Comments on structural fire response and collapse analysis

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Some context

- Commercially unacceptable now to build tall without addressing extreme events
- Demand for information and knowledge has been unprecedented
- High-rise building design and expectation from this design has changed - and did so very quickly

- Current trend in London is “are you compliant with NIST”
- We had to take an interest

Responding to demand

- We had to be in a position to provide practical advice
- Therefore we had to understand the events of 9-11 from the human response, through to emergency response, and onwards to the collapse mechanism
- Focusing on the collapse or the structural fire response

Designing Structures for fire

- Typical composite steel frames
- Complex geometries + long span systems
- WTC 1 and 2 representations
- WTC 7 (confidential)
- Post-tensioned slabs
- Spalling prevention design
- Madrid Fire – structural response
- High-rise design for extreme events (various)

NIST investigation

- We support the call for specific performance based objectives for structural design for fire
- Within a risk assessment framework
- Not so concerned with local collapse
- Support design for burnout – but not until the profession has a realistic post-flashover fire model

Recommendation 9. NIST recommends the development of: (1) performance-based standards and code provisions, as an alternative to current prescriptive design methods, to enable the design and retrofit of structures to resist real building fire conditions, including their ability to achieve the performance objective of burnout without structural or local floor collapse: and (2) the tools, guidelines, and test methods necessary to evaluate the fire performance of the structure as a whole system. Standards development organizations, including the American Institute of Steel Construction, have already begun developing performance-based provisions to consider the effects of fire in structural design.

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NIST investigation – some comments

- Thermal resistant façades and subdivision of floor plates a real concern
- Commercially we have to ask what greater robustness will this give a client?
- Trying to prevent a fire from occurring or trying to limit its size
  - Reliance on single lines of resistance
- We would propose instead design with redundancy
- Designing the structural system itself to withstand the effects of fire

Structural response to fire

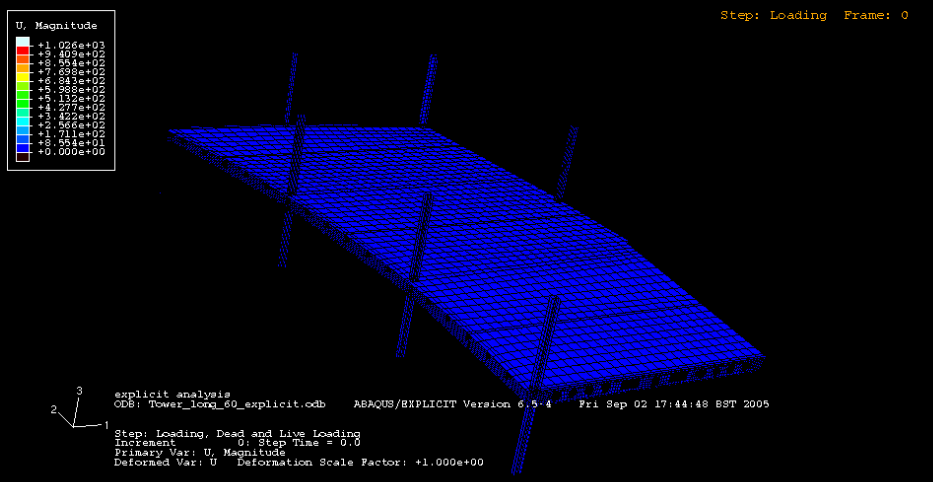
- Very specific material and geometry changes take place in fire
- Expansion of all the materials and therefore the structural dimensions
- Degradation of the material strength and therefore their ability to carry load

