The World Trade Center Destruction and the Role of the Quoted Expert

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THE EVIL EVENTS OF SEPTEMBER 11, 2001, shocked the world. Horrific, unthinkable images—fully fueled 767s slamming into two of the world's tallest buildings, burning and ultimately collapsing them to the ground—mask the true tragedies of the day. More than 3,000 people were killed, including hundreds of fire-fighters, who selflessly rushed into the doomed structures, fully intending to climb several hundred feet of stairs and save others, as if this were just another building fire.

A Paradigm Shift for Structural Engineers

Who would have conceived of intentional aircraft impact in the design of a building? How could the towers have withstood the impacts and resisted collapse for 56 minutes and 104 minutes with such gaping holes in the structural systems? Who would consider the combined effects of aircraft impact, explosion, and a hydrocarbon fire? How could the towers have collapsed—and collapsed entirely?

The structural-engineering community found itself in the unenviable position of trying to explain what happened to the public—no easy task, even with what was known about the sequence of events. It is our considered opinion that no structural engineer could have honestly expected the results we all saw, much less explained the sequence of events that led to the collapses so quickly after impact. Nonetheless, many were almost immediately asked for opinions. Many accommodated these requests, some with unfortunate results.

First Do No Harm

Presumably none of the *professionals* who were asked for their opinions were on the scene prior to being asked for their opinion. So, on what did they base their statements?

One well-respected engineer was contacted while at a job-site trailer for one of his projects. Although he had not seen any of the TV coverage, he gave honest and correct answers to the questions that the reporter asked. When the final article appeared, and after he and others had benefit of video footage and newspaper photographs, this deservedly respected engineer was undeservedly made to look unknowledgeable.

Another engineer was quoted as saying that no commercial building of this type would have been designed to resist the impact of an airplane. Fortunately for both that engineer and the reporter, a second engineer suggested that such a definitive statement could not be made, because he thought that the Twin Towers actually had been designed for large-aircraft impact. This was, in fact, the case, and verified in numerous contemporary published sources as well as in a verbal statement made one week earlier at an

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international conference by one of the structural engineers who designed the building.

So, how do these and the numerous other incorrect, uninformed, and misquoted statements get into print? In an attempt to inform the public, the news media looks for experts to interview. They pursue their own sources and those on lists of experts provided by the various institutions and organizations that attempt to both help and get their own names and/or agendas in front of the public. The number of *experts* available in the beginning of this process is exceeded only by the appetite of the news media for the quotes they can generate.

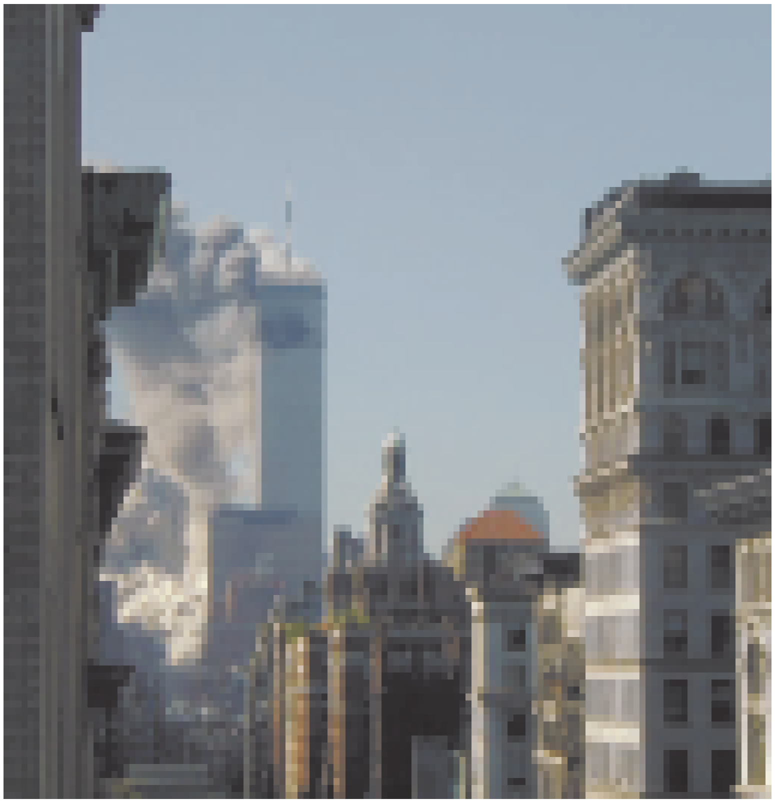
Fortunately, the field quickly narrows to those experts who were found to have provided reliable interviews. At the same time more information continues to become available, thus further improving the accuracy of statements made by the experts. Regardless, the real need for society and the profession is a long-term evaluation of the evidence to determine what we can do better in the future.

