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Structural fire response to multi-storey fire

Structures in Fire Forum – September 2025

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Background

Fire safety goals

- The building to comply with Building Regulations;
- Structure to meet the requirements of Part B3 of the Building Regulations
- B3 functional requirement is:

"The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period."

- Concerned with life protection only
- No property protection/operational continuity goals

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Feasibility study

Fire severity assessment

- The fire severity assessment undertaken in Stage 2 showed fire severity of 109 minutes
- Therefore, a detailed structural finite element modelling was undertaken to determine an appropriate level of fire protection to each element of structure
- The proposed structural fire protection enables the structure to achieve compliance with the Building Regulations B3

Level 4

	TF=10	TF=50	TF=100	TF=200
SR=90%	110min	107min	105min	100min
SR=93%	103min	101min	99min	93min
SR=95%	97min	96min	93min	88min

Level 25

	TF=10	TF=50	TF=100	TF=200
SR=90%	116min	115min	110min	102min
SR=93%	109min	106min	103min	96min
SR=95%	103min	100min	97min	90min

Fire severity assessment results

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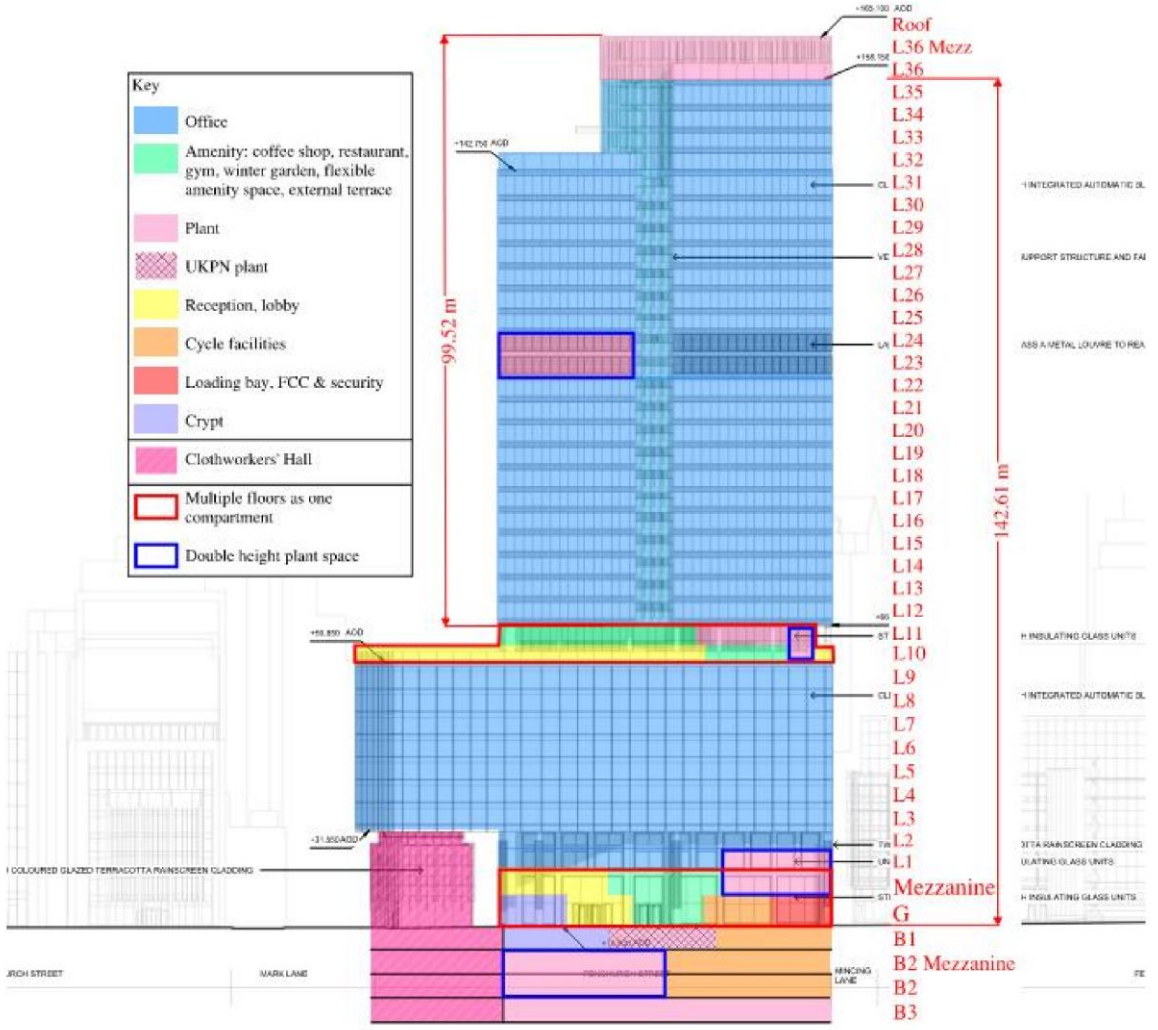
Building Overview

Scope of optimisation solution

- Proposed structural protection layout involves a combination of 90- and 120-minutes elements
- 90-minute fire protection applies only to certain elements within office spaces over above ground levels
- Current SFE solution relies on the single floor fire i.e., the levels are assumed to be 120-minute fire compartments. However, multifloor assessment allows for having up to 2 unprotected openings per floor connecting up to 3 office floors.



Building Use

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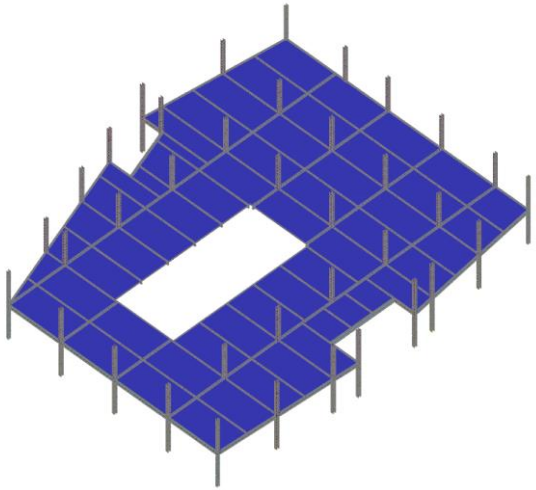
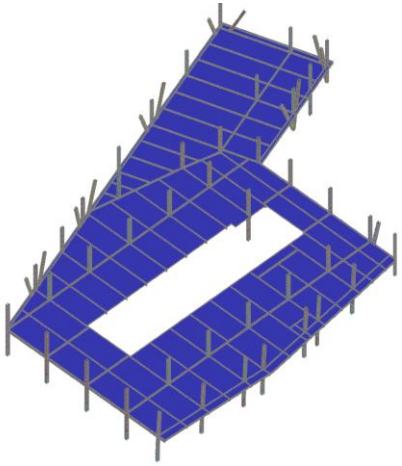
Numerical models