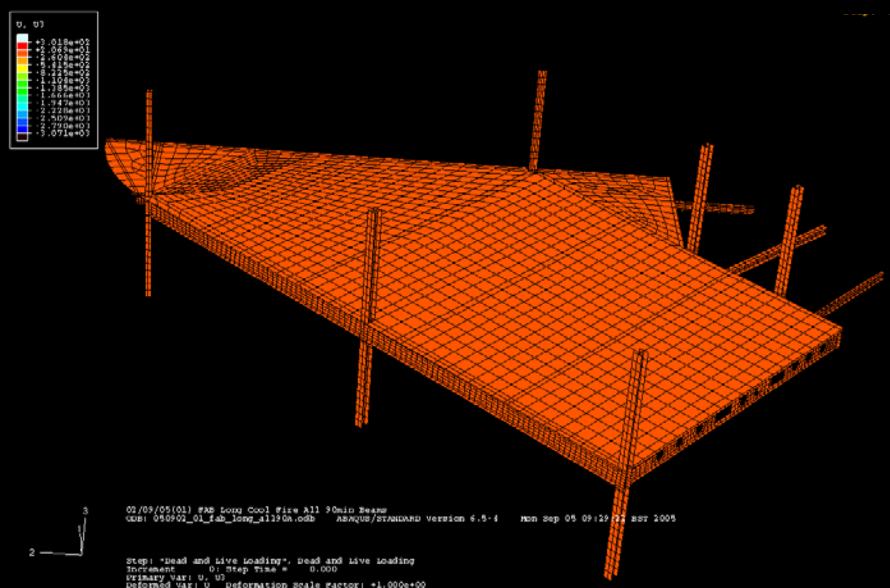
Structural response to fire

- But structures seem to perform very well in fire and various events or real tests on multi-storey buildings have demonstrated this
- Fire proofing is not the sole means of protecting a structure in fire

Recent analysis on code compliant buildings

- 2 buildings
- Same construction form
- Same agreed design basis fires
- One collapses, One does not





Why did Building B fail and not the Tower Building A?

- Fire proofing ratings identical
- Slab depth and temperatures identical
- Slab spans ~4.5m
- Beam spans ~12m
- Beam temperatures similar
- Columns offset in Building B not in Tower Building A
- Columns 10.5m apart in Building B, 9m in Tower Building A
- Yet column sizes the same

Significance?

