TMS Hot Topic Symposium Examines WTC Collapse and Building Engineering

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A special symposium was held at February's 2002 TMS Annual Meeting in Seattle, Washington, to discuss materials issues arising after the World Trade Center (WTC) collapse. The speakers in this session examined the collapse and speculated on materials and processing issues that could help harden new as well as existing buildings against this type of overwhelming stress and massive fire. These types of demanding situations may arise from terrorist attacks, but have also been known to result from such natural events as earthquakes and severe weather.

Chris Musso, with contributions from his co-author Thomas Eagar, analyzed the WTC collapse with an engineer's eye. Musso is a graduate student and Eagar is the Thomas Lord Professor of Materials Engineering and Engineering Systems, both at the Massachusetts Institute of Technology (Cambridge, Massachusetts). Musso and Eagar co-authored a paper for the December issue of *JOM* on the WTC collapse; the February symposium was an extension of that article.

Musso gave a thorough and very instructional description of the engineering factors that contributed to the collapse of two of the buildings at the WTC site. He discussed the structure of the buildings, the physics of the impact of the aircraft, and the characteristics of the resulting fire. He then described the materials in the structure and how these materials were affected by events.

From pictures of thick black smoke billowing from the towers, Musso inferred a fuel-rich situation which limited the temperature of the fires. Though this established that the steel structure did not melt, the exact method of failure of the towers is not known. The evidence suggests that failure of truss supports and buckling of external or internal columns contributed to the

TERRORISM'S IMPACT STILL OCCUPIES GOVERNMENT, RESEARCHERS

Maureen Byko

When the twin towers of the World Trade Center (WTC) collapsed, structural engineers immediately went to work to figure out why. Although the buildings were destroyed shortly after they were hit by passenger planes, evidence was available not only from the rubble, but also from photographs, video and audio recordings, and witnesses. Interest in the investigation remains high, as shown by the strong attendance at a TMS symposium on structural issues in the WTC attack, held during the 2002 TMS Annual Meeting. Following is information that was not presented during the symposium, but follows up on details provided in the December 2001 issue of *JOM*.

Researchers Believe High Plane Speed Accelerated South Tower Collapse

Researchers trying to explain why the WTC's south tower fell first, although it was struck second, estimate the passenger jet that hit the south tower had been flying as fast as 943 km/h, about 161 km/h faster than the other hijacked plane, according to a February 23 report by *New York Times* reporters Eric Lipton and James Glanz.

The speed of the two planes at impact has been calculated using a mix of video, radar, and recorded sounds. Research by government and private scientists has resulted in two estimates, both of which show that when United Airlines Flight 175 hit the south tower at 9:02 a.m., it approached much faster than American Airlines Flight 11, which hit the north tower at 8:46 a.m. The United plane was moving so fast, in fact, that it was at risk of breaking up in midair as it made a final turn toward the south tower, traveling at a speed far exceeding the 767-200 design limit for that altitude, a Boeing official told the *New York Times*.

The south tower, struck between the 78th and 84th floors, fell within 56 minutes and the north tower, hit between the 94th and 99th floors, fell after 102 minutes. The buildings' collapse has been attributed to a combination of structural damage and fires. The difference in the towers' survival times, which translated into a difference in evacuation time for tenants and rescue personnel, could be related, in part, to the planes' speeds, researchers said.

The flight-data recorders from the two planes have not been found. However, Eduardo Kausel, a professor of civil and environmental engineering at Massachusetts Institute of Technology (MIT), studied videos of the attack and estimated that the United plane was traveling an estimated 864 km/h, while the American plane was traveling 690 km/h. The U.S. Federal Bureau of Investigation estimated both plane speeds higher, at 943 km/h for the United flight and 795 km/h for the American one. Although the estimates vary, in both cases, the planes were flying much faster than they should have been at that altitude: the aviation agency's limit below 3,084 m is 462 km/h.

Because kinetic energy varies as the square of its velocity, minor differences in speed can translate into major variations of the energy absorbed by the buildings upon impact. Therefore, although the United jet was traveling only about 25 percent faster than the American jet, it would have released about 50 percent more energy on impact.

Even at a speed of only about 805 km/h, a partly loaded Boeing 767 weighing 134 t would have created about 3 billion joules of energy at impact, the equivalent of 0.75 t of TNT, according to another team of researchers at MIT. Only about 6 percent of that energy would be consumed by cutting more than 30 exterior steel columns, said Tomasz Wierzbicki, a professor of applied mechanics at MIT, who did his research with a student, Liang Xue. About 25 percent would be spent destroying floor structures and 56 percent damaging structural columns in the core.

