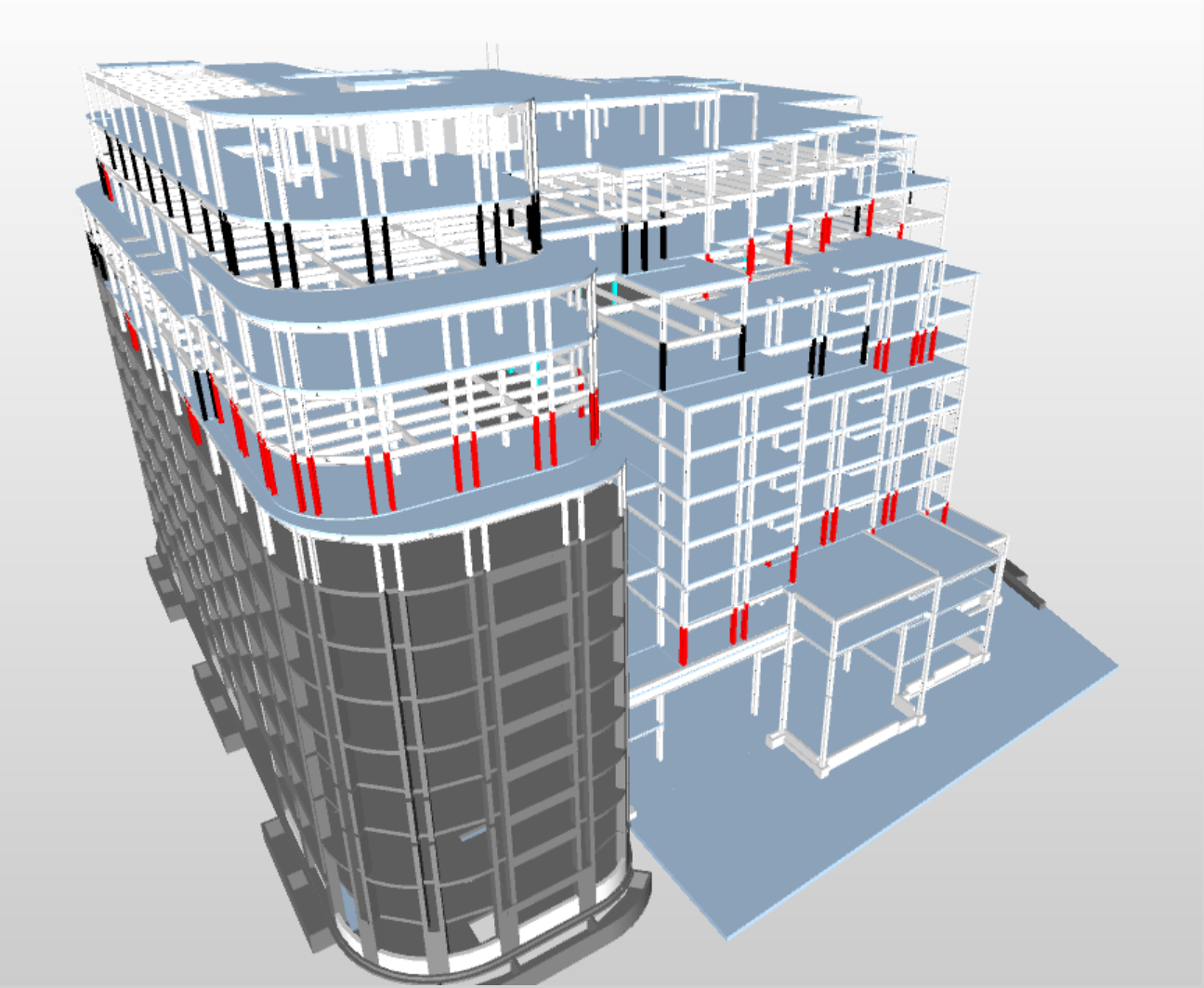
STRUCTURES IN FIRE FORUM

ARUP

Structures in Fire Forum

Fire Resistance of Retrofit Steel Columns in Existing Frames



Zena Protcenko, Yavor Panev

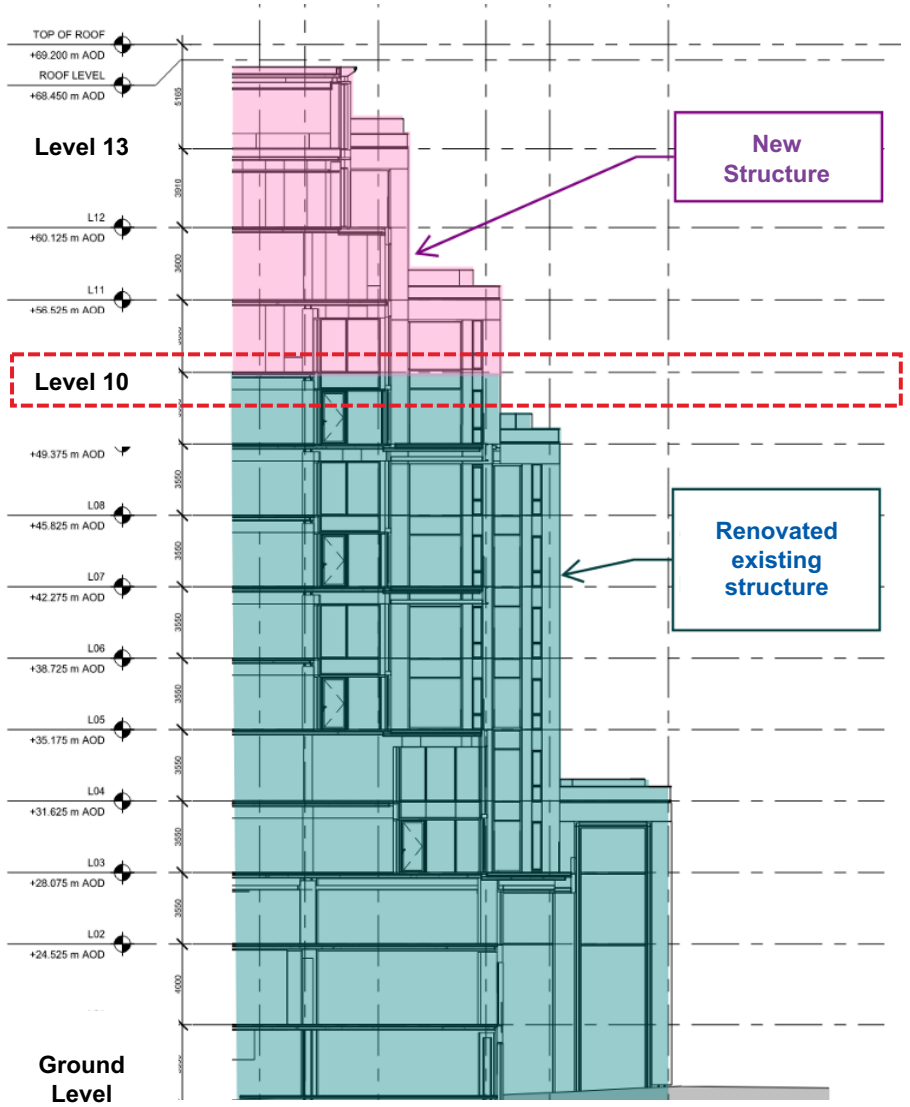
May 2023

Edinburgh, UK

Project Description

Introduction

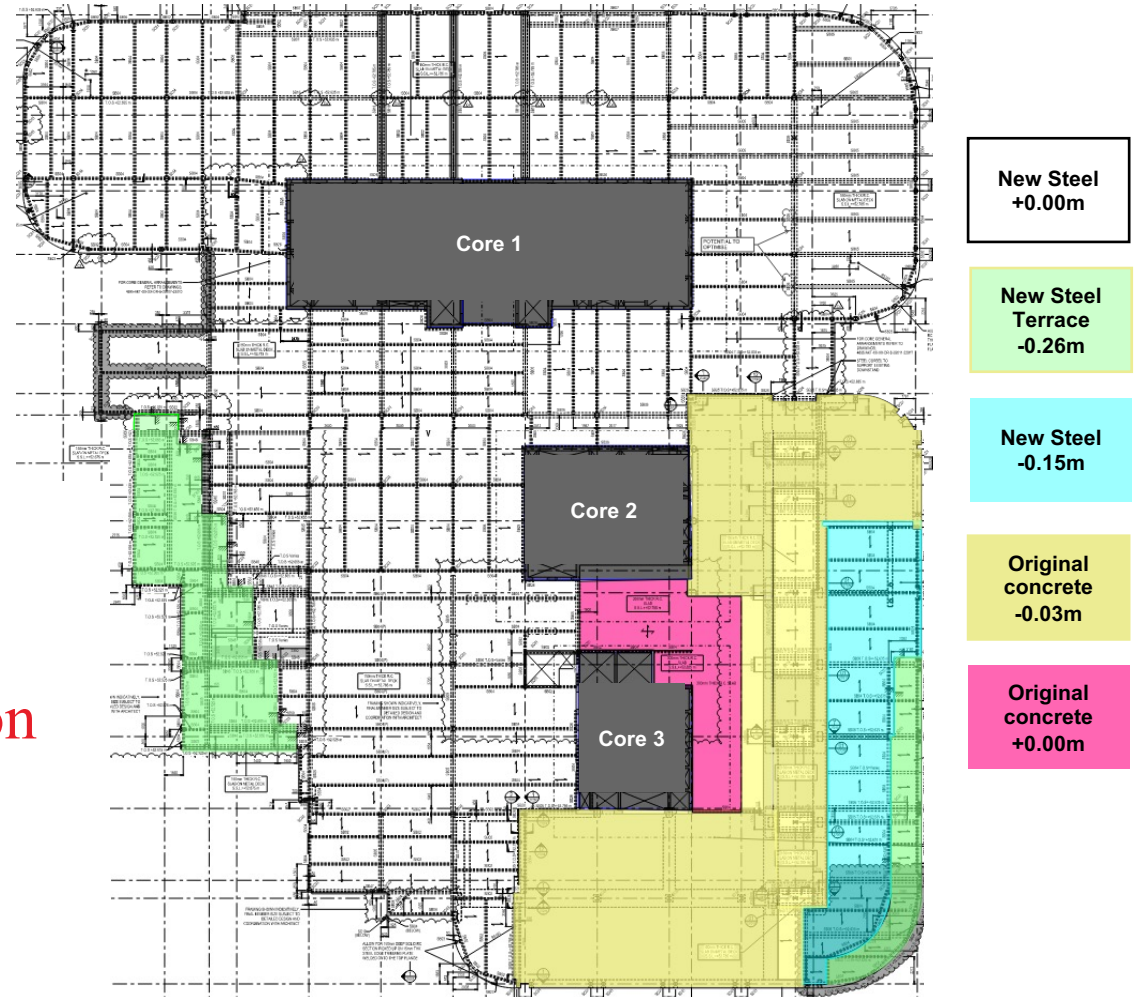
- Large retrofit scheme in central London
- Existing building is 9-storey all concrete structure
- Proposed building is 13-storey steel and concrete hybrid structure
- Structural fire engineering (SFE) team involved in fire protection design of steelwork
- Fire severity analysis showed baseline fire resistance required from 120 min to 90 min across upper levels



Structural Appraisal

Goals and aims

- Numerical modelling done to capture the global behaviour under the Fire Limit State
- Performance of the structure to meet functional requirements of B3 of Building Regulations (2010):
  - Prevent runaway deflections and limit service deflections
  - Columns remain stable
  - Maintain floor-to-floor compartmentation
- Level 10 is chosen to be modelled as it captures important retrofit details