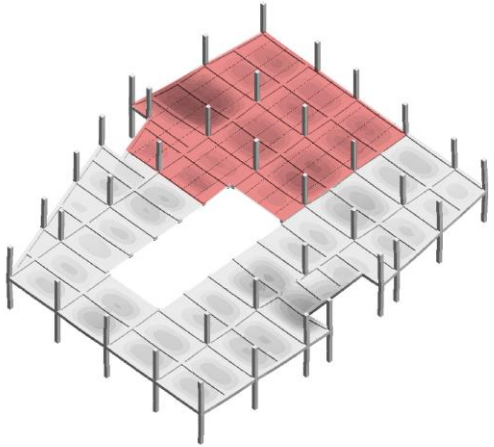
Stage 3

Level 27 model



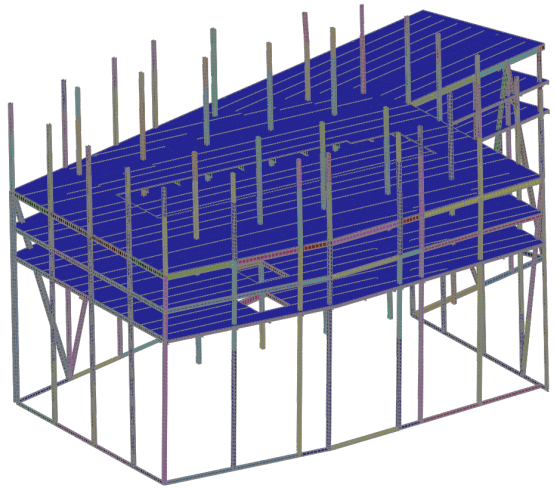
Stage 3

Level 4 model



Stage 4

Level 27 model



Stage 4

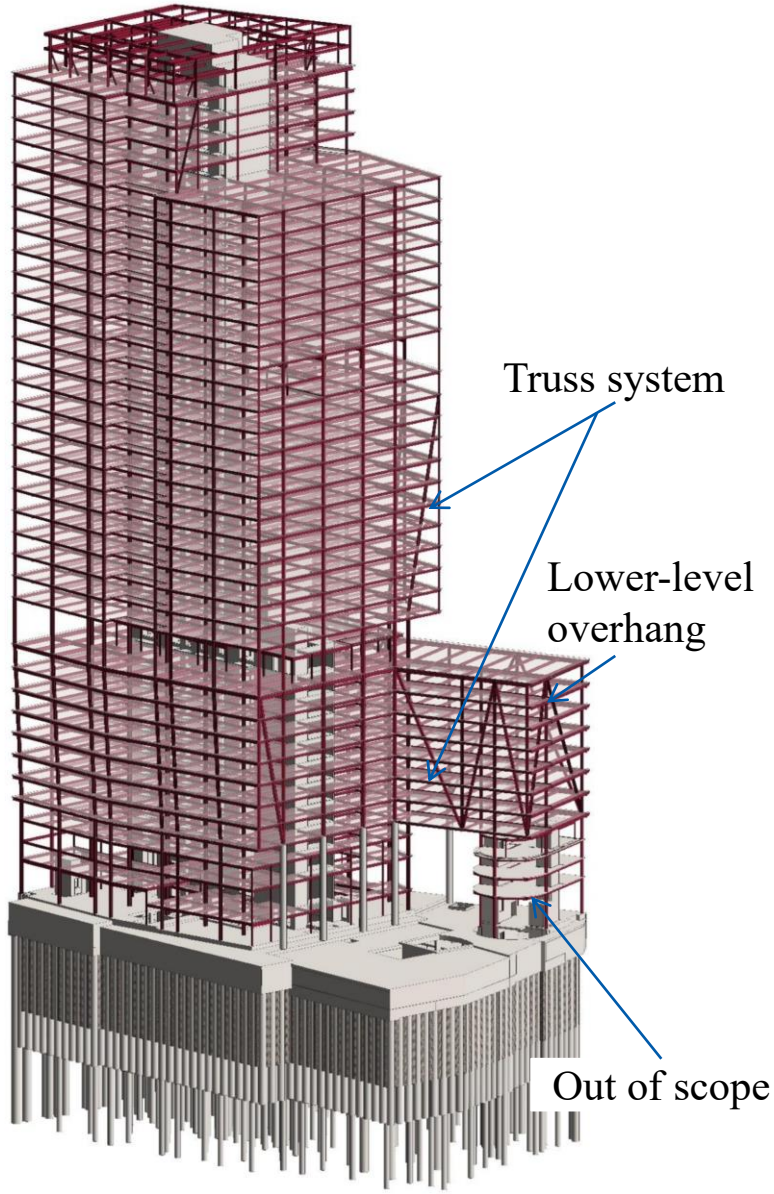
Level 8-10 model

Models feature prefabricated planks representation

Structural Appraisal

Scope of optimisation solution

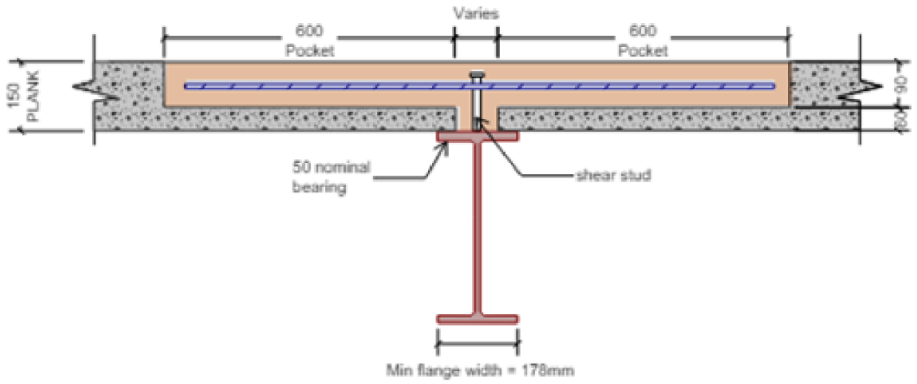
- Structure is primarily steel with concrete slabs and cores (most steel beams are castellated for services)
- Exterior steel truss system to minimise number of columns on public ground
- Transfer beams and columns on upper levels
- Floor slab comprised of prefabricated 150 mm planks with typical size of 2.25 by 4.5 m



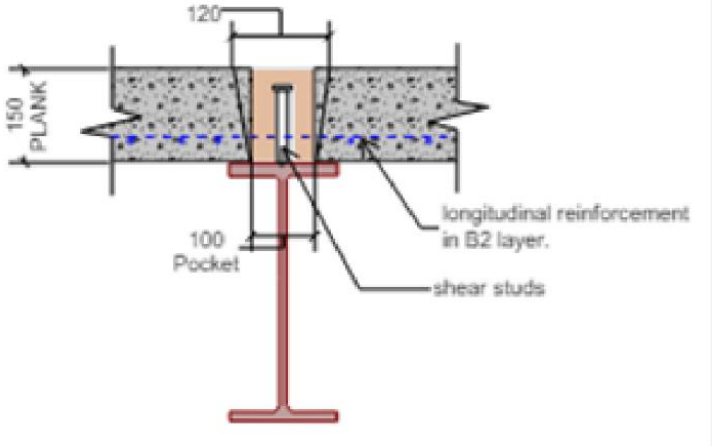
Structural Layout

Structural Appraisal

Prefabricated plank elements



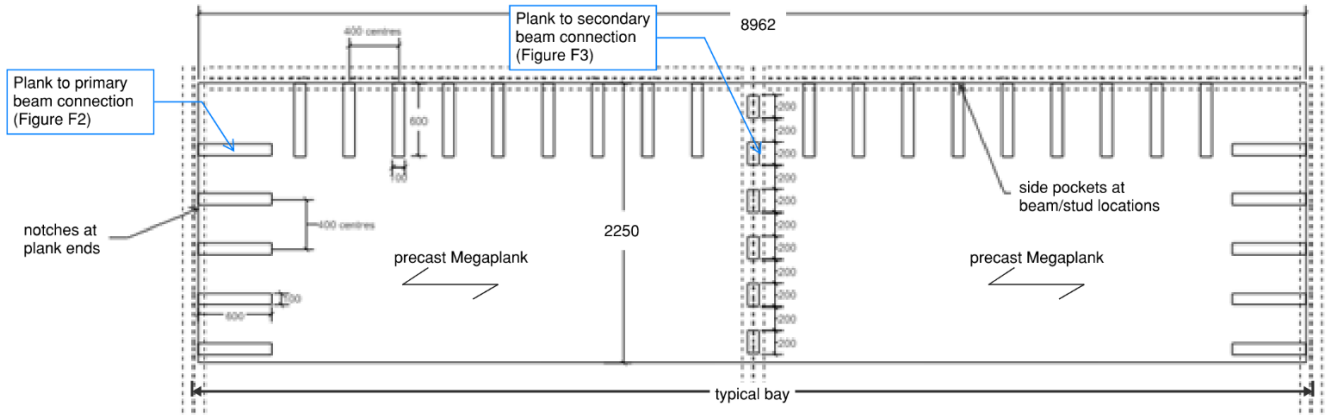
Primary steel beam joint detail



Secondary steel beam joint detail

Composite action achieved by:

- 600 mm deep pockets over edge primary beams with additional 12 mm lapping reinforcement connected to shear studs
- Midspan pockets over secondary beams with continues B2 (H12 @ 200) layer reinforcement connected to shear studs



