A Catastrophic Collapse: Windsor Building Fire (Madrid, 2005)

Montalva A. PE. Hinman Consulting Eng., San Francisco, CA, US
Pons i Frigola, V. Oficina Tecnica de Ingenieria Forense, Valencia, Spain
Herrera O. Oficina Tecnica de Ingenieria Forense, Valencia, Spain
Gilsanz, R. P.E. Gilsanz Murray Steficek LLP, New York, US
Pons i Grau, V. Oficina Tecnica de Ingenieria Forense, Valencia, Spain

Introduction

On February 13, 2005, a fire in the Windsor Building, one of the tallest buildings in Madrid, Spain, burned for 26 hours and caused the partial collapse of the structure. At the time of the fire the building was being renovated to comply with Spain's fire safety and protection building code. The renovation had been undertaken voluntarily and without any legal obligation.

Illustration 1: Windsor Building

The Windsor Building was designed in 1975 by the Estudio Alas-Casariego, an architectural consulting firm founded in 1953 by Genaro Alas and Pedro Casariego. The design team for the building included Genaro Alas, Pedro Casariego, Luis Alemany, Ignacio Ferrero and Manuel del Rio.

The Windsor Building was an office tower with commercial and parking spaces located at the lower levels. With a total height of 106 meters, this building at the time of the disaster was the eighth tallest building in Madrid.

The five basement levels were used for parking. Commercial space was located between the ground and 3rd floors. Three mechanical floors, at the fourth, seventeenth and top levels, were distributed throughout the building.

The second mechanical floor divided the building's two large volumes of office space into 13 floors below and 10 floors above the 17th level. Each office floor was approximately 1000m^2.

Structural Description

The typical floor of the Windsor Building was 25m x 40m, with an interior concrete core. The typical floor slab was a 20cm + 3cm deep bi-directional reinforced concrete waffle slab with 60cm x 60cm permanent formwork from ceramic fillers.

Three steel beams and concrete columns of the interior frames spanned 13m parallel to the short side of the building and were spaced 6m perpendicular to this side. From a simple inspection of the drawings the objective of these frames is unclear, but they assist in increasing the clear span of the slab and could potentially be part of the lateral system of the building. A concrete core replaced these frames as shown in Illustration 3.

The slab spanned 6m to the perimeter of the building. The edge of the slab was supported by a 100cm x 23cm reinforced concrete beam embedded into it, and this perimeter beam was supported on steel columns.

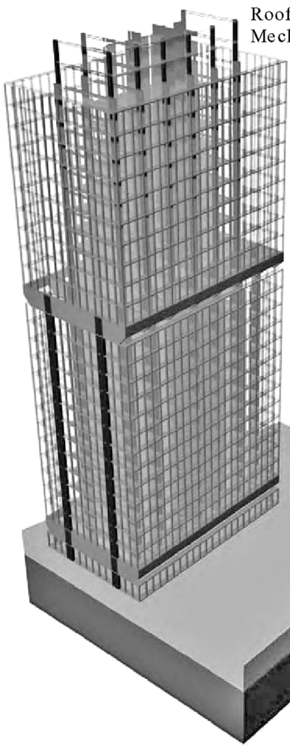

Illustration 2: Floors Distribution in Height

The building's office space was divided into two volumes by mechanical floors (Illustration 2). Floors 17 to 27 (Illustration 3), situated between Mechanical Floor #2 and the Roof/Mechanical Floor #3, had nine interior concrete columns and a concrete core. The entire perimeter of these floors was supported on steel columns. These columns were built-up sections formed by welding two UPN shapes (similar to C-shapes) into a box shape.

Mechanical Floor #2 (Illustration 4) was also a transfer floor. The slab system at this level was a bi-directional concrete slab. Eight floor-to-ceiling concrete transfer girders provided support to the entire perimeter by transferring the load to the concrete columns and core of the floors below. This transfer system allowed minimizing the size of the perimeter steel columns which otherwise would have had to increase in size with the accumulated load as the columns moved to the lower levels. These girders had mechanical and door openings to accommodate the use of this floor. The enhanced strength of this floor was an important factor in the analysis of the building's collapse.