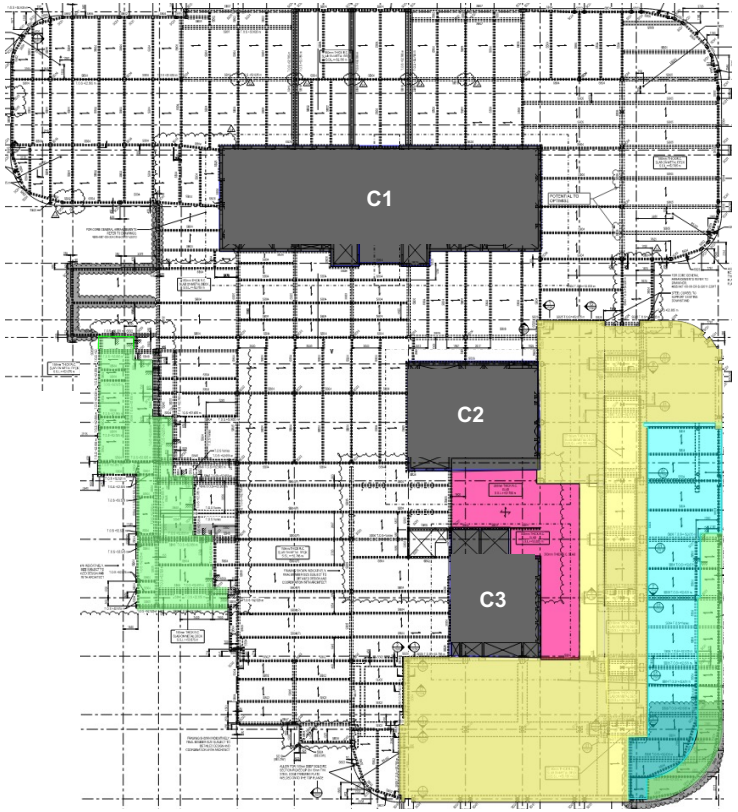


Level 10 GA

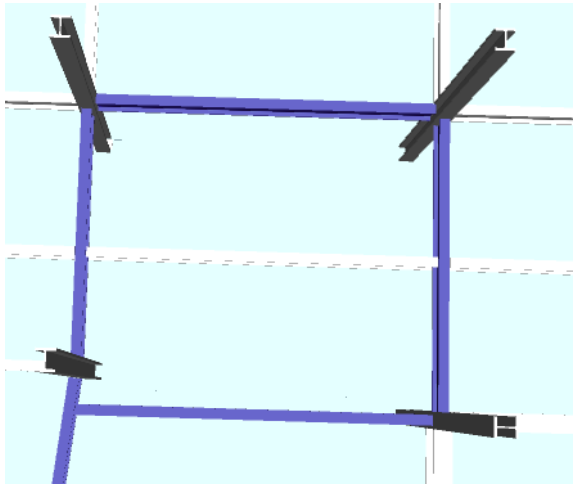
ARUP

Structural Appraisal

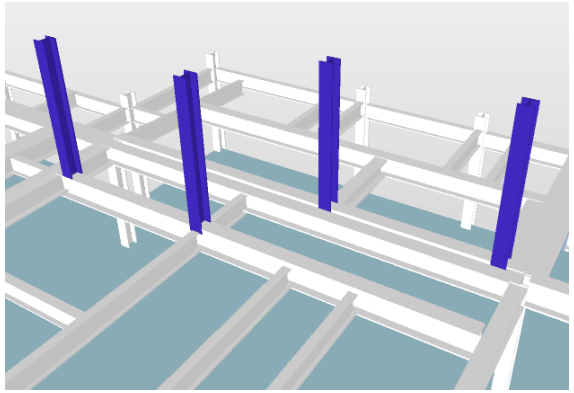
Level 10 Structural Design



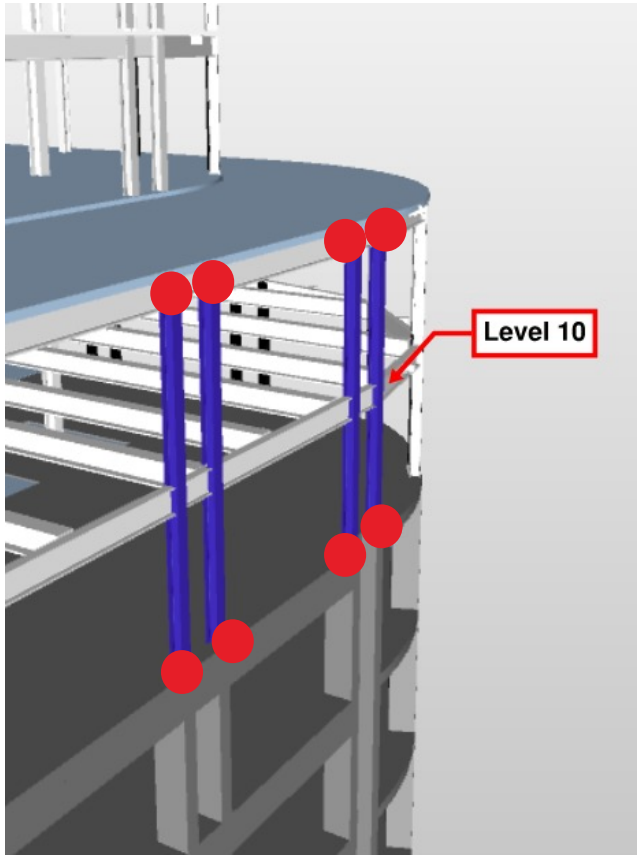
