Why they stood—and how they fell

Silverstein Properties, Inc. released a report in October 2002 that takes an in-depth look at the structural behavior of the Twin Towers of the World Trade Center during the events of 9/11.

The following was edited from a press release from Silverstein Properties, Inc., dated Oct. 23, 2002.

Silverstein Properties, Inc. has released engineering reports reflecting the results of a detailed and comprehensive examination of why the Twin Towers of the World Trade Center stood for as long as they did following the Sept. 11, 2001 terrorist attacks, and why they ultimately collapsed. The Silverstein studies establish that the strength and redundancy of the superstructure of the towers allowed them initially to withstand the high-speed impact of a Boeing 767 and save the lives of thousands of occupants below the impact floors. The studies also show that each collapse was initiated separately by a combination of the immediate damage from the impact of an airliner and the resulting fires on the floors that were struck. The collapse of Tower 2, the first to fall, did not cause or contribute to the collapse of Tower 1.

Silverstein furnished the reports to the National Institute of Standards and Technology, the federal agency charged with studying the collapses of the World Trade Center buildings. The studies were conducted by some of the pre-eminent engineering firms in the country, including Weidlinger Associates, LZA Technology / Thornton-Tomasetti, Hughes Associates, ARUPFire and Z-Axis. An additional study of the response and capabilities of the FDNY on 9 / 11 was conducted by Howard Safir of SafirRossetti. Based on extensive analysis of available data, including original structural engineering plans, thousands of photos and dozens of videos, and the use of advanced computer modeling and fire evaluation techniques, the engineering team retained by Silverstein was able to recreate the condition of each tower at various critical points from impact to collapse.

COMPUTER MODELS SHOW HOW THE BUILDINGS REACTED TO THE STRIKES

Using software developed for the Department of Defense, the engineers from Weidlinger Associates, led by Matthys Levy, P.E., and Dr. Najib Abboud, developed sophisticated and detailed computer models of the effect of each plane's impact on the towers to understand what happened within the building on the impacted floors. Working with researchers from LZA Technology / Thornton-Tomasetti, led by Dan Cuoco, P.E. and Dr. Gary Panariello, P.E., the team determined that the impacts destroyed 33 out of 59 perimeter columns in the north face of Tower 1, and 29 out of 59 perimeter columns in the south face of Tower 2. Computer analysis by Weidlinger showed further that the planes also destroyed or disabled approximately 20 out of 47 columns in the center of the core of Tower 1, and approximately five out of 47 columns in the southeast corner of the core of Tower 2.

Because the towers were designed with a redundant system of perimeter and core columns, connected at the top

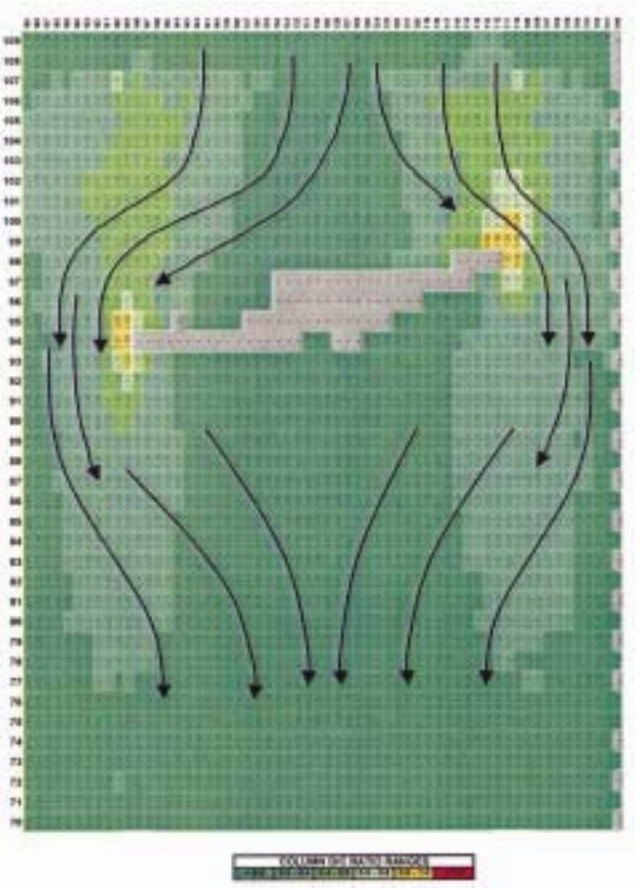

Figure 1. Diagram illustrating the way Tower 1 redistributed loads to other columns on its north face, and prevented immediate collapse, as modeled by Weidlinger Associates.

with a steel framework known as a "hat truss," the weight or "loads" meant to be carried by the impact-damaged columns were redistributed to the remaining columns. This load redistribution allowed the towers to remain standing for as long as they did. The team concluded that, absent further fire damage, the towers would not have collapsed. Matthys Levy of Weidlinger stated: "The fact that Tower 1 stood for 103 minutes after losing approximately 53 column lines and that Tower 2 stood for 56 minutes after losing approximately 34 column lines is a testament to the strength of the buildings and the skill of Leslie Robertson and the other engineers who designed them. I believe that few, if any, other buildings could suffer that amount of damage and not collapse immediately."

