SINGLE POINT OF FAILURE

How the Loss of One Column May Have Led to the Collapse of WTC 7

By Ramon Gilsanz, P.E., S.E., and Willa Ng

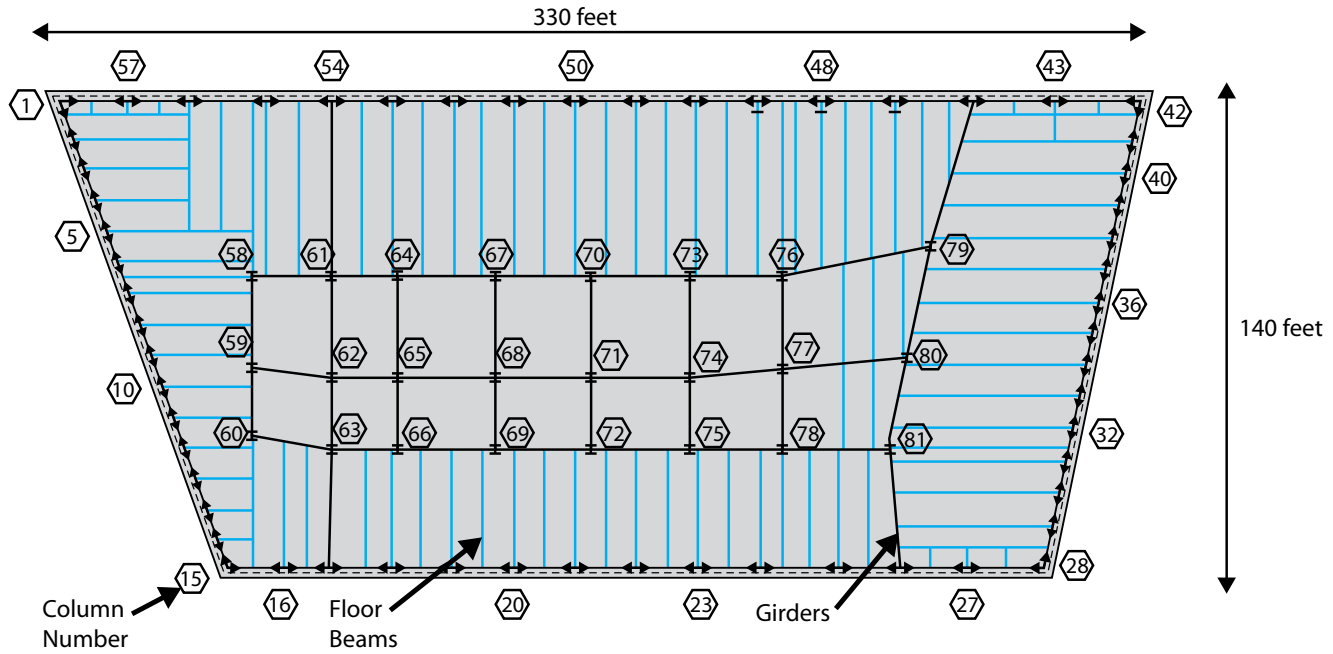
The collapses of World Trade Center 1 (WTC 1) and World Trade Center 2 (WTC 2) on September 11, 2001 were attributed to the impact of two airplanes and the ensuing fires. The subsequent collapse of World Trade Center 7 (WTC 7), which was not directly struck by airplanes, is more of an enigma. Additionally, the nature of its collapse, which occurred nearly seven hours after WTC 1 and WTC 2 failed, has led to rampant speculation.

The following analysis shows that, although there were several phases leading to the global collapse of WTC 7, the building likely would have remained standing if not for the failure of one critical column. The location of this column, and its role as a key structural component, meant that its local failure caused the global failure of WTC 7.

The Federal Emergency Management Agency (FEMA) Building Performance Assessment Team and the National Institute of Standards and Technology (NIST) formed a team to analyze the collapse of WTC 7. The effort began with the collection of structural pieces, existing plans, eyewitness accounts, and photos and videos taken that day. This information led to the formation of several probable collapse theories. The team then created a computerized model of the building, using existing plans and information, to test these theories.

WTC 7, one of the seven buildings that formed the World Trade Center complex in New York City, was bounded by Washington Street, West Broadway, Barclay Street and Vesey Street. This 47-story commercial office building was approximately 330 feet long, 140 feet wide and 610 feet tall, and was constructed over a pre-existing electrical substation owned by Con Edison. The original plans for the substation included the construction of a high-rise tower above it. However,

World Trade Center 7, on the north side of the World Trade Center Complex. The collapse of WTC 1 sent flaming debris into the southern face of WTC 7 and initiated a chain of events that would eventually lead to collapse.



