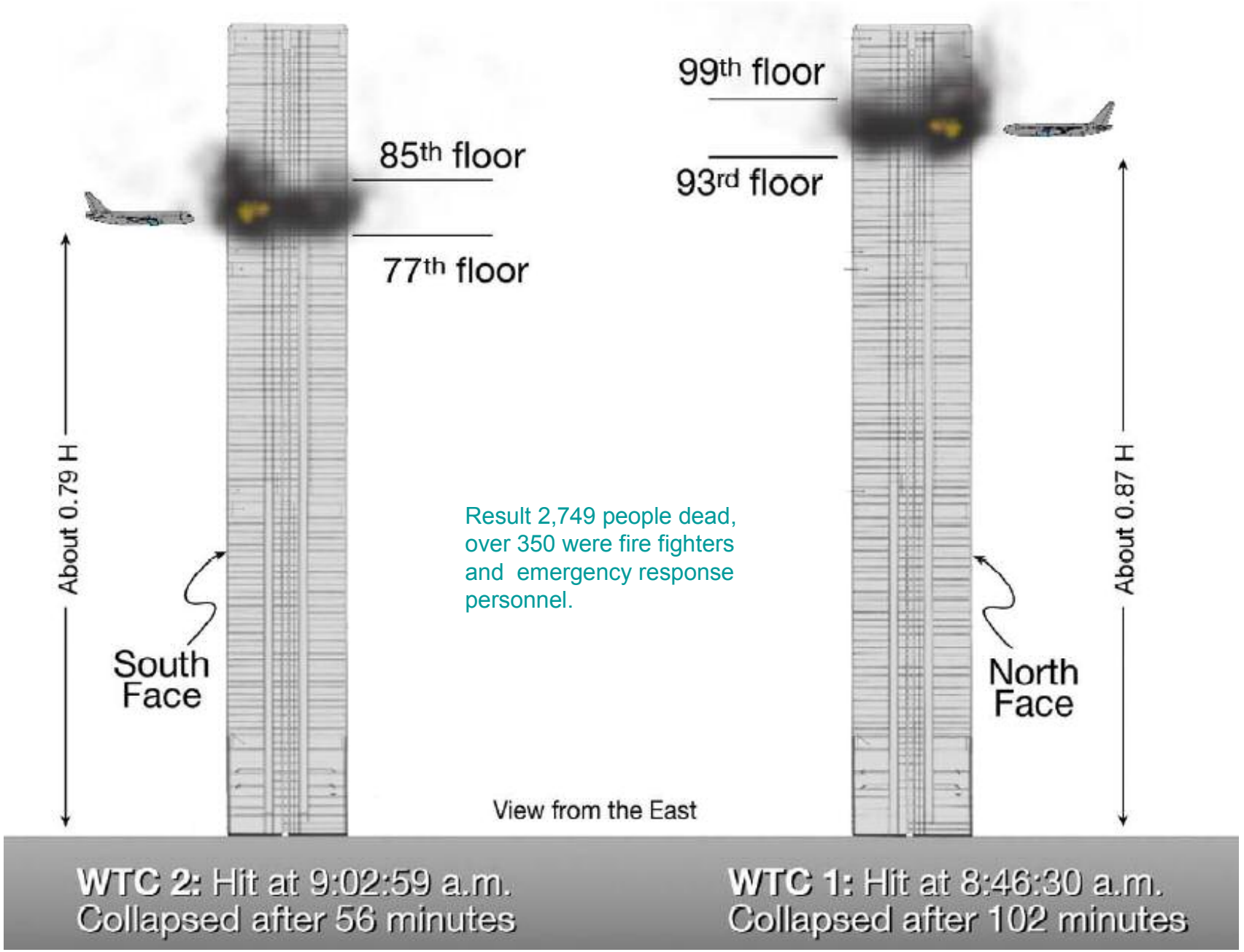
World Trade Center Investigation Objectives

- Determine:
  - why and how the WTC Towers collapsed following the initial impact of the aircraft, and
  - why and how the 47-story WTC 7 collapsed
- Determine why the numbers of injuries and fatalities were so lowor high depending on location, including technical aspects of fire protection,occupant behavior, evacuation, and emergency response
- Determine the procedures and practicesthat were used in the design, construction, operation, and maintenance of the WTC buildings
- **Identify, as specifically as possible, areas in current national building and fire model codes, standards, and practicesthat warrant revision**



http://wtc.nist.gov/pubs/Media_Public_Briefing_040505_final.pdf

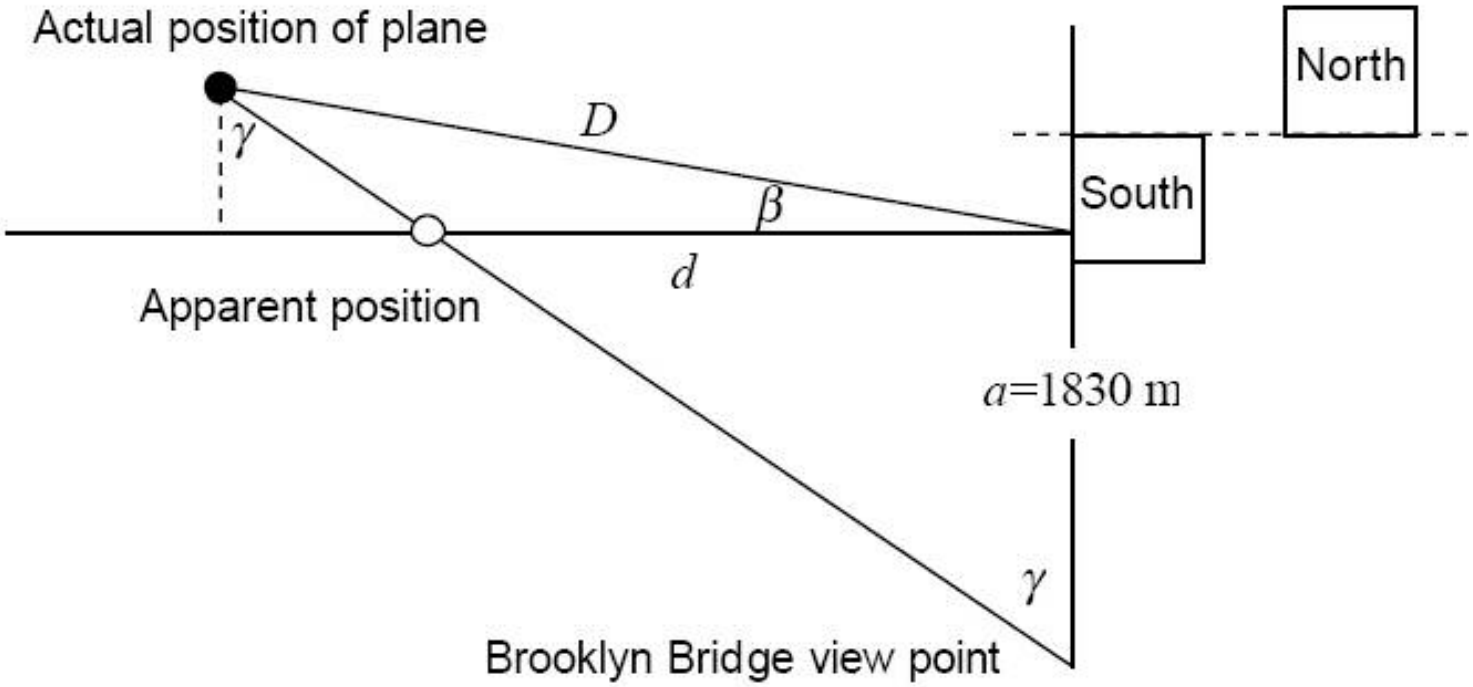
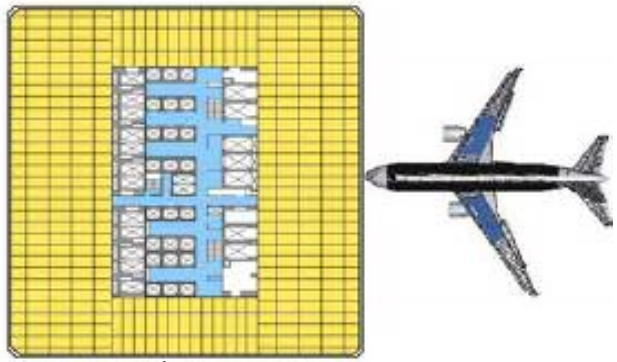


