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Analysis of Structures in Fire Using General Structural Analysis Software

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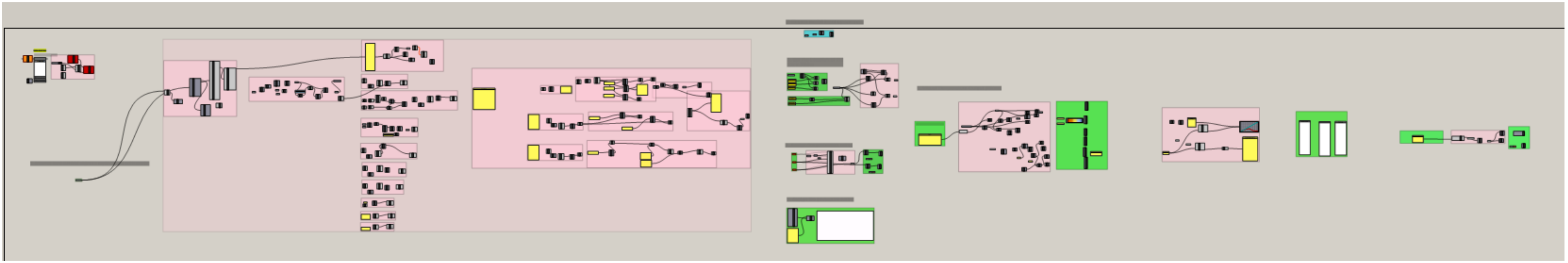
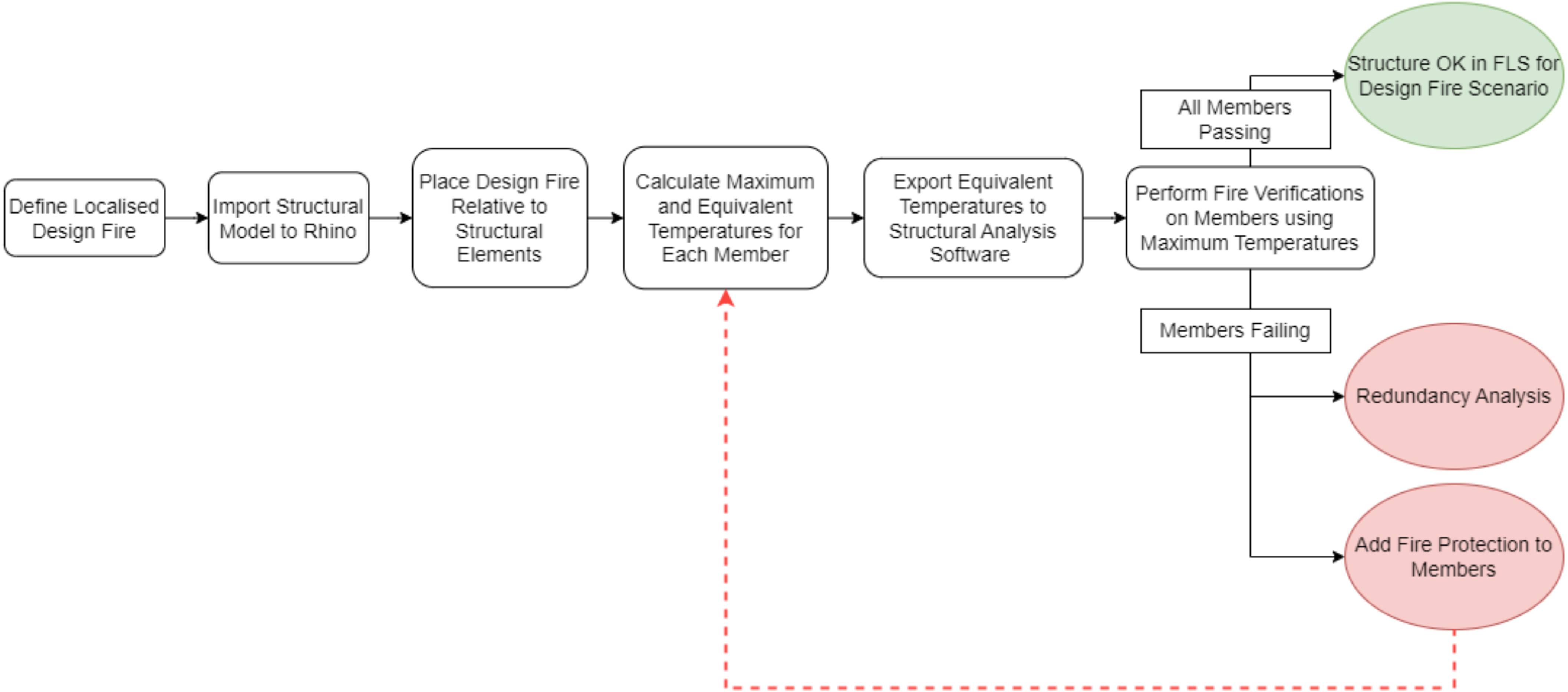
Predicting steel frame behaviour in fire

- Internal forces arising from localised fires are often detrimental to steel frame structures
- Proprietary FE software (ie SAFIR, Vulcan, LS-Dyna) is expensive and time consuming
- General structural analysis software (Robot, RFEM etc.):
    - Models often easily obtained for a project
    - Lack functionality required
- A workflow create to allow general structural analysis software for steel frame buildings exposed to localised fires
- Limited to relatively low temperature scenarios (localised fires in large open spaces)