New & Old structure interaction



Eccentric columns and beams



Transfer structures



Pin Connections

Façade column discontinuity

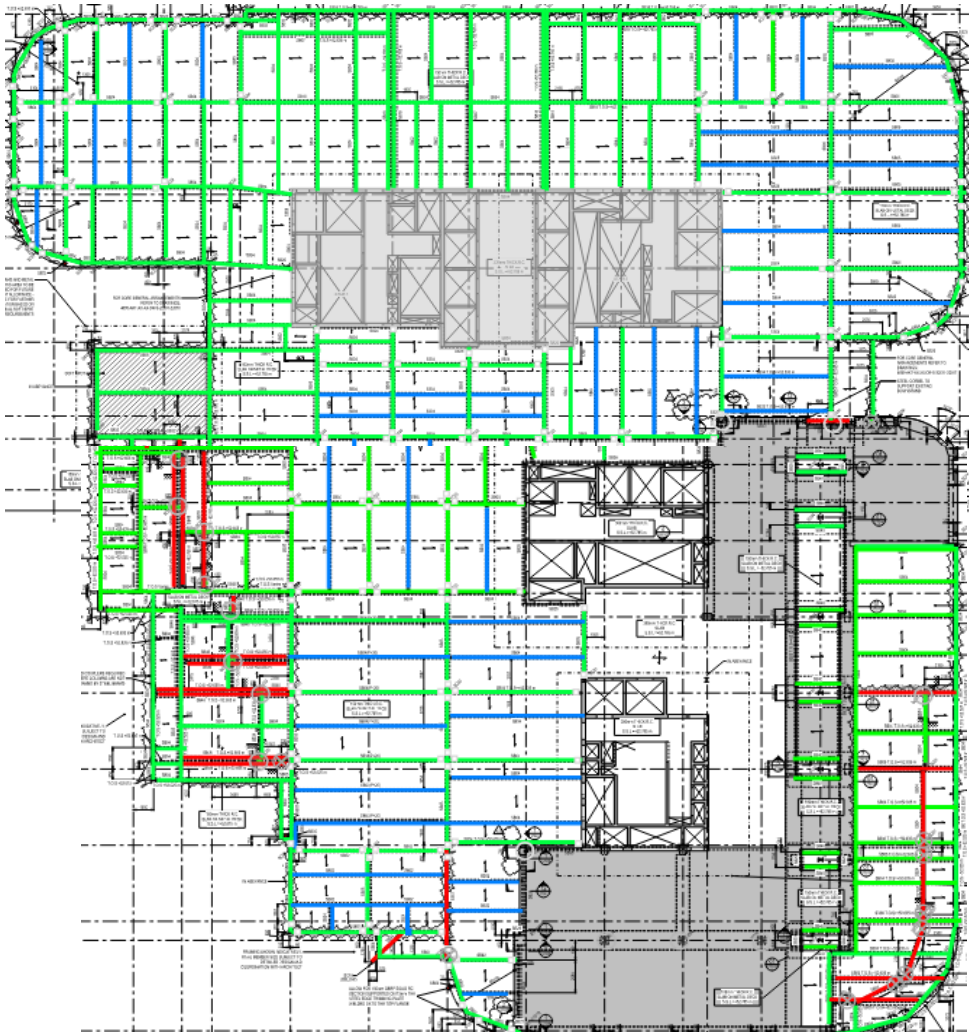
ARUP

SFE Study

Fire Protection Layout