Fig. 8: Plan view of approach to South Tower, as seen from Brooklyn Bridge

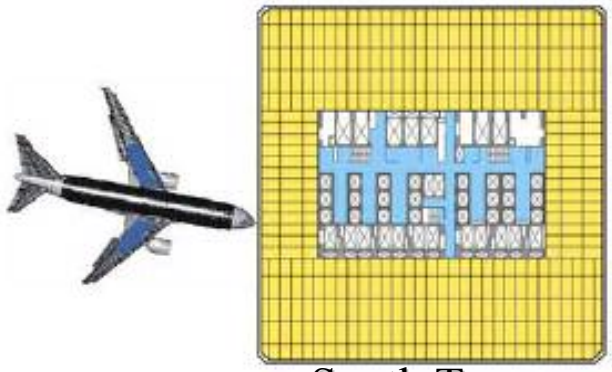
Point of impact:

Close to the center and nearly normal to the building (hit about 0.87 height)

WTC 1



North Tower



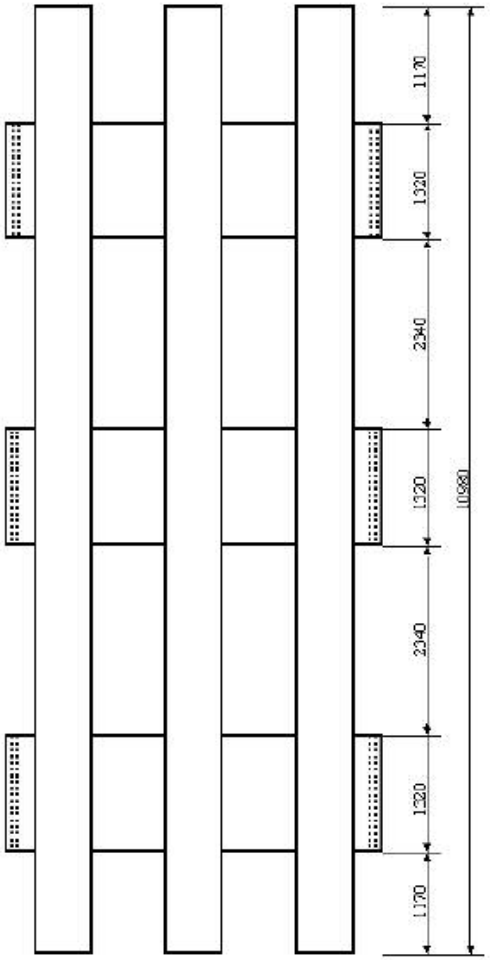
South Tower

WTC 2

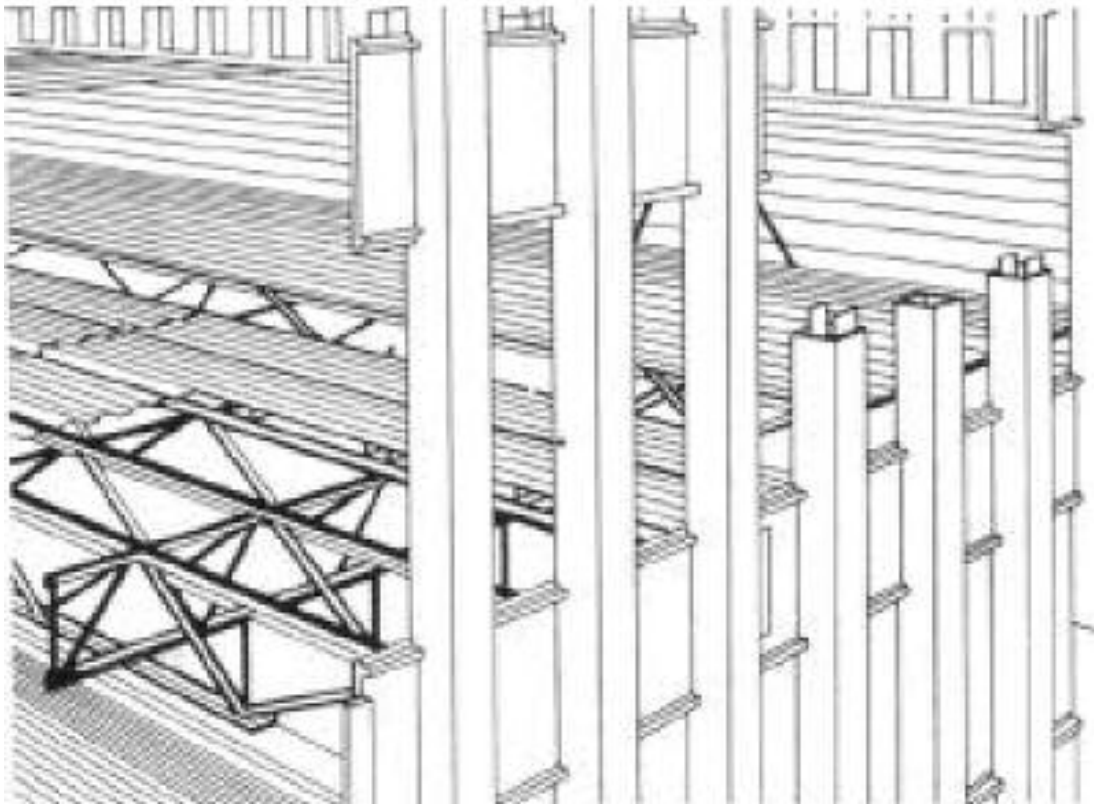
Point of impact:

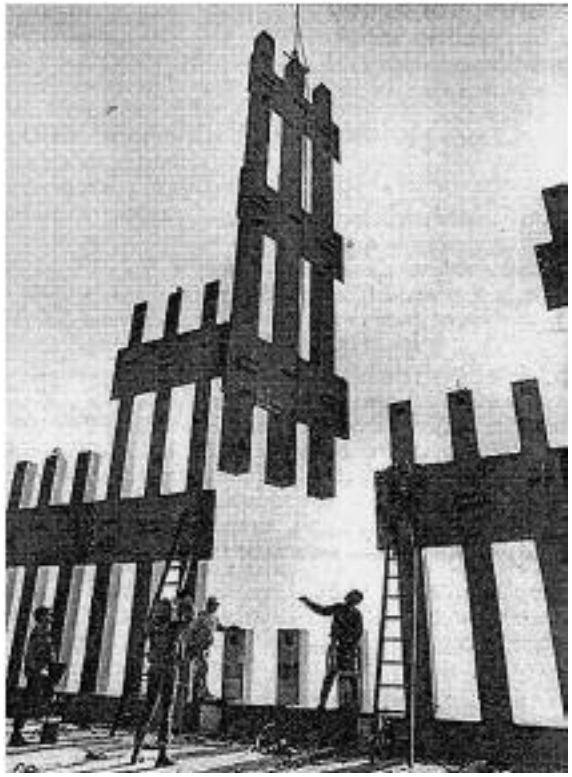
Close to the corner and with an angle to the building (hit about 0.87 height)

Target	Flight	Aircraft	Impact Time	Velocity	
				km/hr	mph
North Tower	AA-11	Boeing 767-200	8:46:20 AM	691	429
South Tower	UA-175	Boeing 767-200	9:02:48 AM	810	503



The 64m wide façade is, in effect, a prefabricated steel lattice. The exterior columns are narrowly spaced and finished with a silver-colored aluminum cladding. The main building block of the outer structure was a prefabricated element, which was comprised of 3 floors, was 11 m high and 3.07m wide.