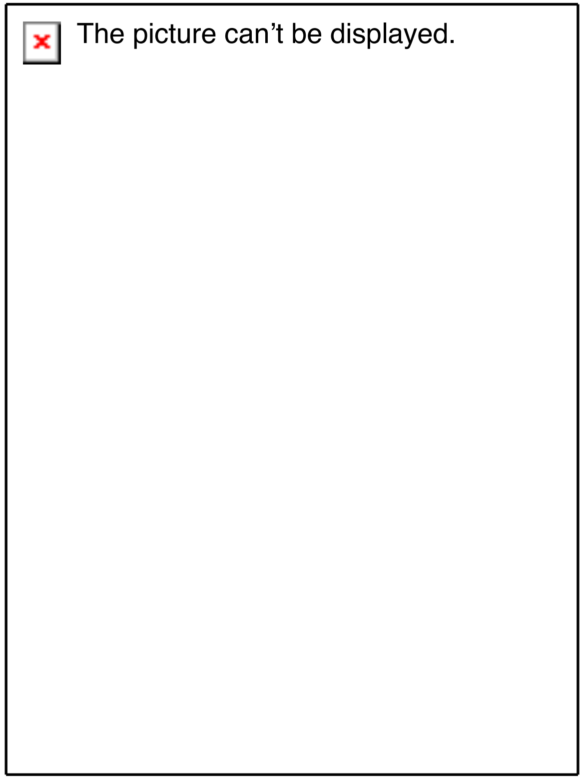


Workflow Overview



Defining the localised design fire

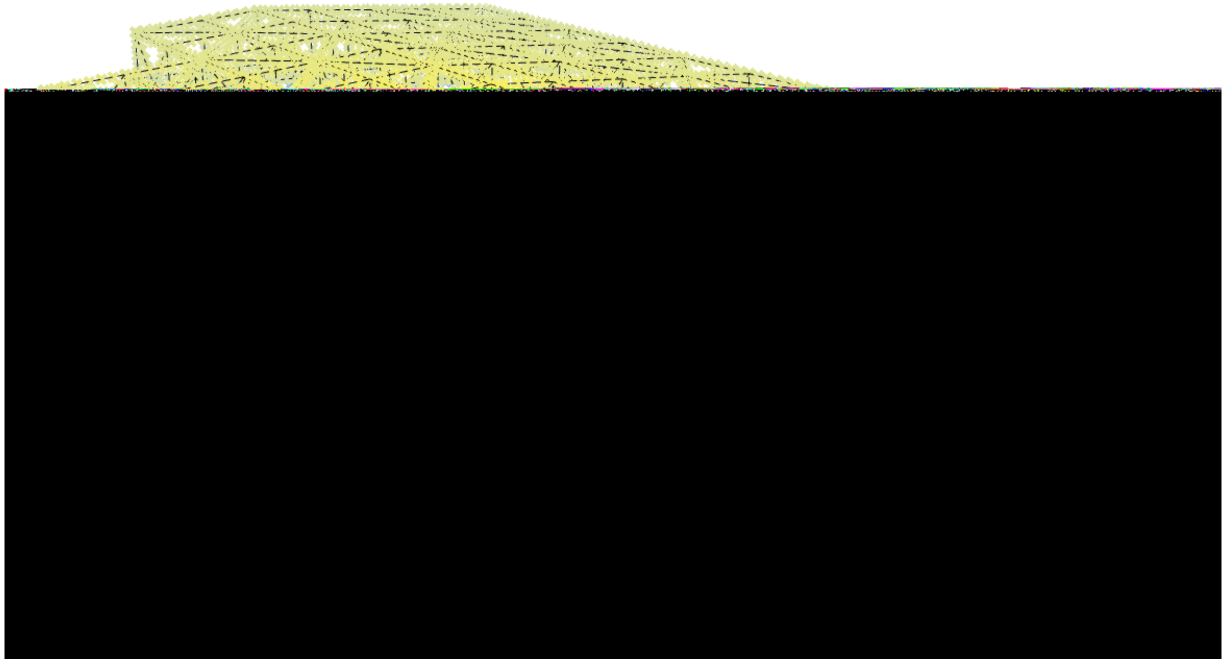
- Modelled based on equations described in the SFPE Handbook
- Conservatively idealised in a cylindrical shape
- Split into three main geometrical components:
  - Continuous flame
  - Intermittent flame
  - Thermal plume



- Each zone has different parameters to calculate radiative/convective heat transfer

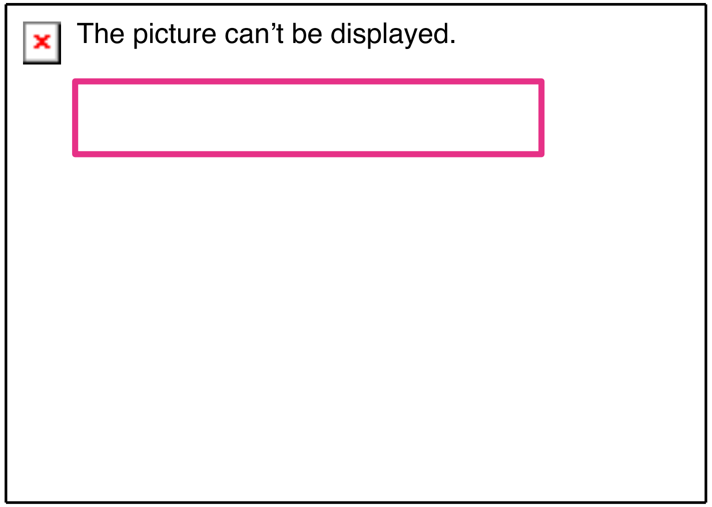
Steel Temperature Model

- In-house python script based on equations from EN 1993-1-2 for protected and unprotected steel
- Allows temperature of an element to be calculated anywhere in 3D space in relation to design fire