Plant view of plank arrangement

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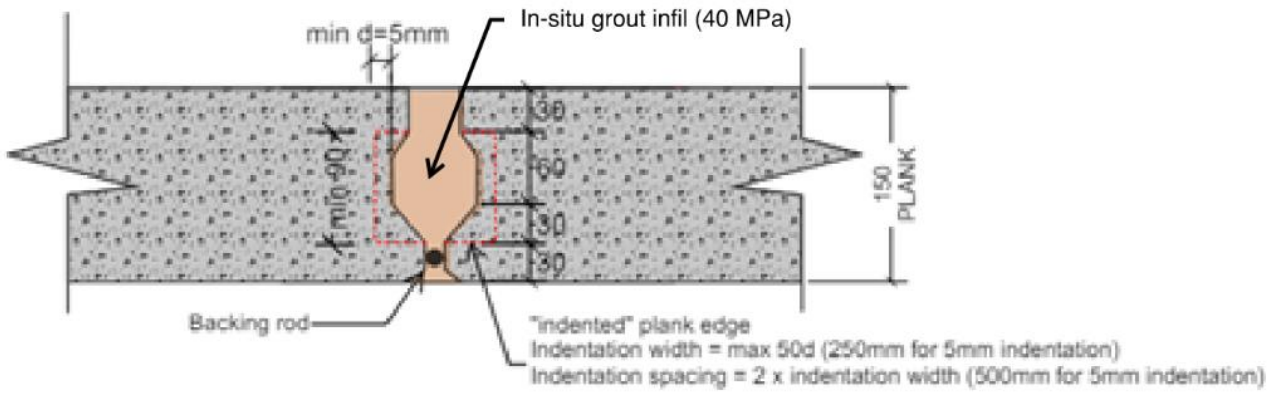
Structural Appraisal

Prefabricated plank elements



Plank to plank connection detail

Joint between prefabricated planks:

- In-situ 40 MPa high flow grout
- Rough edge concrete
- Shear capacity of 81 KN/m

Assessment methodology

Does the loss of material strength and increased deflections that occur at fire limit state cause structural destabilisation and failure?	The non-linear model can capture the reduction of material properties and the extent of thermally induced deformations and forces and therefore determine if a structural stability failure would occur or not.
Will large deflections lead to breach of compartmentation due to cracking?	Peak reinforcement strains have been calculated. These allow an assessment of the risk to cracking of the concrete floor slab and hence the risk to breach of horizontal floor compartmentation. Risk of differential displacements between individual prefabricated planks was monitored using dedicated FEA models testing different plank arrangements
Will cellular beams reduce the robustness of the building?	The global numerical models consider conservatively the reduced bending capacity of a cellular beam. The localised failures of the beams has been considered separately using SCI P355. A maximum critical temperature is specified in the model (typ. 550°C), such that both global and local checks are satisfied.
Will the thermal expansion of the floor structure destabilise the multi-floor truss or inclined columns?	The global numerical models enable the assessment of load transfer to, and displacement of, the truss and inclined column members. Stability of these elements can therefore be demonstrated.

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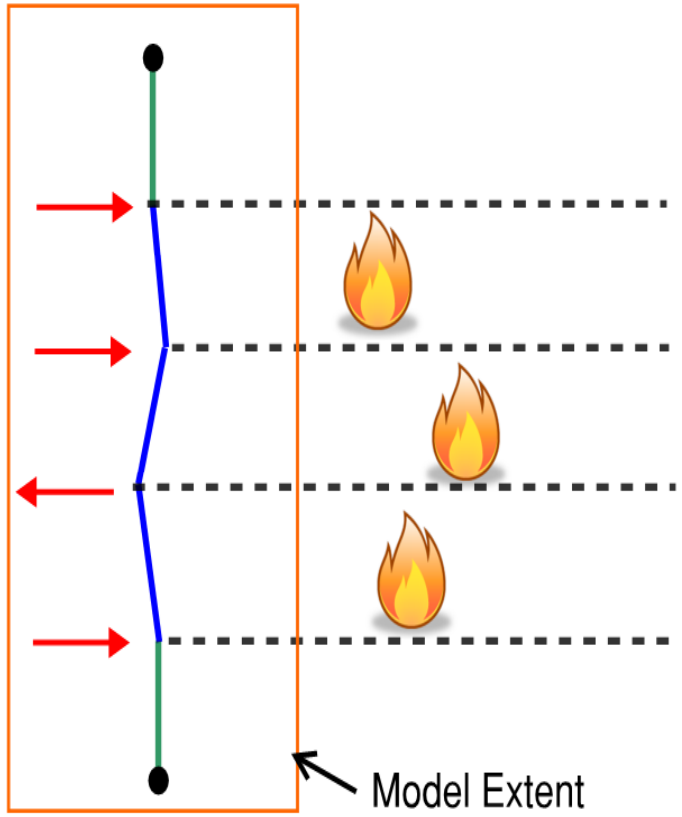
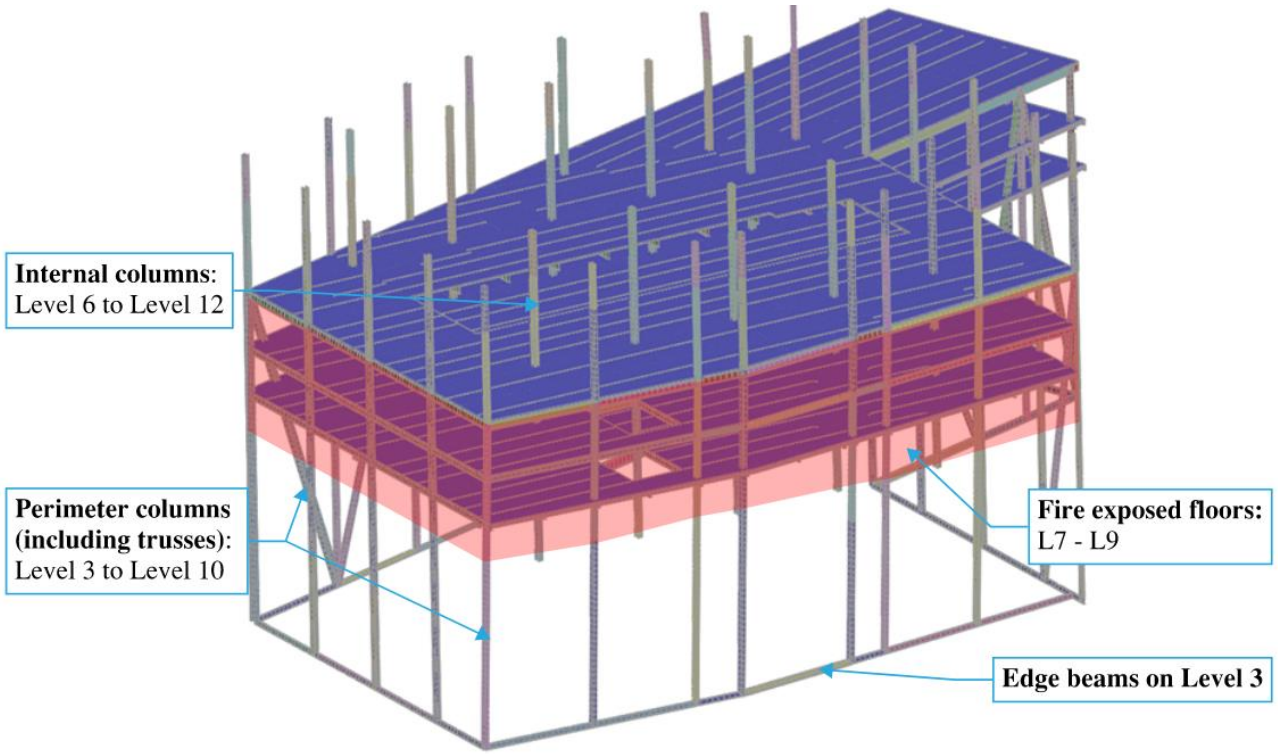
Assessment methodology

Specific to the multi-floor fire

- Additional consideration given to:
  - Column stability when exposed to combination of heating expansion and cooling contraction on various floors
  - Enhanced lateral expansion caused by internal floor systems heated from both sides
  - The structural stability of the internal floorplates when subject to double sided heating
- Benchmarking the response to various assessment criteria required iterative approach resulting in 61 different simulation cases considered in this work

