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Kodur, V.K.R.

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ROLE OF FIRE RESISTANCE ISSUES IN THE FIRST EVER COLLAPSE OF A STEEL-FRAMED BUILDING – WTC 7

V.K.R. Kodur, Ph.D., P.E.
Senior Research Officer
Institute for Research in Construction
National Research Council of Canada
Ottawa, Canada K1A 0R6

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ABSTRACT

The September 11th terrorist incidents have caused colossal destruction and significant damage to a number of buildings in the World Trade Centre (WTC) vicinity in New York. The catastrophic collapse of the twin towers has shocked the whole world and was attributed to two extreme events - impact of the aircraft and the ensuing fires. However, the collapse of WTC 7, a 47-storey building, has shocked everyone much more since this collapse was entirely due to fire. Further, this was the first ever collapse of a steel-framed building under fire. Thus, fire resistance issues played a major role in the collapse of the WTC 7.

The role of fire resistance issues in the collapse of the WTC 7 building is discussed in this paper. An overview of the structural system and fire protection design features is presented. The effect of fire growth and fire intensity on the performance of structural systems is discussed. A review of the performance of steel-framed tall buildings in earlier fire incidents is presented. The different "fire and structural" conditions that existed in WTC 7, prior to the collapse that were crucial to the collapse, are highlighted.

Key words: World Trade Center, WTC 7, Collapse, September 11, Fire Resistance

1 ABSTRACT

The September 11th terrorist incidents have caused colossal destruction and significant damage to a number of buildings in the World Trade Centre (WTC) vicinity in New York city. The catastrophic collapse of the twin towers has shocked the whole world and was attributed to two extreme events - impact of the aircraft and the ensuing fires. However, the collapse of WTC 7, a 47-storey building, has shocked everyone much more since this collapse was entirely due to fire. Further, this was the first ever collapse of a steel-framed building under fire. Thus, fire resistance issues played a major role in the collapse of the WTC 7.

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2 INTRODUCTION

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. This was a 47-storey steel-frame building and was constructed in 1984.

The majority of WTC 7 was made up of office occupancies and government agencies, including the US Secret Service, CIA, IRS and New York City's Office of Emergency Management (OEM). This office building contained an electrical substation, a power plant, comparable in size to that operated by a small commercial utility, as well as a significant amount of diesel oil storage. WTC 7 was a typical steel-frame building and had a design with numerous transfer for gravity and lateral loads.

On September 11, 2001, the impact of two aircraft on the twin towers of the WTC set off a chain of events. The massive impact damaged the structural system at certain section of the towers and initiated severe fires on several floors. While the two towers withstood the impact, the severe fires that followed the impact brought down the "twin towers", WTC 2 and WTC 1, at different intervals - 59 and 89 minutes, respectively, following the impact. After the collapse of the twin towers, several buildings in and around the WTC complex were on fire. At about 5:20 p.m. on that day, WTC 7, which was one of the major components of the WTC complex, collapsed.

The performance of WTC 7 is of significant interest given that this building did not appear to suffer major damage due to the impact from an aircraft or debris from collapsing towers. As such, this collapse appears to be primarily due to the effects of the fire exposure (FEMA 2002). Furthermore, this was the first ever collapse of a steel-framed building under fire. Therefore, fire resistance issues appeared to have played a major role in the collapse of the WTC 7 building.

An overview of the factors that led to the collapse of the WTC 7 and the probable collapse mechanism of this building is detailed in the FEMA report (FEMA 2002) and is based on the "building performance study" commissioned by the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers. In this paper, the role of fire resistance issues in the collapse of the WTC 7 is discussed. The effect of diesel fuel, fire growth, fire defence systems and fire intensity on the collapse WTC 7 towers is examined. The information presented here is based on the preliminary assessment contained in the FEMA report (2002) and further detailed analysis is being undertaken by National Institute of Standards and Technology.

3 FEATURES OF WTC 7

3.1 General

WTC 7 was a 47-storey, steel-frame building located across Vesey Street from the remainder of the World Trade Center Complex. The building was 635-foot-high and had a trapezoidal-shaped floor plate. The typical floors in WTC 7 had an area of approximately 42,000 ft^2 per floor with a total of 1,868,000-square-foot office space for the entire building. Each floor in the tower was constructed with about 25,700 tons of steel, and weighing an average of 27.5 lb/ft^2. Figure 1 presents a typical floor plan and elevation for the WTC 7 building.