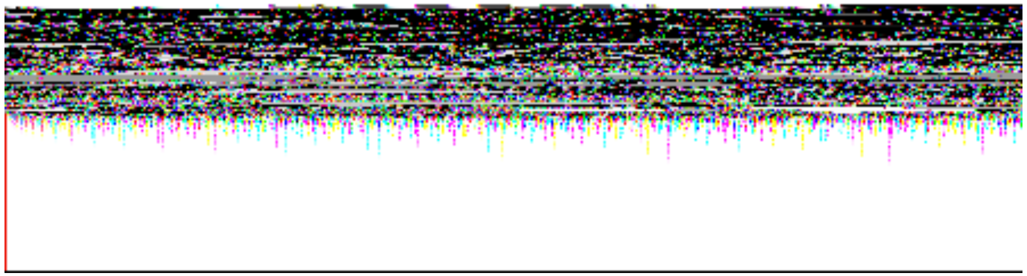
Equivalent Stiffness

- Overestimation of axial force in heated restrained member due to ignoring the reduction in Young's Modulus at elevated temperatures



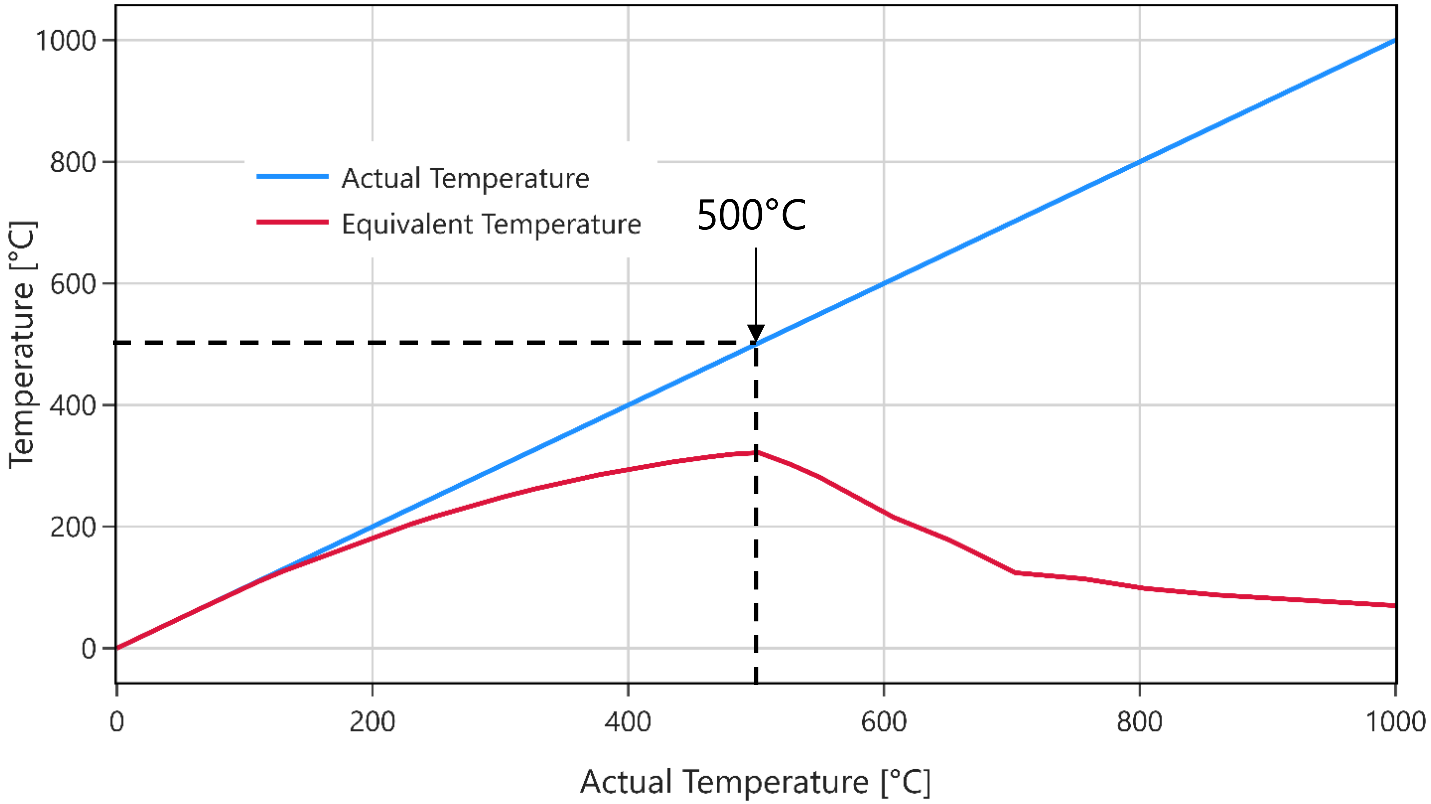
- for $20°C \leq \theta_a < 750°C$:

$$\Delta l/l = 1{,}2 \times 10^{-5}\, \theta_a + 0{,}4 \times 10^{-8}\, \theta_a^2 - 2{,}416 \times 10^{-4}$$



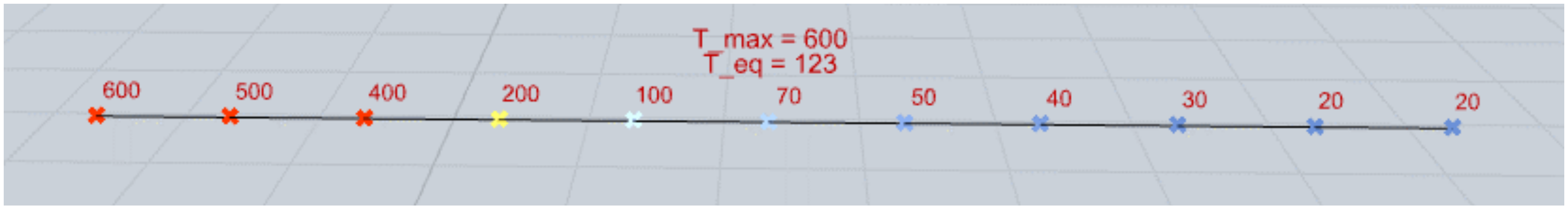
Equivalent Stiffness

- Stiffness rapidly decreases at higher temperatures
- Max equivalent temperature taken when actual temperature reaches 500°C (conservative)