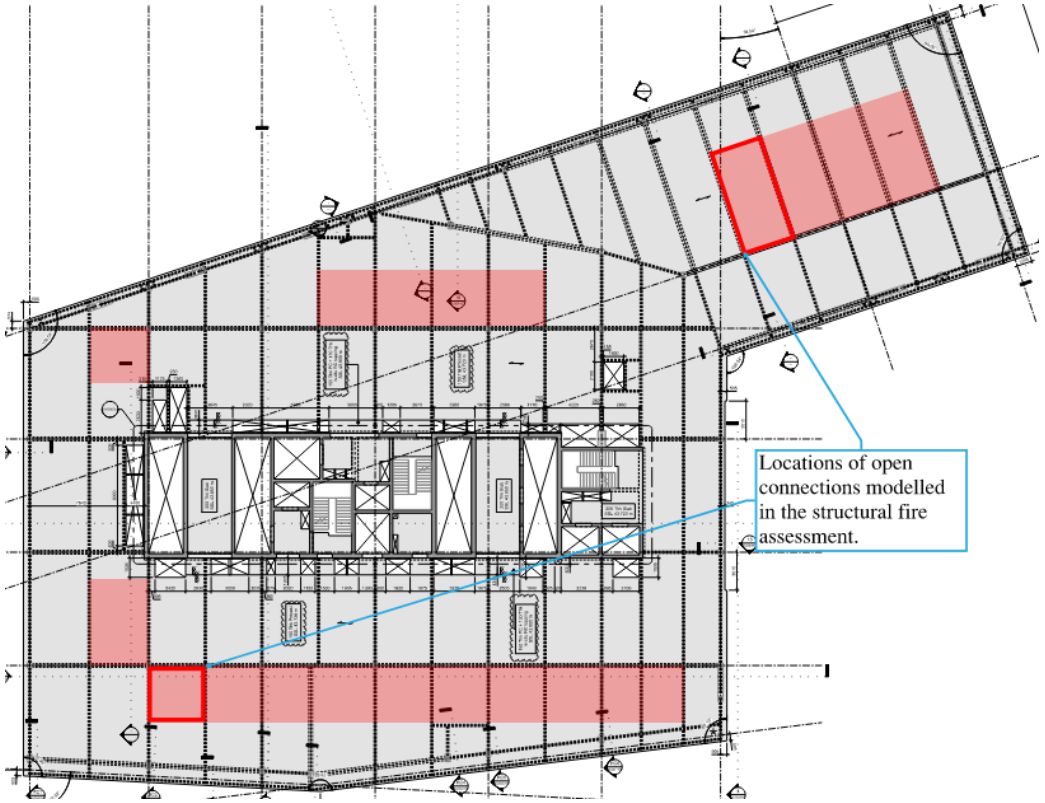


Model geometry

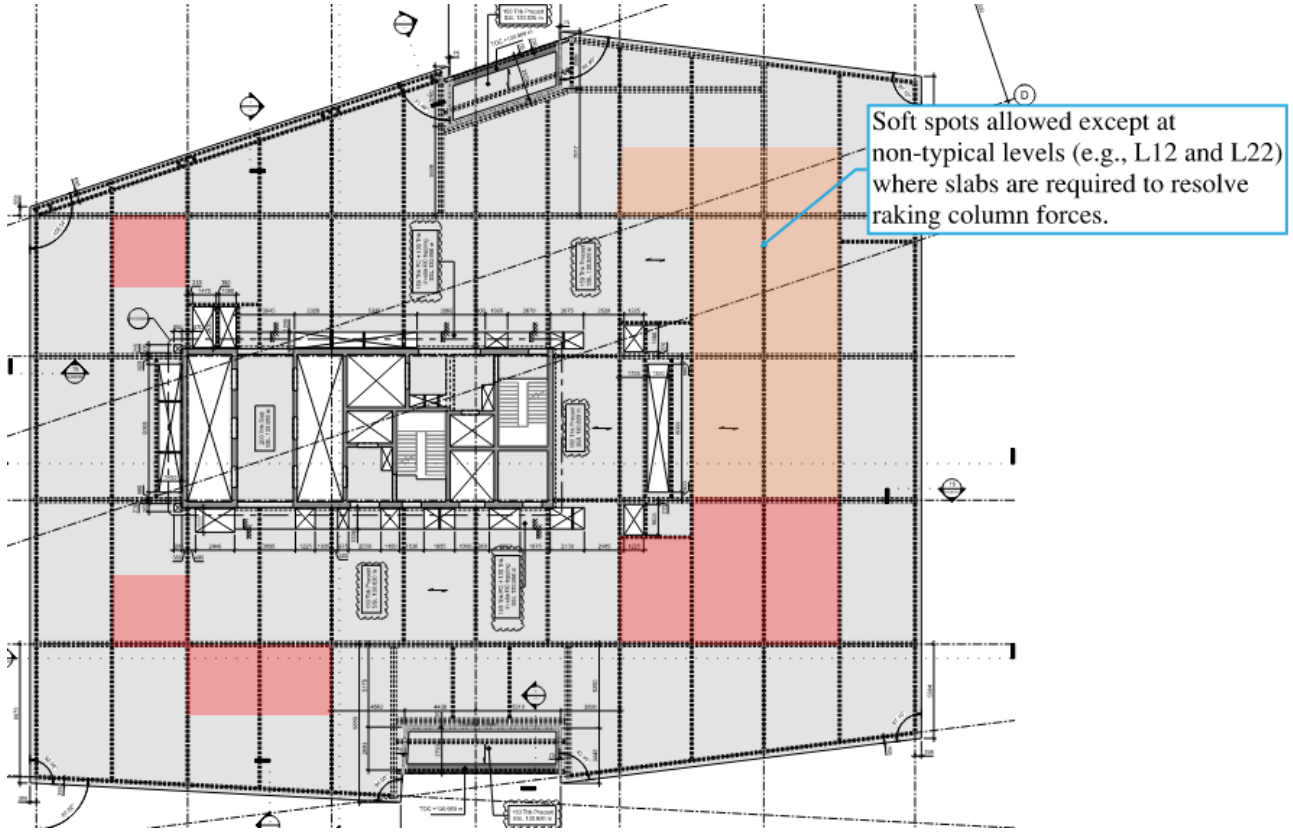


- Critical structural like perimeter truss top chord is situated at Level 10
- Presence of highly utilised inclined columns at the south façade,
- Presence of hanging columns,
- Slender double-height columns between Level 10 and 12
- Level 10 supports elevated retail and plant loading and incorporates transfer systems supporting level 11 mezzanine
- Higher floor area at low-rise floors were which will lead to larger lateral deflections at perimeter columns

Allowable opening locations



Typical low-rise floor



Typical high-rise floor

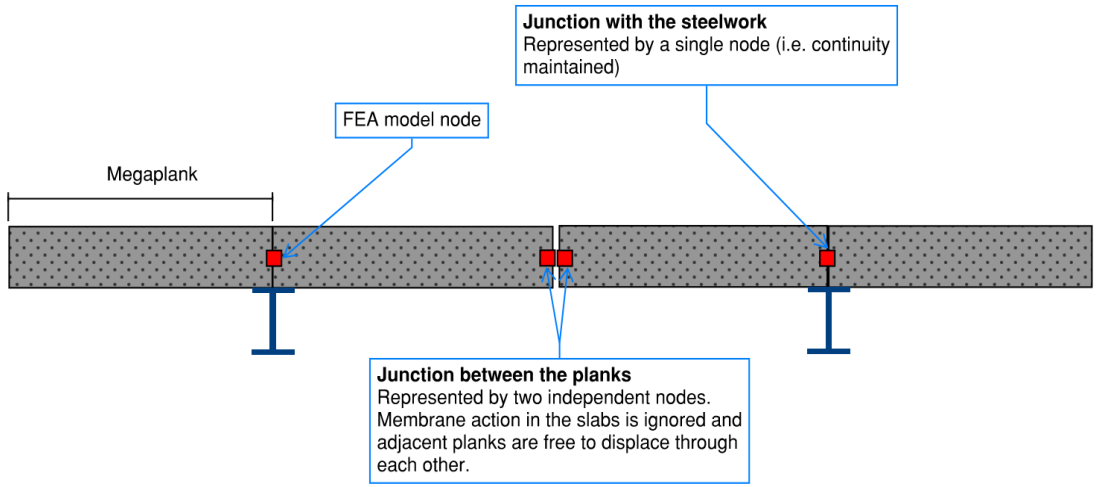
Prefabricated planks

SFE Full-floor models

- Reinforcement location and specification updated as per design drawings
- Two bounding cases of inter plank joint representation:

➢ Complete mechanical interaction preserved across the joint

➢ No mechanical interaction between individual planks



FEA model representation

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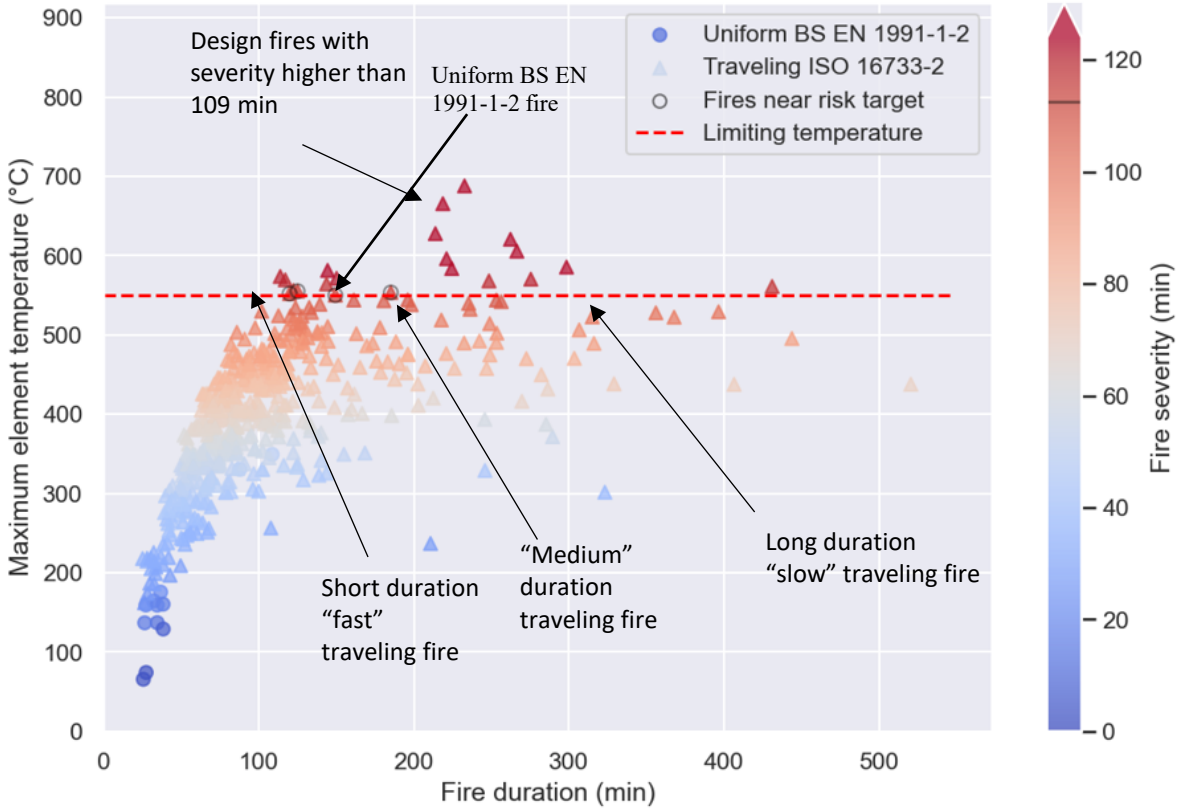
Design fires

Original design fire based on the Monte Carlo analysis



Scatter plot of maximum steel element response against fire duration for the sampled design fires

Boundary conditions for design fires informed by the fire severity assessment:

- Standard fire
- BS EN 1991-1-2 fire of 109 min severity
- Three traveling fires of 109 min severity

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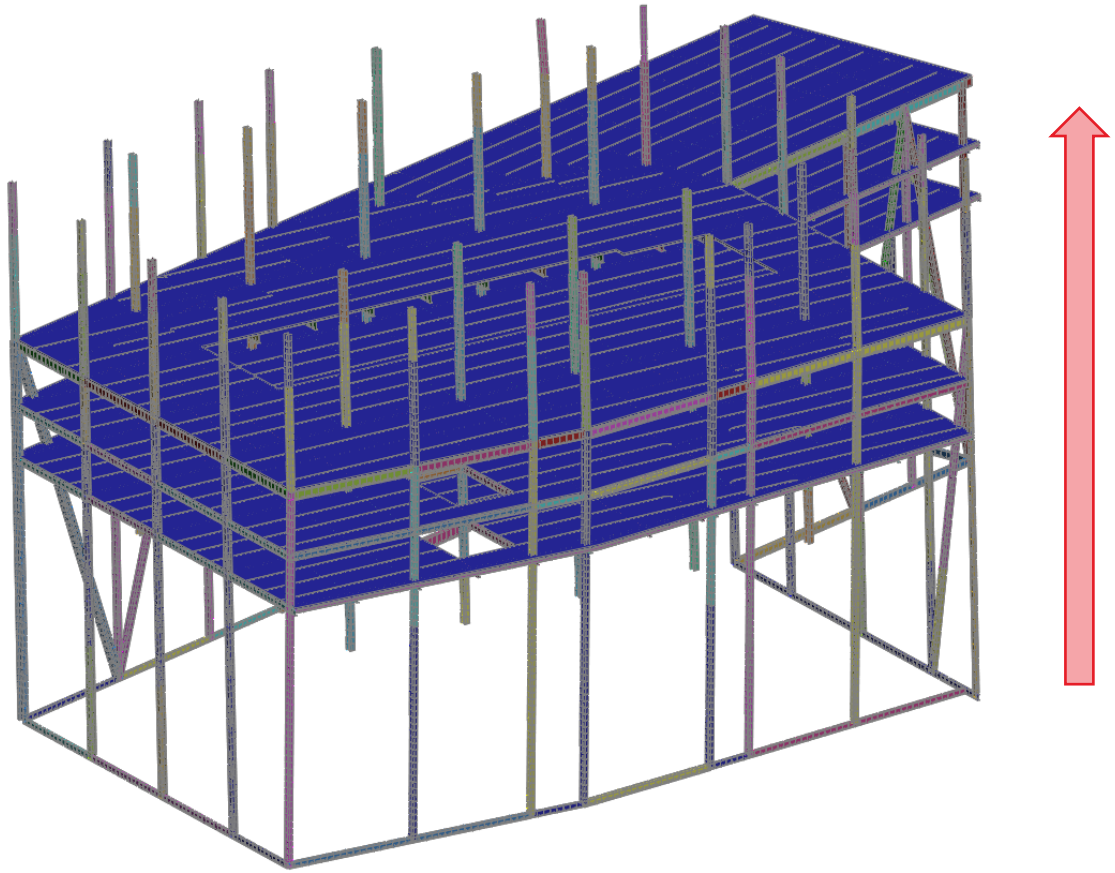
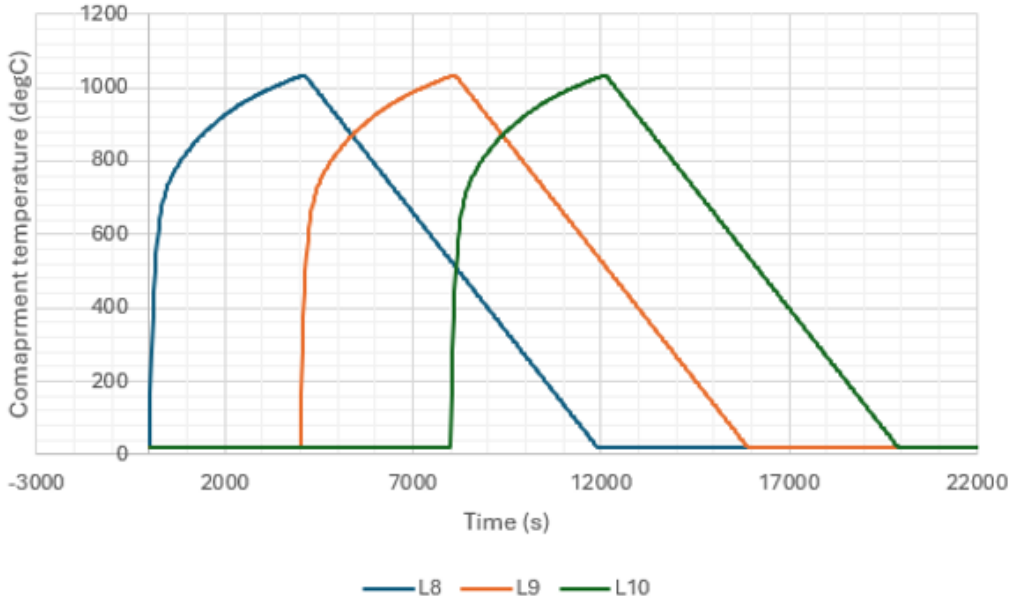
Design fires

