

The Collapse of Building 7 by Arthur Scheuerman December 8, '06

WTC's Building 7 was a 47-story office building completed in 1987 by Silverstein Properties on land owned by the Port Authority. It was built according to PA-NY-NJ codes developed for tenant alterations in the tower buildings. Building 7 was not hit by any planes but had some damage from parts of Tower 1 impacting the south wall. Because of the damage to the building and the failure of the water supply, after talking to the owner, the Fire Department decided to evacuate the building and not to attempt to control the fires but to let them burn out. Since it was a "fire resistive" building, there would have been every expectation that the fires would burn out without any local or global collapse. However, given that the towers had collapsed and that there had been a serious interior collapse of Building 5, there was concern, and the collapse area around the building was cleared. The building suffered global collapse from fire after several hours of uncontrolled burning. There were no known injuries or fatalities in the collapse.

Building 7 was built over an existing Consolidated Edison power station. Above the seventh floor, the construction was very similar to that of the towers: with long-span outer floors, large open areas, unknown fireproofing on the steel, little lateral bracing in the core, and most likely weak column splicing.

Since the perimeter wall columns were shear walls that resisted wind loads, the long-span floors (53 feet) acted as a diaphragm, transferring loads between exterior walls and between the walls and the core; the center core structure, as in the towers, supported only gravity loads. One important difference was that instead of steel bar-joists, the primary floor structure was more typical in that it had two-foot-deep wide flange steel I-beams, nine feet on center, composite with a concrete slab.

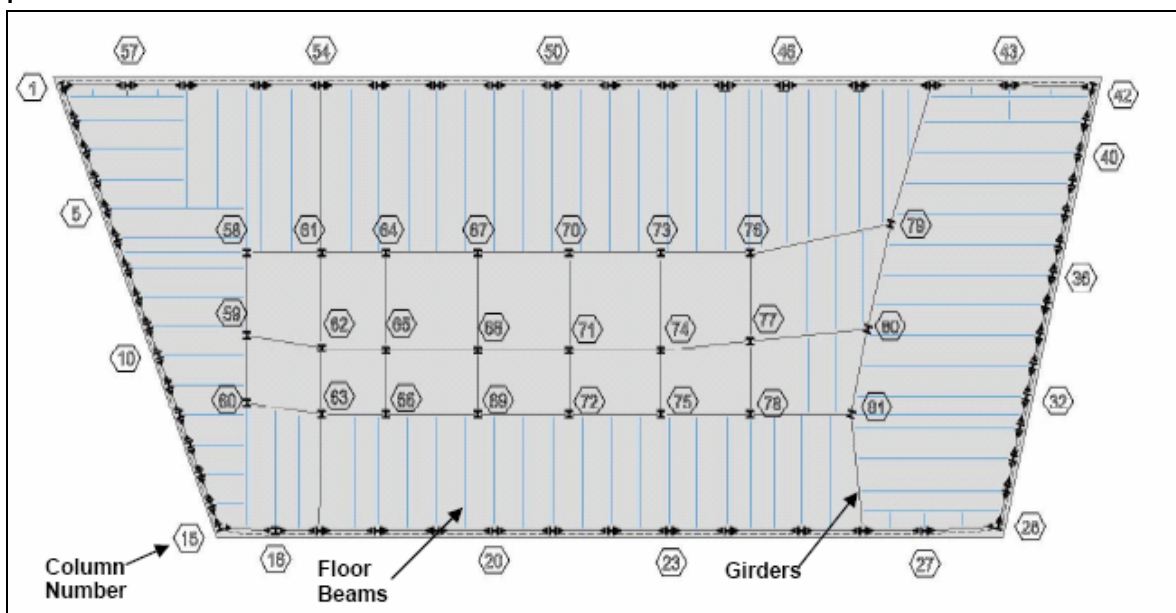


Figure 20a. Floors 8 to 45 plan. (Courtesy of NIST)



Photo 21. Building 7 before September 11 (left) and hours before collapsing (right). (Courtesy of Fire Department of New York.)

The long-span steel I-beams had $\frac{3}{4}$ -inch diameter by five-inch-long steel shear studs, about two feet on center that projecting into the concrete. These studs provided bonding and composite action under load with the $5\frac{1}{2}$ -inch concrete floor. Shear studs were not provided in the core.