Maximum Element Temperature and Equivalent Temperature

- Members split into nodes
- Steel maximum and equivalent temperature calculated at each node
- Average equivalent temperature is used to calculate internal forces and maximum temperature used for member verification
- It should be noted that members heat at different rates and therefore temperatures should be calculated at multiple time steps



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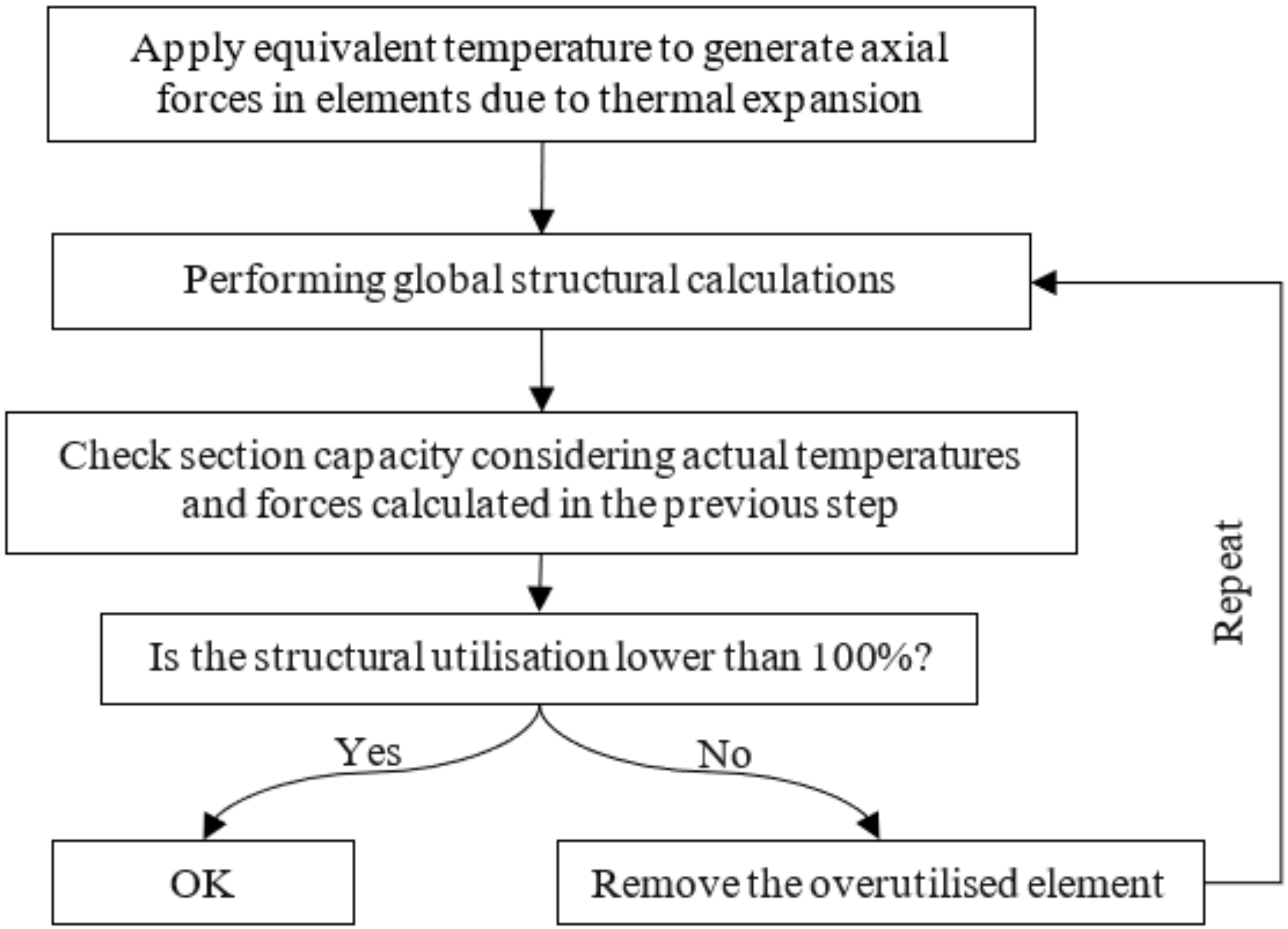
Structural Analysis Overview



