World Trade Center Towers: impact, fire, evacuation and collapse

ITSEMAP Servicios Tecnológicos MAPFRE (*)

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It may be stated without any doubt at all that the attack on the World Trade Center of New York was the most notable event in recent history from a social and economic point of view, and above all with respect to international insurance and reinsurance. As a result of its extreme importance it has become part of our lives since the morning of September 11. Even today each sector is analysing and evaluating its consequences in the short and long-term. It is the obligation of engineers who work in prevention and safety to remain aloof from other considerations which the attack may bring to mind and analyse the events from a technical point of view in order to check information and obtain conclusions and experiences which are valid for the future. This article gives an

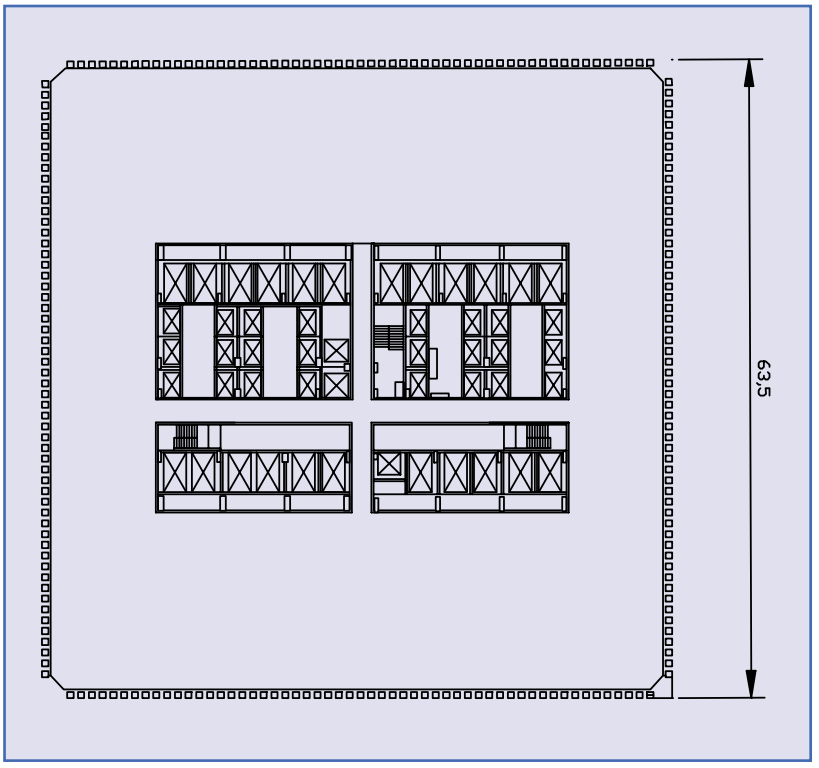

Figure 1: Floor plan of each of the towers

(*) Article extracted from ITSEMAP Security Section's Study.

overview of the initial conclusions of a study which ITSEMAP Servicios Tecnológicos Mapfre is carrying out with respect to this.

The main aims of this study are a technical analysis of the behaviour of the twin towers as high-rise buildings with regard to *material resistance* up until the buildings' collapse, the *functioning of the fire prevention systems* and an analysis of the evacuation capacity of the towers.

It is important to bear in mind that, given the emblematic nature of the towers, their construction details are known in great depth: architecture, structural elements, evacuation routes, etc.

This is why, in order not to distract the reader's attention, this article purposefully does not include an abundance of descriptions and figures.

ANALYSIS OF THE TOWERS COLLAPSE

The analysis of the towers' collapse may be carried out in the following phrases:

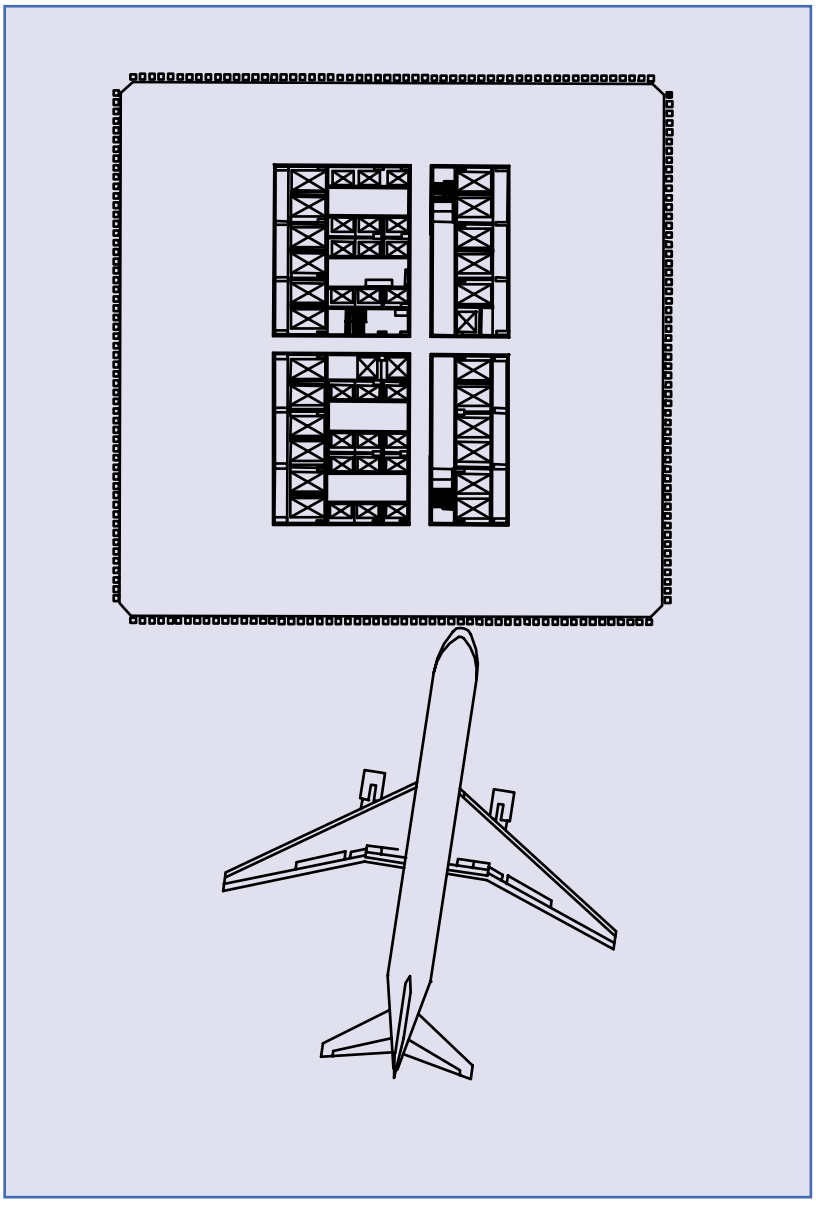

Figure 2. Comparative ilustration of the sizes of the aircraft and tower crossection

1. Structural behaviour after impact

With regard to this, and as information of interest, it is indicated that the relevant data in order to estimate the energy brought into play in the loss are:

Data for the B-767 aircraft:

- Maximum weight: 179 T (includes cargo, passengers and fuel)
- Fuel: aviation kerosene (Combustion Heat:44.7 MJ/kg)
- Estimated quantity on impact: 85,000 L
- Estimated velocity on impact 300 - 400 km/h

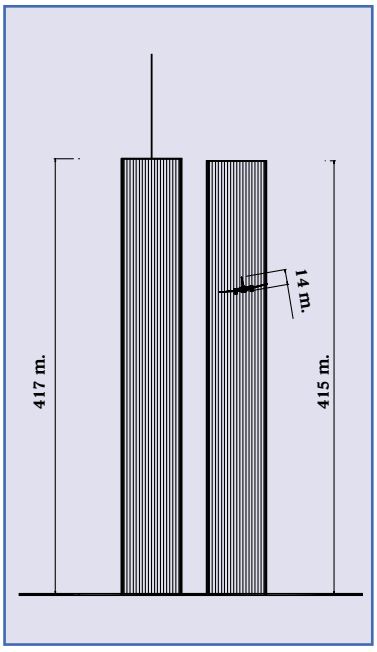

Figure 3. Elevation of the North and South towers. Comparison of the aircraft which impacted the South Tower (2nd impact) with the dimensions of the towers. Scale diagram.

These data may be used to calculate the kinetic energy ($1/2\ m \cdot v^2$) and the amount of movement ($m \cdot v$) of the aircraft as a basis to estimate the shearing force on a horizontal section of the tower (F) and the flector moment at the base of the tower ($F \cdot h$).

It may be seen that these mechanical loads are inferior to the global loads for wind (320 km/h) foreseen in the design of the building.