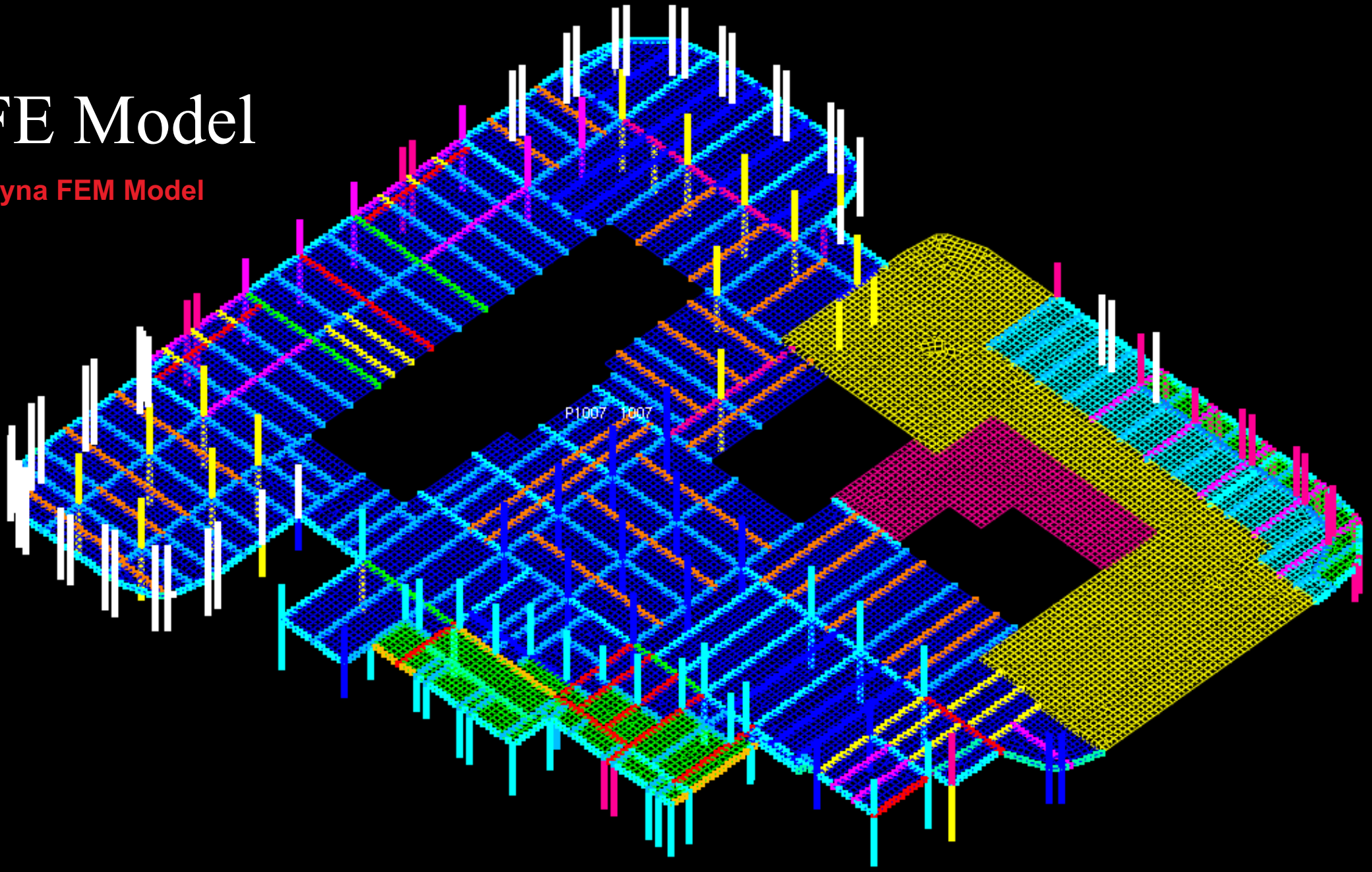
- Bay-to-bay fire protection
  - Transfer / Life safety risers = 120 min
  - Primary Beams = 90 min
  - Secondary beams = 90 min or 0 min
- Fire protection to induce tensile membrane action