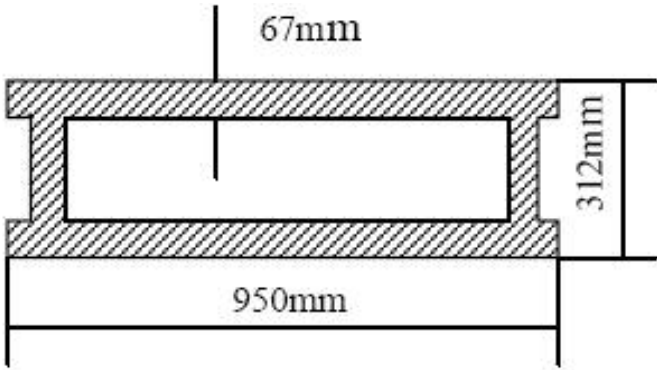




The prefabricated panel consisted of three columns connected by 3 transverse plates, called spandrels. The steel columns are of square cross-section (*b´b´t*=356mm´356mm´9.5mm). and they were spaced 570 mm apart from each other.

The segments were staggered and bolted to their neighboring elements in every direction,

.



Core columns

Inside each tower there were 44 large, concrete reinforced, steel columns, which enclosed elevators, stairways, and utility space. From photographs available, it has been determined that each column had a thickness of 67mm, and dimensions of 950mm´312mm in rectangular cross section. It is not certain if all core columns shared identical cross section, but our calculations could easily be revisited when more precise data on their exact geometry becomes available.

Some Specific Questions Some Specific Questions

How and why did WTC 1 stand nearly **twice** as long as WTC 2 before collapsing (102 min. vs. 56 min.) though they were hit by virtually identical aircraft?

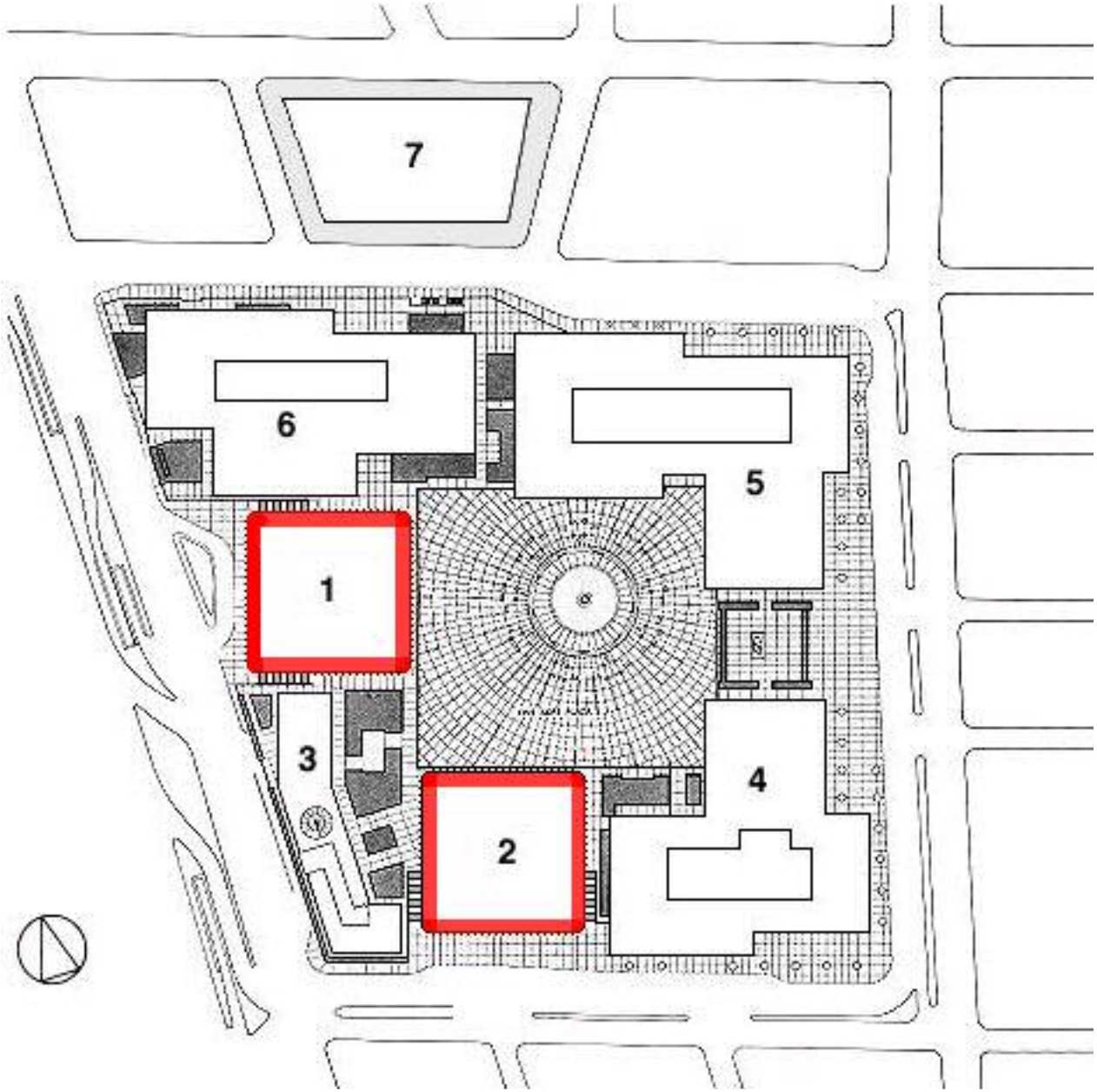
What factors related to **normal** building and fire safety considerations not unique to the terrorist attacks of September 11, 2001, if any, could have delayed or prevented the collapse of the WTC towers?

Would the undamaged WTC towers have remained standing in a **conventional** large building fire scenario?

What factors related to **normal** building and fire safety considerations, if any, could have saved additional WTC occupant lives or could have minimized the loss of life among the ranks of first responders?

How well did the procedures and practices used in the design, construction, operation, and maintenance of the WTC buildings **conform** to accepted national practices, standards, and codes?

