Built to *last* or built to fail?

Raul Angulo and Paul Kayley examine whether office fuel loads could cause the complete collapse of WTC 7 and what this means for firefighting confidence today

WTC 7, the third high-rise to collapse on 9/11, was located about 100 yards (91.4m) north of WTC 1, was a 47-story steel building, stood 610 ft. (186 m), contained 82 columns, concrete-on-steel deck composite floor assemblies, was clad in red granite masonry, and was fully sprinklered. The building was not hit by an aircraft, and no firefighters died in the collapse.

Fires burned on numerous floors for seven hours, then it completely collapsed symmetrically in freefall, within its own footprint at 5:20 pm. This event wasn't exclusive to New York City (NYC). The effects it had on understanding fire behavior within high-rise buildings, including best- practices in strategy and tactics, have affected the international fire service as well.

In high-rise fires, civilian evacuations can be confusing and complex. The capacity for exponential fire growth, and the ease with which occupants and rescuers can become trapped, causes us to rely on the designed strength of the building to save lives, contain the fire, and extinguish it from inside. The tragic 2017 Grenfell Tower fire which killed 72 people, has been one of the most graphic examples since 9/11, and following its inquiry, high-rise firefighting has become a topic of heightened interest within the UK fire service.

Fire resistance and firefighter confidence

It's imperative for firefighters to understand fire behavior in high-rise buildings, and have complete trust and confidence in their high-rise operational procedures. Yet, following the Grenfell fire, it became apparent that firefighters involved in that incident feared the building would collapse like the WTC , which of course, it did not. Grenfell Tower burned vigorously throughout, for over 19 hours, yet remains standing to this day. In fact, historically, no modern Type-I fire-protected high-rise has ever completely collapsed due to fire.

> **"Historically, no modern Type-1 fire-protected high-rise has ever completely collapsed due to fire."**

So, given what we know about the performance of these buildings over decades, why were these UK firefighters in fear of total collapse, and did that additional fear and stress compromise their psychological and operational effectiveness, thereby potentially endangering them and others? This is a valid question to reinforce, or critically review the legitimacy of our current firefighting practices and our civilian rescue "protect-in-place" procedures.

Reassessing fire-induced collapse

Addressing this fear starts by understanding what really caused the global, freefall collapse of WTC 7. Over recent years, a growing body of evidence regarding WTC 7 has become available, calling into question the beliefs which were responsible for the misapprehensions of those UK firefighters at Grenfell. For many of us, this is still a visceral and emotional subject, but it's been 24 years since 9/11. Strong sentiments have died down enough to ask the hard questions and objectively ▸

consider more reasonable, scientific, and physical explanations.

There were two federal investigations with different variations of the collapse hypothesis. The May 2002 FEMA report was inconclusive as to the cause of the collapse of WTC 7, but it suggested that there were not enough combustibles (office Class A fuels) on those floors to reach and sustain temperatures to sufficiently weaken the structural members. The second report from The National Institute of Standards and Technology (NIST) was published in November 2008.

WTC 7 was fully sprinklered, yet it was constructed with the more stringent fire resistance requirements for a Type IB (unsprinklered) construction, specifically a 3-hour rating for the columns and a 2-hour rating for the metal deck and floor support steel.

WTC 7 had normal office combustible load levels ranging from 20-32 kg/m2, which was only enough material to burn for approximately 30-45 minutes in any given location. These time frames were accepted by NIST. In fact, NIST was more conservative on burn times, acknowledging that office fires did not persist for more than 20 to 30 minutes in any given area, which is consistent with videos and photos.

The limits of office fuel loads

Structural steel melts at 2,732ºF (1,500ºC). It is unlikely that a high-rise fire would be able to reach and sustain that temperature with office furnishings as its fuel load unless the steel was under direct flame contact for an extended period of time. However, for Type I design purposes, it is usually assumed that all capacity is lost at approximately 2,200ºF (1204ºC). The strength of steel essentially remains the same until the temperature reaches approximately 600ºF (316º C).

When steel is heated to 1,000ºF-1,100ºF (538ºC - 593ºC), it loses about 50% of its load bearing capacity. This is the failure point in fire resistance rating test like the ASTM E119. The loss in strength and stiffness are temporary for temperatures that do not exceed 1,300º F (704ºC) for more than 20 minutes. Even if the structural steel beams and girders are deformed, the steel will regain its pre-fire strength once the temperatures start to drop, either by the fire entering the decay stage, or if the fire is extinguished with water. So, could office fuel loads really produce and sustain temperatures greater than 1,300ºF (704ºC) for more than 30 minutes to weaken the steel girders?