Cardington Tests



SFE Model

LS-Dyna FEM Model



SFE Model

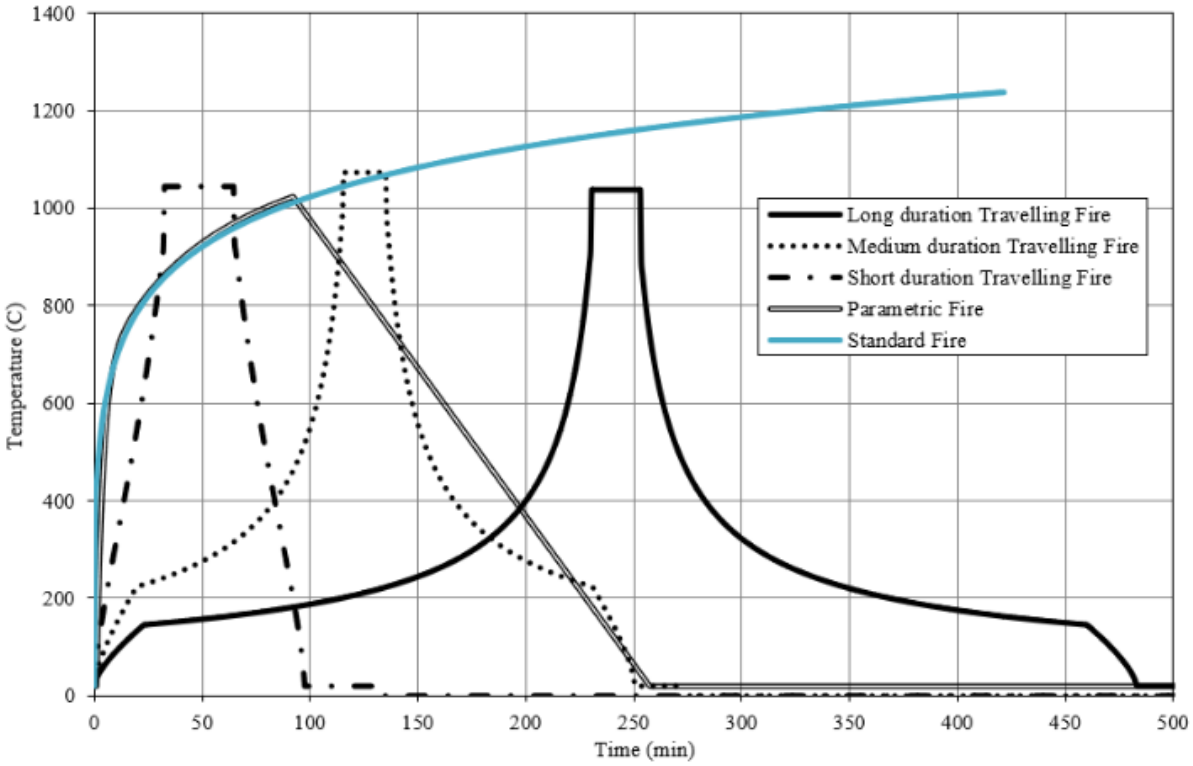
Fire Scenarios

Floorplate tested against a range of fires to 90 min severity:

- Standard
- Parametric
- Travelling fires

Key response variables studied:

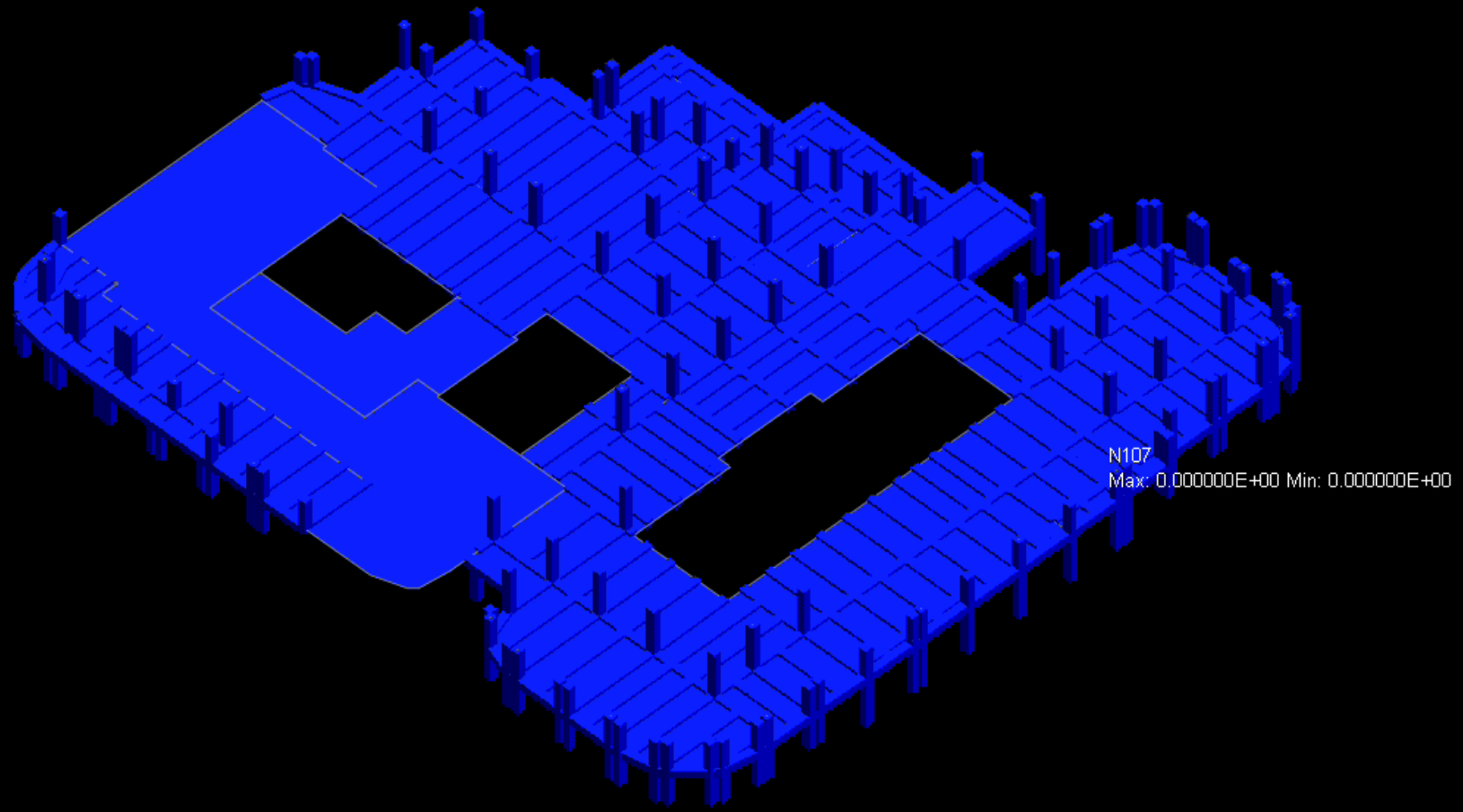
- General stability and reaction forces
- Member deflections and displacements
- Plastic strains within steel and slab reinforcements