Similar sorts of floor-failure mechanisms, as those responsible for the towers' collapse, might have been responsible for Building 7's interior column failure, which triggered the progressive collapse. NIST studies (2, Appendix L) show that failure of one or more of three key interior columns on the east side of the building would travel vertically to the roof, collapsing all the floors and producing the initial kink in the east penthouse roof, the first indication of collapse as videotaped. That the west penthouse roof sank into the building, as seen on the videotape, five seconds after the east penthouse sank indicates a horizontal collapse progression to the rectangular core, imploding the building.

I believe the collapse was unlikely to have started below the 5th floor, since the construction below the 5th floor was more conventional. These lower floors were reinforced with much lateral bracing and thick, reinforced membrane floors that would redistribute any lateral loads throughout the lower floors. The 5th floors to 7th floors were transition floors. There was speculation about the fire's being on these floors and fed from oil-fired generators supplied from tanks on the lower floors, but I have seen no hard evidence of fire from this source.

The fire shown in photos 21 and 22 appears to be a very severe, but ordinary, office fire and was well above the area supplied with oil lines. There is a strong possibility that this building collapsed from this office fire alone. NIST was scheduled to complete its analysis of the cause of the collapse in June 2006. This report is my contribution toward the analysis.



Photo 22. The north side of Building 7. Fires are on the 7th and 12th floors. (Courtesy of NIST.)

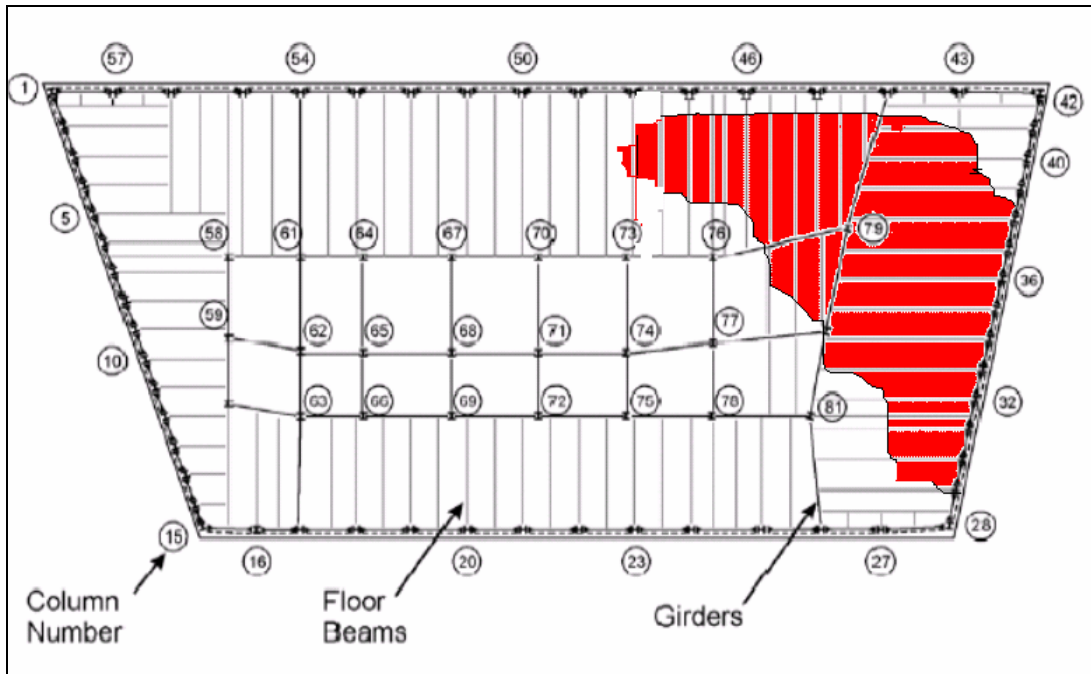


Figure 21. The approximate fire location on the east side of floor 12. (Courtesy of NIST, modified by author)

Fire is coming out of eight windows on the east side on the 12th floor. This fire must have dropped down to the 11th floor, since a later photo shows fire at four windows on the 11th floor. There was also fire showing at multiple 12th-floor windows on the north side. This is a serious high-rise building fire that would have necessitated multiple alarms to control. There were various other fires on different floors. These photos were taken at around 2 p.m.; the building collapsed about three hours later, after the 12th-floor fire had burned out.