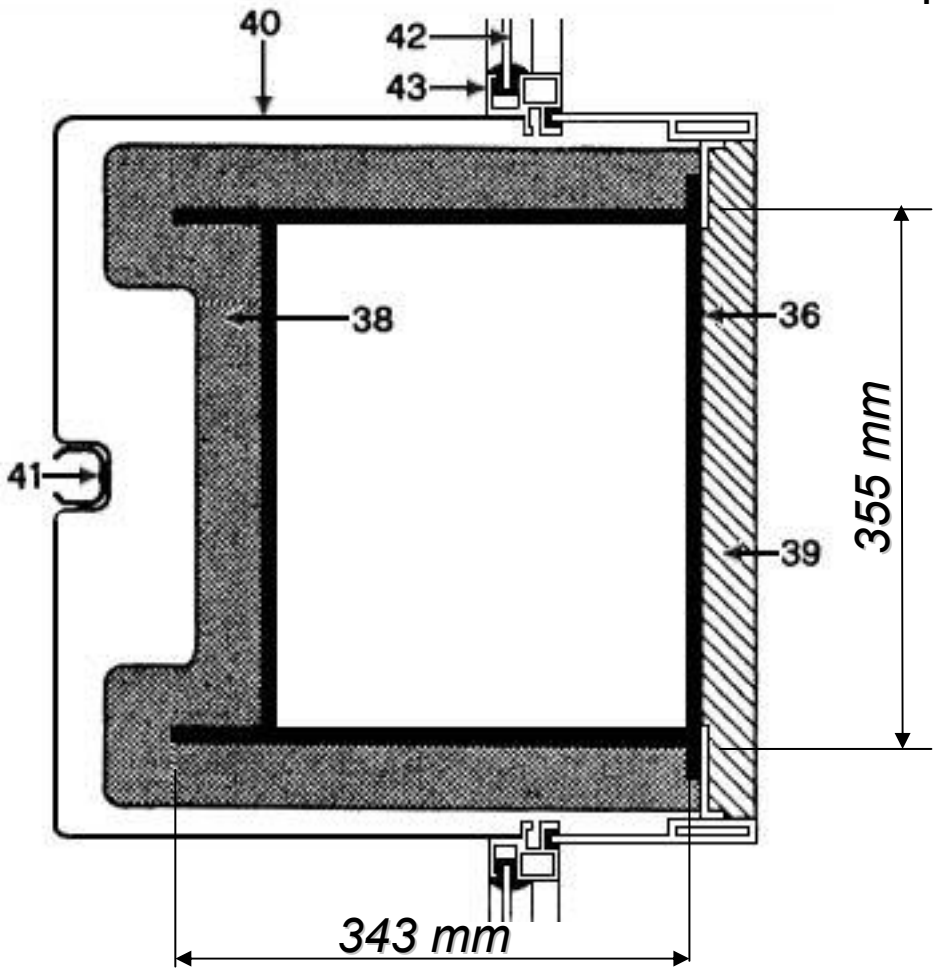
Plan of the World Trade Center complex



1 WTC
– North Tower
2 WTC
– South Tower
3 WTC
– Hotel
4 WTC
– South Plaza Building
5 WTC
– North Plaza Building
6 WTC
– US Customs House

Cross Section Through Exterior Box Column

Fire proofing of external columns

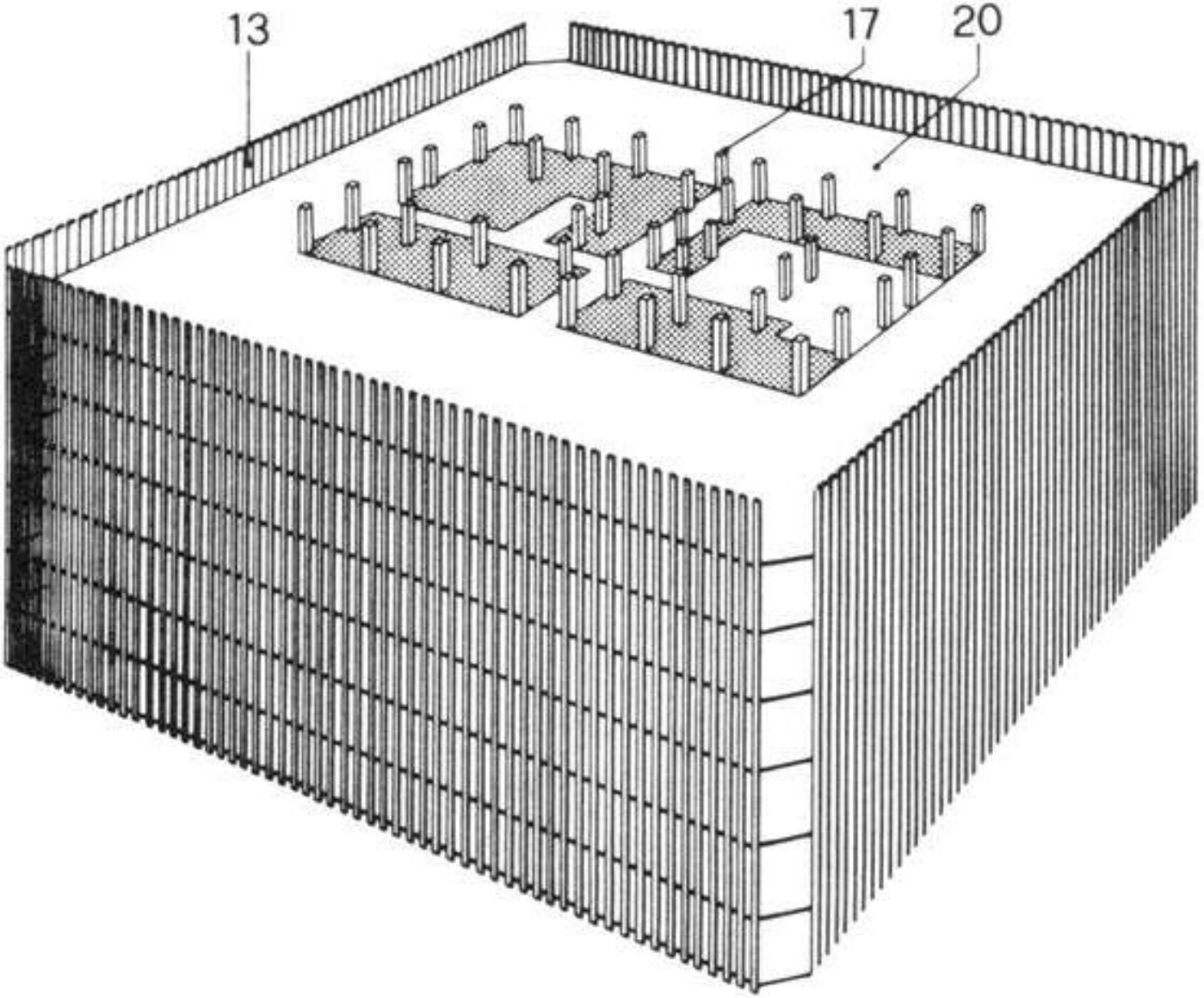


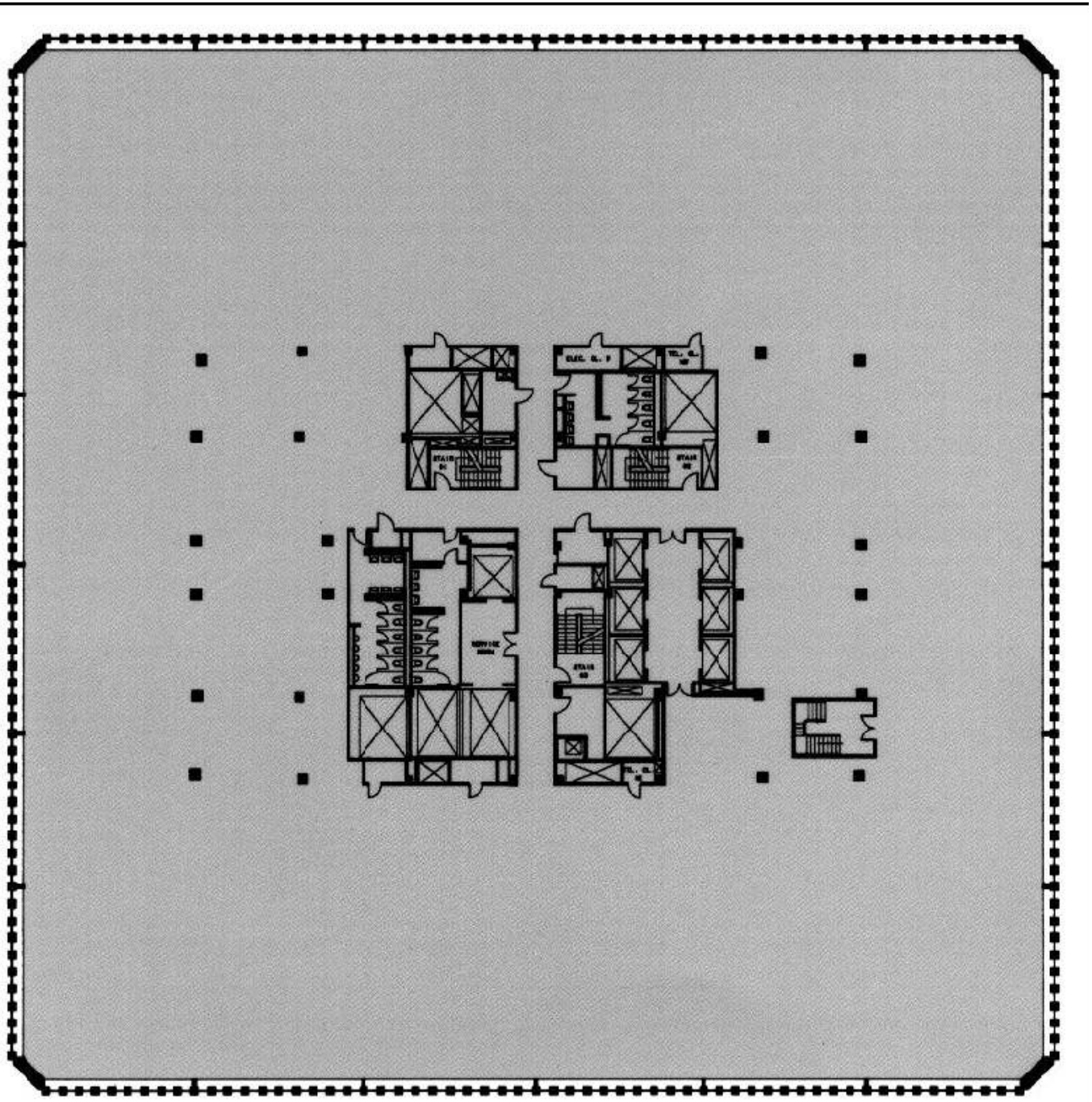
The numbers in the figure denote:

36 - the steel column
38 – fire proofing
39 - fire resistant plaster
40 - aluminum facade
41 - stainless steel window washing track
42 - window glass
43 - the window frame.

http://thewebfairy.com/nerdcities/WTC/wtc-demolition.htm

A conceptual view of the structural system





Typical Floor plan

Damage to the exterior columns of the North Tower immediately after the impact.

Before colliding with the North and South Tower, the planes banked to the left and hit the Tower with a roll angle of approximately 26° and 35°. This roll angle will have significant influence on the number of destroyed floors.

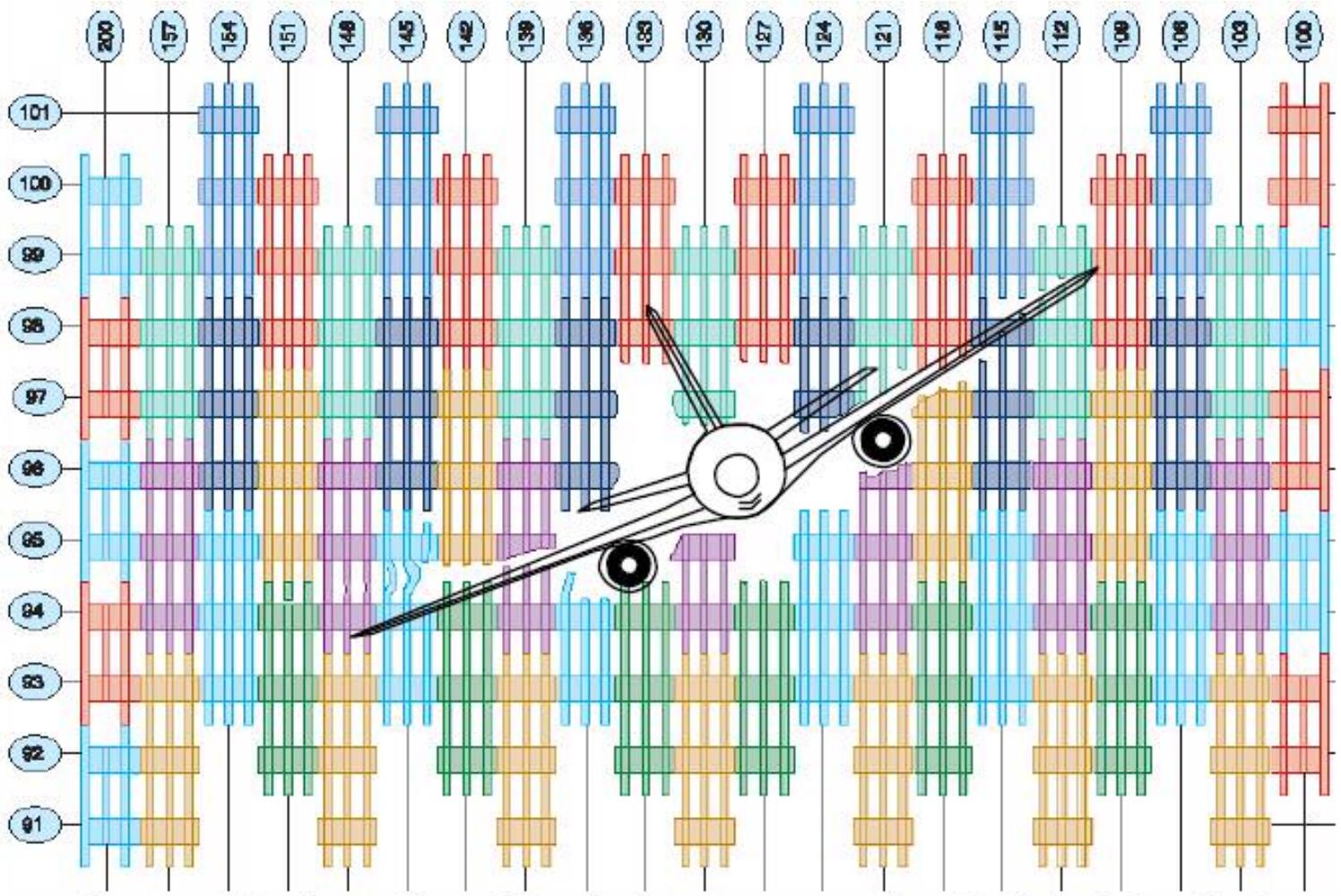


Figure 15(a). The outline of the airplane superposed on the hole driven in the exterior wall of the North Tower

