the contractor prematurely removed the temporary braces of the tilt-up wall panel before permanent connections at the top and bottom of the panel were made.	Construction. 3 Killed.

Reinforced Masonry Wall **(58)**	The masonry contractor did not provide adequate bracings to prevent collapse of the wall. The bracings were deficient because they were neither properly proportioned nor connected.	Construction. 1 Killed.
1,965' high TV Antenna Tower **(59)**	The contractor removed the bolts connecting the diagonals, a horizontal strut and redundant members resulting in a significant reduction of the load-carrying capacity of the tower legs.	Construction. 2 Killed, 3 Injured.
Scaffold Inside a Boiler **(60)**	The selection and design of the base beams supporting the scaffold were flawed. The beams were significantly undersized and not capable of supporting the intended load.	Design. 2 Injured.
Pedestrian Bridge **(61)**	The stability of the bridge girder during construction and placement of wet concrete was not considered by the structural engineer of record. Adequate top lateral bracings were not provided.	Design. 1 Killed, 9 Injured.
Light Gage Metal Framed Building **(62)**	The incident occurred because the contractor failed to provide proper lateral bracings to the studs by means of straps.	Construction. 0 Injured.
Wood Roof Trusses **(63)**	The truss erector did not provide temporary bracings during erection, as per the industry standard.	Construction. 1 Killed.
Custom Cantilever Finishing Platform **(64)**	The scaffold was overloaded beyond its rated load. In addition, the imposed loads were not uniformly distributed over the platform; instead, they were concentrated at one area.	Design. 1 Killed. 3 Injured.
1,000foot-high TV Antenna Tower **(65)**	The contractor placed a hoist (winch) at a location that produced eccentricity between the load and the center of gravity of the tower. The contractor did not perform a structural evaluation of the tower to determine the maximum tension in the load line that could safely be applied.	Construction. 3 Killed.
Reinforced Concrete Parking Garage **(66)**	The structural design of the slab/beam-column joints was flawed. The concrete contractor did not provide the required embedment length for the welded wire mesh at the intersection of the exterior columns and the exterior edge of the beam. The concrete contractor failed to detail, fabricate and place bottom reinforcing steel.	Design and Construction. 4 Killed, 21 Injured.
Steel Bridge Girder (Demolition) **(67)**	Inadequate lateral torsional buckling strength of girder overstressed the girder and led to collapse.	Construction 1 Killed.
Gantry Crane **(68)**	The structural design was flawed as it did not provide a proper lateral load-resisting system in the north-south direction. A large inertia force that occurred when the crane suddenly stopped caused the crane to fail.	Design. 1 Killed.
Balcony of an Apartment Building **(69)**	Improper embedment of an overhang balcony beam inside CMU wall caused the balcony to collapse under wet concrete.	Construction. 1 Killed, 2 Injured.
Townhouse Building **(70)**	Lack of an adequate number of single post shores under the floor to be cast. Improper placement of tunnel formworks, i.e., leveling jacks were not turned down to the floor slab to transfer the load.	Construction. 2 Killed, 3 Injured.
Scaffold Towers **(71)**	The scaffold was overloaded. Scaffold legs were not properly braced, which significantly reduced its compressive capacity.	Construction 4 Injured.
Precast Concrete Parking Garage **(72)**	Lack of horizontal bracing for the double tee during the jacking process. Lack of lateral bracing for the exterior columns.	Construction 1 Killed.
Steel Rebar Cage **(73)**	Inadequate lateral support for the rebar cage. Lack of use of standard procedure for the installation of rebar cage.	Construction 1 Killed, 3 Injured.
Steel Framed Craneway (Demolition) **(74)**	The flamed cuts made to the steel frames rendered them unstable and eventually resulted in an unplanned collapse.	Construction 2 Killed, 4 Injured.
Wood Roof Trusses **(75)**	Inadequate lateral and diagonal bracings for the wood roof truss.	Construction 5 Injured.
Concrete Roof with Masonry Wall Building (Demolition) **(76)**	Lack of temporary bracing and supports during the demolition of the central portion of the building.	Construction 0 Injured.