Connection Design

- Important to consider connection design for increased axial loads and moments
- Possible to investigate how plastic deformations and bolt hole tolerances assist in dissipating increased forces

$$dF_{add} = dL / L \times EA$$

$$dL_{req} = dF_{add} / (EA) \times L$$

Where:

dF_{add} – additional force in connection above ULS

dL_{req} – change in length of the element

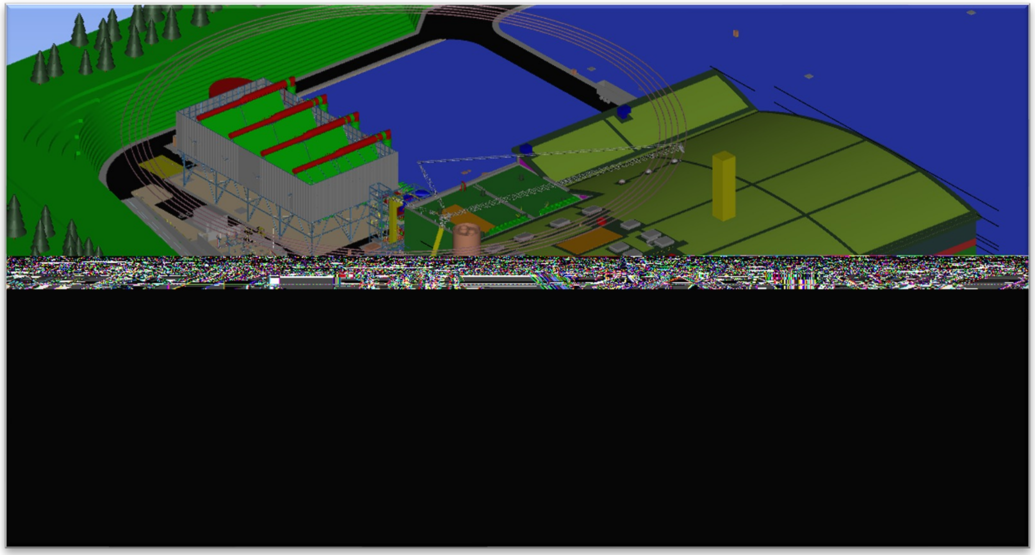
L – length of the element

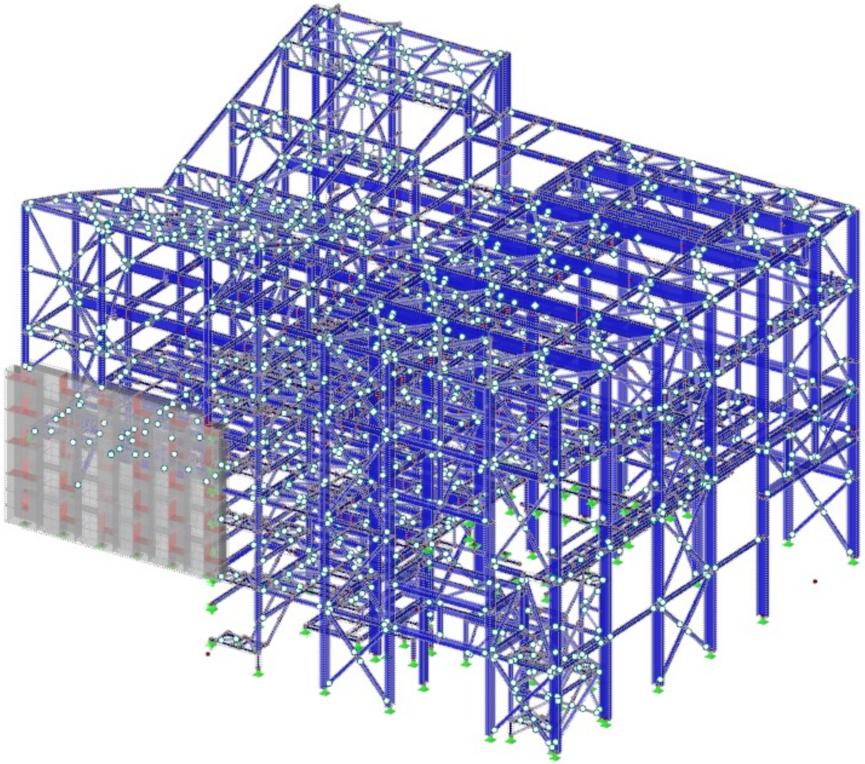
A – cross sectional area of the element

E – Steel Young’s Modulus

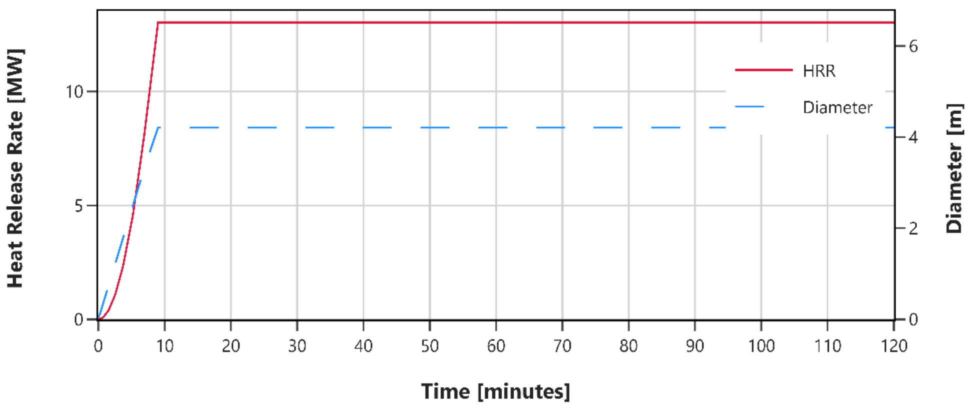
CASE STUDY: Typical Waste-to-Energy plant