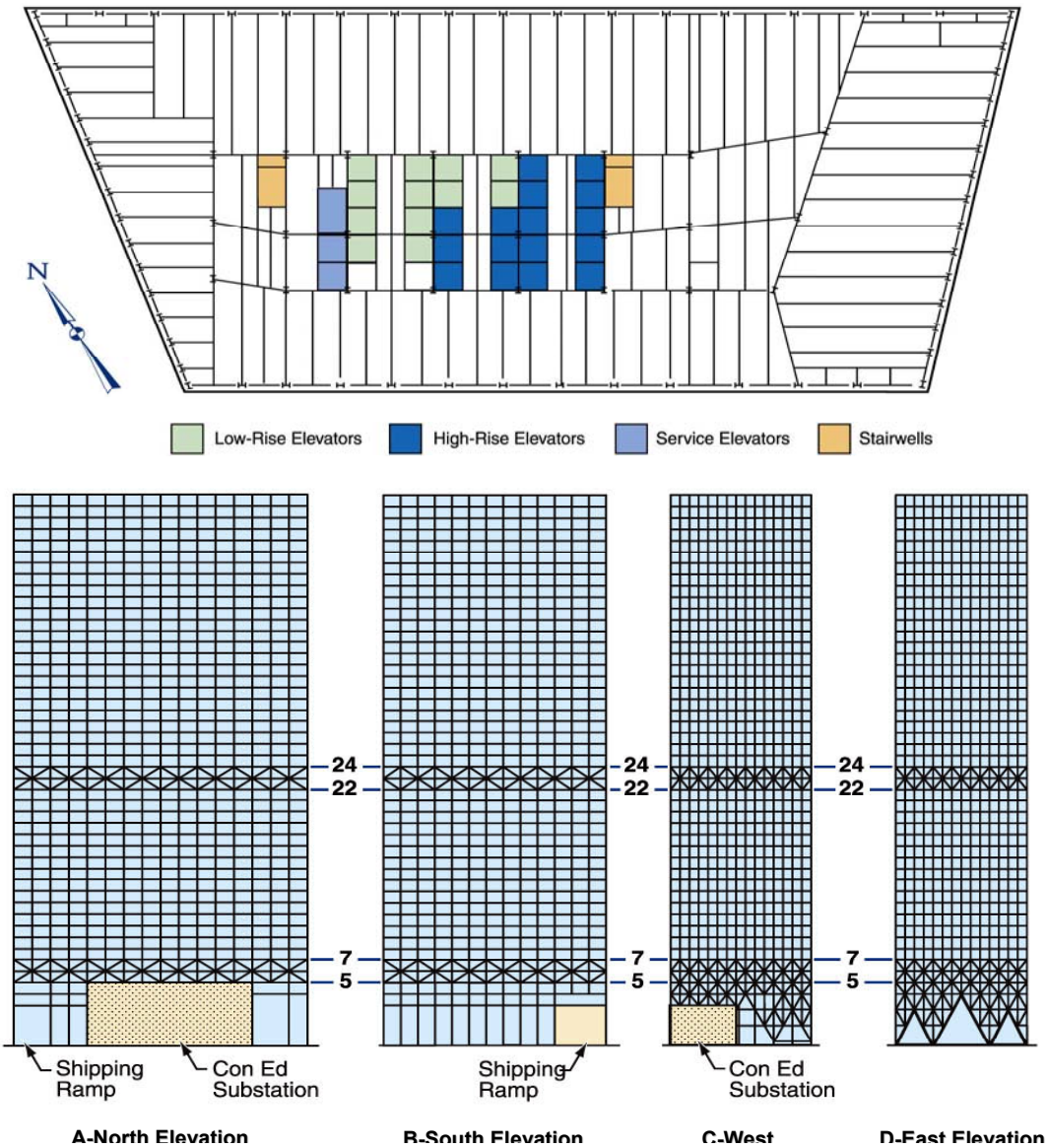


Figure 1 Typical floor layout and elevation in WTC 7

This building was an air-rights building, being constructed over a Consolidated Edision (Con Ed) substation located on the lower four floors. The next three levels contained switchgear and emergency generators. The top 40 stories contained office space, including space for New

York City's Office of Emergency Management (OEM) on the 23rd floor. This building contained a significant amount of fuel for emergency power and to supply the generators. A total of about 91,000 litres of diesel fuel were stored below grade (FEMA 2002, Milke 2003).

