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Publisher's version / Version de l'éditeur:

Canadian Consulting Engineer, 45, Aug/Sept 4, pp. 47-49, 51, 2004-08-01

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The Collapse of WT7 : a Canadian researcher who studied the World Trade Center disaster reports on the collapse of a building beside the twin towers

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NRCC-44753

A version of this document is published in / Une version de ce document se trouve dans :
Canadian Consulting Engineer, v. 45, no. 4, Aug/Sept. 2004, pp. 47-49, 51

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Fire Resistance Issues in the Collapse of Building WTC 7

By V.K.R. Kodur, Ph.D., P.Eng

The collapse of the WTC 7 building next to the twin towers was the first-ever collapse of a steel-framed structure as a result of a fire. An NRC researcher who was part of the WTC investigation team provides this analysis of the fall of WTC 7.

The attacks on the twin towers at the World Trade Center (WTC) on September 11, 2002 led to the collapse of another building in the complex, WTC 7, a 47-storey building located across the street north of the main WTC complex. The building fell late in the afternoon of the same day.

The performance of WTC 7 is of significant interest because it did not appear to suffer major damage from the debris resulting from the collapse of the twin towers. The collapse of WTC 7 appears to have been due primarily to the effects of exposure to fire[1] – making it the first-ever collapse of a steel-framed building as a result of fire.

An overview of the factors that led to the collapse of the WTC 7 and the probable reasons for it are detailed in a report issued by the U.S. Federal Emergency Management Agency[1] (FEMA). Among the factors analyzed with regard to their role in the collapse were the following: fire resistance issues, the effect of diesel fuel stored on lower floors, fire growth, fire defence systems, and fire intensity. The information presented here is based on the preliminary assessment contained in the FEMA report (2002) and further detailed analysis is being undertaken by the National Institute of Standards and Technology.

The Building

The World Trade Center (WTC) Complex in Manhattan, New York, comprised of seven buildings designated WTC 1 through WTC 7. The twin towers, comprising WTC 1 (North Tower) and WTC 2 (South Tower), were the primary components of the WTC Complex. These two buildings built in the late 1960's were 110 stories above grade and were the world's tallest buildings for a while. WTC 7, located across Vesey Street on a block of land north of the main WTC complex, was the next tallest building in the WTC family.

WTC 7 was a 47-storey steel-frame building and was constructed in 1984. It was 635 feet high and had a trapezoidal-shaped floor plate (Figure 1). The typical floors had an area of approximately 42,000 square feet, with a total of 1,868,000 square feet of office space. WTC 7 housed a Consolidated Edison substation located on the lower four floors, and fuel storage tanks (3,000 - 6,000 gallons and 2,000 - 12,000 gallons) located at ground level. The 7th floor housed generators and day-storage fuel tanks. The next three levels above contained switchgear and emergency generators, and the top 40 stories were office space. WTC 7 was linked to the World Trade Center plaza by two pedestrian bridges.

The Structural System

The floor framing from the 8th to the 46th floor consisted of composite beams that spanned from the core to the perimeter. The floor slab was an electrified composite 3-inch metal deck with 2.5-inch normal weight concrete topping spanning between the steel beams. The floor framing below the 8th floor was similar to the floors above, but formed slabs were utilized in portions of the structure in lieu of a composite deck, and an electrified floor slab was not used throughout.

There were numerous gravity column transfers between floors, including three interior gravity column transfers between the 5th and 7th floors, which contained the diaphragm floors, belt trusses and transfer girders. There were a total of eight transfer girders located between the core area and the north elevation at the 7th floor. Their purpose was to transfer the building column loads above the 7th floor back to a line of building columns through the roof of the Con Ed substation. In addition, they formed part of a truss along the north elevation between the 5th and 7th floors that transferred other column loads.