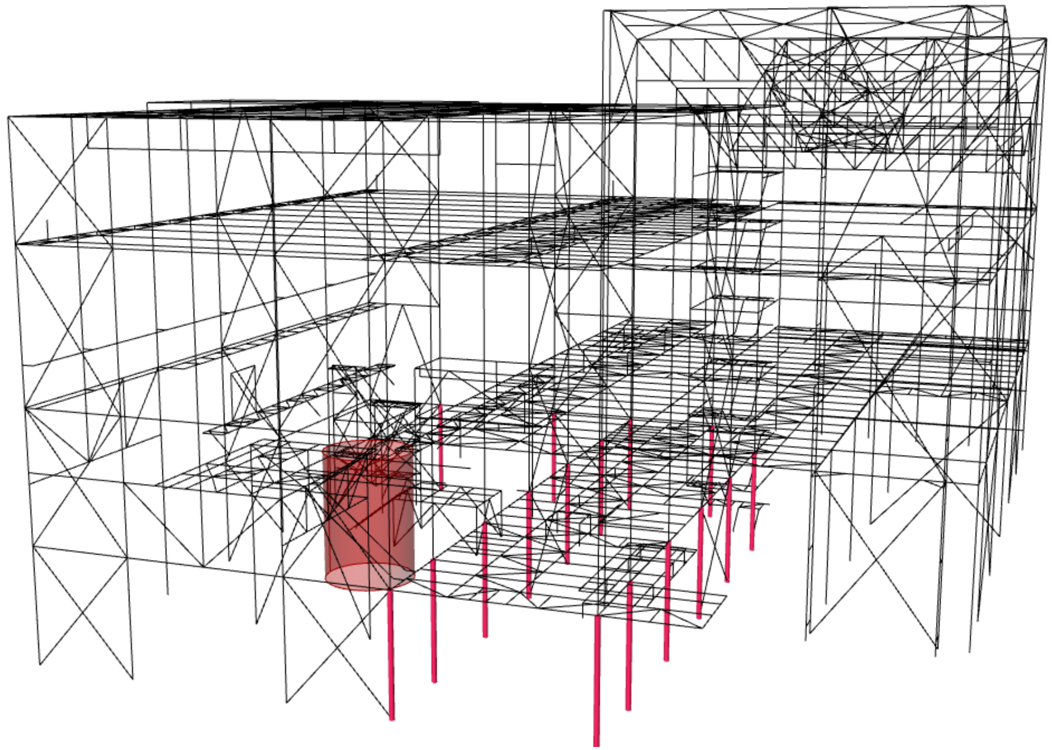
- Requirement for fire protection (NFPA 850): all steelwork supporting fire-rated walls to be protected to R120