When considering these typical office fuel load levels in context with what we know about the building's fire resistance values, it's clear that the passive fire protection was well in excess of what was needed to resist the fires it experienced. Even in the unlikely event of a localized failure, steel-framed high-rises are designed to be highly redundant structural systems. Thus, if a localized failure occurs, it does not result in a symmetrical freefall collapse of the entire structure.

Current and well-established firefighting and rescue procedures, both in the UK and the USA, rely on the fact that these modern fire-resistant structures are designed and constructed to tolerate fire severity in excess of that which the building is anticipated to be exposed to. Rather than relying solely on fire extinguishment, firefighters depend on the strength and durability of the construction to outlast, by wide margins, the burn time of interior fuels.

This margin of resistance has achieved such a level of confidence that some Type I buildings are allowed to be constructed without automatic sprinkler systems, which in turn provides the assurance for fire departments to use interior strategy and tactics as the primary method to combat high-rise fires without the fear of building collapse. In fact, it is this confidence in the inherent qualities in the construction of these fire resistive buildings that allowed the FDNY to set up their initial command posts inside the lobbies of WTC 1 and WTC 2.

High-rise fires that did not fall

At the 1988 First Interstate fire in Los Angeles, a 62-story high-rise, the fire extended at an estimated rate of 45 minutes per floor and burned intensely for approximately 90 minutes on each level. Its sprinkler system was not yet operational. This resulted in two floors being heavily involved at any given point during the fire. Floors 12 to 16, were destroyed by fire. Total firefighting efforts took over 8 hours.
It was this same understanding of Type I construction that gave the LAFD the confidence to remain inside the interior of the First Interstate building for the eight-hour duration of the incident. There was no fear of total global, freefall collapse. Later, structural engineers determined that the building suffered no major structural damage from the fire. It stands in service today as the Aon building.

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At the 1991 One Meridian Plaza fire in Philadelphia, a 38-story high-rise, nine floors were destroyed by fire. The incident spanned 19 hours. After 11-hours of unimpeded fire in the building, the chief withdrew all companies fearing a structural collapse, but it never happened.

The 2004 Parque Central Tower fire in Caracas, Venezuela, burned for 17 hours. Its sprinkler system had been deactivated due to a combination of issues. The building remains in use today. In 2009, the Beijing Mandarin Oriental Hotel caught fire in China. Its sprinklers were unfinished and not yet in operation. The entire building was engulfed in flames and spectacularly burned for several hours. Today, the same building is a luxury 5-star hotel.

What caused WTC 7's freefall?

In the videos of the collapse of WTC 7, it descends for the first 2.5 seconds at the acceleration of gravity, also known as "freefall." If the falling material encounters any resistance whatsoever, it will fall at a slower rate. All three visible corners of WTC 7, and several other points along the roofline, over a span of 328 ft. (100 m), were measured to transition instantly from full support to freefall simultaneously within 0.2 seconds. The perimeter walls fall straight down without tipping, and the building falls symmetrically within its own footprint. Under what circumstances have you seen this pattern of collapse previously?

Sudden transition to freefall rules out a progressive collapse by fire or any other known natural mechanism other than explosive demolition. Freefall continued for about 2.5 seconds, equivalent to removal of all support columns over 8 floors, low in the building. This could not have been a pancake collapse because pancaking of floors would produce a series of jolts that would slow the rate of descent. The only way for the upper floors to accelerate uniformly downward through the building is for ALL of the underlying support columns to be removed simultaneously.

Yet, NIST's computerized theory proposes thermal expansion pushed the unrestricted girders (for lack of shear studs) against the supporting columns, restricting them from expanding and causing them to buckle. The buckling would then have caused the girder to break away from the column. This began a cascading chain of failures of eight additional floors, bringing down the entire building like a house of cards.

NIST's final report concluded that the collapse was primarily caused by normal office-fueled fires, not from falling debris from WTC 1. They acknowledged that this extraordinary, rare event, "fire-induced progressive collapse" didn't fit with any textbook examples of our understanding of how buildings collapse during a fire, but were otherwise similar to fires experienced in other high-rise buildings – an unprecedented claim. If this building fire is considered in isolation, without the biases and prejudices of the day when it occurred, this would undoubtedly be the most well-known case study in the world. ■

About the authors

Captain Raul Angulo is a 38-year veteran of the Seattle (WA) Fire Department, and author of the new NFPA textbook Engine Company Fireground Operations 4th Edition, published by Jones and Bartlett Learning. He is an international instructor on fireground strategy and tactics, and a member of the Editorial Advisory Board for Fire Apparatus and Emergency Equipment magazine. He has been an FDIC International instructor since 1996.

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