Floors 4 to 16 (Illustration 4), between Mechanical Floor #1 and Mechanical Floor #2, had a distribution system similar to the typical floors above, but included four concrete columns on the short side of the perimeter which carried the load from the transfer girders along the short side of Mechanical Floor #2.

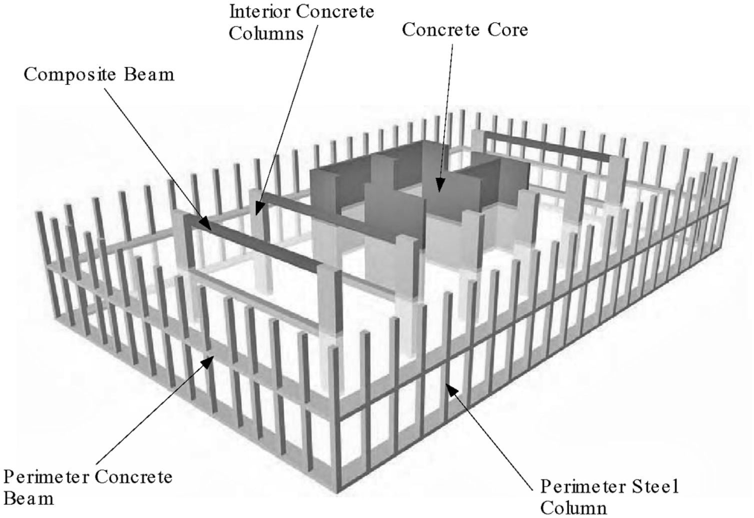

Illustration 3: Typical Floor 17 to 27

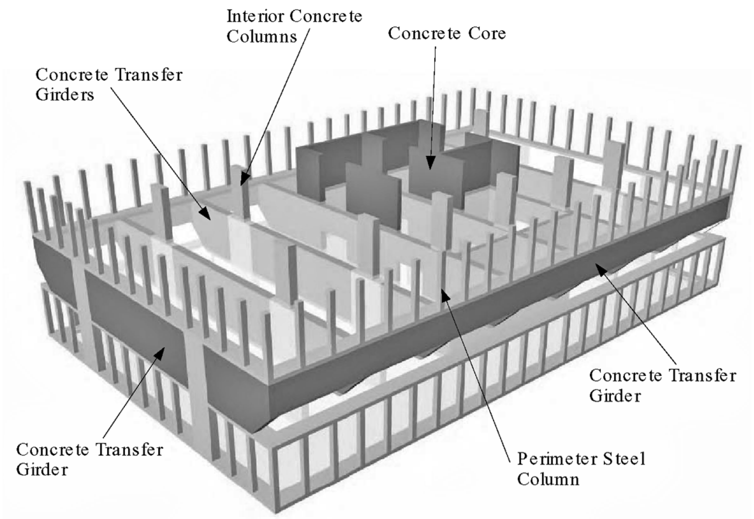

Illustration 4: Mechanical Floor #2

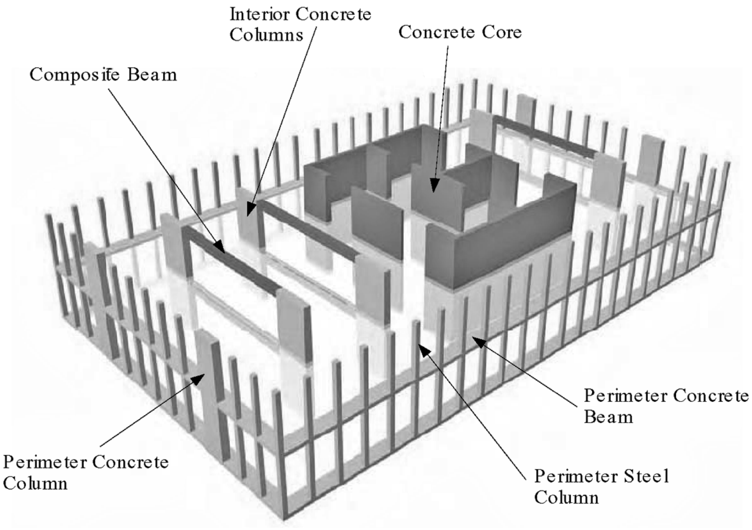

Illustration 5: Typical Floor 4 to 16

Renovation Work

At the time of the fire the Windsor Building was undergoing extensive renovations, the intent of which was to update the building to comply with the latest fire building codes in Madrid, including all local and state codes.