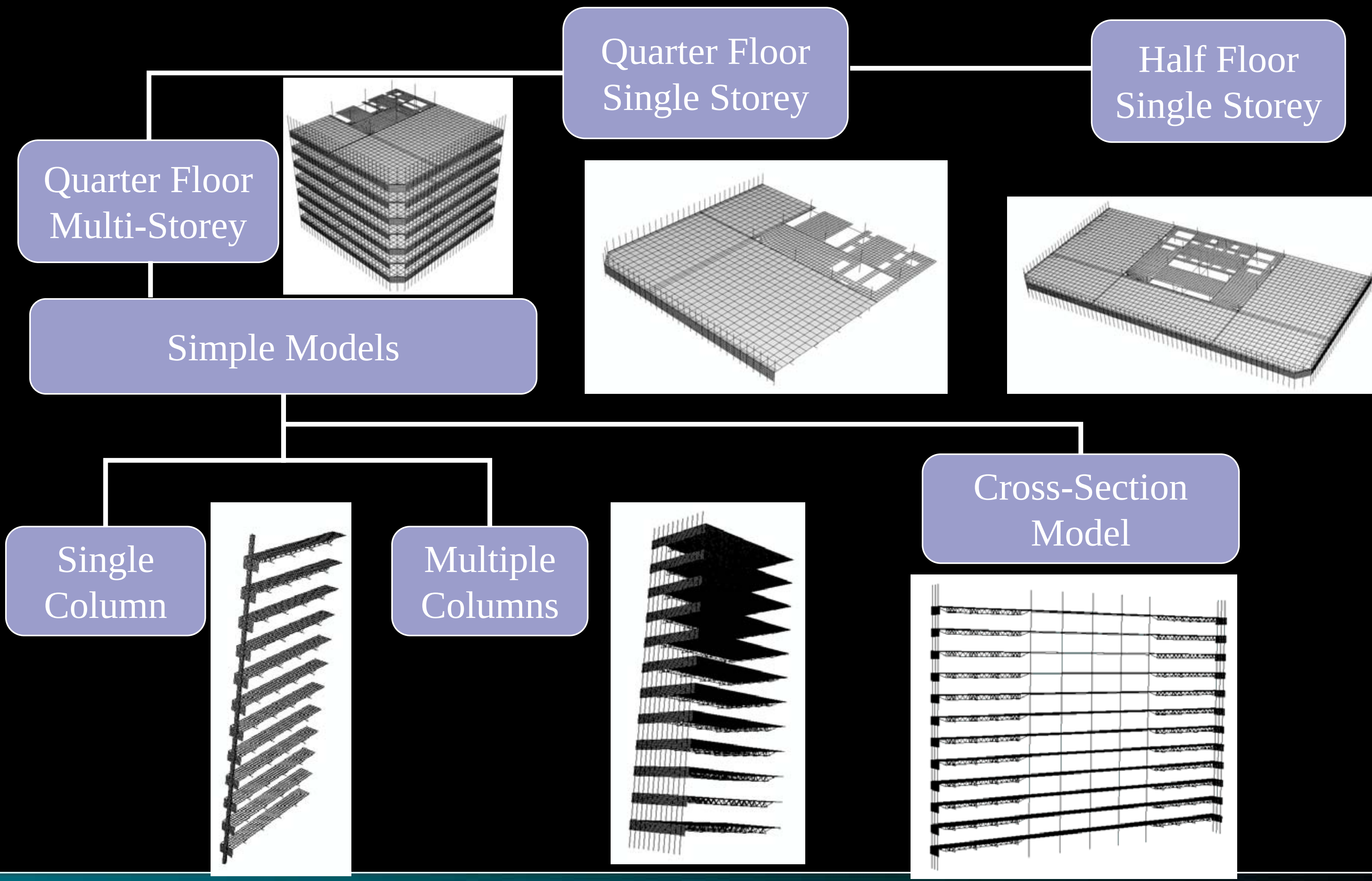
- If the buildings had been designed with columns that could cope with the long span beams as they expanded in the fire, collapse would not have occurred
- Fire proofing is therefore but one aspect of limiting structural response to fire
- The design of the structure itself we see as the most critical aspect requiring change for the future
- We do not believe this has made a significant entry to NIST’s recommendations

WTC studies

- We have developed complex models of a representation of WTC1
- This was not a forensic analysis
- Purely to understand if that structural form had any specific collapse mechanisms