WTC 7 was linked to the World Trade Center plaza through two pedestrian bridges. The bridges spanned 95 feet over the arterial roadway separating WTC 7 and the plaza from the structure's 3rd floor. The larger of the two bridges, the Plaza Bridge, had a plan area of about 11,000 square feet. A smaller pedestrian bridge also spanned across the roadway as a 100-foot-long single box girder. A brief description of structural and fire protection design features is highlighted here. Full details of the various design features can be found elsewhere (FEMA 2002, Salvarinas 1986).

3.2 Structural System

The floor framing from the 8th floor to the 46th floor of WTC 7, was similar to a typical steel-framed office building. The gravity framing consisted of composite beams that spanned from the core to the perimeter. The floor slab was an electrified composite 3-inch metal deck with 2-1/2 inch normal weight concrete topping spanning between the steel beams. The floor framing below the 8th floor is similar to that for the typical floors above, except that 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 floors 5 to 7 floors. The 5th and 7th floors 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 Con Ed substation roof. In addition, they formed part of a truss along the north elevation between the 5th and 7th floors that transferred other column loads.

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.

Further details on diaphragm, trusses**,** transfer girders, connections and column splices can be found elsewhere (FEMA 2002, Salvarinas 1986).

3.3 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, approximately 4 feet 10 inches wide, in WTC 7. Stair 1 was located on the west side, and Stair 2 was located on the east side in the central core. Both exit stairways discharged directly to the exterior at the ground level. The stairways were constructed of fire-rated construction using gypsum wallboard. Subsequent to the 1993 bombing incident, battery-operated emergency lighting was provided in the stairways and photoluminescent paint was placed on stairs to facilitate emergency egress. There were approximately 30 elevators serving the various levels of WTC 7.

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

The passive fire protection to structural members was similar for this building as for WTC 1, 2, though using a cementitious spray-on fireproofing (SFRM) for 3-hour fire resistance rated column designs and 2-hour fire resistance-rated floor-ceiling assemblies (FEMA 2002, Milke 2003). The trusses were presumably protected in a manner similar to that followed for the columns. Concrete floor slabs provided vertical compartmentation to limit fire and smoke spread between floors (FEMA 2002).

4 THE INCIDENT

On September 11, 2001 American Airlines Flight 11, enroute from Boston to Los Angeles was hijacked and slammed into the north tower of the World Trade Center between the 94th and 98th floors at 8.46 a.m. Shortly thereafter (at 9.03 AM), a second hijacked plane, United Airlines Flight 175, was slammed into the south tower of the WTC between the 78th and 84th floors. Both aeroplanes that struck the towers were Boeing 767-200ER aircraft and were loaded with heavy amounts of jet fuel for transcontinental flights (ENR 2001, FEMA 2002).

The massive impacts from each of the aircraft resulted in severe structural damage at several floor levels in each tower. However, the structures remained standing, at least initially, despite this heavy but localized damage. The subsequent, intense fires that followed, further weakened the already damaged structure, resulting in the collapse of the floors, initiated at the floor with the worst fire conditions. The impact load of the collapsing floors on the structure below started a progressive collapse and resulted in the complete collapse of the towers.

After the collapse of the towers, several buildings in and around the WTC complex were on fire. By the end of the day, four buildings completely collapsed, three buildings were severely damaged by fire leading to partial collapses, and seven buildings sustained significant damage, while numerous others suffered minor damage. Fires were observed on multiple floors in WTC 7 following the collapse of WTC 2 (Smith, 2002). Various reports (photographic evidence) and fire-fighter observations indicated that fires were burning on many of the floors throughout the day. Finally at 5:20 p.m., WTC 7 was razed to the ground and this was attributed to a fire-induced collapse.

5 FIRE PERFORMANCE OF STEEL FRAMED BUILDINGS

High-rise buildings are designed to be able to survive a fire, even if the fire has to burn itself out. The strategy is to ensure that structural systems are strong enough (or protected well enough from fire) that they do not give away in the time it takes for everything inside an office building, like office contents and furniture, to burn.

A recent survey on the collapse of multi-storey buildings exposed to fire has indicated that a fire-induced collapse in a multi-storey building can be classified as a low frequency, high-consequence event (Ikwankiw and Bietel 2002, Bietel and Ikwankiw 2003). The events related to the September 11, 2001 terrorist attacks on the WTC complex in New York were the dominant fire and collapse events of this survey (represented 4 separate incidents out of a total of 22 incidents).