One of the main deficiencies of the building was fire sectorization, horizontal through the floor and vertical through the curtain wall and the interior core.

The major renovation work relating to fire protection included:

- New exterior emergency stairwells.
- Fire sectorization of updated utilities, existing stairwells, floors and basement.
- Full replacement of the curtain wall, including fire-protecting the perimeter steel columns. This fire-protection work had been partially executed at the time of the fire.

Forensic Investigation on the Windsor Fire and Collapse

As part of the forensic investigation, several steps were taken to identify the cause of the fire and to provide an explanation for the building's collapse.

The fist step was to identify the condition of the building before the fire. Architectural, structural, mechanical and electrical drawings of the original structure and other relevant documentation were reviewed along with documentation of the renovations which had already taken place. A detailed report of the utilities, the fire protection system and the evolution of the ongoing renovations was provided.

A study was made of the building's compliance with the fire building code and, as part of this study, the fire load evaluated based on the building report. According to the Fire code RD

2267/04, the thermal load for commercial office use is 800 MJ/m^2. Calculations show that the fire load at the time of the fire was over 1065MJ/m^2, 1.33 times higher than that stipulated by the fire building code. This discrepancy brings the risk level of this building from a low-level under building code design to a medium level.

The next step was to investigate the event. A fire timeline was obtained from eye-witness interviews, phone and e-mail communications, fire system registries, firefighters' reports and other sources. A weather report which included not only the temperature but the direction and speed of the wind at the time of the fire was obtained. This provided a baseline for identifying the origin and dynamics of the fire.

Illustration 6: Building Condition at Lower Floors

Following the event a field inspection was performed. Access to the building was limited due to the extent of the collapse. Illustration 6 shows the condition of the building on the levels below Mechanical Floor #2. The interior partitions had been completely burned, the ceramic fillers showed the thermal effects of the fire and had fallen onto the floor, and the perimeter columns had begun to show the effects of thermal buckling.

Illustration 7: Building Condition at Upper Floors

Above Mechanical Floor #2, the building was extremely unsafe. Floor slabs were partially or totally collapsed and only the area surrounding the building core was accessible. Illustration 7 is of the floors above Mechanical Floor #2 as seen from the building core.

Based on this collected information, and with the aid of simulation tools and engineering judgment, the probable cause and propagation factors of the fire were proposed.

Cause, dynamics and simulation of the fire

Minutes before the first fire alarm was triggered, there is evidence that a single person left the building. This person's office was located on the 21st floor, where it is believed the fire started. This person was a smoker and apparently threw a partially extinguished cigarette into a trash can which was probably filled with paper. There was no proof that the fire was intentionally begun; however, the evidence points to personal negligence as a cause.

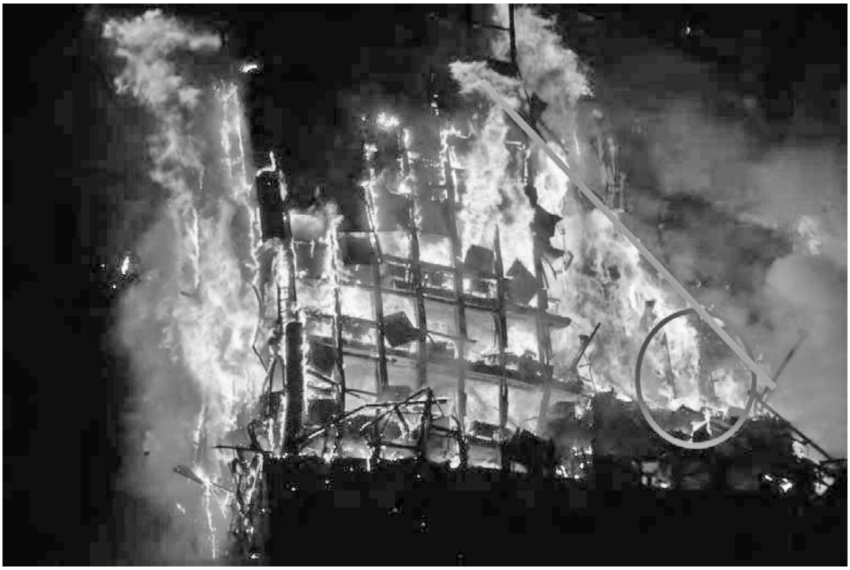

Illustration 8: Fire Evolution

Illustration 8 shows a higher level of destruction at the right side of the east façade, where the fire presumably started.