WTC 1 Building

Aircraft Impact Damage to WTC 1

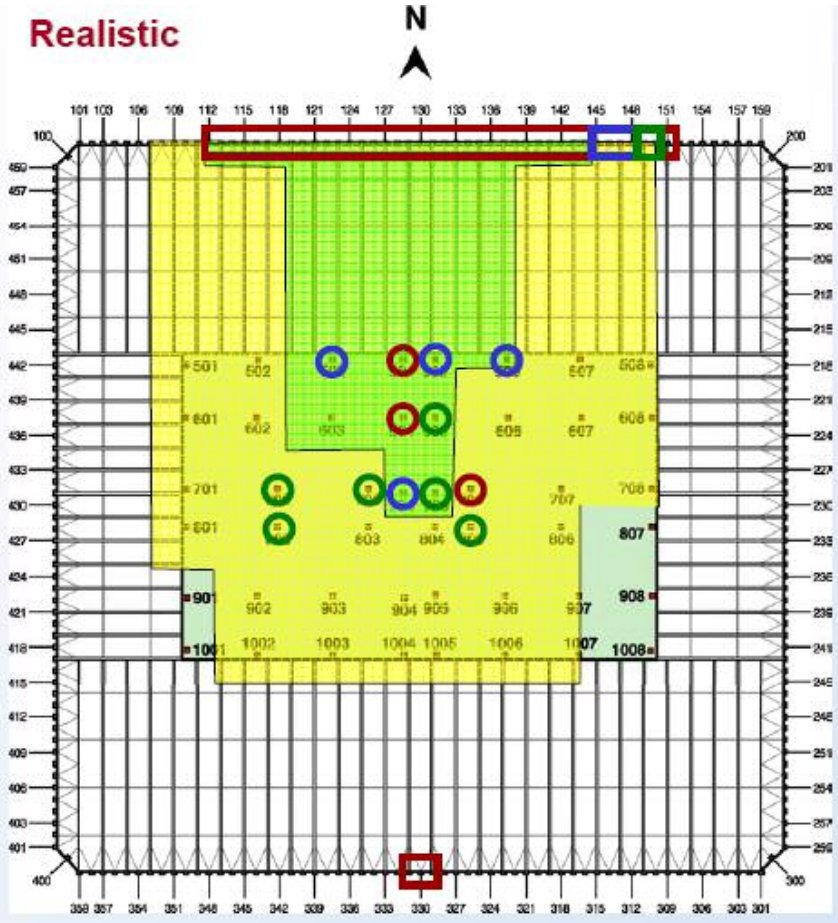
Floor and Wall Damage

- Fireproofing and Partitions
- Floors

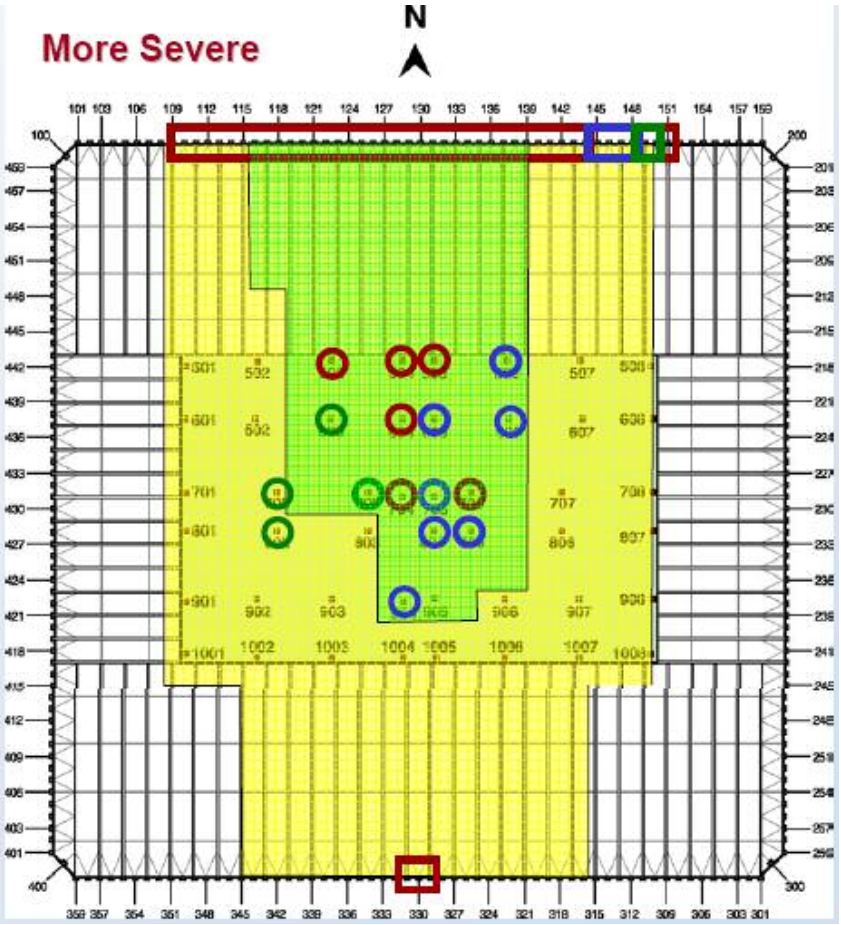
Column Damage

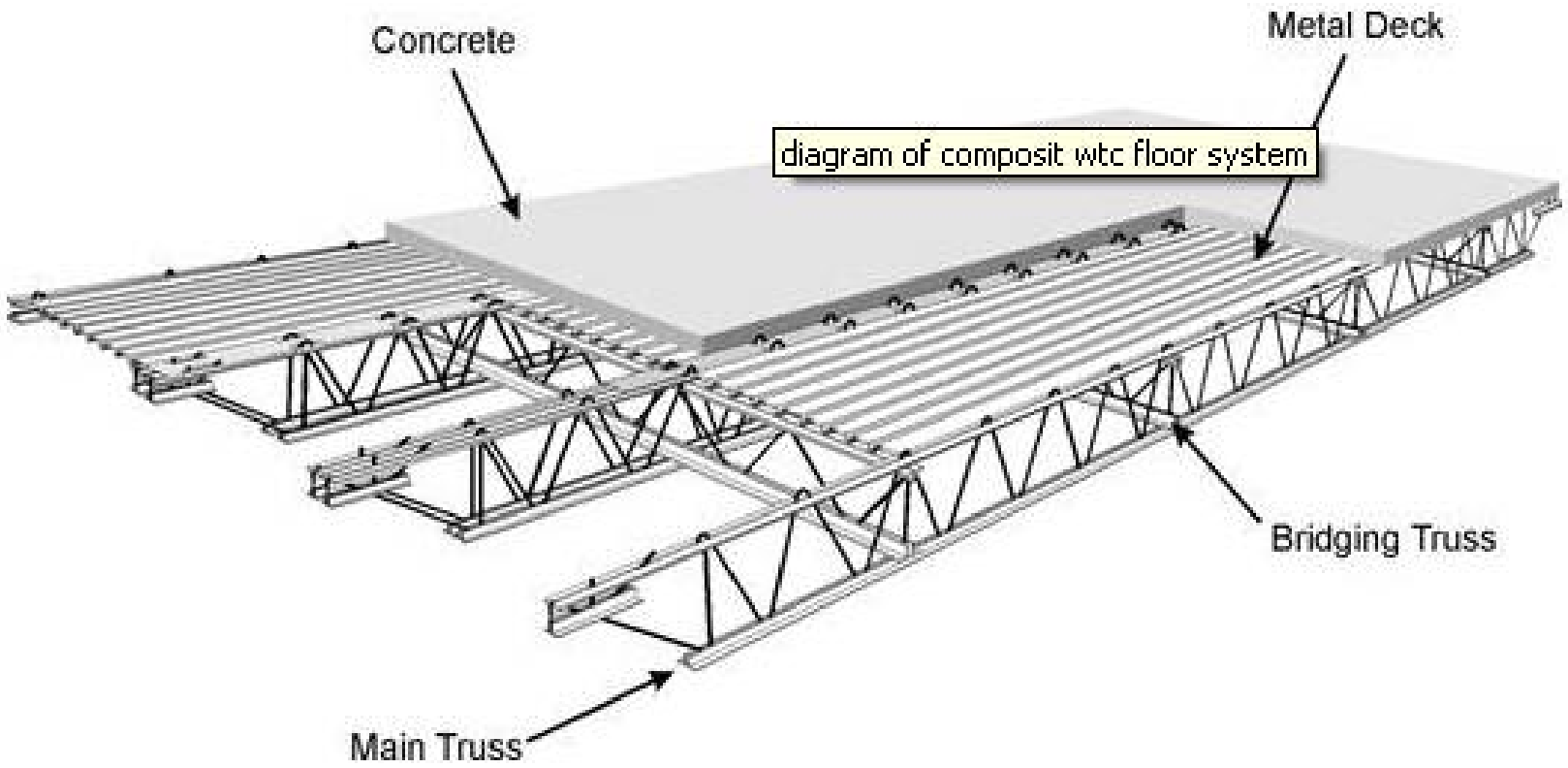
- Severed
- Heavy Damage
- Moderate Damage