Collapse Initiation Hypothesis

With a serious large area fire on the 12th floor, the two foot wide, long-span steel beams on the 13th floor, depending on the amount of fireproofing insulation installed, could have expanded and bowed, sagged or buckled downward and possibly twisted out or flopped over from the uncontrolled fire. The fire may have been burning long enough to weaken the steel causing a sag and catenary action. This same mechanism could have been happening on the 11th floor with the beams on the 12th floor being heated from both sides. Unlike the bar-joint failure producing early pull-in forces, short-span, steel I-beam composite floors usually maintain push-out forces caused by their expansion, during the fire, while the floors sag into tensile membrane action. It is unknown whether long-span floors act the same way. The large area of the concrete slab may have limited or increased tensile membrane action. As the steel beams first expanded from the heat, the studs might have pulled the slower expanding concrete into tension, possibly cracking it and removing some compression capabilities. This would have allowed the steel beams to bow or buckle sooner

from the loads and thermal forces and the floor to sag and put torque on the connections to the girder on the east side. The sag could have separated the wire mesh bond in the concrete over the girder. The girders themselves may have been sagging also.

As the sagging steel beams and girders cooled after burnout, they began to contract. Since they would have been seriously deflected downward, the beams would have been unable to overcome the inertia and lift the floor loads as they contracted, and strong pull-in forces would have developed. The office furnishing and equipment loads on the 13th floor might have shifted down the slope toward the middle of the floor, increasing these pull-in forces. A question that needs to be studied is, what forces are developed by the shrinking of long span steel I-beams and girders in relation to the sag and temperature change, and over what distance does this force operate when the floor begins contracting after burnout?

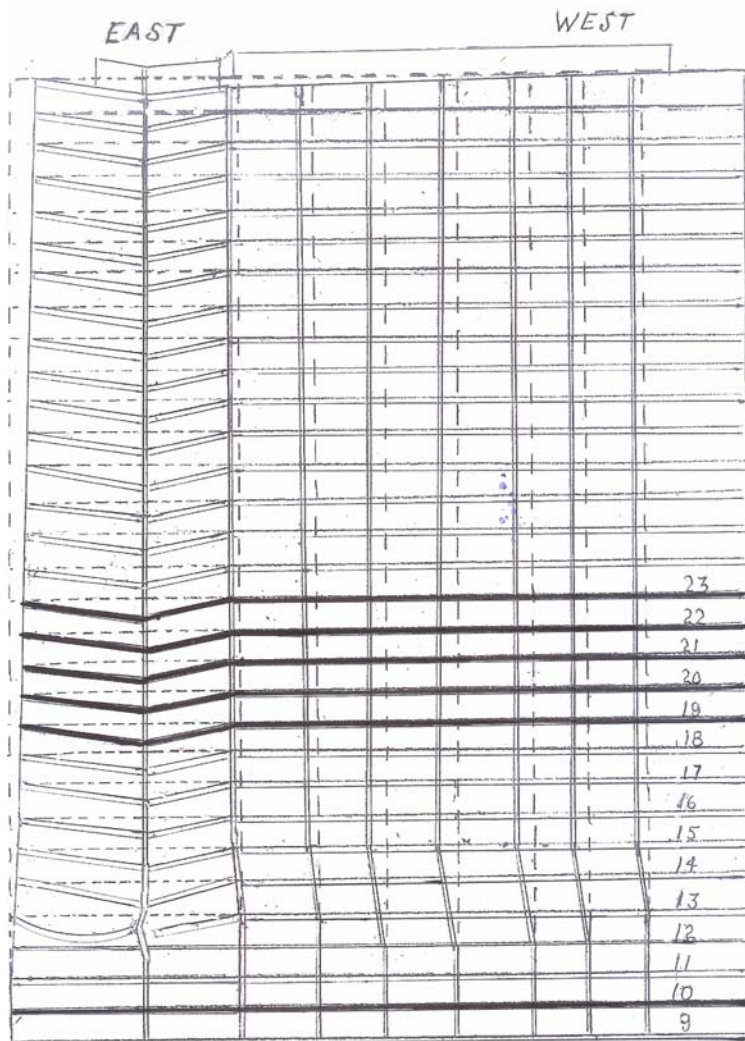
The increasing tension or torque in the 13th floor's connections from suspension forces as the floor bowed, buckled, or sagged or from contraction forces in the sagging floor as the floor cooled and contracted after burnout could have started an edge detachment, or rip failure, detaching the beams along the north-south girder along the line of columns 79, 80, and 81. The "typical floor beam-to-girder and girder-to-core column connection was a single shear plate," (2, Appendix. L, 7) but certain floors had reinforced connections. This could have disconnected the west side of the east floor from this girder, allowing tension in the remaining portion of the floor to laterally displace one or more columns and break the column splices as the beams contracted. The sinking of the east roof penthouse before any other visible failure indicates that the three key columns (79, 80, and 81) were the first to fail. These were massive columns and most probably adequately fireproofed and would not have failed directly from heat.