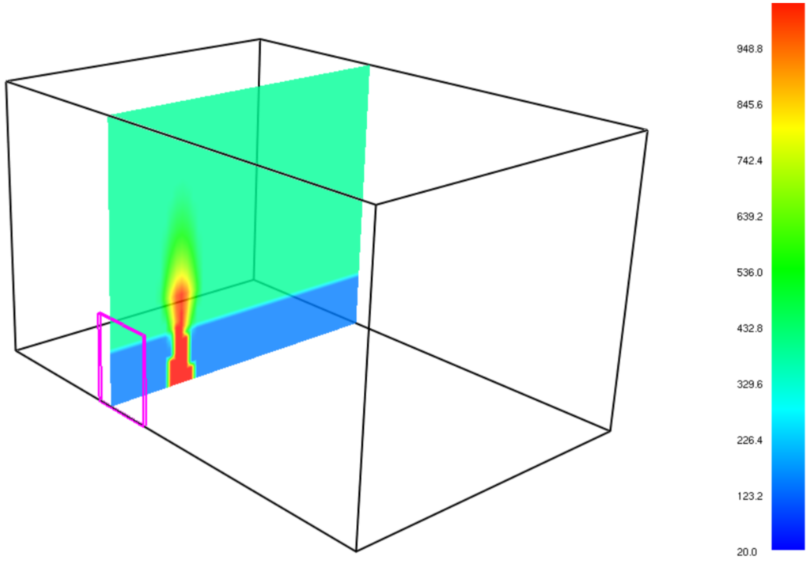
CASE STUDY: Design Fires

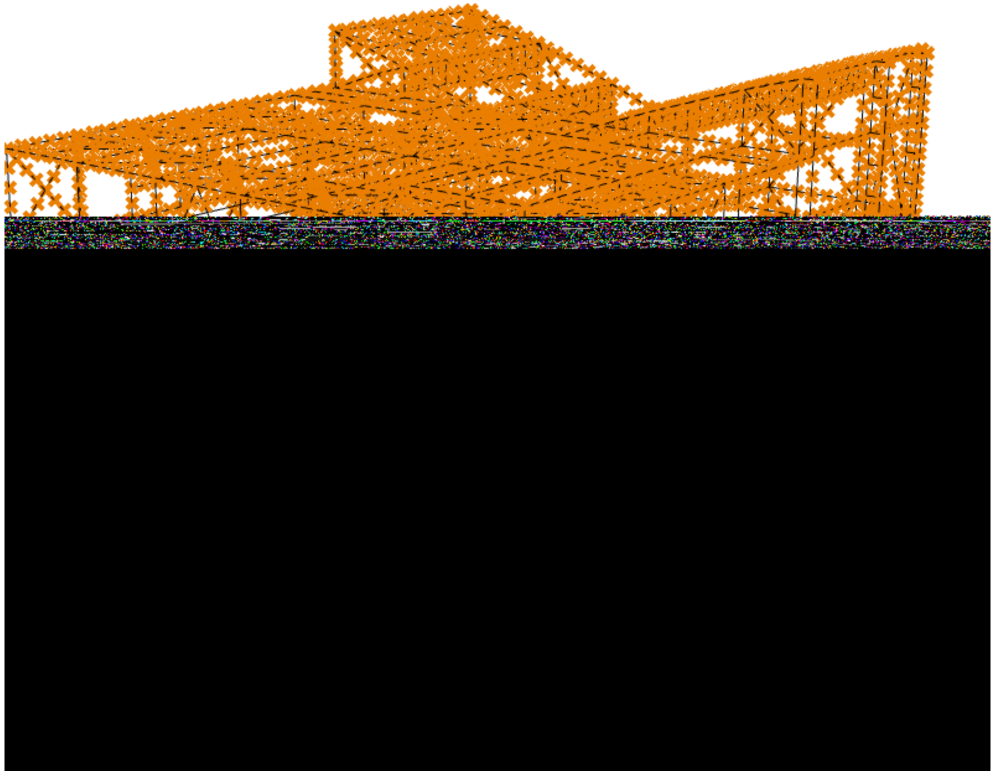




CASE STUDY: Heat Transfer

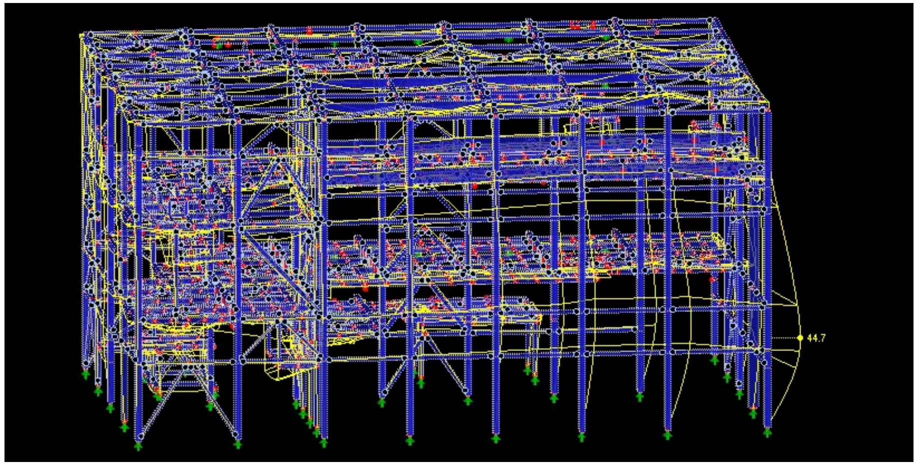
- Zone model (CFAST) used to obtain smoke temperatures
- Temperature calculated for each node