Apart from WTC incidents there were four major and most often quoted fire incidents in steel- framed office buildings in recent years (Wang and Kodur 2000, FEMA 2002). The main features of the buildings and the fire duration in the four incidents are listed in Table 1.

The steel in the 1st Interstate Bank Building, One Meridian Plaza, and Churchill Plaza office building were protected with spray-applied protection. With the fire occurring while the Broadgate complex was under construction, the steel beams had not yet been protected.

In One Meridian Plaza, the column assemblies had fire resistance ratings of 4 hours, while the floor-ceiling assemblies had ratings of 3 hours. When fire occurred in this building, the fires

burned for 19 hours (uncontrolled for the last 11 hours), leaping from floor to floor and burning out as combustible materials were used up. However, the building did not collapse. Similarly, none of the other buildings, mentioned above, did collapse. Thus in most major high-rise fires in North America, and elsewhere in the world, the conventional approach to survive a fire (allowing for complete burnout) has worked well until the WTC disaster. However, in the case of WTC 7, the building collapsed approximately 7 hours after the collapse of WTC 1.

Table 1 : Fire Incidents in Steel-Framed Buildings

Building	No. of Storeys	Fire Incident – Date	Protection	Fire Duration (hours)
1st Interstate Bank Building, Los Angles, USA	38	May 4-5, 1988	Protected	3½
Broadgate, Phase 8, London, UK	14	1990	Unprotected	4½
Churchill Plaza office building, Basingstoke, U.K.	12	1991	Protected	2-4
One Meridian Plaza, Philadelphia, USA	54	February 23-24, 1991	Protected	19

In addition to these experiences in real fire incidents, Building Research Establishment in U.K., in collaboration with British Steel, performed six experiments in the mid-90's to investigate the behavior of steel-frame buildings under real fire scenarios. These experiments were conducted on an eight-storey steel-framed building, which was designed similar to an office building in Central London. In many of these tests, columns were protected and steel beams were left unprotected. Despite the temperature of the steel beams reaching 800 to 900°C in three tests (well above the traditionally assumed failure temperature of 600°C), no collapse was observed in any of the six experiments (Kirby 1997). This excellent performance, of no collapse, was attributed to a number of factors such as whole building behaviour, redistribution of loads, tensile membrane action, which is not accounted for in conventional methods of evaluating fire resistance.

The above review clearly demonstrates that the collapse of a protected steel-frame high-rise building, when exposed to an uncontrolled fire, is not common. Furthermore, with the recent experiences of the lack of collapse in steel-frame, high-rise buildings despite having serious fires, the collapse of WTC 7 poses a paradox.

6 COLLAPSE OF WTC 7

The collapse of WTC 2 at 9.59 a.m. initiated a chain of events in WTC 7. Media reports and fire service personnel observations provide some clues to the nature of the fires and probable collapse mechanisms in this building. These reports indicate that fires were observed on multiple floors of WTC 7 after the collapse of WTC 1 [Smith, 2002]. Fires were burning on the south side of WTC 7 at 6, 7, 8, 10, 11 and 19 floor levels. These reports also suggest that the smoke was light grey coloured and that a majority of this smoke was emanating from the south side of WTC 7.

As the day progressed, the fires raged mainly on lower floors and never burned out, and in the chaos of Sept. 11, the fire department eventually decided to stop fighting the blazes. The burning of fires continued at different storeys for most of the afternoon. However, media reports and firefighter accounts indicate that the fire on the 6th floor burned (continuously) for the entire duration of the time that fires were noted in WTC 7. The smoke, which was light grey coloured in the beginning turned to dark grey around 4 p.m. and appeared to be much more buoyant.