Because of the total collapse of the upper floors, it was impossible to perform an investigation of the fire path at the site. Therefore, a computerized simulation of the fire was done to show the fire's development inside the building, given the assumptions previously established.

The computer software used was FDS 4.06, developed by the National Institute of Standards and Technology (NIST). FDS is an application for the computerized simulation of fires based on the techniques of fluid dynamics. This model was correlated with phenomena described by eye-witnesses and with photographs of the fire.

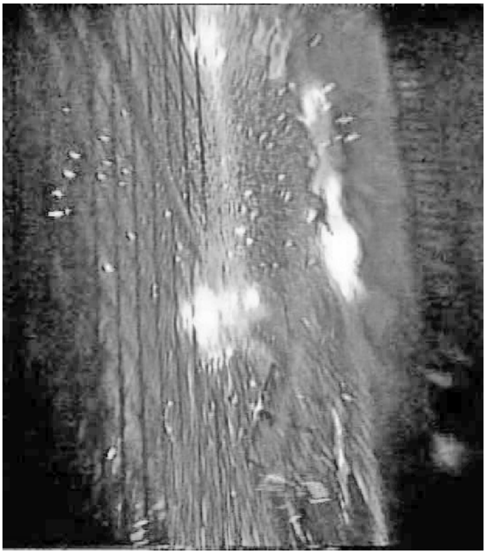

Illustration 9: Fire Explosion

Illustration 9 shows the fire exploding on the 21st floor due to the high fire load.

Based on all the information collected and the analysis of that information, the following conclusions were drawn:

- The fire started on the 21st floor and propagated rapidly throughout the 21st floor by making use of the openings provided by the false ceiling. The lack of compartmentalization aided in fire propagation.
- The fire traveled upwards through the interior utility conduits and the exterior facade system. Due to the elevated fire load, the facade melted and the double skin curtain wall acted as a chimney which spread the fire upwards.
- The aluminum used in the curtain wall fabrication melted due to the elevated temperatures. This produced "fire drops" which helped to propel the fire downwards. The elevated fire load aided in the downward propagation.

Collapse description and evaluation

The floors above Mechanical Floor #2 collapsed in the fire. The steel columns on the upper levels did not have fire protection in place at the time of the fire, and hence were more vulnerable.

Illustration 10 shows the extent of collapse on the upper floors. The collapse extended to the interior concrete wall on the side of the building where the fire presumably started, and to the first span of frames on the opposite side.

Illustration 11 shows the slab system folded one over the other due to the perimeter steel column failure on the 21st floor.

Illustration 10: Collapse Extension

Illustration 11: Building Collapse

Illustration 12: Lower Levels Damage

Even though Mechanical Floor #2 did not act as a barrier to the downward propagation of the fire, due to its strength the progressive collapse of the building was contained within the upper floors.

The lower levels had a further advantage over progressive collapse due to the fire protection of the perimeter columns and the concrete columns which existed on the short sides of the building facade. However, Illustration 12 shows steel columns on the lower levels with early stages of thermal buckling.

Conclusions

An extensive forensic investigation was performed to evaluate the cause and propagation of the Windsor Building fire. This work included a joint effort between fire consultants and structural engineers to evaluate the weaknesses and strengths of buildings and their structural systems in the event of a fire.

The importance of the horizontal and vertical compartmentalization of buildings was stressed, in particular high-rise buildings with difficult access for firefighters, in order to contain the fire in isolated areas and minimize the extent of casualties.

Also important is the behavior of the curtain wall when exposed to high temperatures. Its failure can introduce venting points, thus increasing the effects of the fire.

From a structural point of view, this event demonstrated the importance of fire protection in steel structures and the benefit of combining steel and concrete elements in the building design.

Also, the introduction into the building system of a strong floor reduces the extent of building collapse in case of fire and provides shelter to the building occupants.

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