Plan view of typical framing for the upper floors of WTC 7. Columns are identified by number.

the final footprint of WTC 7 was larger than the originally planned high-rise tower. As a result, there were discontinuities between the columns in the Con Edison substation and the columns for the rest of WTC 7. Braced frames, transfer trusses and transfer girders at floors 5 through 7 transferred loads between the discontinuous columns. These elements, though serving the purpose of shifting loads from one set of columns to another, also essentially "tied" the columns to each other. The columns were numbered for ease of identification and will be referred to by their number herein.

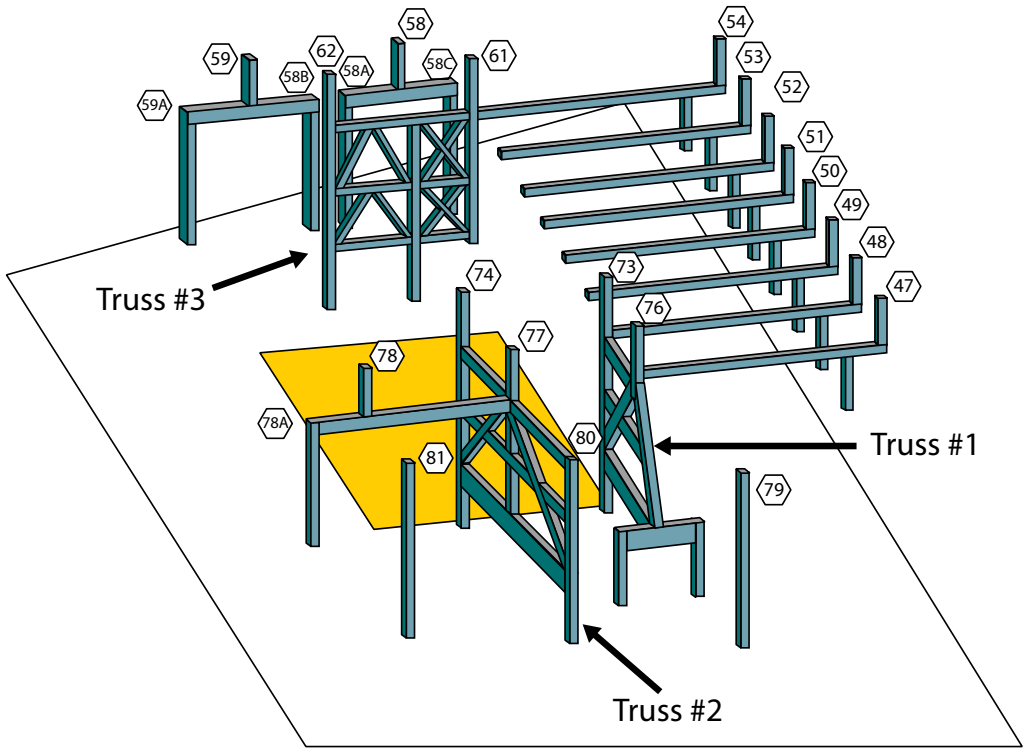
The failure of WTC 1 and WTC 2 sent flaming debris into the southern face of WTC 7. This impact and fire damage initiated a sequence that would lead to global collapse. Eyewitness observations by building occupants, NYPD, FDNY and bystanders indicated that the damage was located on the south face between floors 8 and 18, and that there was a fully involved fire on the south side of floor 7, which included the transfer elements. From 3:00 to 5:00 PM, fires were still burning in the building, which may explain why it took several hours for it to collapse. The continued heat of the fire weakened steel structural components until they failed at 5:21 PM, nearly seven hours after the collapse of WTC 1 and WTC 2.

WTC 7 Collapse Sequence and Observations

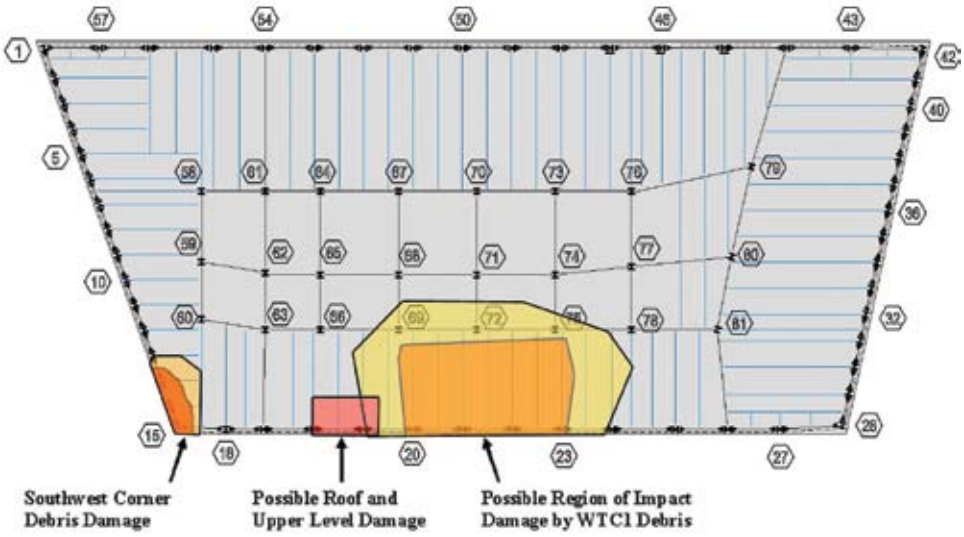
The final collapse of WTC 7 occurred over 8.2 seconds and was recorded on several videos from locations northeast and northwest of the building. Study of these videos led to the development of the timeline of the visible external sequence of events. The images accompanying this article are taken from a CBS News Archives video to show key points observed during the collapse. As seen in the photos, a kink develops in the east penthouse before it falls into the building. The west penthouse then fails, followed by a kink in the entire façade of the building. Total collapse follows.