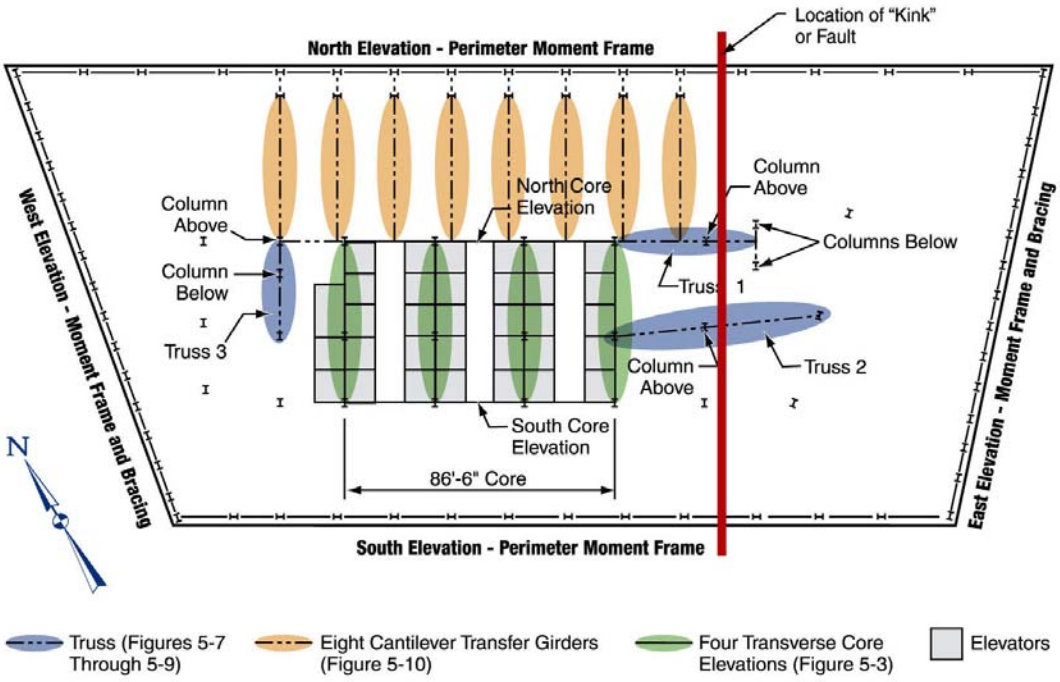


Figure 2 Area of potential transfer truss failure in WTC 7

Finally, at about 5:20 p.m., the collapse sequence was initiated in WTC 7. First, the penthouse on the east side of the roof disappeared from view, then about 10 seconds later the penthouse on the west side disappeared. Subsequent to the disappearance of the west penthouse, the progressive collapse started, apparently on a lower floor. Videotape records of the collapse from the news media clearly indicate that the upper 30 to 35 stories appear to descend intact, indicating the collapse was initiated on a lower floor. In addition, just prior to the collapse, a crack or "kink" or fault line (FEMA 2002) develops along the north wall in the vicinity of the east penthouse located over transfer trusses 1 and 2 on the eastern side (see Figure 2).

The collapse of WTC 7 produced a small debris field as the façade was pulled downward, suggesting an internal failure and implosion. In the case of the twin towers the debris was showered over a wider radius as the frames were "peeled" outward (FEMA 2002).

One proposed mechanism of the collapse was a failure of transfer truss 1 or 2 due to fire exposure on that level. Fuel loads were reportedly light in the vicinity of the trusses except for pipes carrying diesel fuel to and from the generators (Milke 2003). While some fuel was found in the underground tanks once they were recovered, the exact role of the diesel fuel is not fully clear at this time.

The nature of fires and their destructive structural effects are the subject of an ongoing investigation by the National Institute of Standards and Technology (NIST).

7 ROLE OF FIRE RESISTANCE ISSUES

Based on the documented information so far, it can be inferred the fire issues played a major role in the collapse of the WTC 7. Some of these factors are discussed in this section:

7.1 State of the Structural System.

Media reports and firefighter 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

(FEMA 2002, Milke 2003). However, some eyewitness accounts reported that there was damage to the southwest corner of the bridge (connecting WTC 7 to the complex) after the collapse of WTC 2. The collapse of WTC 1 at 10.29 a.m. caused some damage to the southwest corner of WTC 7 at 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 the WTC 7 might have suffered some level of damage, however the exact extent and nature of damage to the structural system is unknown at this time.

In the case of the twin towers, the impact of aircraft caused massive damage to structural members and left the structural system in a very highly stressed state (FEMA 2002, Kodur 2003). In WTC 7, given the number of fires that were observed after the collapse of WTC 1, there must have been some level of damage to the structural members on the south side of WTC 7. However the impact damage to the structural system of WTC 7 (from the falling debris of the twin towers) is not that significant. Neverthless, the debris impact might have resulted in significant breakage and damage to the glass which is crucial for the burning of fires. As the day progressed, the continuous burning of fires, at multiple floors, has exposed the various structural elements to high temperatures and has reduced the strength of the structural system of WTC 7 at those floor levels (FEMA 2002).