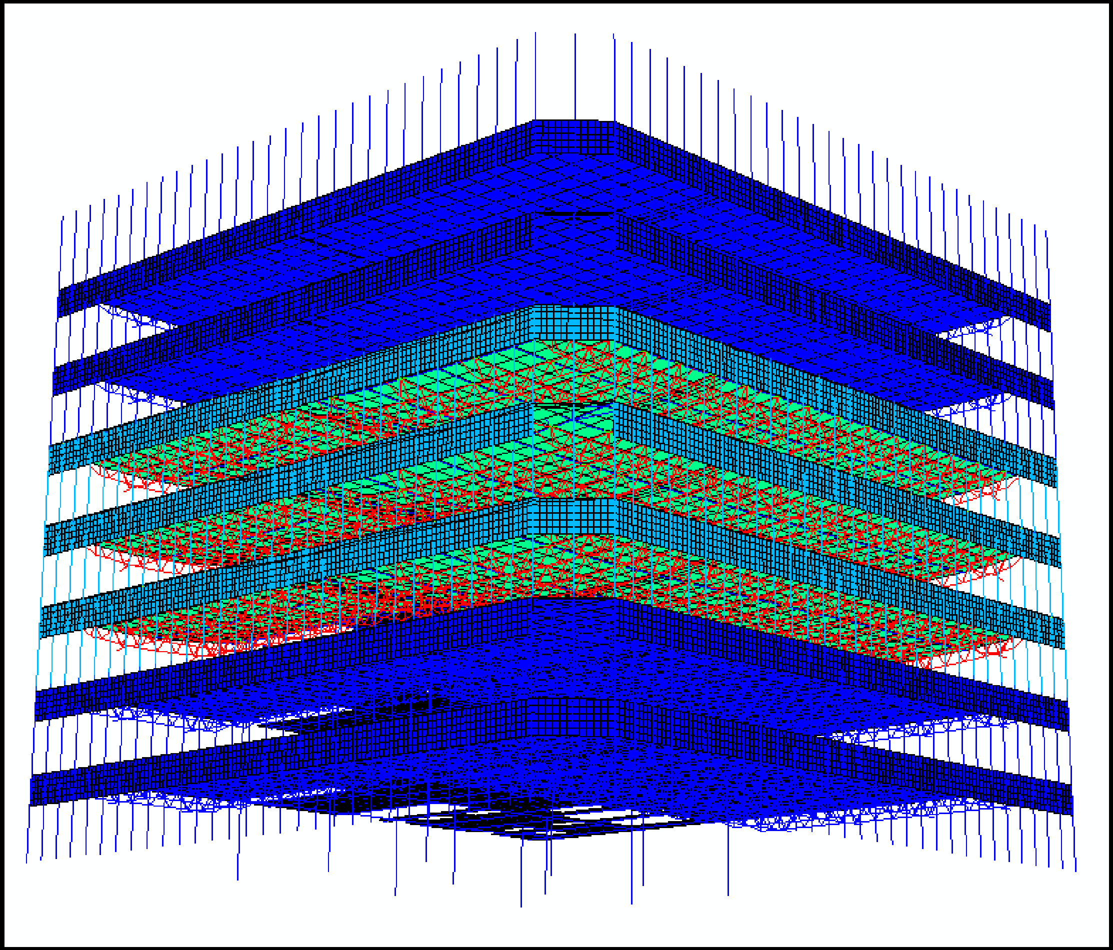
- Ongoing work

3-D Modelling Strategy



Fire Temperatures

3 Floor Fire Modelled



Analysis of **1 hour** (3600s)

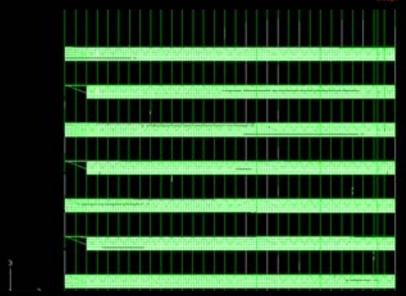
Trusses undergo rapid heating to reach 800°C in a very short time