What Do We Know?

It is still important for the structural engineering profession to try to determine, with some level of surety, exactly what happened and how the structures responded each step of the way.

In order to add some level of organization to this long-term study, the American Society of Civil Engineers and its structural engineering institute formed a team with the American Institute of Steel Construction, the American Concrete Institute, the Society of Fire Protection Engineers, the National Council of Structural Engineering Associations/Structural Engineers Association of New York, and other professional organizations. This group will collect data, including still photographs and videos of the entire duration of the catastrophic event. That will be followed with an analysis of the actual structure and the physical data collected at the site. A final report will be issued, and any recommendations appropriate to the evidence will be made to the appropriate building-regulation organizations.

With this brief discussion as background, we will attempt to provide a summary of what is believed to have happened to the Twin Tower structures. The reader should keep in mind that, although we have significant experience in dealing with steel building structures, neither of us has been to the site. So, like the other experts, our assessments are based on studying photographs and videos and carefully reading the reports from the site. This article was written two months after September 11. We had the benefit of time that experts quoted in those days immediately after the attack did not have. We are providing this analysis in the hope that it will help the reader put into perspective the talents of past and current structural engineers and what may have been heard and what will be heard about how these structural symbols of American ingenuity behaved.



The World Trade Center Towers are struck…

The Structural Concept of the World Trade Center Towers

The twin towers were each 110 floors and more than 1,353 feet tall. The structural system consisted of a perimeter moment frame for gravity and lateral loads and a core gravity frame. These two elements were tied together at each floor level with a floor diaphragm and at the top of each tower with an outrigger system.

The 208-foot-wide facade was a prefabricated steel lattice, with 14-inch-square steel box columns on 39-inch centers acting as wind bracing to resist all overturning forces. The central core had larger rectangular steel box columns to carry gravity loads primarily. Some lateral loads were transferred to the core by the tower-top outrigger system.

There were no columns within the building between the perimeter and the core systems, allowing for an expansive column-free floor space. The floor construction was of prefabricated steel trusses with metal deck and concrete floor slabs. The floor framing system spanned 60 feet from the perimeter to the core in most cases and was 33 inches in depth.

The Timeline of Events

The Twin Towers of the World Trade Center were known as Tower 1 and Tower 2. They were also referred to as the North Tower (Tower 1) and the South Tower (Tower 2). In