Applied over three floors



- 109 min equivalent uniform BS EN 1991-1-2 parametric fire involving the whole floorplate
- Upward vertical fire spread represented by delayed ignition at each floor
- Various delayed periods considered ranging from 0 min (simultaneous exposure) to 200 min (single floor burnout)



Temperature time curves of parametric fire with delay of 4000 s

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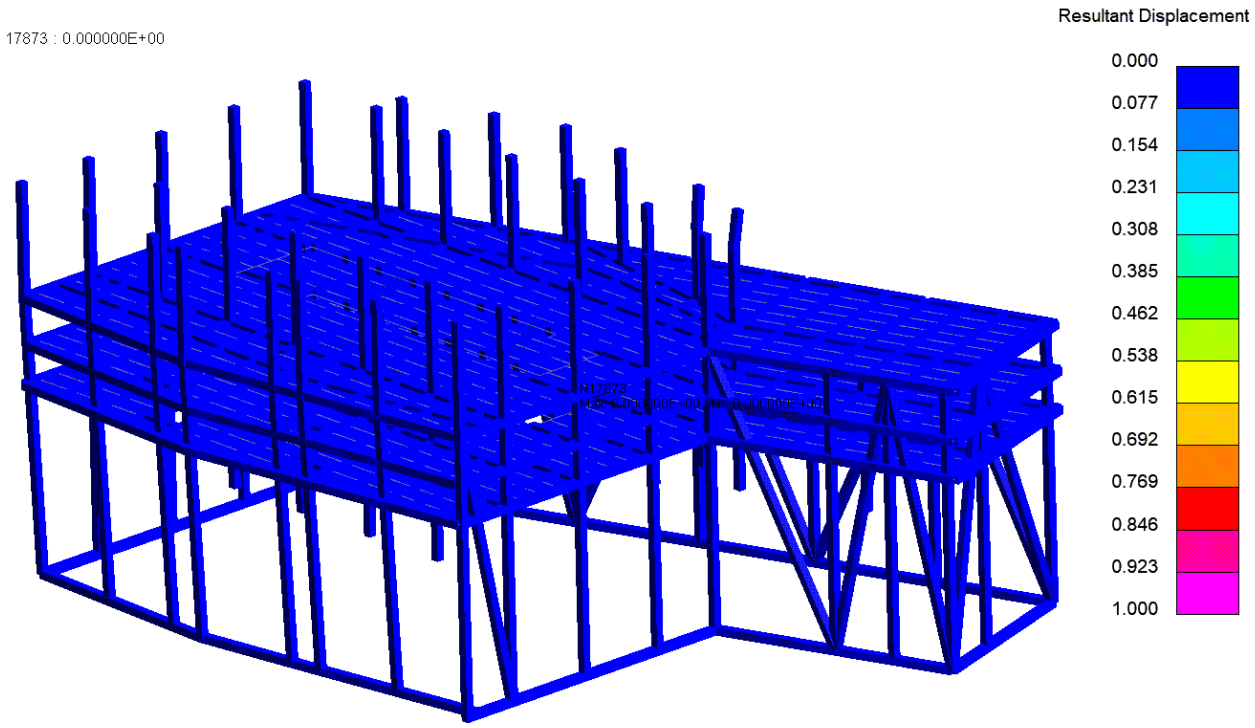
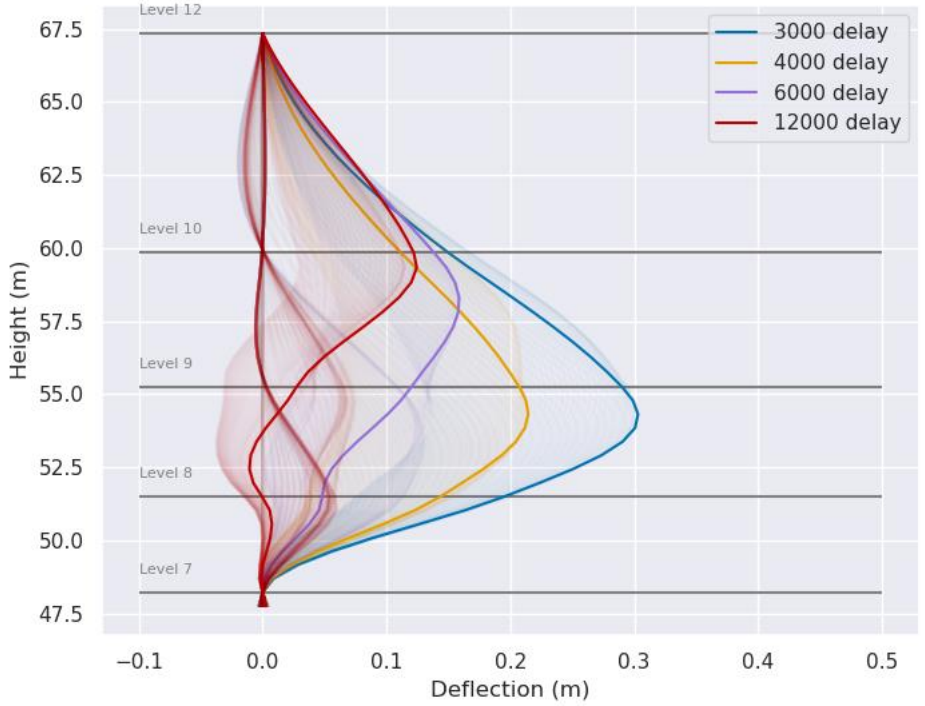
Thermomechanical response