Perimeter columns and spandrels heat linearly to 400°C after 3600s

Slab temperatures evaluated at 5 discrete points through the depth

Core assumed to be at ambient

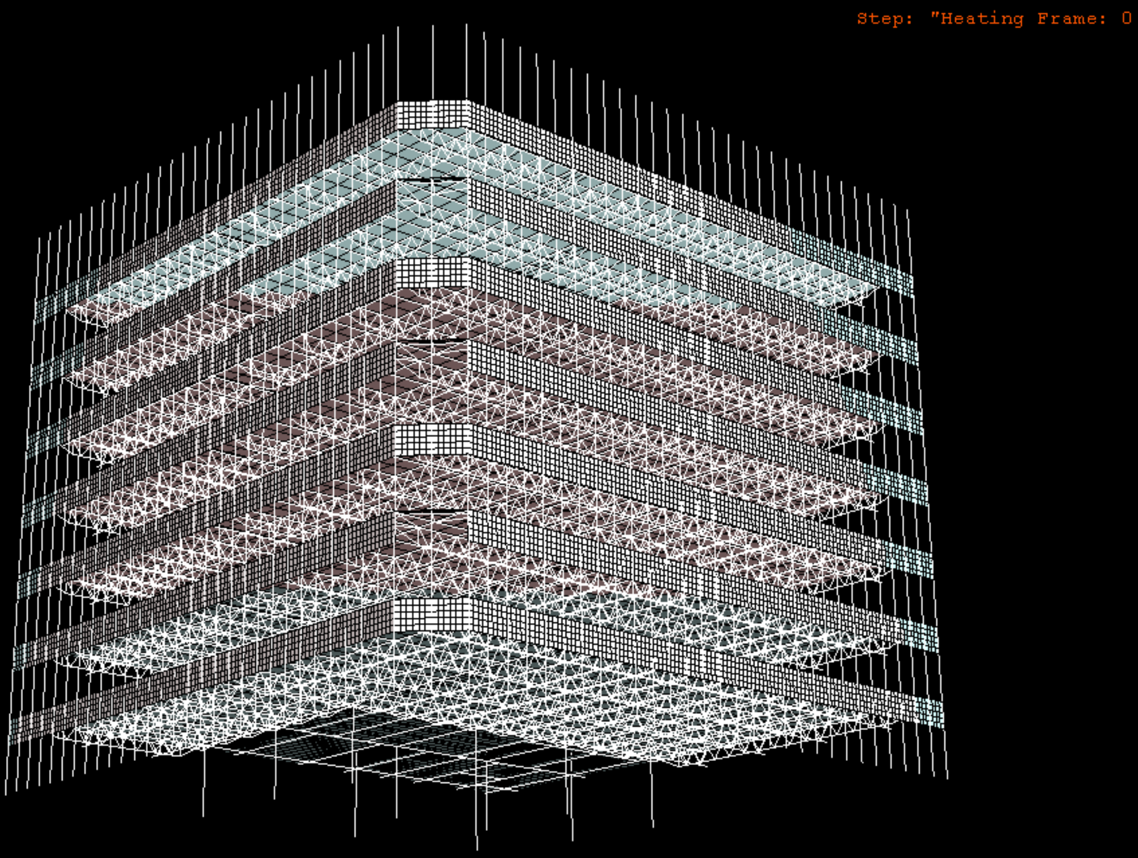
Quarter Floor: Collapse Mechanism

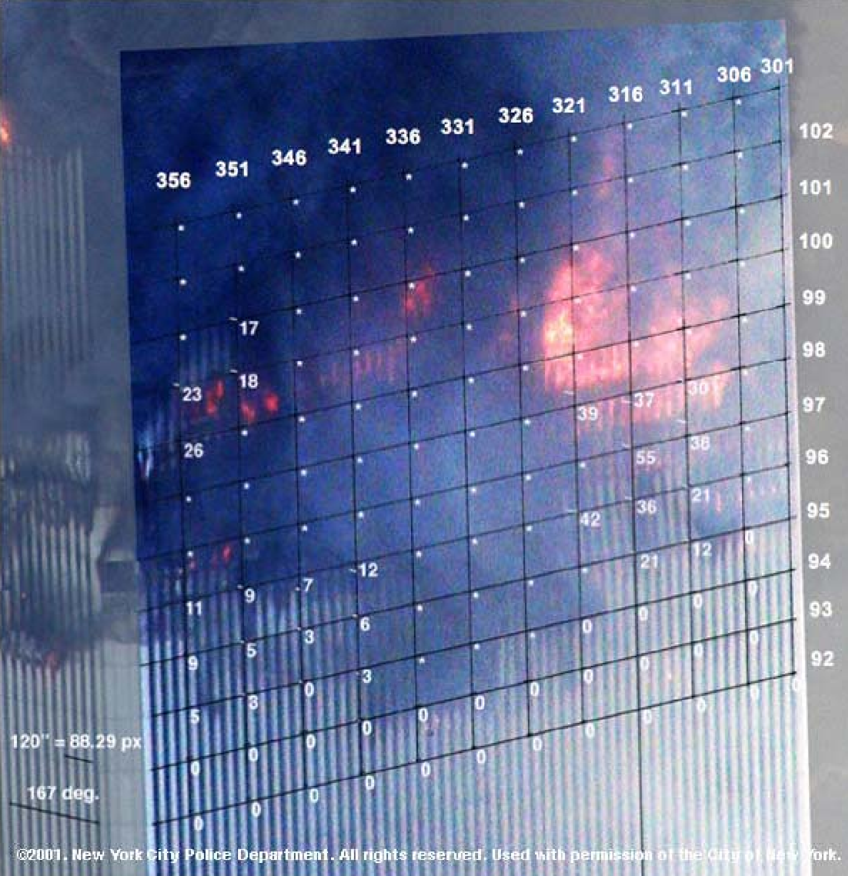


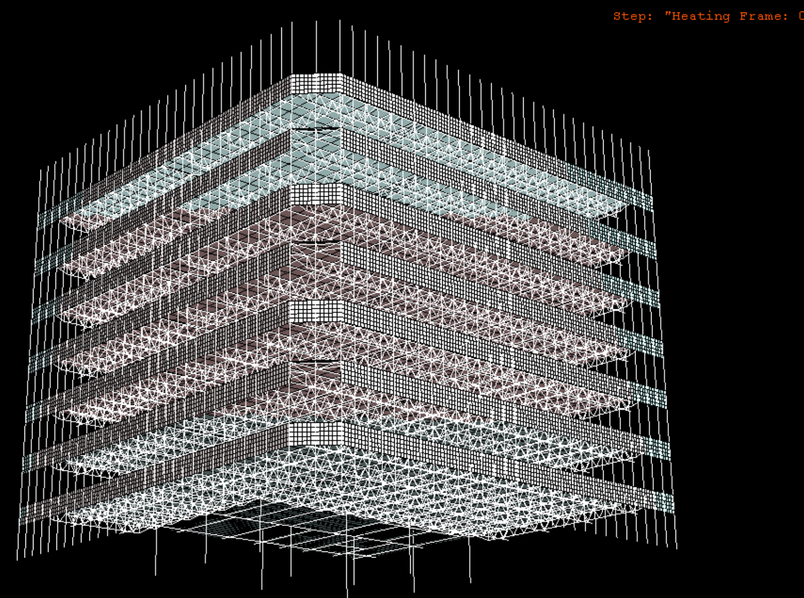
Large inward bowing of columns at failure