The girder along the line of columns 79, 80 and 81 could also have sagged and detached with the remaining girder creating pull-in forces on the column(s) as the girder buckled from the heat and/or contracted from cooling

A less likely scenario is that the floor attachments to Columns 76, 77, and 78 initially failed. As the 13th floor sagged and contracted as it cooled, the floor could have initially detached at these east core columns. The loss of restraint could have allowed the remaining tension in sagging and contracting floors to laterally deflect one or more of the three key columns (79, 80, and 81). There was a layer of welded wire mesh reinforcement placed in the concrete over the girders along columns 79, 80, and 81; this additional reinforcement might have strengthened these connections and thus caused the core connections to fail first. There was also some fire on the 11th floor, and possibly the 14th floor. This could have assisted the failure of Columns 79, 80, and 81 by producing additional lateral forces.

Vertical Progression

The failure of columns 79, 80, and 81 on the 13th floor put all the long-span



floors above into suspension.

Since the columns were widely spaced and floor spans were on the order of 50 feet, with a column failure, the floors would not have been able to effectively redistribute their loads to other columns, and the collapse would have progressed upward to the top of the building. A semi-plastic hinge would have formed along the north-south girder because of the single-plate, bolted beam-to-girder connections. The tensile pull-in forces in all these upper buckled floors would have been great, since these floors were cool and there would have been no expansion-induced sag. (See Part 3, Theory.)

Figure 22. East-West building section as viewed from the north showing column failure and resulting progression, putting all floors above in suspension; and the east roof shed is sinking. Darker floors are reinforced. (Diagram by author.)

This initial column failure was evidenced by the kinking and sinking of the east penthouse into the building's roof and the simultaneous breaking of the windows on the east side of the north wall as it was pulled in by the suspended floors.

NIST studies have shown that because of the large floor areas, the failure of just one [key] column on any one of the lower floors would cause a vertical progression of collapse so that the entire section would come down. (NIST, S. Shyam Sunder lecture) This single-column's failure initiating progressive

collapse is a design defect noncompliant with the NYC codes. The buckling of two or more of these three key columns (79, 80, and 81) would have removed support for all columns directly above, putting all upper floors in immediate long-span suspension with eventual collapse. The breaking of the windows on the east side of the north face simultaneously with the buckling of the roof shed was evidence of this tension as the north wall was pulled and leaned in. This high tension in all the floors above could have failed the floor connections or buckled more columns, depending on the stresses and strains developed. As can be seen in the illustration, the floors would have been equally deflected in the initial collapse because of the geometry of the rigid columns pulling or pushing on the floors. This combination of equal floor deflection along with the exterior walls leaning inward would have created increasing pull-in forces in the floors from the top floor downward.

If the connections had held, the exterior walls and core columns would have been pulled inward with greater forces on the lower floors because of the lean. Because the 14th floor was still intact, even though sagging, if the floor to column connections held the exterior and interior columns more likely would have buckled at that floor. The question that needs analysis is what connections would fail first and what connections would hold with all 35 floors in suspension? NIST reported that the information available indicated that the floor-to-column connections would fail under this scenario without seriously damaging the perimeter or interior columns. However, certain connections on Floors 19 and 20 were reinforced, and Floors 21 to 23 used heavier steel. (2,126) These floors could have developed a higher degree of column destabilizing tensile forces before connection failure cut off these lateral forces.