The analysis also shows that the tremendous force of each airliner crashing into a tower and breaking apart not only fractured columns outright but also stripped other columns of fireproofing (See Fig. 1). No fireproofing is designed to withstand such devastating impacts. The loss of fireproofing left those columns vulnerable to the subsequent fires, which after time, caused them to fail. Additional computer models of the towers assessed the status of each building at the time of collapse. Those models identify the failure of columns that either lost fireproofing or were destroyed on impact as the specific cause of the collapse of each tower.

FLOOR TRUSSES WERE NOT RESPONSIBLE FOR THE COLLAPSES

Failure of the "floor trusses" was shown not to have had any significant role in the initiation of the collapses. A thorough review of photos and videos by a team of fire engineers from Hughes Associates, led by Dr. Craig Beyler, and from ARUPFire, led by Richard Custer, MSc, shows that the floors of the towers survived the initial airplane impacts, suffering only localized damage from the crashes (See Fig. 2). Their studies also found, on the basis of an extensive review of smoke plumes and fire spread in each tower, that the ensuing fires did not lead to the collapses of impact floors before the towers fell. In addition, the computer modeling of the collapses demonstrated that the failure of columns alone, independent of the floors, explains the collapses. These findings build on the work by the Federal Emergency Management Agency study in its World Trade Center Building Performance Study of May 2002, which suggested that the floor truss system in the Towers "should be subjected to more detailed evaluation." The FEMA study states that the floor truss systems "should not be regarded" as "design deficiencies."

THE FIREPROOFING WAS INSPECTED REGULARLY

The studies also refute speculation that the fireproofing in the Twin Towers had not been properly monitored. While maintenance records were destroyed in the collapses, inspection reports for the Twin Towers were located and analyzed. A study of those reports confirmed that fireproofing on the structural steel was regularly examined. The researchers concluded that the structural integrity inspection program conducted by the Port Authority represented a greater standard of care than is generally followed for high-rise office buildings in New York City. The analysis also showed that fireproofing was stripped from the structures only in the paths of the aircraft debris.

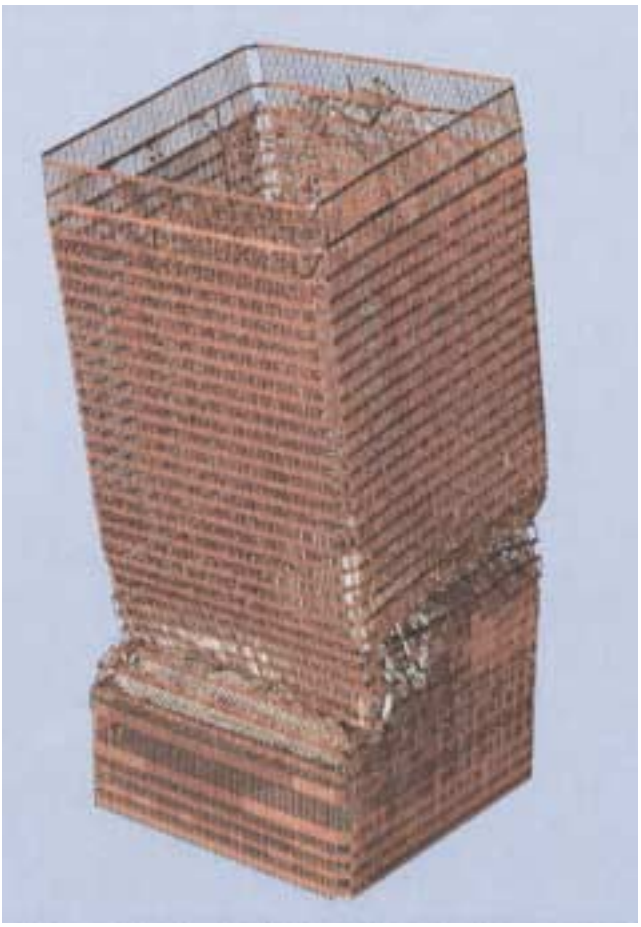

Figure 2. One frame from the computer model of the initiation of the collapse of Tower 2 performed by Weidlinger Associates.

THE REASON WHY TOWER 2 FELL FIRST

The studies conducted on behalf of Silverstein also answer the question of why Tower 2, struck 16 minutes after Tower 1, fell first. Photogrammetric studies of videos showed that American Airlines Flight 11 hit the middle of Tower 1 almost dead on at a speed of approximately 500 MPH. In contrast, United Airlines Flight 175 struck Tower 2 off center and on a diagonal flight path at approximately 550 MPH. The team concluded that because Tower 2 was hit off center, Tower 2 was left without one of its corner columns in the core of the building and, like a table losing one of its legs, had less ability to redistribute the weight meant to be carried by the weakened or lost columns; this effect was further accentuated by the fact that Tower 2 was struck at approximately 12 floors lower than was Tower 1. In contrast, the core of Tower 1 after impact retained its corner columns and, like a table with all four of its legs, was better able to redistribute the weight meant to be carried by lost columns.