7.2 Diesel Fuel

WTC 7 contained an electrical substation, a power plant, comparable in size to that operated by a small commercial utility, as well as a significant amount of diesel oil storage for emergency power and to supply the generators. An array of fuels was present throughout the building. There were 5 storage tanks (3 of 6,000 gallons and 2 of 12,000 gallons) at various locations at ground level. Day tanks provided fuel oil for generators at the 2nd, 5^{th,} 7th and 9th floors serving various clients. In addition there was a Con Edison 4-inch diameter gas line with 0.25 psi (low) pressure going into WTC 7 for cooking purposes.

Prior to collapse massive fires were located on 7th 8th 12th and 13th floors. The 7th floor held the OEM generators and day tanks storing fuel. At present, the exact role of diesel fuel in the development of the fire or accelerating the fire growth is not known. However, the smoke emanating from the fires, prior to the collapse of this building, turned to dark grey, a characteristic of oil fires. Furthermore, these fires and smoke appeared to be much more buoyant indicating that the fire size (heat release rate) was much higher. This behaviour points to some role played by diesel fuel in initiating or accelerating the fires prior to the collapse of WTC 7.

7.3 Fire Growth

Fires were observed on multiple floors in WTC 7 following the collapse of WTC 1 (Smith, 2002). Photographs of the south face of the building and firefighter observations indicated that fires were located on multiple floors. Some reports suggest that the fire located on the 6th floor burned for the entire duration of the time that fires were noted in that building. Until mid-afternoon, fires were burning on the south side of WTC 7 at 6, 7, 8, 10, 11 and 19 floor levels. The limited amount of smoke emanating from these fires, the majority of which was emanating from the south side, was light grey coloured. This type of fire is characteristic of fires from the burning of office contents.

Since the sprinklers were not operating and there was no firefighting, the uncontrolled fires burned throughout the day. As the day progressed, the burning of fires continued and smoke was emanating from upper floors on the south side of this building. A camera from the north of the building recorded light gray, modestly buoyant smoke emanating from the building throughout much of the day. Reports also indicate that occasionally there were limited fires on the north, east

and west faces during later stages of the day. In the mid-afternoon the fires were burning on the 7th 8th 12th and 13th floors. The 7th floor held the OEM generators and day tanks (FEMA 2002).

In the afternoon, around 3:30 p.m., television reports indicate that a severe fire was burning in WTC 7. Approximately one hour before the collapse, the smoke became dark gray and appeared to be much more buoyant. Large smoke (of a darker colour) was rising from the north and east faces of the lower floors of the building. The smoke, which was light grey coloured in the beginning, turned to dark grey, characteristic of oil fires, around 4 p.m. and appeared to be much more buoyant. Further reports suggest that these fires raged mainly on lower floors and never burned out. By 5:00 p.m., significant amounts of dark smoke were rising from the lower floors of the building. These observation 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 fully understood at this time. Many reports speculate the presence of fuel tanks as a probable reason for the massive fires prior to collapse. Additional studies are required to gather information on diesel fuel and fire contents and also to develop fire growth scenarios at various levels in this building.

The simultaneous fires across several floors at the same time generated fire conditions significantly more severe than those anticipated in typical building fires (FEMA 2002). The maximum fire temperatures attained in the WTC 7 fires were in the range of 1,000° to 1,100°C. In Figure 3, the time-temperature curves from two standard tests and typical building fires based on temperature measurements acquired in experiments involving office furnishing conducted by DeCicco, et al., (1972) in the Hudson Terminal Building (30 Church Street, New York), is compared. Temperature development in the WTC 7 fires in the later stages is likely to be closer to the ASTM E-1529 curve.