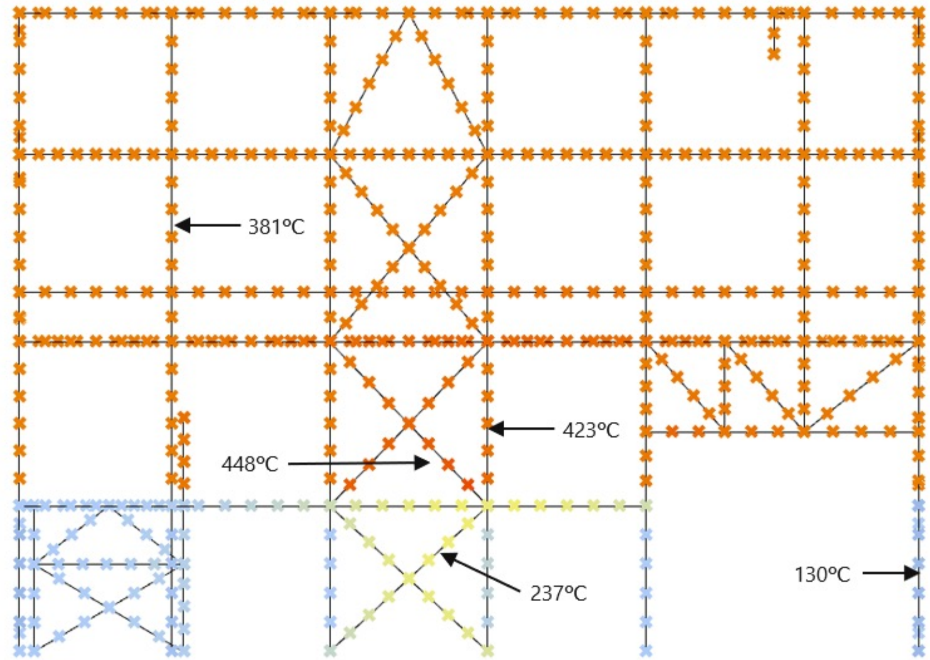




CASE STUDY: Thermo-Structural Analysis

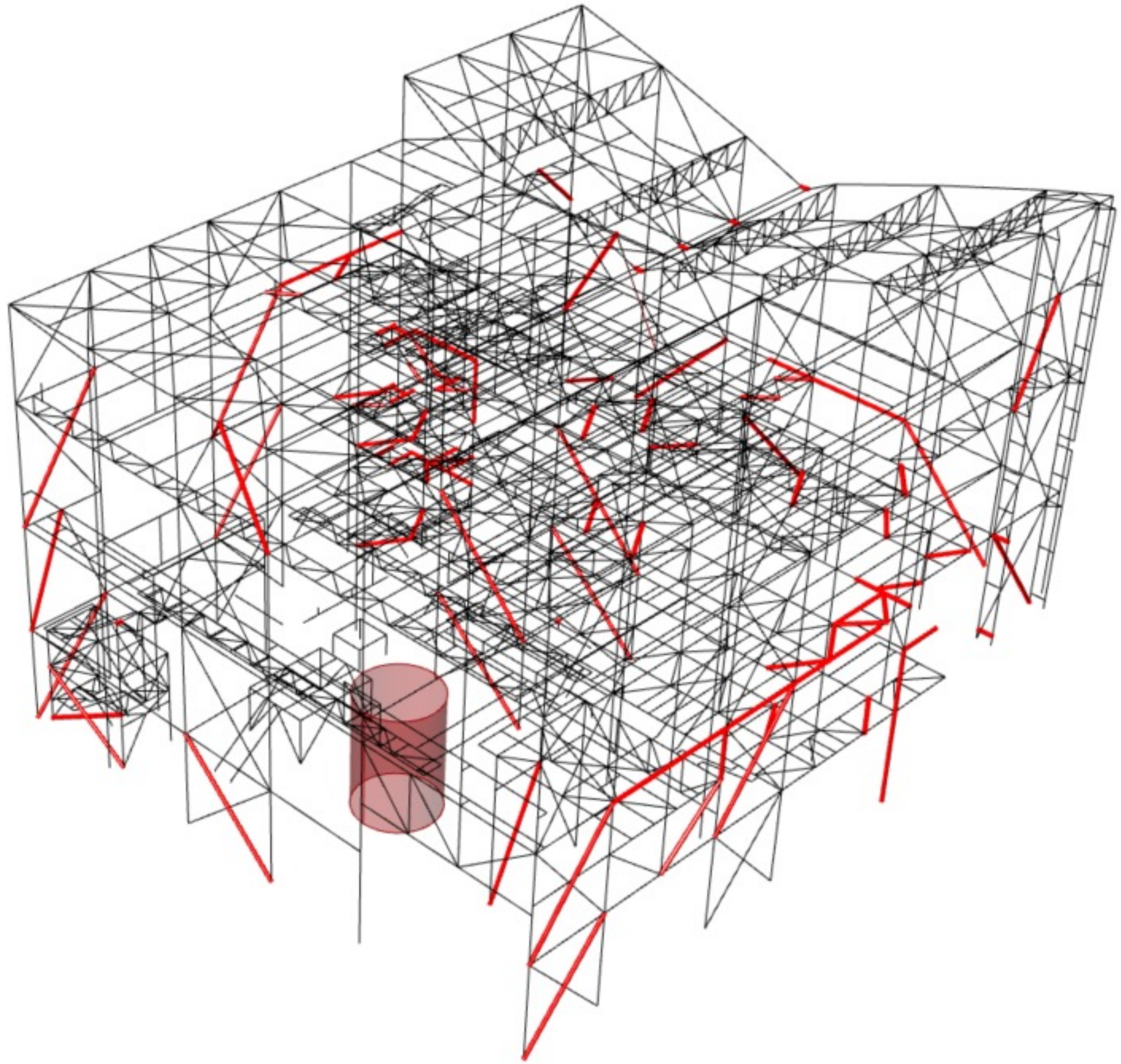
- Equivalent temperature input to RFEM to account for thermally induced forces
- EC3 checks for each member undertaken using maximum temperatures





CASE STUDY: Thermo-Structural Analysis

- Redundancy analysis
- Connection design



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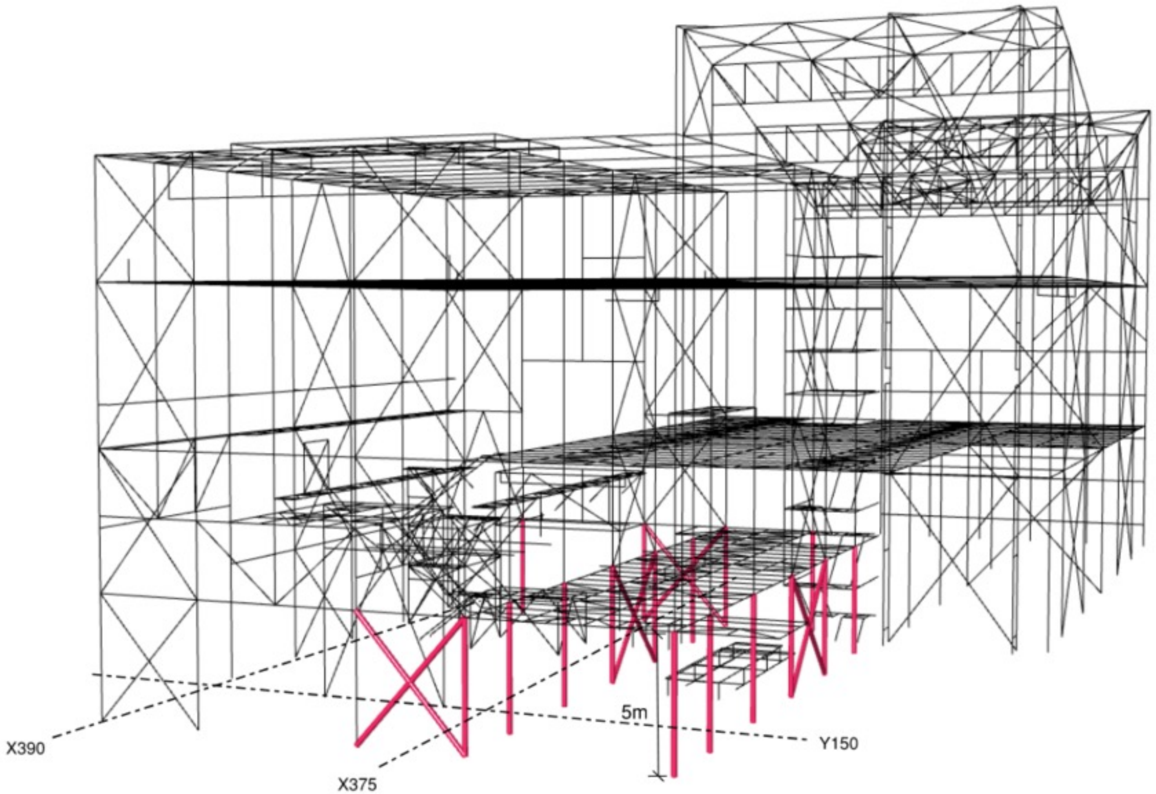
CASE STUDY: Results

- Analysis showed partial protection of R60 required
- Recommended to increase section size of some members



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Thank you for listening!

Any questions?

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