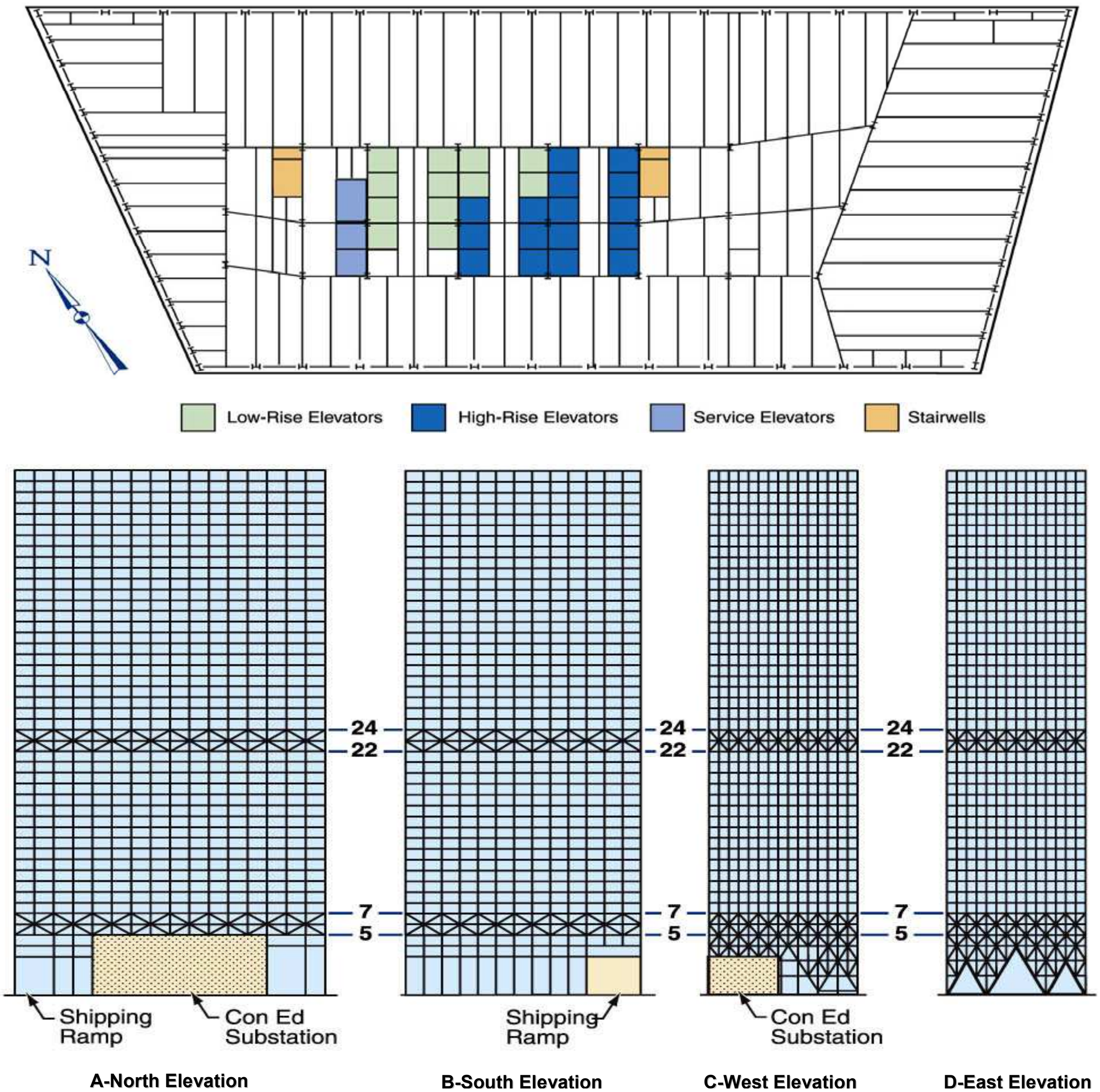

Figure 1. Typical floor layout and elevation for WTC 7

All lateral loads were resisted by means of perimeter moment frames along the four exterior walls. From the 7th floor down, lateral loads were resisted by a combination of bracing and moment frames both in the core and around the perimeter.

Fire Protection Systems
The fire protection features in WTC 7 included sprinklers, smoke control systems, fire detection systems, compartmentalization, egress systems and structural fire protection measures. There were two main exit stairways, about 4 feet 10 inches wide. There were approximately 30 elevators serving the various levels of the building.

WTC 7 was fully sprinklered. The sprinkler system on most floors was a looped system fed by a riser located in Stair 2. The primary water supply for the suppression system was a dedicated fire yard main that looped around most of the complex. This yard main was supplied directly from the municipal water supply.

