THE WORLD TRADE CENTER COLLAPSE – A CASE STUDY

Neil Schulman
2018 Project Management Symposium
The World Trade Center Collapse – A Case Study

• One needs to understand how the World Trade Center was constructed, to comprehend why the towers collapsed.

• Lessons learned - Best practices
The World Trade Center Collapse – A Case Study

• When the World Trade Center was designed, most skyscrapers were built with a dense grid of steel beams and columns that had limited open floor space on each floor.
The World Trade Center Collapse – A Case Study

• The architect and engineers for the World Trade Center used a revolutionary design and construction method to maximize the open floor spacing and still build as high as possible.

• The structural steel framework design was the most significant feature of the towers.
Most buildings spaced the vertical steel columns evenly across the floor.

The tower design was different, and called for the columns to be moved to the exterior walls and the central core of the structure.

These columns supported the buildings weight, but without lateral or side-to-side support from the floors, these columns would have buckled.
WTC Steel Skin
WTC Exterior Steel Construction
Engineering for non-Engineers

• The floors were built upon trusses, similar to beams, which connected and bridged the distance between the core columns and the exterior columns.

• The trusses were connected to the columns with bolts on each end. The result of this design created a large open floor area without column interferences.
WTC Finished - 1973
Engineering for non-Engineers

• This case study will attempt to clarify various details of the collapse, indicating that the building was not structurally deficient, but still the towers collapsed.

• We will examine the design, the airline impact, the fire, the ultimate collapse, and the lessons learned from the collapse.
Engineering for non-Engineers

• By examining the building's destruction step-by-step, you are learning how buildings fail and discovering ways we can build stronger structures — all by answering this question:

• What caused the Twin Towers to fall?
WTC Collapse – September 11
What caused the Twin Towers to fall?

- **Design**: Like most buildings, the Twin Towers had redundant design, which means that when **one system fails**, **another carries** the load.

- Each of the Twin Towers had 244 columns around a **central core** that **housed** the elevators, stairwells, mechanical systems, and utilities.
What caused the Twin Towers to fall?

• **Airline Impact...When** the commercial jets struck the Twin Towers, some 10,000 gallons of jet fuel fed an enormous fireball.

• But the impact of the Boeing 767 aircraft and the burst of flames did not make the Towers collapse right away.
What caused the Twin Towers to fall?

- The impact of the aircraft (1) compromised the insulation (spray on fireproofing) that protected the steel from high heat; (2) damaged the sprinkler system of the building; (3) sliced and cut many of the interior and exterior columns, and (4) shifted and redistributed the building load among columns that were not immediately damaged.
What caused the Twin Towers to fall?

• The Fire...and the heat from the fire... Even if the sprinklers had been working, they could not have maintained enough pressure to stop the fire. Fed by the spray of jet fuel, the heat became intense.
What caused the Twin Towers to fall?

- Jet fuel burns at 800° to 1500° F. This temperature is not hot enough to melt structural steel.

- However, engineers say that for the World Trade Center towers to collapse their steel frames didn't need to melt — they just had to lose some of their structural strength from the intense heat.
What caused the Twin Towers to fall?

- Steel loses about half its strength at 1,200° F.
- The steel will also become distorted (i.e., buckle) when heat is not a uniform temperature — the exterior temperature was much cooler than the burning jet fuel inside.
- Videos of both buildings showed inward bowing of perimeter columns resulting from a sagging of heated trusses on many floors.
What caused the Twin Towers to fall?

• **The Ultimate Collapse...collapsing floors....**

• **Because the aircraft hit** the buildings at an **angle**, the fires from impact covered **several floors** almost instantly. As the weakened floors began to **bow** and then **collapse**, they **pancaked**. (progressive collapse)
What caused the Twin Towers to fall?

• This means that **upper floors crashed down on lower floors** with increasing weight and momentum.

• The entire portion of the building above the area of impact fell in a unit, **pushing a cushion of air below it** in the impact area.
What caused the Twin Towers to fall?

• The fires were fed by new oxygen and pushed outward, creating the illusion of a secondary explosion.

• With the weight of the plunging floors' building force, the exterior columns buckled.
Why Did the Collapsed Towers Look So Flat?

• Before the attack, the Twin Towers were 110 stories tall. Constructed of lightweight steel around a central core, ...the World Trade Center Towers were about 95% air. After they collapsed, the air space was gone. The remaining rubble was only a few stories high.
The Bottom Line

• The floors were built upon **trusses**, which bridged the distance between the exterior and core columns.

• Connected with **two bolts** on each end, these spans of rigid steel framework prevented the columns from bowing inward or outward.
The Bottom Line

• **Spray-on fireproofing**, further protected the integrity of the steel floor trusses, while the central columns were shielded by fire-resistant drywall.
The World Trade Center towers were actually built to withstand the initial impact from a common jetliner -- the Boeing 707.