Overview

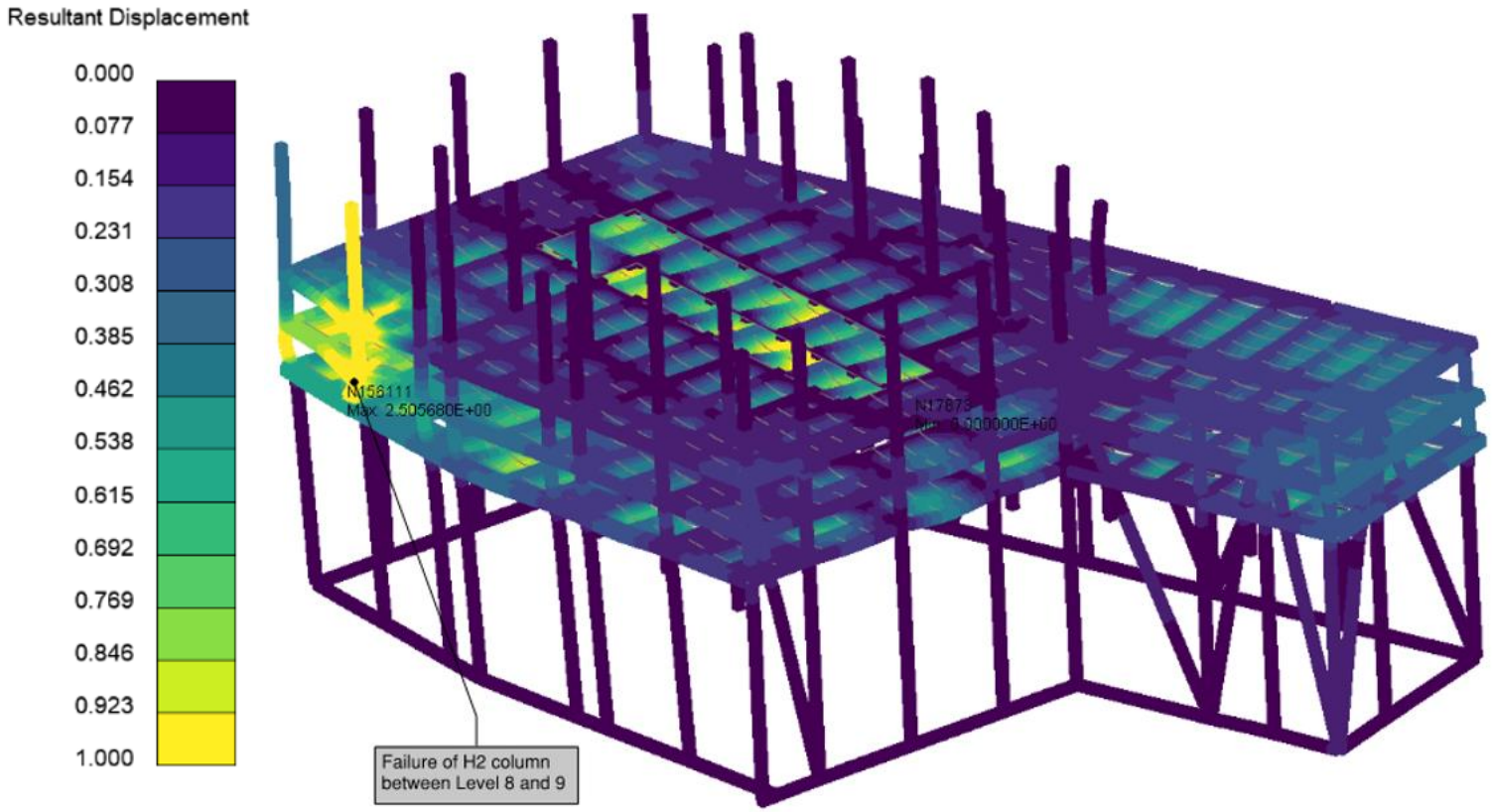




Deflection shape of the H2 column with different delays

Assessment criteria achieved for exposure to design fires with delay period more than 3000 s

Identified failure mechanism



Structural failure conditions:

- > 300 mm lateral deflection
- 0.48 FLS utilisation at ambient
- 357 ºC failure temperature
- 544 ºC average beam temperature @ time of failure

Fire conditions leading to failure:

- Less than 2000 to 3000 s design fire delay (based on slab representation assumptions)
- At least 24 m fire bed length or 490 m2 (~ 20% floor plate) fire area needed per floor to introduce 300 mm lateral deflections

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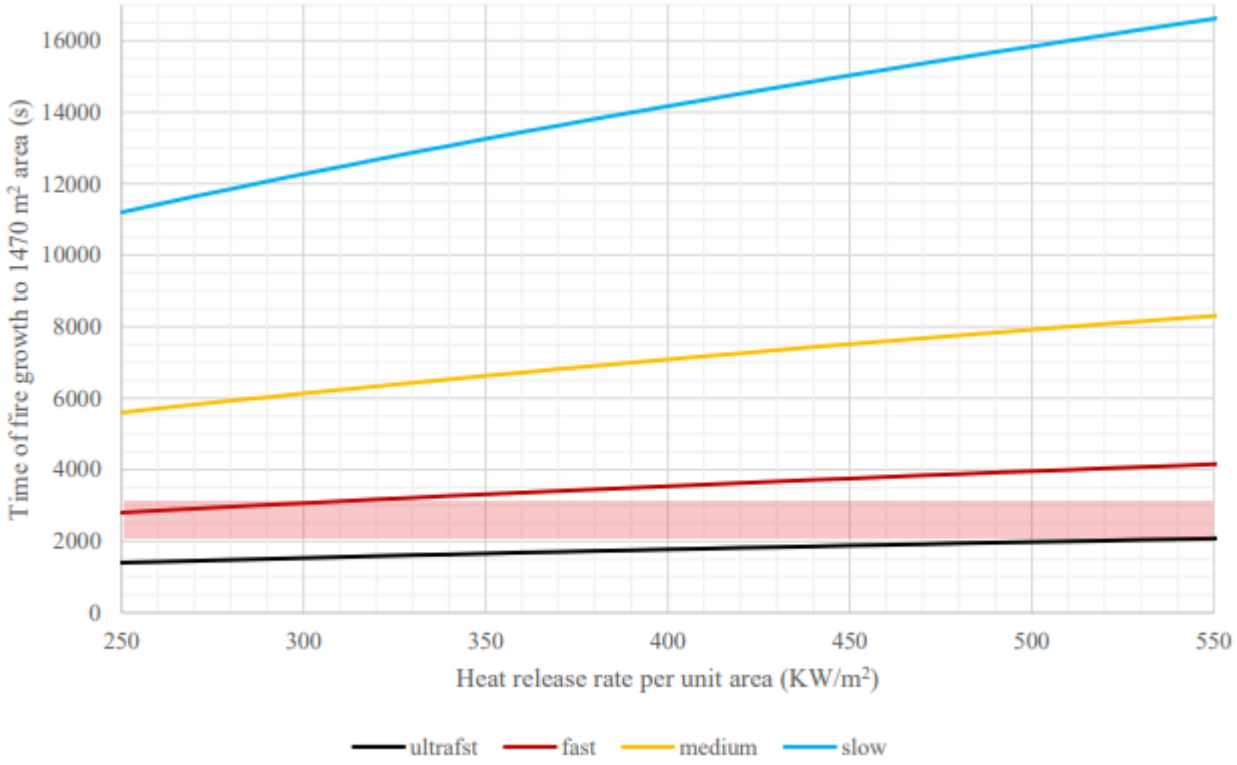
Risk assessment

Qualitative appraisal of the likelihood of the identified failure conditions:

- Fire escalation to a total of 1470m^2 over 3 floors within 3000 s requires more severe growth profile than a “fast” fire.
- A2 – medium BS 9999 risk profile for the building if sprinklers are not considered.
- Routes of vertical fire spread are limited to low fire load circulation stairs and external wall construction which is assessed separately

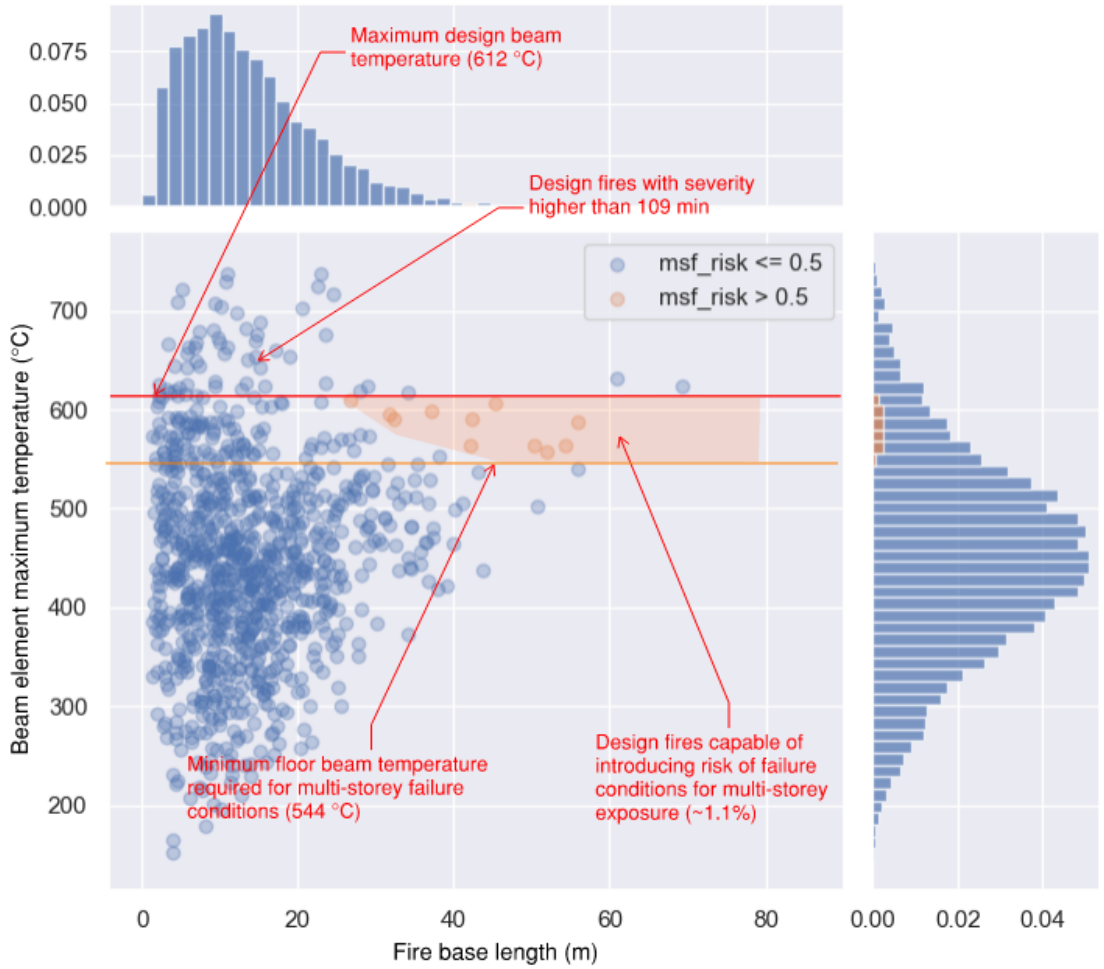


Required time for fire growth to a total area of 1470 m^2 over 3 floors

Risk assessment

- Very low likelihood of structural significant fire to eventually develop to failure leading conditions considering the characteristics of the design fires adopted in the Monte Carlo fire severity study
- Internal slabs are heated from both sides with the same intensity. Insulating action of suspended floor system, furniture, and debris is not considered
- Functioning sprinkler system additional reduces the likelihood of fire escalation