Horizontal Progression West

One of NIST's hypotheses involving the horizontal progression is that the impact of the debris from the falling floors hit a transverse truss between Floors 5 and 7 and rotated the truss, which would have pulled a line of core columns eastward, collapsing the core. This is certainly possible and may have happened, but probably not until after the core had already started collapsing from the tensile forces of the floors in suspension.

Floors 21 to 23 had slightly heavier steel framing than the others (shown darker in diagram, Figure 22). Portions of Floors 10, 19, and 20 had reinforcing plates on the bottom flange, and certain connections were reinforced. If other floor connections failed, these strong connections might have held and pulled a line of core columns eastward, especially if impacted by falling debris from the collapsing floors above. The fact that Core Columns 76, 77, and 78 on all the floors would have been subjected to pull-in with increasing pull-in on the lower floors should be figured in.

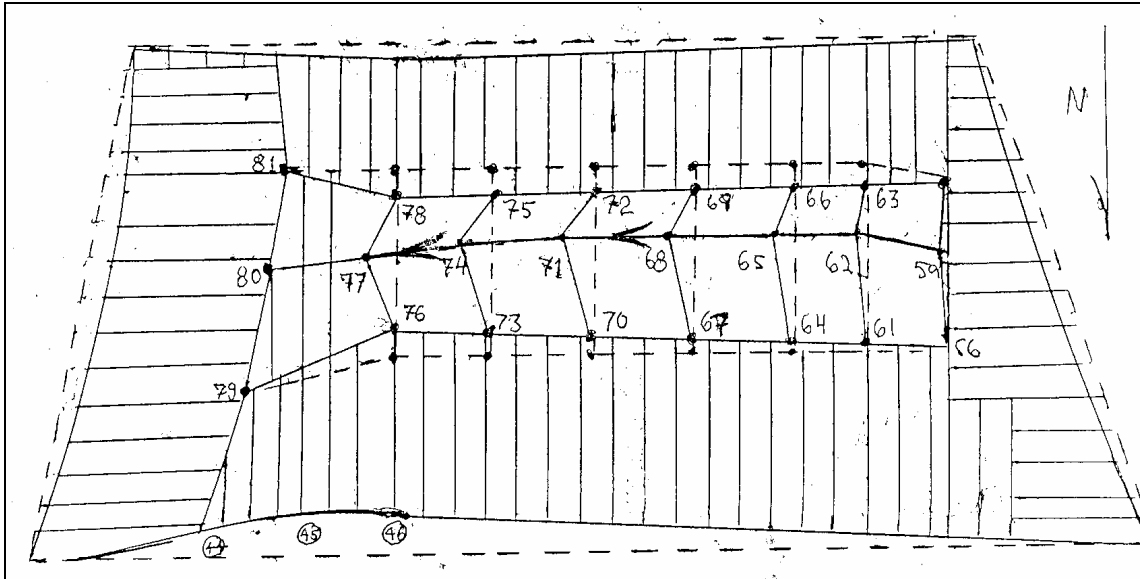


Figure 23. The buckling of Columns 79, 80, and 81 would have allowed the east side floors directly above these columns to go into suspension and would have produced these strains in the remaining structure on all the floors above the 13th. (Diagram by author.)

Tension in the floors above the buckled key columns could have put floor connections to the core columns under immediate severe lateral stress on all the floors above 13. These lateral stresses would be greater on the lower floors because of the exterior wall's leaning inward more at the top. If the floor connections to Column 77's connection held on any of the levels above the 13th floor, the middle line of Core Columns 77 to 62, and possibly 59, could have been pulled eastward under the lateral forces. This line of middle core columns would more easily have been pulled eastward, since there were elevator shafts along this line and there were fewer floors that could have restrained these columns and floor beams from deflection. The connections to columns 76 and 78 on any floor above the thirteenth would probably fail first allowing the connection to column 77 to hold and pull the line the line of core columns 77 to 62 and possibly 59 eastward.

The reinforced connections on Floors 19 to 23 could have made it more likely that these connections would have held and buckled the middle line of core columns and destabilized the remaining core columns. As this middle line of columns deflected, they would have pulled the remaining core columns inward toward the middle line, possibly buckling all the core columns on a floor. Debris hitting the girders and beams might have assisted in deflecting the middle line of columns. Columns 78 to 63 and/or 76 to 61 could have been pulled inward since the attached beams would not have shear studs connecting them to the floors. The elevator shafts without floors would offer little resistance to this inward buckling. These core columns which probably had weak splices would have had

to buckle on only one floor to collapse the core structure and implode the whole building.