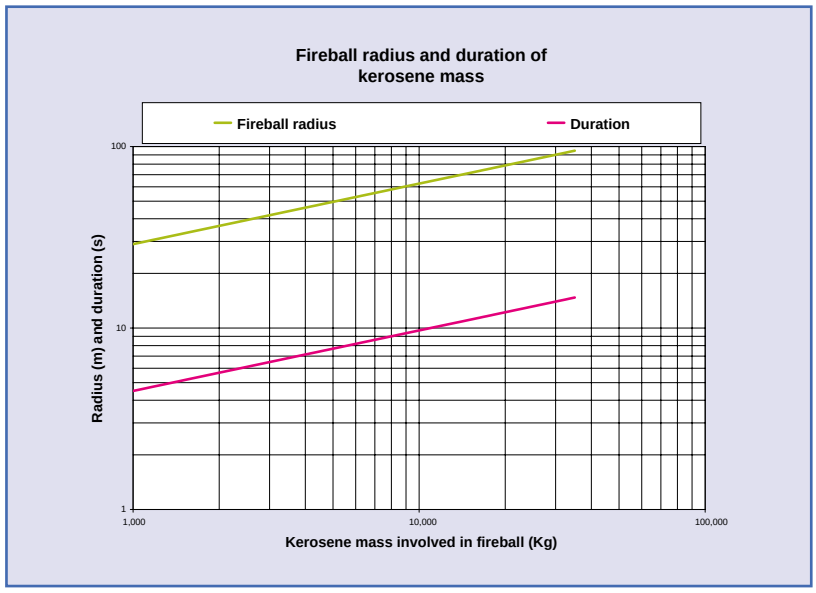

Figure 4: Fireball characteristics.

It may be established that the mechanical energy of the impact was absorbed by the structure of the buildings through their deformation and fracture, this without any doubt reducing the load bearing capacity of the structure, but without causing collapse.

The wingspan of the planes (48 m) and the dimensional of the tower (63 m sides) may be used to estimate that the reduction in vertical load (weight of the upper floors) would be around 20 - 25%, this - in the absence of significant external loads and a perimeter load bearing capacity of the structure independent of height - explains the initial stability of the structure after the impact.

2. Structural behaviour when affected by fire

The tower structure had fire protection systems which guaranteed the maintenance of its mechanical characteristics when the affected by a "standard" fire for two hours (FS-120 min).

The **"fire stability of the structure" (FS)** refers to its capacity to carry out load bearing functions in the case of a "standard" fire under the conditions of a "normalised" temperature change situation. This means that the structure of the towers would have "resisted" more than two hours in a generalised "standard" fuel fire.

The fires which affected the towers however took place in two phases:

- *Quasi-instantaneous fire*, in the form of a fireball producing a high intensity fire brought about by the effects of aircraft fuel dispersion caused by the impact together with the expansion of the gases caused by the combustion of the hydrocarbon itself. This event is of limited duration and, using images, was estimated at some ten seconds. The situation portrayed in figure 4 results in a kerosene mass of approximately 10,000 kilograms taking part in each impact.
- *Static fire*, of the residual mass of fuel not burnt in the previous phase.

Given its greater duration, this is the phase which weakened the structure enough to cause its collapse. It should be noted that the combustion of hydrocarbons, such as aviation kerosene, subjects the structure to conditions which are notably more severe than the "standard" fire for which the fire protection systems were designed.

Exhaustive analysis allows for the forecasting of the reduction in load bearing capacity of a structure as a function of time for a specific fire.

This would give the explanation for the difference in time until the collapse of both buildings, since the structural damage of the impact and the reduction in "cold" residual load bearing capacity, as effects of