However, this aircraft was smaller than the Boeing 767s that struck the buildings in 2001, and the precautionary design didn't take into account any weakening of the steel superstructure caused by fire and heat.
The Bottom Line

• We will never know for sure exactly what structural stresses and failures caused the World Trade Center towers to collapse. However, two government reports provide slightly different explanations of the possible processes that ultimately brought the buildings to the ground.

• The first of these reports was authored by the Federal Emergency Management Agency (FEMA), while the second was done by the National Institute of Standards and Technology (NIST).
The Bottom Line

• Both studies blame two general events for the collapse of the World Trade Center towers. The first was the initial impact of the airplanes. This occurrence caused significant damage to the buildings' external and core columns and increased the strain on those that remained intact.

• The impact also dislodged the spray-on fireproofing that protected the floor trusses and the fire-resistant drywall that encased the core columns.

• This left the buildings' steel components vulnerable to the second critical event: the fires sparked by the airplane collisions.
The Bottom Line

• While the two government reports came to the same general conclusions, they disagreed on some of the specifics.

• The FEMA report blamed the failure of the bolts connecting the floor trusses to the external columns. According to this theory, the floor trusses began to sag when weakened by the fire, pulling at these bolts and causing them to sheer off. The force of the collapsed floor then caused the next floor to fail, and the next, and so on in a phenomenon known as pancaking. With no lateral support, the vertical columns soon buckled, and the buildings collapsed.
The Bottom Line

- The **NIST** report also blames sagging floor trusses for the collapse, but suggests that the floors actually **pulled** the exterior columns inward, causing them to buckle. This brought the top section of the buildings down through the impact zone with a force too great to be stopped.
Could the Towers Have Been Made Stronger?

- The Twin Towers were built between 1966 and 1973.

- No building constructed at that time would have been able to withstand the impact of the attacks in 2001.
Could the Towers Have Been Made Stronger?

• Both buildings actually **withstood the impact** of the large aircraft bound for the West Coast on 9/11.
• The **North Tower** did not collapse until it gave most people over **90 minutes** to evacuate.
• The **South Tower** had nearly an **hour** to evacuate after it was hit.
The Legacy of 9/11 on Building Construction

• Architects want to design safe buildings. However, owners and developers don't always want to pay for over-redundancies. How can you justify expenses that mitigate outcomes of events not likely to happen?

• The legacy of 9/11 is that new construction in the United States must now adhere to more demanding building codes. Buildings are required to have more durable fireproofing, extra emergency exits, and many other fire safety features.

• Yes, 9/11 changed the way we build, at local, state, and international levels.
Lessons Learned and implemented in the New One World Trade Center Building

• It has a **concrete core**, with very **thick concrete walls**. The **thick concrete slabs** are designed to withstand high winds and earthquakes.

• There is also a **rocklike anchor**, referred to as the buildings **podium**, that has some hefty blast-resistant walls at the base.

• There are **state of the art fire suppression systems**, **specially protected elevators**, and a separate dedicated **stairway for fire and safety personnel**.

• It may not be the tallest building in the world, but it is certainly the safest commercial structure in the world.
Lessons Learned and implemented in the New One World Trade Center Building

• Also, the design of the New One WTC incorporates several new safety features intended to speed potential evacuation. Extra-wide staircases interconnect at various floors so evacuees could cross over if one of the stairwells were blocked. All the stairs have exits direct to the street rather than opening in to the lobby.
After September 11, 2001

• In addition, the New One World Trade Center safety systems now exceed the requirements of the New York City Building Code; elevators are housed in a protected central building core; protected tenant collection points are on each floor; extra-wide pressurized staircases are part of the design; sprinklers, emergency risers, and communication systems are concrete-protected.
The New One World Trade Center - Sustainability

The building achieved LEED Gold through a range of sustainable features:

- Energy performance exceeds the NYC Building Code requirements by 20%
- Low-water bathroom fixtures
- Sustainable wood from sustainable harvested forests
- Exterior glass curtainwall allows daylight to reach 90% of office areas
- Low energy consumption equipment including fans, pumps, and elevators
- High-tech Building Management System (BMS)
- Stormwater runoff is stored in retention tanks to be used for cooling, fire protection, cooling, and irrigation
- Over 40% of the materials used in construction were recycled including gypsum boards, ceiling tiles, and glass
- Structural steel was produced from 95% recycled materials
- Over 87% of the construction waste from the project was diverted from the landfill
- No VOCs (volatile organic compounds) allowed
- 34% of the construction materials were regionally sourced and manufactured within 500 miles of the project
- All life-safety systems, including exit stairs, communications antennae, exhaust and ventilation shafts, and elevators are encased in a concrete core that’s a minimum of 2 feet thick
- Sick building prevention utilizing a carbon dioxide monitoring system
- 400 trees were planted at the site

- “Eleven seconds to eleven years”
- https://www.youtube.com/watch?v=NbA89YbWoL8
Conclusion

• Many say the New One World Trade Center is everything it should be.

• Best Practices - We can, however, learn from the collapse of the original towers, and take steps to construct safer buildings, and minimize the number of casualties in future disasters.

• Hope you have a better understanding now of what happened on September 11, 2001.

• Thank you.