Spandrels undergo significant buckling

Short-span double trusses see smaller deflections than longer spans







- Similar collapse mechanism as seen in the WTC
- But with no impact included

Comparison with Project 6 work

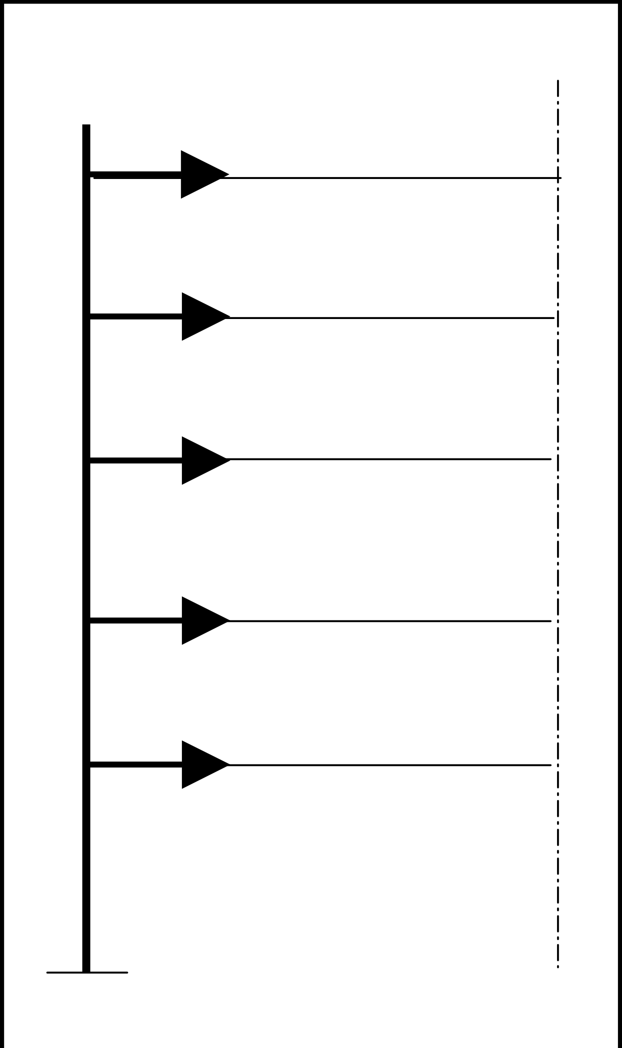
- This form of quantification of response has not been presented in Project 6
- But is required to reach the highly significant conclusion about the role of fire proofing
- Must be carried out to assess real designs
- It is our view that without including the floors correctly in the global models, collapse, or the lack of collapse, cannot be captured nor quantified

Differences in global model approach

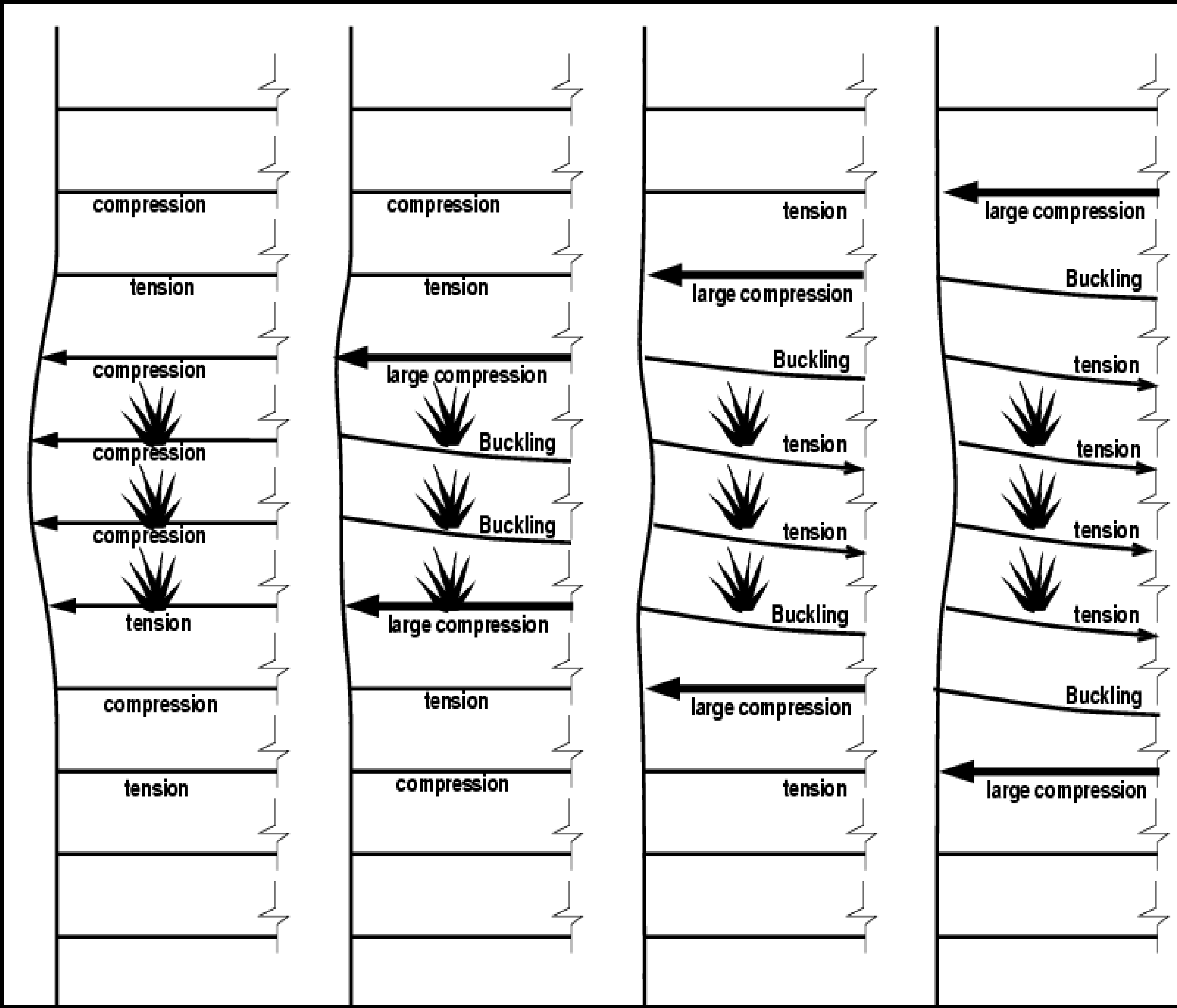
- NIST model:
- Detailed forensic model of the fire
- Floors represented as membranes only-no trusses, purely elastic
- Thermal expansion on columns only
  - Not on the floor systems
- Deflected shape not calculated
- Compatibility of deflections across the floor not calculated
- No push out forces modelled
- Pull forces on columns manually added to model
- Material stiffness of floor modelled only