Realistic

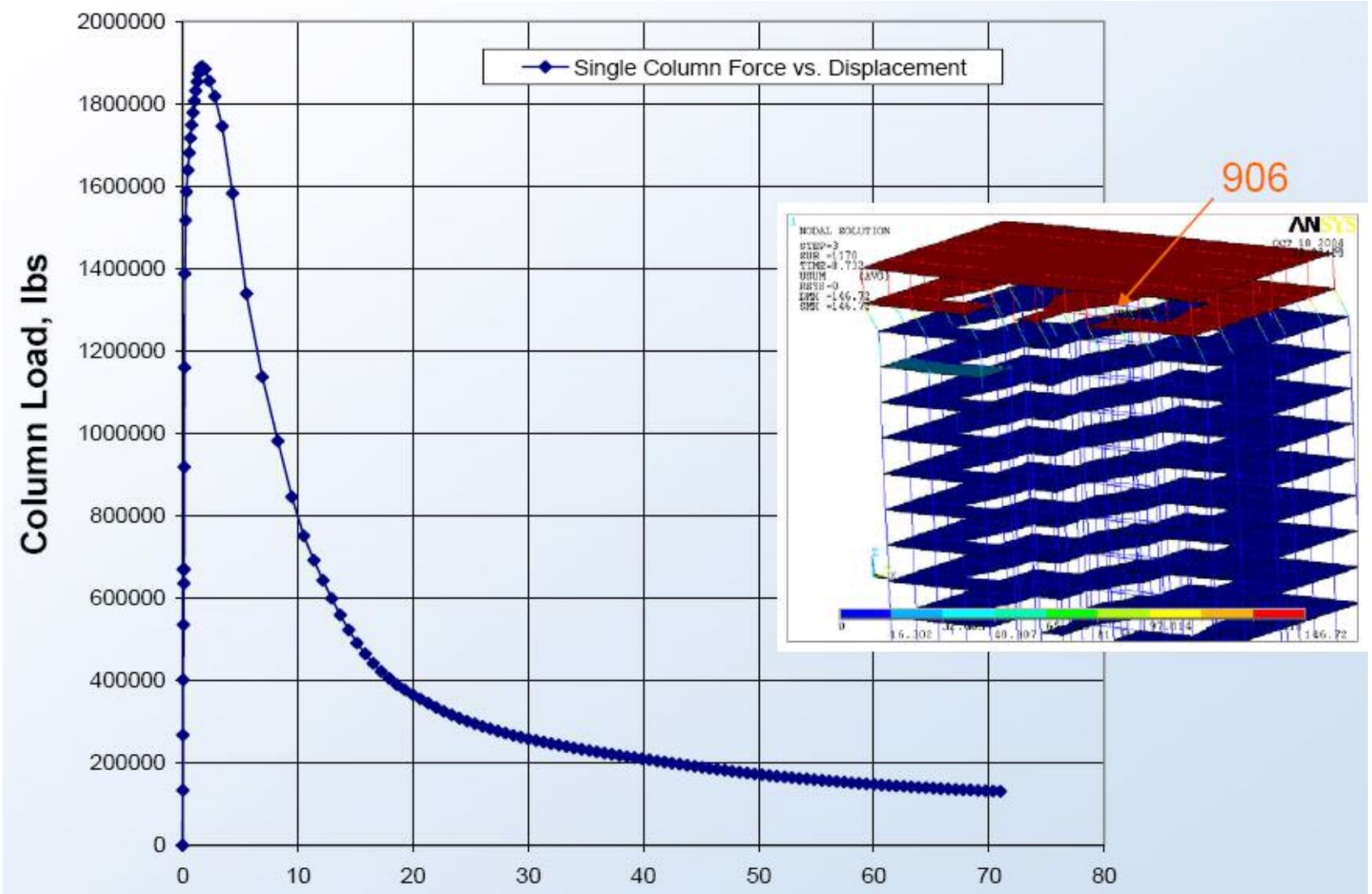


More Severe




Concrete
Metal Deck
diagram of composit wtc floor system
Bridging Truss
Main Truss

Buckling of Core Column 906 at Room Temperature Due to Displacement-Induced Collapse Analysis



That’s what is left from the World Trade Center

WTC 1 Collapse

Initiation of global collapse was first observed by the tilting of building sections above the impact regions of both WTC towers.

WTC 1 tilted to the south in this view from the northeast.

http://wtc.nist.gov/media/P6StructFireResp&Collapse2.pdf

Fireball From Impact on South Tower

Top of South Tower Collapsing

Determining the Probable Collapse Sequence

Research has been undertaken to:

- Conduct extensive sensitivity analyses to determine most influential factors for each analysis step.
- Determine three sets of most influential factors for each analysis step: realistic case, more severe case, less severe case.

- The first analysis sequence considers the set of factors for the ***realistic case*** in each of the steps.
- A second analysis sequence is conducted to confirm the results for the realistic case.
  - ► If the results for the realistic case suggest the possibility of more damage due to impact and fire, the second analysis sequence considers the set of factors for the ***more severe case*** in each of the steps.
  - ► If the results for the realistic case suggest the possibility of less damage due to impact and fire, the second analysis sequence considers the set of factors for the ***less severe case*** in each of the steps.

- The analysis sequence is repeated with additional cases for the set of factors to determine the probable collapse sequence that best matches the observations.

Leading Hypothesis for Collapse of WTC 1 (1)

The following chronological sequence of major events led to the eventual collapse of WTC 1; specific load redistribution paths and damage scenarios are being refined to determine the probable collapse sequence for WTC 1:

Aircraft impact damage to perimeter columns, mainly on the North face, resulted in redistribution of column loads, mostly to the adjacent perimeter columns and to a lesser extent to the core columns.

After breaching the building's perimeter, the aircraft continued to penetrate into the building, damaging floor framing, core columns, and fireproofing. Loads on the damaged columns were redistributed to other intact core and perimeter columns mostly via the floor systems and to a lesser extent via the hat truss.

The subsequent fires, influenced by the impact damaged condition of the fireproofing:

- Softened the core columns and caused them to shorten, resulting in a downward displacement of the core relative to the perimeter which led to the floors (1) pulling the perimeter columns inward, and (2) transferring vertical loads to the perimeter columns.
- Softened the perimeter columns on the South face and also caused perimeter column loads to increase significantly due to restrained thermal expansion.

Leading Hypothesis for Collapse of WTC 1 (2)

Due to the combined effects of heating on the core and perimeter columns, the South perimeter wall bowed inward and highly stressed sections buckled.

The section of the building above the impact zone began tilting to the South as the bowed South perimeter columns buckled. The instability rapidly progressed horizontally across the entire South face and then across the adjacent East and West faces.

The change in potential energy due to the ownward movement of the building mass above the buckled columns exceeded the strain energy that could be absorbed by the structure. Global collapse then ensued.

Sequence of Collapse of North Tower

Interconnection between one or more floors and the perimeter frame failed near the top of the building.

WTC 2 Collapse

Leading Hypothesis for Collapse of WTC 2

The following chronological sequence of major events led to the eventual collapse of WTC 2; specific load redistribution paths and damage scenarios are being refined to determine the probable collapse sequence for WTC 2:

Aircraft impact damage to perimeter columns mainly on the South face, resulted in redistribution of column loads, mostly to the adjacent perimeter columns and to a lesser extent to the core columns.

After breaching the building's perimeter, the aircraft continued to penetrate into the building, damaging floor framing, core columns, and fireproofing. Loads on the damaged columns were redistributed to other intact core and perimeter columns mostly via the floor systems and to a lesser extent via the hat truss.