Photo 23. Façade kink. (Courtesy of NIST)

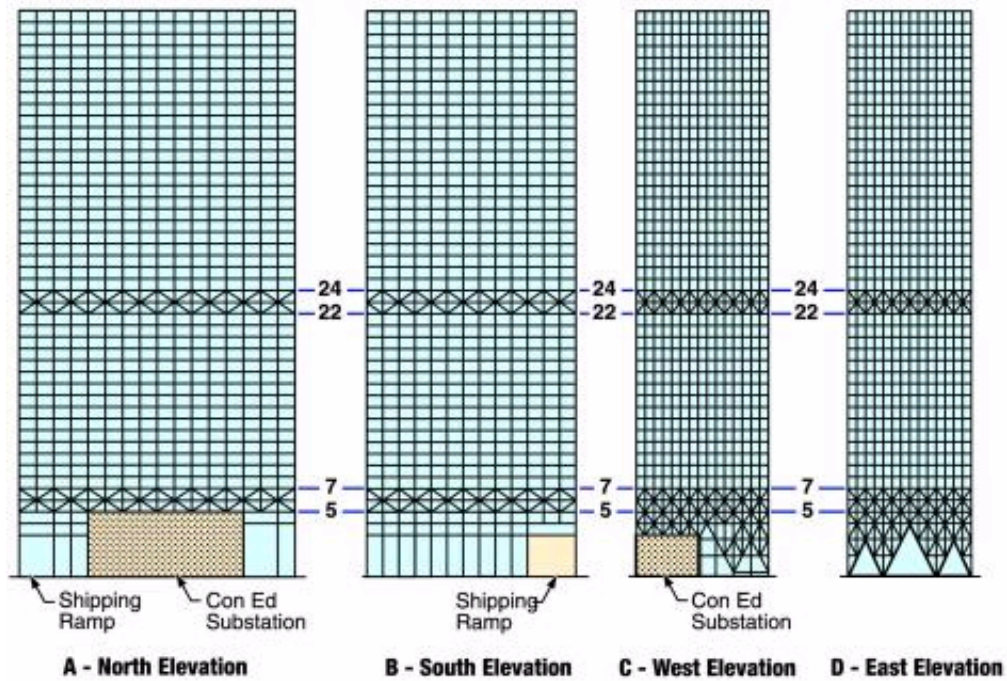


The massive façade kink, which increased as the perimeter wall came down as a unit, was aligned with Columns 76, 77, and 78. This supports the idea that these particular columns were the first core columns to fail on one or more floors and were followed by the remaining core columns, pulling in the entire exterior facade. The pull-in tension on a particular floor or floors could have buckled, say columns 76 to 61, This pull-in tension on the remaining core columns was possibly assisted by a floor or floors disconnecting from the girder along the east-west axis of the core, since “shear studs were not indicated in the design

drawings for the core girders” (NIST). A line or lines of core columns buckling would have collapsed the core and put all the west side floors into suspension putting extreme lateral forces on remaining perimeter column connections on all the upper floors, buckling the entire perimeter wall.

Five seconds after the east penthouse failed, the west shed disappeared into the roof indicating that the core failed before the building began descending. The breaking of the vertical line of windows near Column 54 on the east side of the north wall simultaneously with the sinking of the east penthouse indicates that the wall was being pulled inward by the floors in suspension.

The evidence of dust expulsions from floor to floor *upward* from the southwest corner near the roof, said to be from “detonations,” would have been caused by the floors’ disconnecting sequentially in the corner as the tensions in the suspended collapsing floors increased from core failure. That these failures were upward shows that there were sequentially increasing tensions in lower floors due to exterior wall’s leaning inward.



NOTE: Belt trusses located at floors 5-7 and 22-24.