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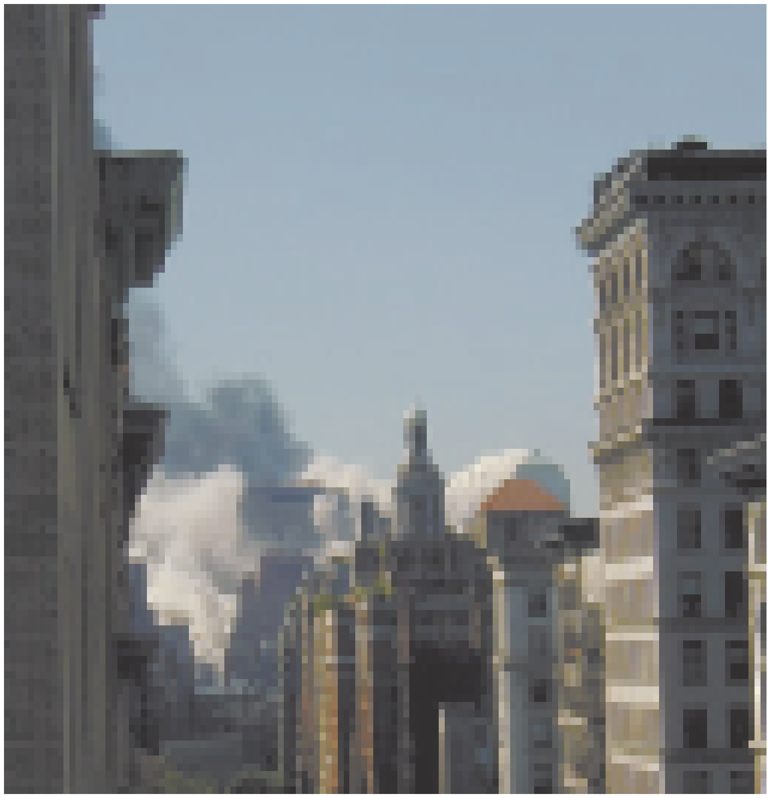
photographs, Tower 1 can be recognized as the tower with the large antenna on top.

At 8:48 a.m. on September 11, 2001, Tower 1 was hit from the north by an American Airlines Boeing 767 carrying 92 people and approximately 14,000 gallons of jet fuel. The impact occurred between approximately the 92nd and 95th floors, approximately 200 feet from the top. It appears that the impact severed two-thirds of the 61 columns on the north face as well as several floors at the impact site.

At 9:03 a.m., a United Airlines Boeing 767 with 65 people on board hit Tower 2 from the south at levels 78 to 84, approximately 400 feet from the top and also severing approximately two-thirds of the columns on the south face. Again, several floors at the level of impact were destroyed in the area of impact. Presumably, the structure in the building core was also damaged, but the full extent of that damage may never be known. It is also likely that there was damage to the perimeter columns on the faces opposite to those into which the planes collided because some portions of the plane penetrated completely through the buildings.

Explosions upon impact further weakened the structures. Jet-fuel-fed fires burned over multiple floors in both buildings, and at 9:59 a.m., Tower 2 collapsed. A review of video footage and several still photos indicates that the upper levels of this tower first leaned to the southeast, toward the damaged face of the tower. This tower section then appears to have straightened and, with a small clockwise rotation, initiated the progressive collapse and total destruction of the tower. Essentially, this was tantamount to a 30-story building falling onto a 70-story building.

At 10:28 a.m., Tower 1 collapsed. Again, a review of video footage indicates that the upper levels of the tower progressed fairly straight down as could be seen by observation of the collapsing structure and positioning of the rooftop antenna during the collapse. Much like the collapse of Tower 2, the collapse of Tower 1 was tantamount to a 10-story building falling onto a 90-story building. Although both towers appeared to collapse straight down, falling in on themselves, subsequent investigation at the site has shown that there is extensive damage to surrounding buildings as a result of falling debris.



. . . and Collapsing. Two of six shots by Peter Girgis at NBBJPhotos.

Two other buildings in the complex also completely collapsed. The New York Marriott World Trade Center Hotel, also known as World Trade Center 3, was heavily damaged by debris falling from the collapse of Tower 2. The remaining structure of the hotel collapsed when hit with the debris falling from the collapse of Tower 1. Also, at 5:25 p.m., after almost eight hours of uncontrolled burning, the 47-story World Trade Center 7 building collapsed, again in what appeared to be a straight-down mode. This collapse, however, seemed to initiate in the lower portion of the building. It is believed that a 24-inch high-pressure gas main ran through WTC 7 and that 40,000 gallons of diesel fuel were in tanks in the building. It also housed a seven-story electrical generation substation, thus exacerbating the fire exposure.

Three other buildings, World Trade Center 4, 5, and 6 were all heavily damaged by falling debris and suffered at least partial and at most near-total collapse. Dozens of other buildings in the immediate vicinity suffered impact damage from the falling debris. Hundreds of other buildings farther into the perimeter suffered façade damage and/or were infiltrated by the billowing dust cloud that was pushed in all directions by the collapses.