This sequence of events, with roof elements sinking into a building with an intact façade, suggests an interior failure. An interior failure would explain the appearance of a "controlled" collapse with a relatively small debris field, as seen with WTC 7.

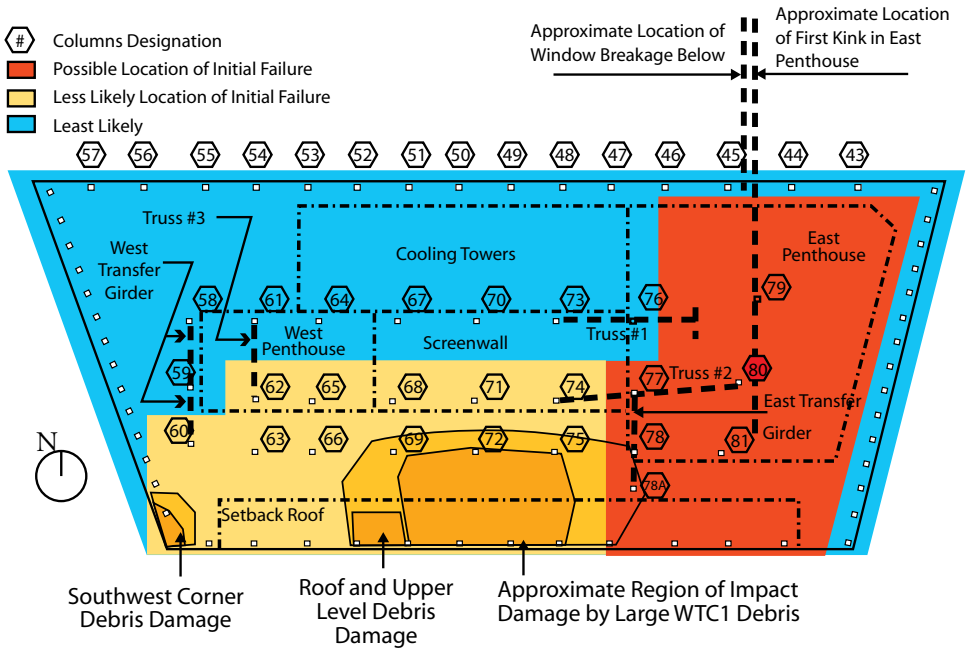
The sequence of final collapse can be interpreted using knowledge of the building's framing from existing plans. For instance, the observed collapse of the east penthouse may signify a failure in a line of columns on the east side of the building (columns 76-81). In particular, interior



Schematic view of transfer trusses and girders between floors 5 and 7.



Possible extent of debris damage from collapse of WTC 1 and WTC 2.



Locations of the collapsed penthouses and the kink in relation to the structural columns.

columns 79, 80 and 81 were located directly below the east penthouse and supported relatively large tributary areas.

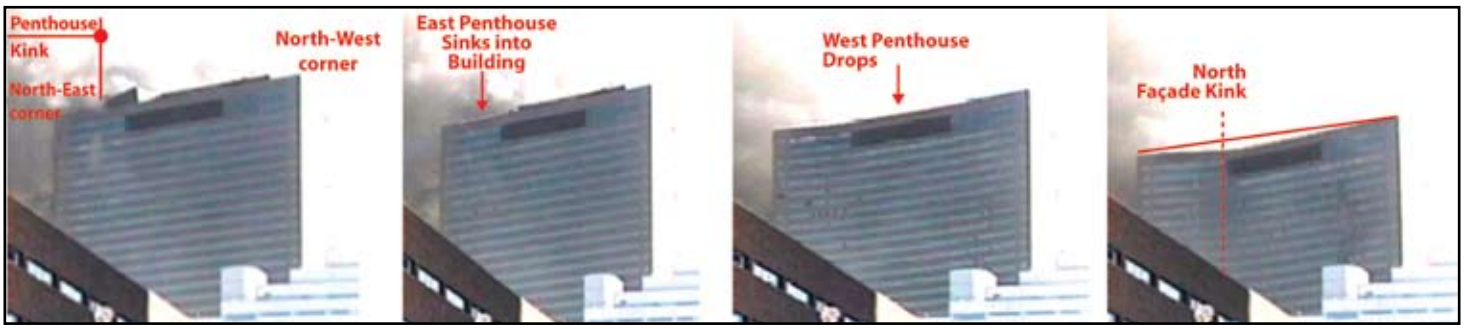
The final collapse hypothesis can be summarized as follows:

