a weekly look at science and techology at stanford

INNOVATION

Why & how the World Trade Towers collapsed

By DEBBIE BEREBICHEZ

In the 1960s, Minoru Yamasaki, architect of the World Trade Center, expressed the founding philosophy behind its construction.

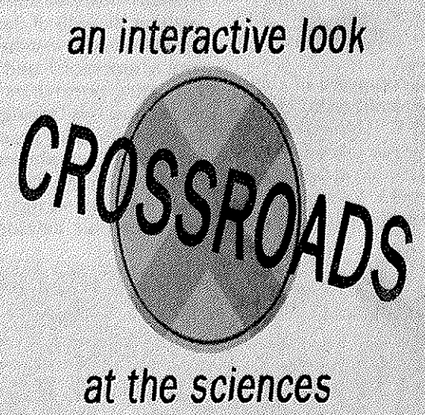
"The World Trade Center should, because of its importance, "become a living representation of man's belief in humanity, his need for individual dignity, his belief in the cooperation of men and through this cooperation his ability to find greatness," he said in his book Architects on Architecture: New Directions in America

On September 11 of 2001, barely 30 years after they opened, the twin towers were lost to a terrorist attack.

To all of us who watched the images of the two planes hitting the North and South towers of the Trade center complex, it was clear that the structures were critically compromised, but perhaps few understood that this was a fatal blow. It should be noted that the towers withstood the attack long enough for thousands of people to escape from the eventual collapse of the buildings.

The north tower was hit at 8:45 a.m. and did not crumble until 10:29 a.m.; the south tower did not fall until 57 minutes after it was hit. However, at the time, the buildings' imminent collapse was not obvious. Since the event was unprecedented — no other skyscraper had ever been hit by an airplane of this size — the outcome would have been hard to predict by anyone. Indeed, there is still some debate and ongoing investigation about the way in which the towers collapsed after the airplanes crashed.

When the two towers were built, engineers John Skilling and Les Robertson used the novel structural design of a rigid "hollow tube" formed by steel columns separated by 22 inches each; this constituted the perimeter of the building.



In the "spine" of the building, there was an internal lift core used for elevators. The floors were made of prefabricated trussel steel spanning the distance from the perimeter to the core. The impact of the plane crash destroyed a substantial number of perimeter columns on several floors of the building, gravely damaging the system. (Fig. 1)

The fire that started inside the building as a consequence of the explosion affected the physical properties of the surviving steel columns. It is speculated that temperatures on the inside of the building reached 1000 degrees Fahrenheit, at which point steel starts behaving like plastic. Above this temperature, the strength and stiffness of steel decrease significantly, in this case causing the perimeter columns to buckle outwards. (Fig. 2)

Inevitably, once the columns supporting a floor weaken, the whole upper structure collapses at the level of impact, causing all floors above it to fall onto the lower still-standing structure. (Fig. 3) Since the resulting collapse is such a huge mass, it begins to gain gigantic momentum and crushes all the floors below it, one by one. This is called "telescoping mode."

A question being asked is whether the terrorists knew in advance that the towers would fall and, if so, in what manner. Had the towers tipped over rather than collapsed onto themselves, many more lives could have been lost and several blocks of lower Manhattan wiped

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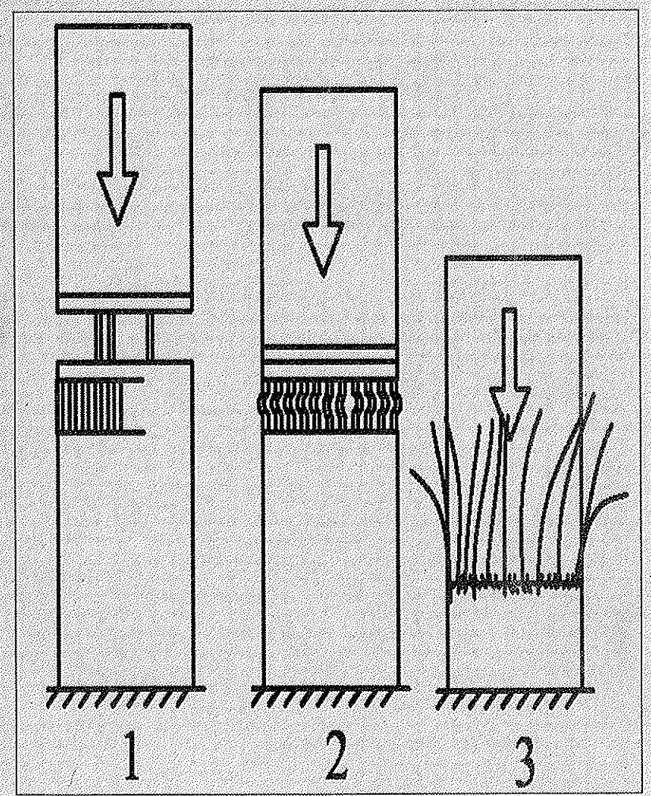

Courtesy of http://www.tam.uiuc.edu/news/200109wtc/images/200109wtc1b.gif

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out. Why didn't the towers tip over before falling? Prof. Bob Laughlin of the Physics Department offered a possible explanation.

"The telescoping mode of falling began first, and there wasn't enough time for the tipping over mode to develop," Laughlin said.

The moment of inertia of a long thin tower is extremely large, so it takes a long time for it to tip over before it crushes one of the floors beneath the top. But once the temperature-weakened steel lost its strength, the top floors were essentially set to freefall, and it took the same amount of time (approximately eight seconds) for them to fall to the ground as it would have taken, for example, a metal coin. This is because at the time the top floors started falling, the structural forces holding the rest of the building up were too small to change the large momentum of the mass falling onto them. As a result, the floors came right down like a stack of pancakes, one on top of the other.

"It was as if the top of the building was acting like a huge pile driver, crashing down onto the floors underneath," said structural engineer Chris Wise.

In general, engineers can predict the outcomes of bridges falling, towers collapsing or any other catastrophe based on an a posteriori analysis of similar past events. They are then able to build stronger and better structures to prevent such disasters from happening again.

For the collapse of the twin towers, however, there was no precedent. Furthermore, there was little that engineers could have done to prevent buildings from falling in the face of terrorist attacks of such a large magnitude.

Consequently, while the knowledge gained from these investigations will help us build structures that are better equipped to withstand potential future catastrophes, it is equally important that we try to prevent terrorism at its roots.