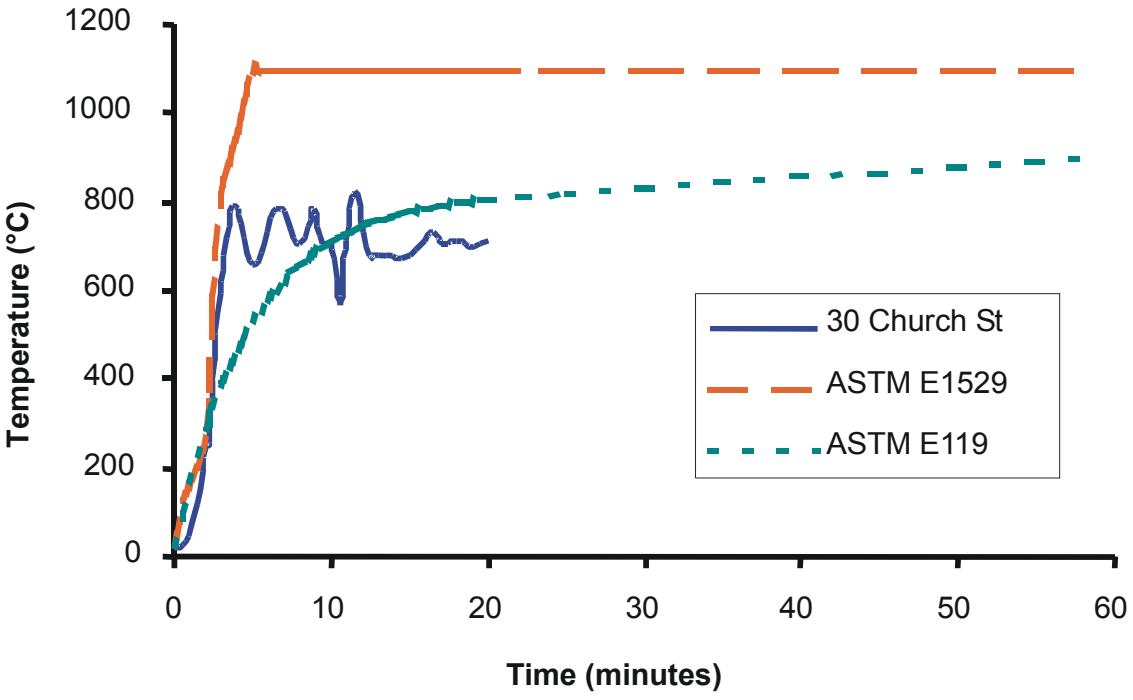


Figure 3 Time-Temperature curves from two standard tests and temperature measurements (DeCicco, et al., 1972) in the Hudson Terminal Building

7.4 Active Fire Protection

Tall buildings, in the event of fire, rely on three basic fire defence mechanisms, namely sprinkler systems, active firefighting and passive fire protection to structural members, to overcome a collapse scenario. In the case of WTC 7, it was a fully sprinklered building. However, the severe fire conditions overcame the building's fire defences considerably faster than expected. Due to the high intensity of the fires, sprinklers, the first level of defence, were either ineffective or non-operational. Water on the WTC site was very limited due to the events on that day.

Also, no manual firefighting actions were taken by the New York Fire Department after the collapse of the towers. Firefighters made an early decision to abandon the active firefighting, the second level of defence (FEMA 2002). This was in part due to possible damage to WTC 7 from the collapse of WTC 1 and WTC 2. The fire proofing, the third level of defence, provided passive fire protection to structural members for a certain amount of time. However, the continuous uncontrolled fires on different storeys weakened the structural members on various floors. Therefore, the failure of the first two basic fire defence mechanisms significantly contributed to weakening the structural system that resulted in the ultimate collapse of WTC 7.

7.5 Performance of Structural Elements

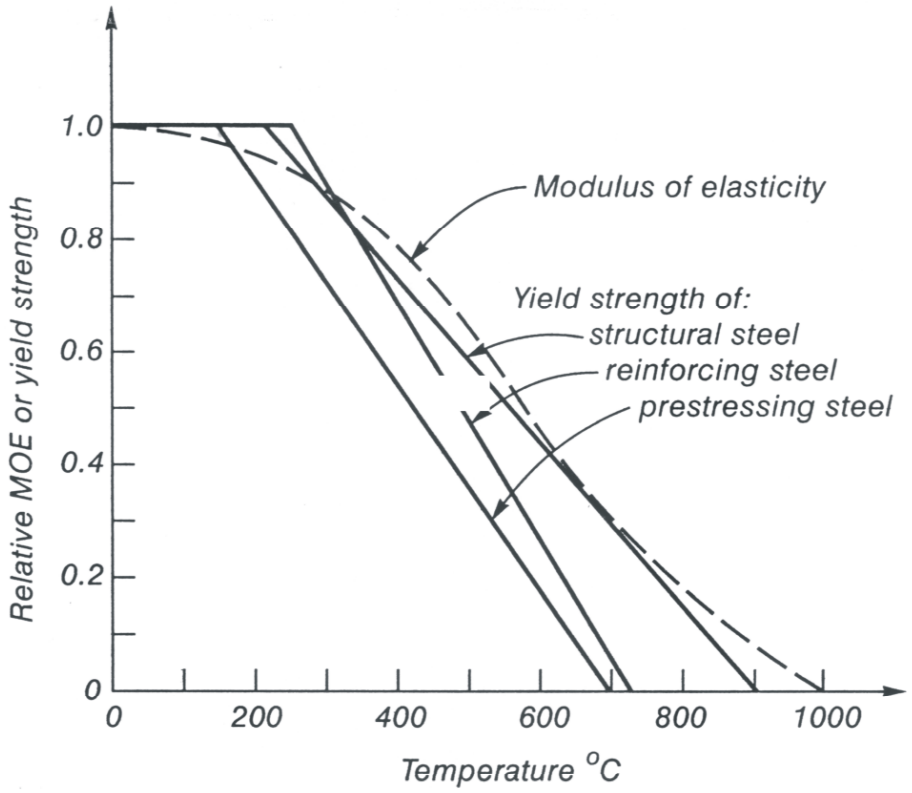
The structural steel-framing and fire protection design features in WTC 7 were quite conventional, when the building was placed into service in 1987. Perimeter steel moment frames, 2-storey belt trusses, and an interior braced core at the lower levels provided lateral resistance features. The floors were typical steel beams with composite deck and concrete topping.