1) Debris from the collapse of WTC 1 and WTC 2 caused damage from impact and fire.
2) Fire significantly weakened structural steel and caused the failure of one or more of the columns on the eastern side of the building, as evidenced in the sinking of the east penthouse. This indicated a vertical progression of failure from the damage on the lower floors to the failure of the penthouse on the roof.
3) The sinking of the west penthouse, as well as the shifting of a clear kink from the east penthouse towards the middle of the structure, indicates that the collapse then progressed horizontally, as the localized failure of the eastern columns was distributed to the other columns through the transfer elements at floors 5 through 7.
4) Global collapse was the ultimate result.

A kinematic model was created to test the final collapse hypothesis and isolate the structural elements that may have contributed to each phase of the failure. It was this testing that isolated one column, 79, as the critical structural component whose failure led to global collapse. A collapse mechanism analysis performed for the removal of column 79 produced a deformed shape with a kink in the roof of the east penthouse, as captured in actual videos and photos taken that day.

The video, photographic and first-person account evidence of the collapse of WTC 7 suggests that the impact of debris and resulting fire contributed to the collapse through the weakening of key structural components. The sequence of collapse, most notably the observed behavior of the penthouses, points to several key columns as the first to fail. The failure of column 79 was pivotal in the subsequent global collapse. As shown in the computerized non-linear structural model, its failure initiated the vertical collapse progression. WTC 7's properties of load transfer at floors 5 and 7, when combined with the failure of column 79, led to a horizontal collapse progression, which in turn ultimately resulted in global collapse.

The results of the research performed on WTC 7 suggest that steps can be taken to avoid vulnerabilities in the design of buildings, though no design can be expected to withstand the events of September 11, 2001. The original designers and builders of WTC 7 could not have had any idea that this structure would have to resist such forces. However, the vulnerability of WTC 7 was that damage, though



Start of the final collapse sequence (7.7 seconds elapsed). Note that the kink in the east penthouse in the first photo "shifts" towards the middle of the building in the fourth photo, indicating horizontal progression of the collapse.

significant, should have caused no more than local failure of structural components. That is, buildings should be designed to survive a local failure, due to blast, fire, impact, etc. but prevent the progression of a collapse throughout the structure.▪

Further Reading

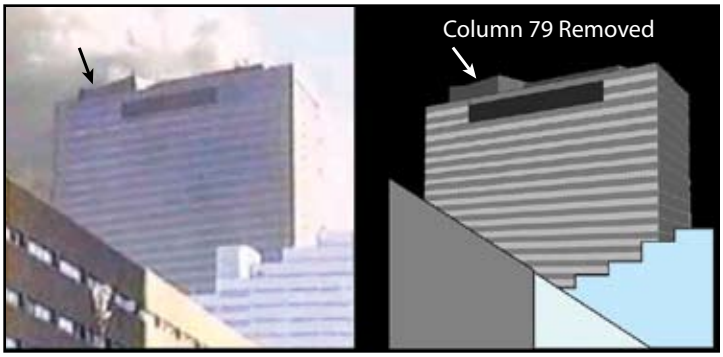
National Institute of Standards and Technology (June 2004), Interim Report on World Trade Center 7, Appendix L

McAllister, T., ed. 2002. World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations. FEMA 403. Federal Emergency Management Agency. Washington, DC, May 2002.

Salvarinas, John J. 1986. Seven World Trade Center, New York, Fabrication and Construction Aspects, Proceedings of the 1986 Canadian Structural Engineering Conference, Vancouver, Canadian Steel Construction Council, Ontario. February 24-25.

Acknowledgements

National Institute of Standards and Technology
Federal Emergency Management Agency
Structural Engineers Association of New York
National Council of Structural Engineers Associations
National Fire Prevention Association
Society of Fire Protection Engineers
American Institute of Steel Construction
New York City Department of Design and Construction
Structural Engineering Institute – ASCE



On the left, a video still showing the kink in the east penthouse. On the right, the kink is recreated when column 79 is removed (simulating a failure).

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