- Arup/Edinburgh model:
- Fire incorporated in a parametric way to represent forensic model (design approach)
- Floors modelled as per the real building
- Including thermal expansion on all elements
- Floor response (deflections and compatibility of deflections across the floor) calculated by model
- Push/pull forces on columns calculated by model
- Support stiffness provided to the columns from the floors modelled accurately

Pull-in force applied by user



Push and pull forces calculated by model



Impact on results

- NIST model:
- Forces on columns applied by user – 10 min steps
- Collapse theory based on fitting pull-in forces to match the deflected shape of the columns from video footage
- Forces not necessarily representative of the real case
- NIST have not calculated response of towers with fire protection applied

- Arup/Edinburgh model:
- Behaviour calculated by the global model for the duration of the fire with no user intervention
- Collapse mechanism caused by thermal expansion, compatibility of deflections, pull/push forces on columns resulting in bending failure of the columns – all calculated by the model
- Collapse theory can be tracked and explained
- Knowledge gained can be used to understand other structural systems in fire

WTC studies

- Based on our observations of collapse without aircraft impact included, and NIST’s representations of the global response of the structure to fire, we do not consider NIST to be in a position yet to conclude had the aircraft not knocked the fire protection off, collapse would not have occurred

Just another modelling “stand off” ?

- Our view is that this main conclusion on fire proofing has serious implications for the future of design:
  - A continuing reliance on fire proofing in lieu of structural detailing for fire - a serious concern;
  - It has resulted in the role of structural design being underplayed in NIST’s final recommendations
- Due to the absence of the acknowledgement that fire must become a design load for structural engineers in order to genuinely improve the structural performance in fire

The Future?

- We want to see
  - design to prevent progressive collapse in fire written into all building codes
  - A move away from total reliance on fire proofing – moving away from ignoring real response to fire
  - An active move by this profession to create fire as a design load for structural engineers
  - This profession to carry out structural fire analysis of buildings in order to improve tall building guidance and advice
- All this within a risk-based framework - we do not believe this level of analysis is needed for all buildings, in all scenarios, all locations

To finish

- Significance of the NIST report
- Continue to work as a community with NIST to implement new design tools in the future

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