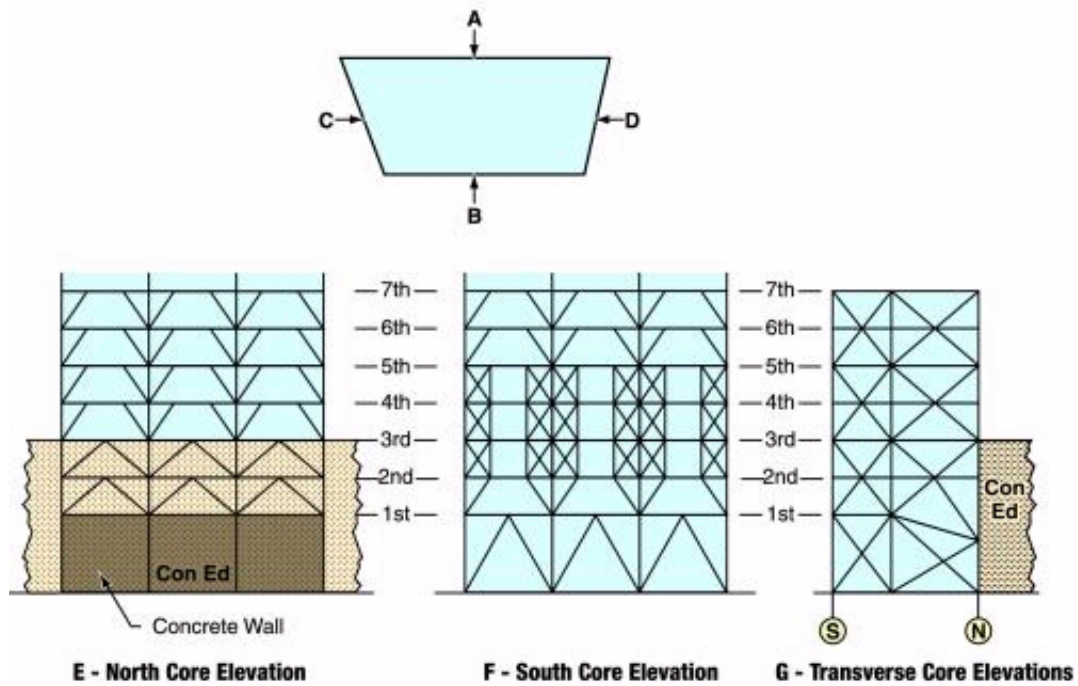


Figure 24. As-built elevations. Building 7.

(Courtesy of NIST.)

The belt truss around the building at the 22nd to the 24th floors stiffened the perimeter wall and probably supported the outer frame so that it came down as a unit above the buckling columns.

There were numerous diagonal braces in the core below the 7th floor. There were also thick reinforced concrete floors on the 5th and 7th floors. The 5th floor diaphragm was 14 inches thick and reinforced with imbedded steel "T" sections. The 7th floor was eight-inch reinforced concrete. This would have made it unlikely that the initial failure started or progressed on these lower floors.

As the core failed, the perimeter walls were pulled inward, with the greatest deflection at the top floors. This "lean in" of the perimeter walls sequentially decreased the pull-in forces on each floor moving upward, and produced increasing forces on each consecutive floor moving lower. Various exterior columns and connections would have failed on the lower floors with the increasing tension. This perimeter wall's buckling was not seen in the videos because it was below the line of sight because of the buildings in the foreground; it looked as though the building had just descended straight into the ground.

The possibility that some weaknesses exist in high-rise buildings constructed with long-span floors and cores without lateral bracing and weak column splices necessitates that all possible failure mechanisms be studied to determine the cause of failure and means to prevent such failure. NIST can do a computer analysis of the forces involved and connection strength to confirm or disprove the analysis and clarify the theory. With the increasing spans and size of floor areas of high-rise office buildings allowed by the use of steel, there is a critical need for new methods to test long-span floors to determine if they are, or can be, adequately protected from fire.

New methods should be developed for testing and determining the forces that affect these floors and their connections under collapse conditions. Long span 'I' beams may be affected by differential heating and expansion of different parts of the web or flanges causing early bowing, buckling or twisting out of alignment, affecting structural integrity. Contraction of sagging steel beams or girders may put extra pull-in forces on columns pulling them out of alignment and buckling them. If these long-span floors cannot be adequately tested and protected against progressive or global collapse, the spans should be reduced and the steel size and strength increased. Surely, lateral bracing of core columns on each floor should be required, the column splice strength increased and alternate load paths should be built in to handle floor loads in case columns fail. In situations where the failure of floor assemblies could affect the stability of the columns, these floors should be considered part of the frame and should have the same degree of fireproofing protection as the columns.