The subsequent fires, influenced by the impact damaged condition of the fireproofing :

- Caused significant sagging of floors on the East side and induced the floors to pull the perimeter columns inward on the East face.
- Softened the core columns on the East side and caused them to shorten, which transferred significant additional load to the perimeter columns on the East face primarily through the floor system and to a lesser extent through the hat truss.
- Softened some of the perimeter columns that were exposed to high temperatures towards the northern half of the East face.

Due to the additional loads on the perimeter columns on the East face and the inward pulling of those columns, the East perimeter wall bowed inwards and highly stressed sections buckled.

The section of the building above the impact zone began tilting to the East and South as both the East perimeter columns and the impact-damaged South perimeter columns buckled. The instability rapidly progressed horizontally across both faces and across the North face.

The change in potential energy due to the downward movement of the building mass above the buckled columns exceeded the strain energy that could be absorbed by the structure. Global collapse then ensued.

Windsor Torre in Madrid

Windsor Torre in Madrid

Initial investigations into the recent fire that devastated the Windsor Torre in Madrid again highlight the problem of steel's performance in fire. Failure was limited to the perimeter steel frame whereas the internal concrete frame survived complete burnout with no collapse.

The fire which started on the 21st floor of the 32-storey building quickly spread due to lack of fire stops between the curtain wall façade and the concrete floor slabs. Designed and built in the 1970s, the tower was built using traditional methods of design. Extensive refurbishment was under way at the time of the fire. Part of the refurbishment programme was to bring the building's fire standards up to date with the installation of a range of active fire prevention and resistance measures.

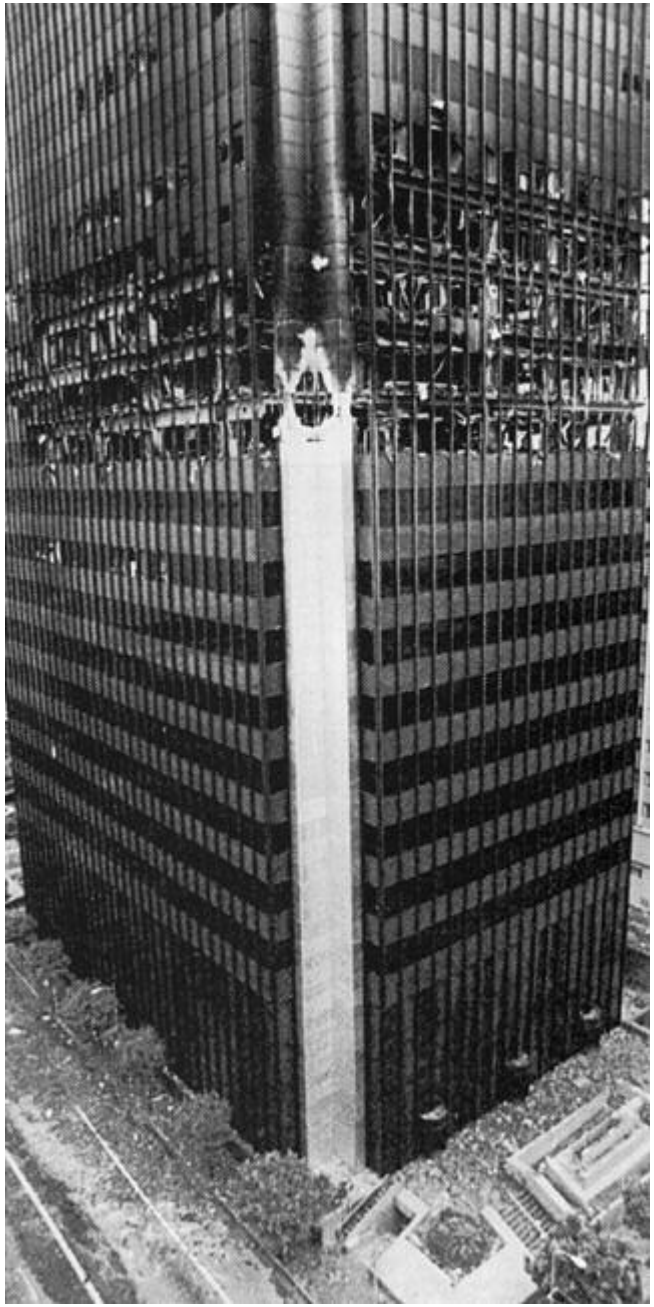
Failure of the structure happened with the collapse of the steel perimeter columns which resulted in the floor slabs collapsing as the edge support was taken away. The massive concrete transfer slab at the 20th floor prevented further progressive failure. However, as the debris fell the cladding below was smashed and the fire spread to lower floors.

The height of the tower and extent of the blaze meant that firefighters could only mount a containment operation. The fire was eventually put out after 26 hours. Preliminary investigations have found that thanks to the concrete slab at the 20th floor and the inherent fire resistance of the central concrete columns and core the building remained standing with the structural failure being confined to the perimeter steel section.

The structural concrete performed extremely well demonstrating once again the robustness of traditional methods of construction. However, the intensity of the fire proved too much for the perimeter steel frame. It is understood that sprinklers were being installed but this is an example of what can happen when sprinklers fail to contain the initial fire.

Interstate Bank Building Fire Los Angeles, California (May 4, 1988)

Occupancy	62-story high-rise office building
Construction	Steel frame; exterior of glass and aluminum Unusually good application of fire resistive coating helped maintain structural integrity in fire
Delayed ReportingBuilding	security and maintenance personnel delayed notifying Fire Department for 15 minutes after first evidence of fire.Smoke detectors on several floors had been activated and reset a number of times before reporting to Fire Department. A maintenance employee died while trying to investigate source of alarms prior to calling Fire Department.
Automatic Fire Sprinklers	Sprinkler system was installed in 90 percent of the building, including on fire floors; valves controlling the systems had been closed, awaiting installation of water-flow alarms.
Interior Design and Contents	Large open area with readily combustible contents contributed to quick fire growth.
System Failures	Main fire pumps had been shut down, reducing available water pressure for initial attack.Radio communications were overtaxed and disrupted by building's steel frame.Fire and water damaged telephonecircuits making them unusable.Sound-powered emergency phone system in building was ineffective.



Interstate Bank Building Fire Los Angeles, California (May 4, 1988)

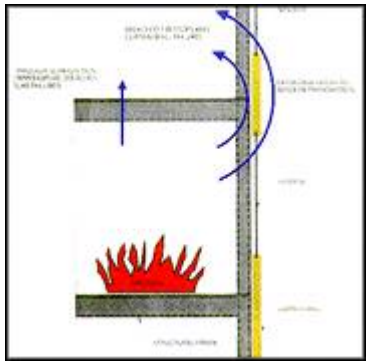
- The fire originated in an open-plan office area in the southeast quadrant of the 12th floor.
- The area of origin contained modular office furniture with numerous personal computers and terminals used by securities trading personnel.
- The cause is thought to be electrical in origin, but the precise source of ignition was not determined.
- The fire extended to the entire open area and several office enclosures to fully involve the 12th floor, except for the passenger elevator lobby, which was protected by automatic closing fire doors

One Meridien Plaza *Philadelphia, Pennsylvania*

Saturday, 23 February 1991, linseed oil-soaked rags left behind by a cleaning crew burst into flames on the 22nd floor of the 38-story One Meridian Plaza in downtown Philadelphia. The fire quickly spread, unimpeded by fire sprinklers, throughout the 22nd floor and then upward.

The twelve-alarm fire burned for 18 hours. The extreme heat caused window glass and frames to melt and concrete floor slabs and steel beams to buckle and sag dramatically.

Large shards of window glass fell from the facade, cutting through fire hoses on the ground around the building. Three firefighters were trapped on a fully engulfed floor, and efforts to rescue them failed.



http://www.search.com/search?chkpt=astg.cnet.fd.search.web?target=http://www.search.com/search?chkpt=astg.cnet.fd.search.web&q=steel%20+fires&tag=srch