A cementitious spray-on fireproofing (SFRM) provided 3-hour fire resistance for the columns and a 2-hour fire resistance for the floor-ceiling assemblies.[1,2] The trusses were likely protected in a manner similar to the columns. Concrete floor slabs provided vertical compartmentation to limit fire and smoke spread between floors.[1]

Fire Performance of Steel-Framed Buildings

High-rise buildings are designed to survive a fire, even if the fire has to burn to extinction. This means the structural systems need to endure fire for the entire time it takes for all combustibles to be consumed.

There have been several severe high-rise fires involving steel-framed structures in recent years. Apart from WTC incidents there were four major and most often quoted fire incidents in steel-framed office buildings in recent years (1988, 1st Interstate Bank Building, Los Angeles; 1990, Broadgate, Phase 8, London, UK; 1990, Churchill Plaza office building, Basingstoke, U.K.; 1991, One Meridian Plaza, Philadelphia). But the failure of WTC 7, was the first-ever structural due to fire considerations alone (WTC 1 and WTC 2 had significant impact damage prior to the commencement of fires).

In addition, recent results from full-scale fire experiments in UK has shown that steel-frame buildings may endure fire longer than their design would indicate. This unexpected performance has been attributed to a number of factors such as whole building behaviour, redistribution of loads, and tensile membrane action, which are not accounted for in conventional methods of evaluating fire resistance. Thus, protected steel-frame high-rise buildings exposed to uncontrolled fires had performed well until the collapse of WTC 7.

Collapse of WTC 7
Much of the information about the fires and collapse of WTC 7 comes from media and fire service reports. WTC 7 fires were first observed after the collapse of WTC 1 in the morning, on the south side of the building at floor levels 6, 7, 8, 10, 11 and 19; these continued at different storeys for most of the afternoon. Media and firefighter accounts indicate that the fire on the 6th floor burned from the start of the WTC incident until collapse.

At about 5:20 p.m., the collapse sequence began. First, the east and west penthouses disappeared from view, followed by progressive collapse, apparently on a lower floor. Videotapes show the upper 30 to 35 stories appearing to descend intact, indicating the collapse was initiated on a lower floor. Just prior to the collapse, a crack or "kink" or fault line[1] developed along the north wall in the vicinity of the east penthouse located over transfer trusses 1 and 2 on the east side (Figure 2).

Role of Fire Resistance Issues

State of the Structural System
Observations indicate that the debris from the collapse of WTC 2 at 9.59 a.m. did not significantly affect the roof, or the east, west and north elevations of WTC 7[1,2], but may have damaged the southwest corner of the pedestrian bridge connecting WTC 7 to the main complex. The collapse of WTC 1 at 10.29 a.m. caused some damage to the southwest corner of WTC 7 (approximately floors 8 to 20), but did not cause any major damage to the roof, or the east-west and north elevations of WTC 7. These reports lead to an inference that the south side of WTC 7 might have suffered some damage, but the severity of damage to the structural system is unknown.

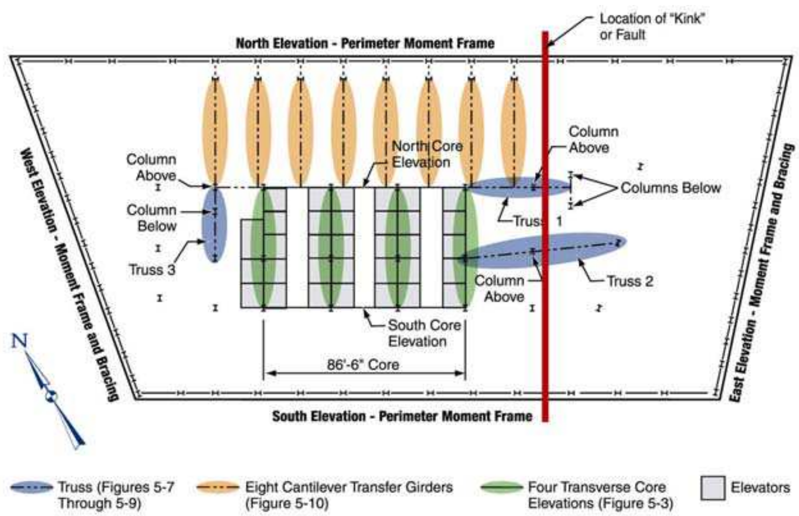

Figure 2 Area of potential transfer truss failure in WTC 7 [1]

Given the number of fires observed in WTC 7 after the collapse of WTC 1, it is likely there was some damage to the structural members on the south side of WTC 7. Also, the impact of debris might have caused significant breakage and damage to the glass facade. As the fateful day progressed, the continuous burning of fires on several floors exposed the various structural elements to high temperatures and reduced their strength.