Concrete Formwork **(77)**	Aluminum shoring legs were overloaded beyond their rated loads. Beams were not centered on U-head. Some joists/stringers were oriented to weak axis.	Construction 10 Injured.
Steel Roof Trusses **(78)**	The steel erector did not follow the generally accepted standard practice to provide stability against lateral-torsional buckling to the girder truss during erection.	Construction 2 Killed, 2 Injured.
Concrete Formwork **(79)**	The collapse was triggered when the defective screw jack at one of the shoring legs failed under an eccentric load, caused by the off-centered stringer inside the U-head.	Construction 0 Injured.
Wood Roof Trusses **(80)**	The truss erector did not provide proper bracings to the long span trusses, in violation of the standard industry practice.	Construction 1 Killed.
Stripping Platform **(81)**	The structural design of the tunnel forms was flawed. The false frame was not appropriately supported and the outer brace was not correctly proportioned.	Design 2 Killed.
Concrete Formwork **(82)**	The concrete subcontractor did not erect the formwork of table No. 15 as per the approved formwork drawings. Other contributing factors were improper reshores, damaged truss members, fewer and out of plumb screw jacks, and improper mudsills.	Construction 3 Killed, 2 Injured.
Bridge Truss (Demolition) **(83)**	The demolition of the last two spans of the bridge was carried out in such a way that the primary structural member was overstressed beyond its ultimate strength.	Construction 1 Killed, 1 Injured.
Concrete Formwork **(84)**	The contractor proceeded to cast concrete on the roof level without having any formwork design drawings. The contractor arbitrarily determined the roof formwork framing without any evaluation. The contractor used damaged aluminum beams in the roof formwork.	Construction 17 Injured.
Precast Concrete Parking Garage **(85)**	A number of steel columns of the parking garage were erected out of plumb, beyond the permitted tolerances. The failed precast plank was installed with only 1inch of bearing.	Construction 1 Killed.
Masonry Wall **(86)**	Lack of lateral bracing. Wind gusts caused the collapse of the improperly constructed and unbraced block wall.	Construction 0 Injured.
Concrete Formwork **(87)**	Early stripping of the beam soffit, reduced concrete cover below the embed, and overloading of an embed during leveling.	Construction 1 Killed, 1 Injured.
Concrete Column Form **(88)**	The contractor used a concrete mix which contained admixtures that yielded a lateral pressure on the formwork greater than its capacity. Also, rate of pouring was too fast.	Construction 2 Killed.
Wood Roof Trusses **(89)**	Lack of temporary bracing and overloading of roof trusses by placing a stack of materials during erection.	Construction 2 Injured.
Post-tensioned Concrete Parking Garage **(90)**	Flawed structural design for beams and columns, and lack of reshores below the third level.	Design and Construction 1 Killed.
Tower Crane **(91)**	Use of polyester and deteriorated slings to suspend the collar, and improper rigging of the collar. Also, slings were not protected against sharp edges for cuts and abrasions.	Construction 7 Killed.
Slab on Grade (Demolition) **(92)**	Lack of underpinning under the CMU wall.	Construction 1 Killed.
Suspended Scaffold **(93)**	The scaffold was overloaded. Due to the traffic vibrations of the bridge deck, the dynamic effect of the suspended swivel bolt significantly contributed to the failure of the supporting tongue plate.	Construction 3 Killed.
Concrete Ramp **(94)**	Lack of support of the precast joists at intermediate points when the slab of the ramp was being poured. The contractor used the 4x4 wooden shores with Ellis Jacks in lieu of required steel shores as per the formwork drawing.	Construction 1 Killed, 1 Injured.
Mobile Crane **(95)**	The crane manufacturer did not design the boom stops to prevent the boom from falling backwards.	Design. 4 Killed, 6 Injured.
Gantry Crane Leg **(96)**	During dismantling of the crane leg, excessive forces were applied at the toe of the leg, which severed its upper supports. As a result, the leg came crashing to the ground.	Construction 1 Killed, 3 Injured.