This continuous burning of fires at multiple floors weakened the structural system of WTC 7 at some levels. Steel loses its strength and stiffness when subjected to high temperatures. A typical steel structural member 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 (Kodur and Harmathy 2002). An unprotected steel member subjected to an ASTM E-119 standard heating environment is able to maintain its structural integrity for about 20 minutes. To limit this loss of strength and stiffness, external fire protection (fire proofing) is provided to the steel structural members to achieve the required fire resistance ratings. Figure 4 illustrates the variation of strength and stiffness in steel as a function of temperature. In the case of WTC 7, the fire scenario might have been more severe than an ASTM E-119 standard fire that is often used as a bench mark for building fires. In addition, the fires were burning on multiple floors simultaneously. The impact of the temperature on the structural members became a function of the thermal properties of the fire proofing and the "heat sink" of each structural member.

A review of the WTC 7 collapse indicates that the progressive collapse was initiated on a lower floor level and that the upper 30 to 35 stories descend intact (FEMA 2003). In addition, just prior to collapse, a crack or "kink" or fault line (FEMA 2002) develops along the north wall in the vicinity of the east penthouse on the eastern side. The east penthouse is located over transfer trusses 1 and 2.

One of the possible collapse mechanisms is the failure of transfer truss 1 or 2 due to severe fire exposure on that level. These huge steel transfer trusses were critical elements in WTC 7 and ran mostly through the 5th, 6th and 7th floors where the fires burned towards the end. As the fires burned uncontrolled, at the lower floors, and raised the temperatures of structural members over a period of many minutes, this induced additional stresses into the damaged structural frames, while simultaneously softening and weakening these frames. The failure of these critical elements (due to massive fires) had a significant impact on the overall structural system and must have initiated the progressive collapse. Thus, the full collapse of the 47-storey

steel-framed WTC 7 occurred approximately seven hours after the collapse of WTC 1and has been attributed to fire causes at the present time.



Reduction of yield strength and modulus of elasticity of steel with temperature

Figure 4 Variation of strength and modulus of elasticity of steel with temperature

Contrary to some reports, the steel did not melt. The melting point for steel varies with the alloy and is in the range of 1,500-1,600°C. Since the fire temperatures did not reach this value it is unlikely that there was any melting of steel.

Detailed modelling of the fire, heat transfer to structural members and structural response under fire, currently underway by NIST, might provide the actual performance of structural elements during the WTC 7 fires and will shed some insights into likely collapse mechanisms (NIST 2003).

8 SUMMARY

The fire development and fire resistance issues played a major role in the collapse of the WTC 7. The falling or impact of the debris from the collapse of the twin towers did not cause significant damage to the structural system, however, it might have resulted in initiating 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; however, resulting fire temperatures were unlikely to be significantly different from other building fires. The loss of fire defence

mechanisms, including sprinklers and active fire fighting, further contributed to weakening the structural members. The intense heat from the fires attacked the structural elements and, over a period of time, resulted in sufficient additional damage to the structural system to initiate a progressive sequence of failures that eventually culminated in the collapse of WTC 7 after burning for about 7 hours.

A current investigation by the National Institute of Standards and Technology (NIST) into the fire growth and performance of structural elements will shed further light on the first ever collapse of a steel-framed building, WTC 7, under fire (Hernandez, 2002).

9 ACKNOWLEDGEMENT

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