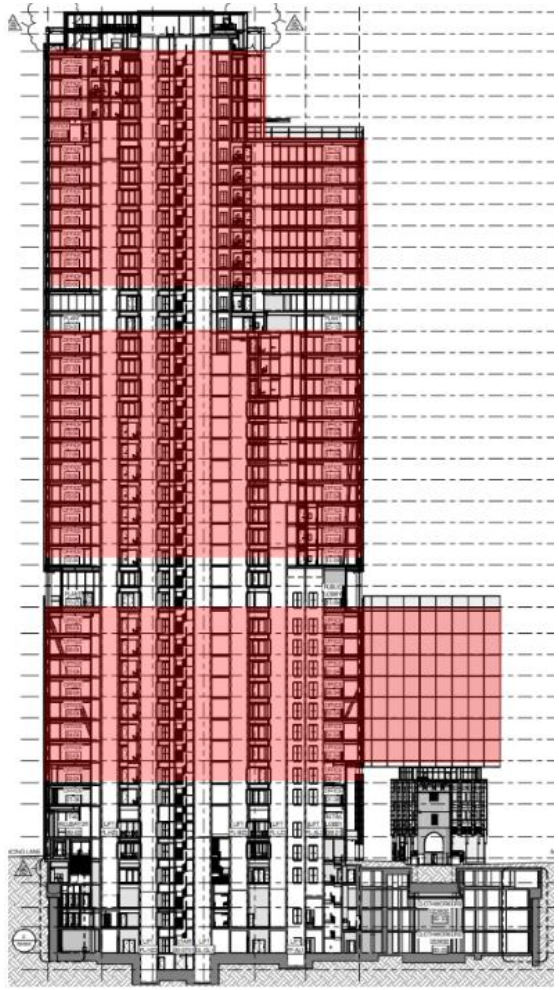
Considering the existing fire strategy provisions and the resulting very low likelihood of triggering multi-storey structural the proposed solution achieves B3 requirement



Scatter plots of design fires matching the identified failure thermal conditions

Fit-out requirements

- Openings can be included only to office floors above level 2
- Current allowance is for up to 2 openings per floor linking together up to 3 floors
- Location and design to be further coordinated with Arup during fit-out stage:
  - Openings should not impact perimeter beams, load transfer beams, raking columns and grid arrangement
  - Additional egress assessment for simultaneous evacuation and escape near voids required
  - Smoke control provisions to be reviewed in line with BS 9999 Appendix G provisions for atria design



Levels where penetrations are allowed

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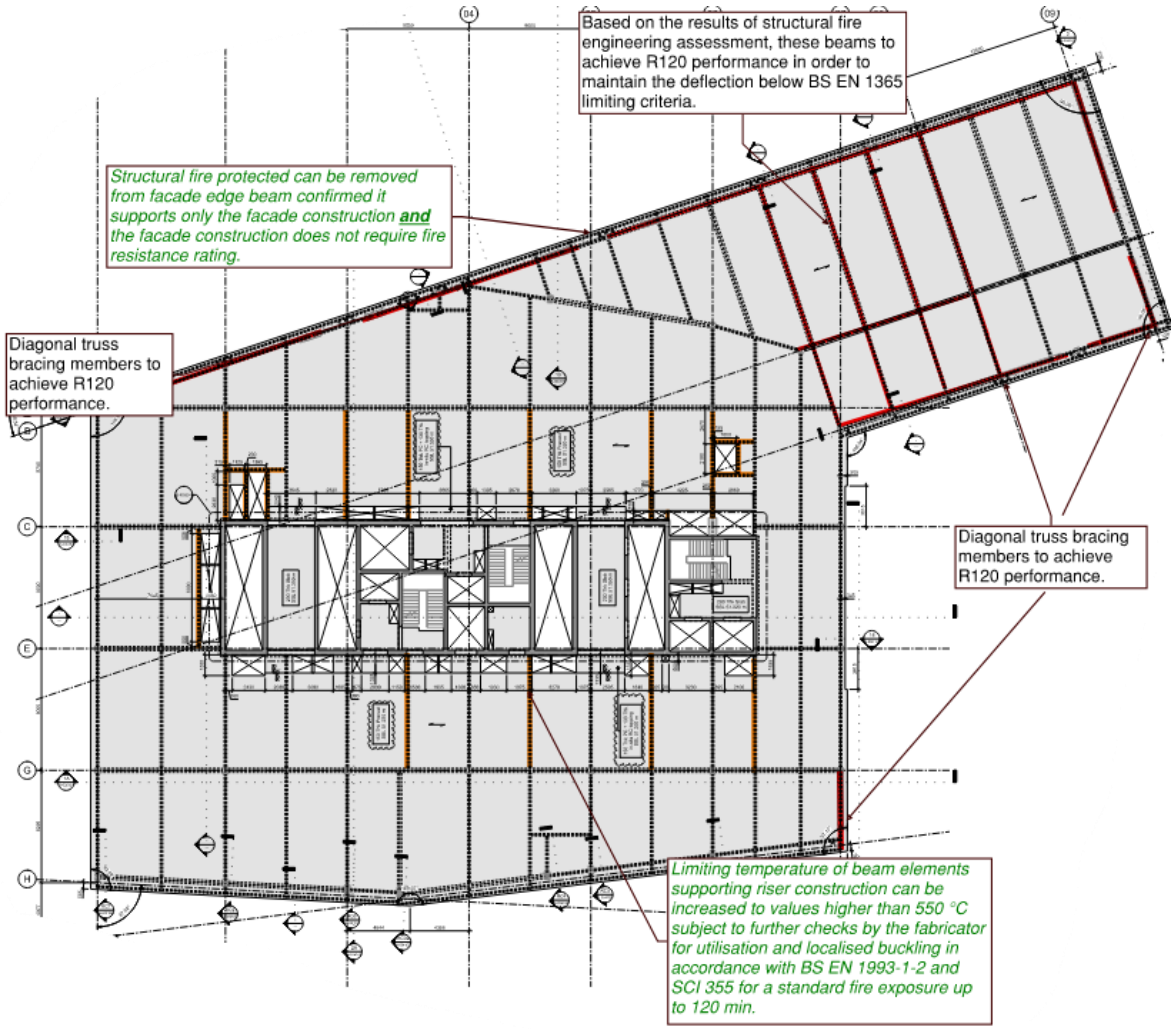
Proposed solution



Typical fire protection solution

Element to be protected to R120 fire resistance at 550 degC limitng temperature

Element supporting riser construction to be protected to R120 fire resistance at 550 degC limiting temperature

Element to be protected to R90 fire resistance at 550 degC limiting temperature at 550 degC limiting temperature

- Slab: 120 min REI
- Columns: 120 min R @ 550 °C LT
- Beams: typ. 90 min R @ 550 °C LT
- Critical beams: 120 min R @ 550 °C LT*
- Riser supporting beams: 120 min R @ 550 °C LT**
- Edge beams supporting façade only: unprotected***

* e.g. truss beams, axially loaded beams, bay arrangements with excessive deflections at FL

** Possible increase of LT subject to SCI 355 and BS EN 1993-1-2 assessment

*** Only for non-fire rated regions of the façade

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