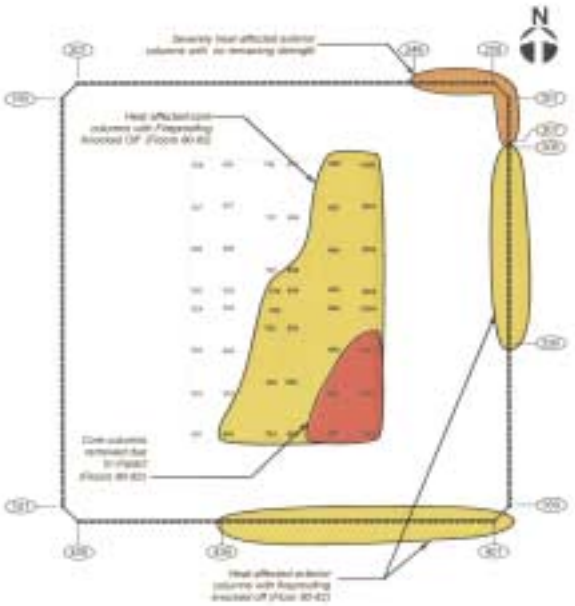

Figure 3. Schematic of impact of floor of Tower 2 showing estimation of core columns damaged by impact (in red) and columns stripped of fireproofing by impact (in yellow).

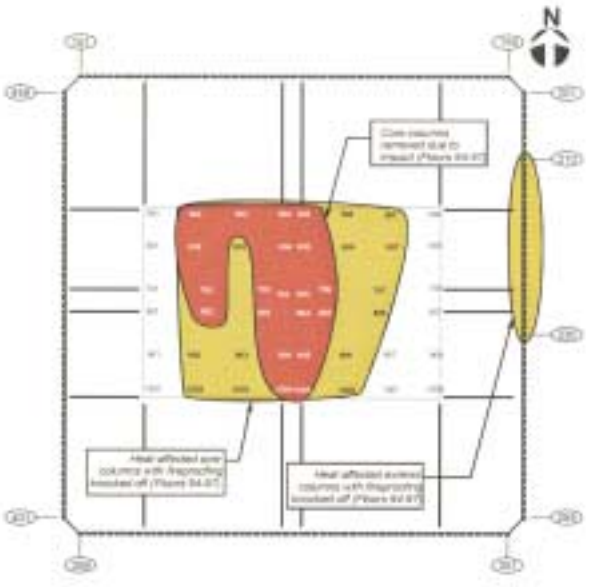

Figure 4. Schematic of impact of floor of Tower 1 showing estimation of core columns damaged by impact (in red) and columns stripped of fireproofing by impact (in yellow).

FIRE TEMPERATURES WERE LOWER THAN TYPICAL FULLY DEVELOPED OFFICE FIRES

Examination of the fires on the impact floors provided further insights. The teams from Hughes and ARUPFire found that the releases of jet fuel acted like huge "matches" to start fires, but - contrary to some speculation - the "matches" burned out quickly and did not cause the fires to be hotter or spread faster. Rather, the fires were fueled by office furniture and floor contents that were initially ignited by the jet fuel. The analysis showed that the fires on the impact floors were not as hot and did not spread as rapidly as normal office fires, primarily because the dust and debris distributed by the crashes inhibited the fires. The engineering team determined average air temperatures in the impact floors to be between 750" F to 1300" F (400" C to 700" C), with higher temperatures at some perimeter locations. Tragically, the fires were nevertheless hot enough to eventually weaken the columns stripped of fireproofing (See Fig. 3 and Fig. 4)

Figure 5. Pattern of heavy debris after the collapse of Tower 2, as mapped by LZA Technology.

THE COLLAPSE OF TOWER 2 DID NOT CAUSE OR CONTRIBUTE TO THE COLLAPSE OF TOWER 1

The engineering analysis led by researchers from LZA Technology/Thornton-Tomasetti examined the way in which each tower collapsed. Once collapse initiated in each tower, essentially all of the interior structure of the tower fell straight down, with floors pancaking on top of one another. The network of perimeter steel columns and spandrels acted like a chute to funnel the interior contents into the tower footprint. Some debris, primarily the perimeter columns, was thrown outward from the face of the tower, creating a lobe pattern of debris. Based on an extensive review of the collapses, debris captured in photos and videos, and observations of engineers involved in the Ground Zero rescue, recovery and cleanup efforts, the team was able to identify the actual pattern of debris from each building collapse (See Fig. 5). This analysis establishes that the collapse of Tower 2 did not cause any significant structural damage to Tower 1. Because the towers were offset, Tower 1 stood out of the way of the falling Tower 2 walls, and pieces of debris only scraped the surface of Tower 1.★