If the plane that hit the south tower had been traveling slower, and the tower perhaps had stood longer, it is still unclear how many more people would have survived. Even though the south tower fell in only 56 minutes, fewer tenants died in it than in the north tower, largely because many of the people who worked in the upper floors had evacuated during the 16 minutes between the two attacks. But extra time might have meant that those

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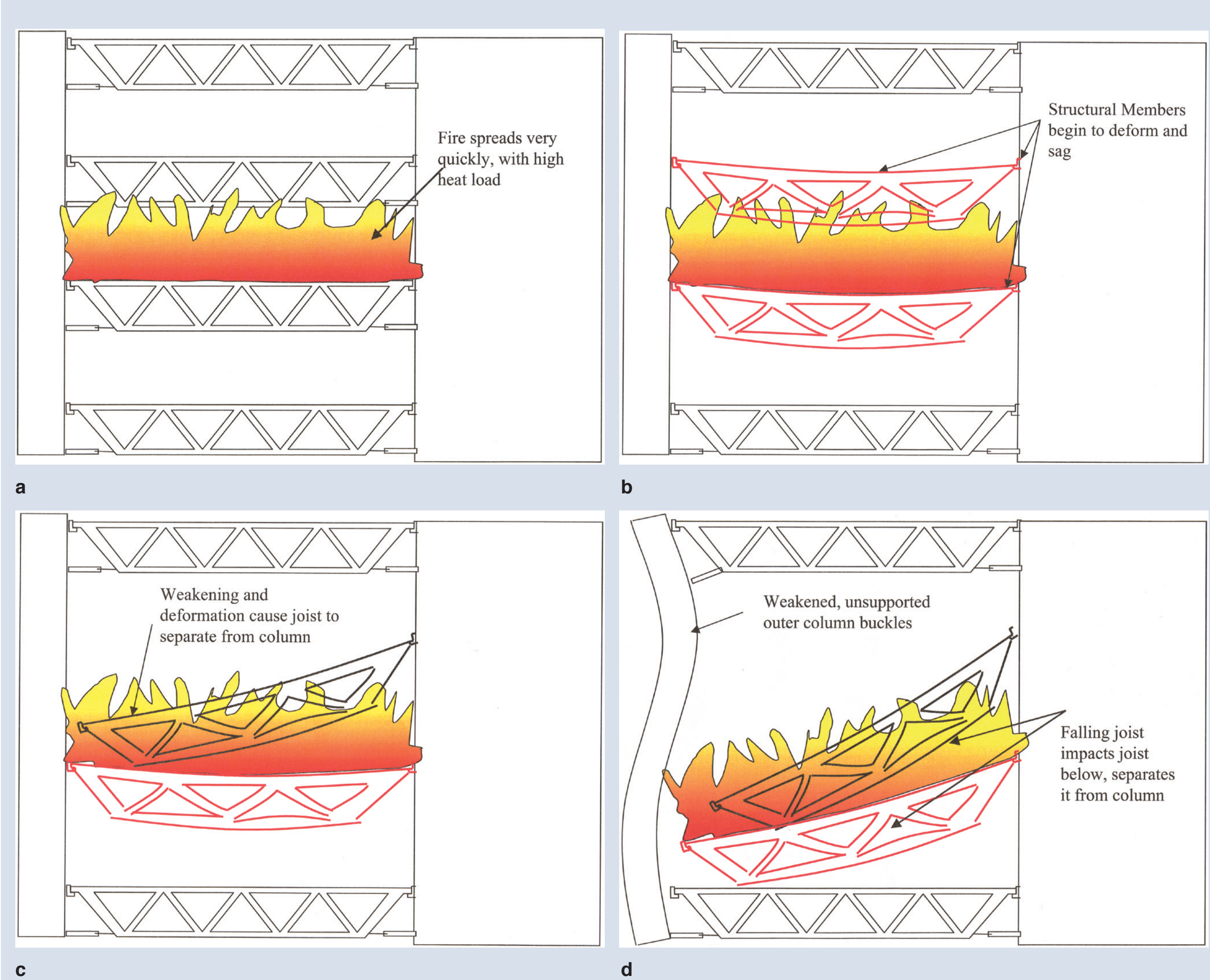

Figure 1. (a–d) An illustration of the progressive structural failure in the World Trade Center collapse.

collapse (Figure 1). Interestingly, because the WTC is a unique building due to its wide cross section near the top (63 meters), it may have survived the impact better than newer buildings. Most newer buildings would have an upper cross section more narrow than the wingspan of a 767 aircraft (48 meters).

Musso concluded by discussing the responsibilities engineers have in the wake of such tragic events. Engineers must work to improve safety and redundancy in building design, as well as improving training, leadership, and communication in building operation.

John Hooper, of Skilling Ward Magnusson Barkshire (Seattle, Washington), revealed a structural engineer's view of materials for construction. His discussion focused on concrete, steel, and wood, which are the materials that most easily meet the stringent cost constraints of the construction industry as well as the code-mandated design requirements. He described why structural engineers tend to use the materials they understand in different ways rather than to develop new materials.

Hooper discussed ways structural engineers make buildings stronger. New material technologies include wrapping concrete with carbon- and glass-fiber composites. The industry primarily utilizes new composite configurations of old materials, such as engineered wood, steel encased in concrete, and concrete poured into steel forms.

The main barrier to the use of new materials is cost, as the materials cost is 15–20% of the cost of building construction. Other barriers include the availability of new materials to contractors as well as the contractors' familiarity with the new material or process. Hooper discussed two reasons that using a proprietary material for construction can be difficult. First, the cost of a unique material or process may be higher than expected, and also the contractor will have a steep learning curve to use an unusual material.

Additional barriers deal with building codes and the need to adhere to existing standards. Years of effort and very aggressive champions are always needed to get a new material into common use. As an example, Hooper discussed the difficulty in persuading building officials to accept fly-ash residue from coal burning as a component in concrete. Adding fly ash makes concrete a more environmentally friendly material, but required federal legislation to overcome skeptics.

Finally, Hooper discussed how computer-aided design is enabling new forms and radical structures.

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