How Did the Towers Stand After the Initial Impact?

Designed for significant wind loads, the Twin Towers had a structural system that afforded the buildings a significant amount of redundancy or reserve capacity—much more than most, if not all, other buildings would have. Upon impact, the perimeter and core framing that remained spanned over the large damaged area, functioning as a very large Vierendeel truss, supporting the loads and resisting progressive collapse.

The actual resistance to progressive collapse observed in the Twin Towers is staggering. Conventional design for progressive collapse would have assumed the removal of a few column elements and made provision for additional strength in the surrounding structure to resist the resulting redistribution of load. In this case, however, a 140-foot-wide segment of one tower was removed—and the tower *still* initially stood up.

Some believe that, had there not been the significant jet-fuel-fed fires, and barring a significant wind load, the

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Twin Towers may have stood in spite of the large amount of structural damage. Although further investigation may suggest other scenarios, it is generally believed that the extent of the fires progressively weakened the remaining structures beyond even their significant reserve capacity.

Why Did the Buildings Collapse?

As with most structural systems, the components all work together to resist the gravity (vertical) and lateral loads. The floor slabs and metal deck brace the trusses that support the floors. Those trusses in turn brace the columns that support the trusses. Thus, damage to one element—or many of these elements as in this case—can impact the capability of the other elements to perform.

It is likely that the deflection of the floor trusses, because of the quickly and significantly elevated temperatures, compromised the floor slabs. This likely then reduced the bracing provided to the trusses, which in turn likely reduced the bracing provided to the columns. At the same time, all of these elements were becoming progressively weaker as the temperatures increased in what was essentially a fire with an inexhaustible supply of fuel.

Alternatively, it may have been that the fires weakened the structure in the core, and the core and floor systems collapsed first, overloading the perimeter. We may never know whether it was the floor system that collapsed first, raining extensive debris onto the floors below, or the inability of the floor system to continue to provide lateral support to the columns that initiated the progressive collapse.

What is clear is that an extremely intense fire over a significant number of floors, coupled with the damage to the structural and fire protection systems as a result of the explosions upon impact, was well beyond what even the most significant building would have been designed to withstand.

Why Did the Second Tower Hit Collapse First?

This can best be understood by looking at the levels at which the impact took place. For Tower 2, there were 26 levels of building above the damaged columns. Thus, the weight of the upper portion of the structure overcame the remaining strength of the structure immediately below more quickly than that same condition occurred in Tower 1, where only 15 levels were supported above the damage.

In the opinion of the writers, both towers withstood extreme damage beyond what could reasonably be expected of any building. Thus, although 3,000 lives were lost, many more were saved because of the time between the initial impacts and subsequent collapses.