Fire Growth
Since the sprinklers were not operating and firefighting was curtailed, the uncontrolled fires burned throughout the day. At 3:30 p.m., large plumes of darker smoke, characteristic of oil fires, were rising from the north and east faces of the lower floors of the building. By 5:00 p.m., significant amounts of dark smoke were rising from the lower floors. Approximately one hour before collapse, the smoke became dark gray and appeared to be much more buoyant. These observations indicate that prior to collapse, the fire size and heat output in WTC fires might have been higher than that of typical office building fires. The reason for the apparent change in fire behaviour at mid-afternoon is not known but the presence of fuel tanks may have been a factor.

Fire Protection
Tall buildings rely on three basic fire defence mechanisms to resist failure: sprinkler systems, active firefighting and passive fire protection for structural members. WTC 7 was a fully

sprinklered building but the high intensity of the fires and water demand on the main WTC site meant the WTC 7 sprinklers were either ineffective or non-operational.

The curtailment of firefighting due to fire department overload meant the WTC 7 fires were allowed to progress. The fireproofing, the last level of defence, provided passive fire protection to structural members for a certain amount of time. However, the continuous advance of the uncontrolled fires on different stories weakened the structural members. Therefore, the failure of the first two basic fire defence mechanisms significantly contributed to weakening the structural system that resulted in the collapse of WTC 7.

Performance of Structural Elements
Steel loses its load-carrying capacity (or about 50 percent of its original strength) at 538°C (1,000°F) when exposed to an ASTM E-119 standard fire that is often used as a benchmark for building fires. External fire protection (fireproofing) is applied to the steel structural members to provide the required fire resistance ratings. Figure 3 shows the variation of strength and stiffness in steel as a function of temperature. The WTC fires, burning on multiple floors simultaneously, may have been more severe than the ASTM E-119 standard fire.

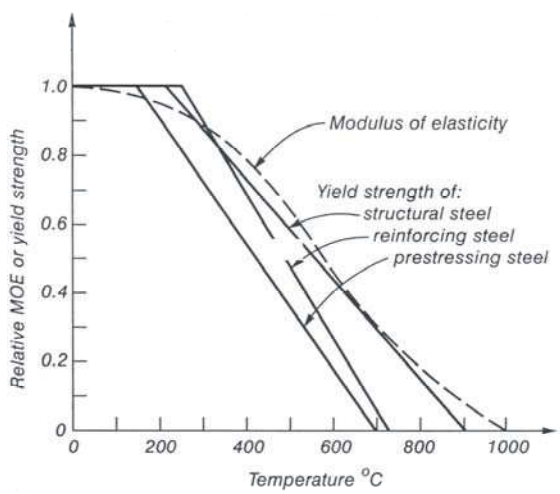

Figure 3. Variation of strength and modulus of elasticity of steel with temperature

Summary
The collapse of the 47-storey steel-framed WTC 7 occurred approximately seven hours after the collapse of WTC 1. Fire development and fire resistance issues played a major role in the collapse of WTC 7. The debris from the collapse of the twin towers, while it did not cause significant damage to the structural system of WTC 7, might have initiated fires at multiple floors. The diesel fuel present in the building must have contributed to some of the massive fires especially in the later stages. The fire intensity and heat output generated from these fires was much more severe than typical building fires. The loss of fire defences, including sprinklers and active firefighting, further contributed to weakening the structural members.

A current investigation by the National Institute of Standards and Technology (NIST) into the fire growth, any impact damage, and performance of structural elements will shed further light on the collapse of this steel-framed building, WTC 7.

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1. Federal Emergency Management Agency (FEMA), "World Trade Center Building Performance Study: Data Collection, Preliminary Observations and Recommendations", Report 403, FEMA, Washington D.C., 2002.
2. Milke, James, Study of Building Performance in the WTC disaster pp. 6-18, Fire Protection Engineering, Spring 2003.

Acknowledgement

The primary technical source for the preparation of this paper is FEMA Report 403 "World Trade Center Building Performance Study". The author, a member of the BPS team, acknowledges the contributions of fellow BPS members.

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