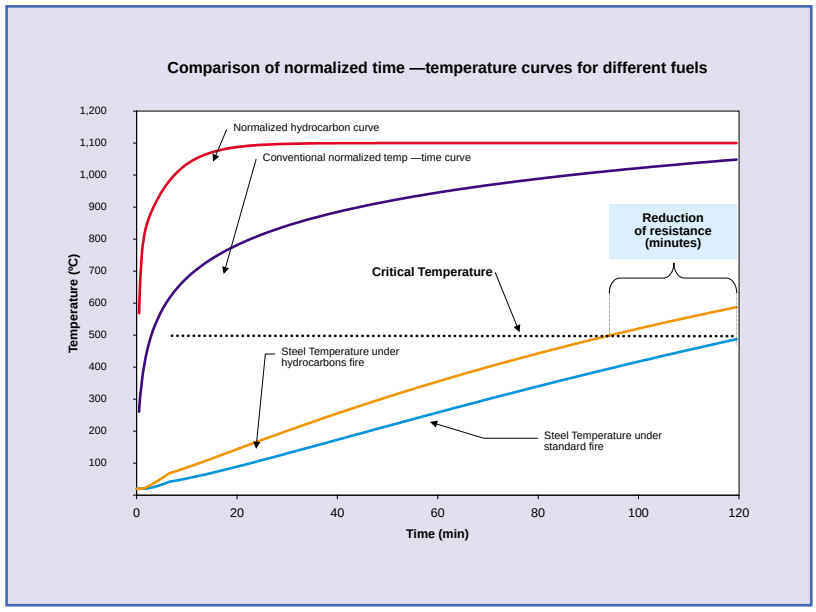

Figure 5: Comparative normalised fire curves for hydrocarbon v. conventional

fires, may be considered analogous. Therefore the damaged tower structure which had to bear the greater load as a consequence of the impact occurring at a lower height (South Tower) resisted less time (54 minutes v. one hour 40 minutes).

3. Structural behaviour after the failure of the floors affected by the fire

The structural failure which was previously explained meant the collapse of the part of the tower above the fire of a height equivalent to 4 - 5 floors (15 - 17 m). The potential energy (m·g·h) would impose a load in the order of dozens of times its static weight on the floors below those affected by the fire. This is notably higher than what the towers were designed for, provoking their total collapse.

The accumulated potential energy of all the floors was finally liberated, producing the wave of pressure and dust which affected many blocks around the World Trade Center.

CONSIDERATIONS WITH REGARD TO THE FUNCTIONING AND EFFECTIVENESS OF THE FIRE PROTECTION SYSTEMS

The towers, as it is required by almost all regulations and standards on fire safety in high-rise buildings, were equipped with automatic sprinkler systems designed to control fires in advanced stages, calculated to release a determined "discharge density" (litres per minute and per square metre) of water in the "area of operation" for the "type of activity". This means that these conventional systems are designed to control fire from its start in a maximum affected area of approximately 200 square metres for this type of risk, and guarantee its control.

However, both the qualitative and quantitative characteristics of the fuel, together with the size of the area affected by the fires in both towers as a consequence of the spillage after the initial impact, greatly exceeded design specifications.

In addition to this, even if the systems had been designed to higher specifications so as to be able to tackle fires such as these, apart from the problems of technical and economic viability, the mechanical damage arising from the impact would have put the towers out of use.

CONSIDERATIONS WITH RESPECT TO THE HEIGHT OF THE TOWERS

As is well known, the first Boeing hit the North Tower between the 103rd and 96th floors at 8.48 a.m. and the tower collapsed at 10.28 a.m., in other words the North Tower remained stable for 1 hour 40 minutes.

The second Boeing hit the South Tower at 9.06 a.m. between floors 73 and 77. The South Tower collapsed at 10 a.m. This tower was stable for 54 minutes, and given the proximity and magnitude of what was happening in the North Tower, it may be hypothesised that the head of safety was already "on alert" at the moment of impact.

Following on from this assessment, it would seem obvious that in the North Tower there would be a 100% loss of life from floor 96 to floor 110 and that from this moment the occupants of the tower would begin to react. It should be remembered that the tower was stable for 1 hour 40 minutes.

The South Tower however had 18 minutes of pre-alert, although consideration must be made for time to identify the situation (without doubt completely unforeseen) and the evacuation response. In contrast to the North Tower however this tower was hit between floors 73 and 77, in other words 37 floors would not be able to be evacuated. This occurred 18 minutes after the first impact, and the tower remained stable for 1 hour.

The first evacuation calculation hypothesis can be made using the estimate consideration of 2/3 of the total (22,500 persons per tower approximately) at the time of the events, for the following tower circumstances:

- Usable stairways: 3 (width: 2 of 1 metre and 1 of 1.2 metres).
- Type: "specially protected".
- Flow rate: 1.2 persons per second and metre width.
- Elevators: "not usable" (conservative hypothesis).

Using these suppositions, the minimum exit time for all the building's occupants would be 65 minutes.

Without any doubt, and with regard to the latest official figures concerning deaths and missing persons - bearing in mind the occupancy conditions and previously mentioned times - it may be concluded that the towers' safety systems functioned efficiently. This does not only mean that the escape routes available to the occupants – whose number and characteristics are known – were used correctly, but also that the training and response of the occupants and emergency personnel (fire-fighters, police, etc.) were essential in order to save the lives of many other people who might otherwise have lost their lives in the already legendary event of September 11, 2001. ■