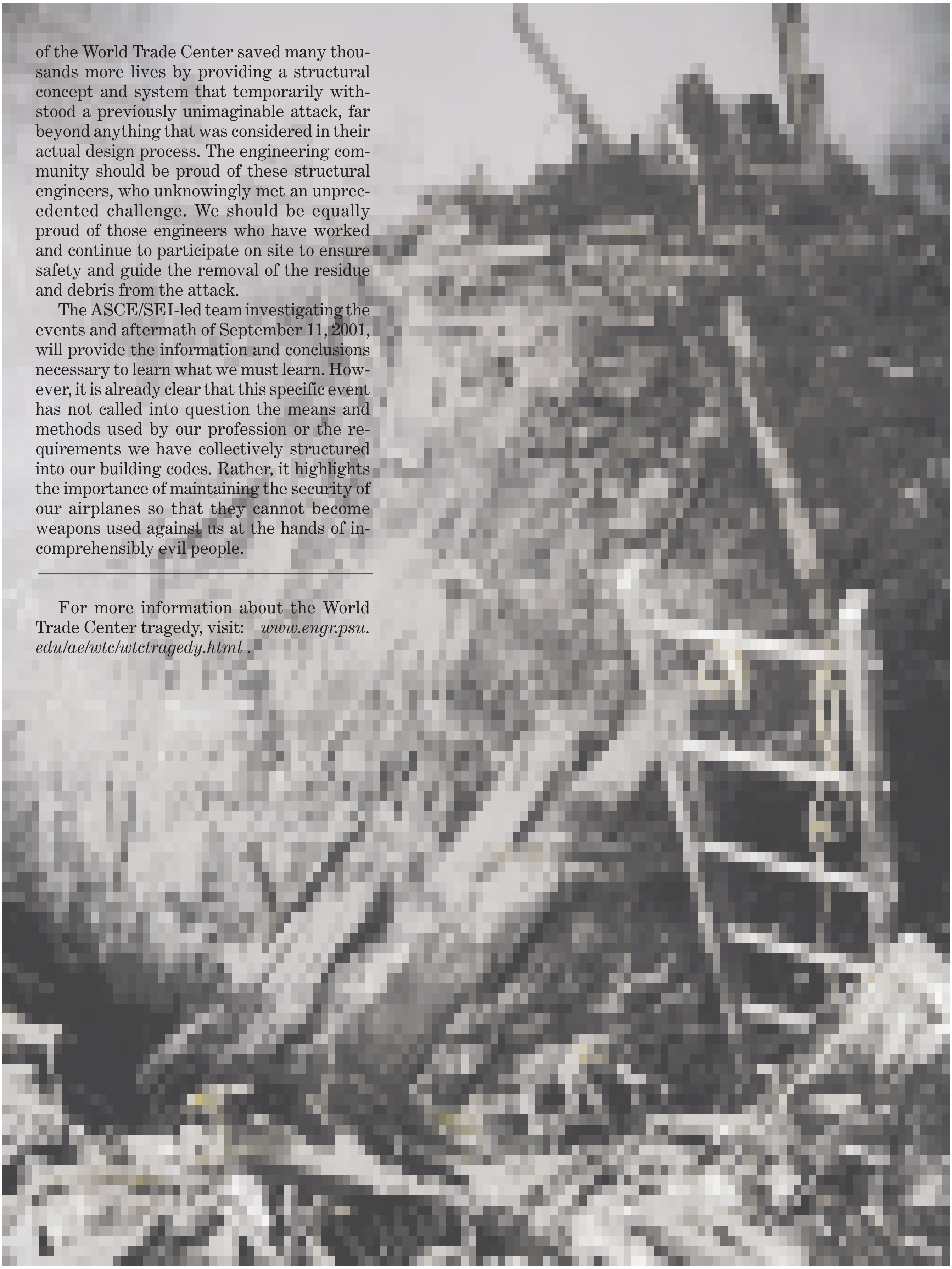
What Must We Learn From This Tragedy?

We as a profession must learn what we can from this tragic event. But we must not jump to conclusions as a result of it—particularly those that are wrong or opportunistic at best. Unfortunately, many so-called experts have already proffered easy answers of little worth, confusing the real issues and answers. Some have even tried to capitalize on the natural fear and uncertainty to advance their own material or product-specific competitive interests. Shame!

It is difficult in light of the thousands who died on September 11, 2001, to assess the structural performance of the World Trade Center and many surrounding structures as successful. But it must be recognized that the designers of the World Trade Center saved many thousands more lives by providing a structural concept and system that temporarily withstood a previously unimaginable attack, far beyond anything that was considered in their actual design process. The engineering community should be proud of these structural engineers, who unknowingly met an unprecedented challenge. We should be equally proud of those engineers who have worked and continue to participate on site to ensure safety and guide the removal of the residue and debris from the attack.

The ASCE/SEI-led team investigating the events and aftermath of September 11, 2001, will provide the information and conclusions necessary to learn what we must learn. However, it is already clear that this specific event has not called into question the means and methods used by our profession or the requirements we have collectively structured into our building codes. Rather, it highlights the importance of maintaining the security of our airplanes so that they cannot become weapons used against us at the hands of incomprehensibly evil people.

For more information about the World Trade Center tragedy, visit: *www.engr.psu.edu/ae/wtc/wtctragedy.html* .



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