D3PLOT:
1: Max N107 : 0.000000E+00, Min N107 : 0.000000E+00

Modelling Results

Floorplate behaviour



Resultant Displacement
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
m

Overall Displacement

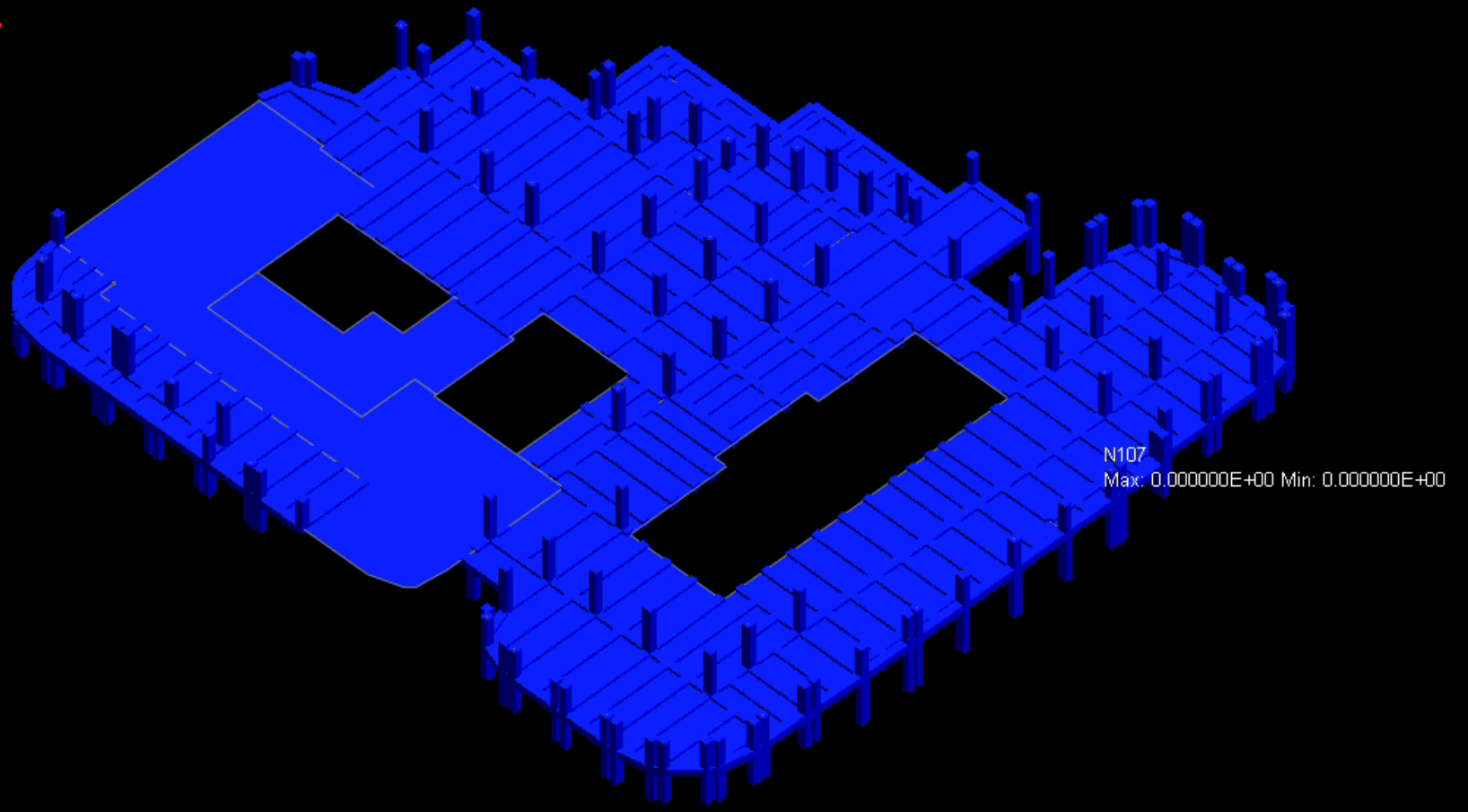
Z
X
Y

Time (x1000) .000000000

D3PLOT:
1: Max N107 : 0.000000E+00, Min N107 : 0.000000E+00

Modelling Results

Floorplate behaviour

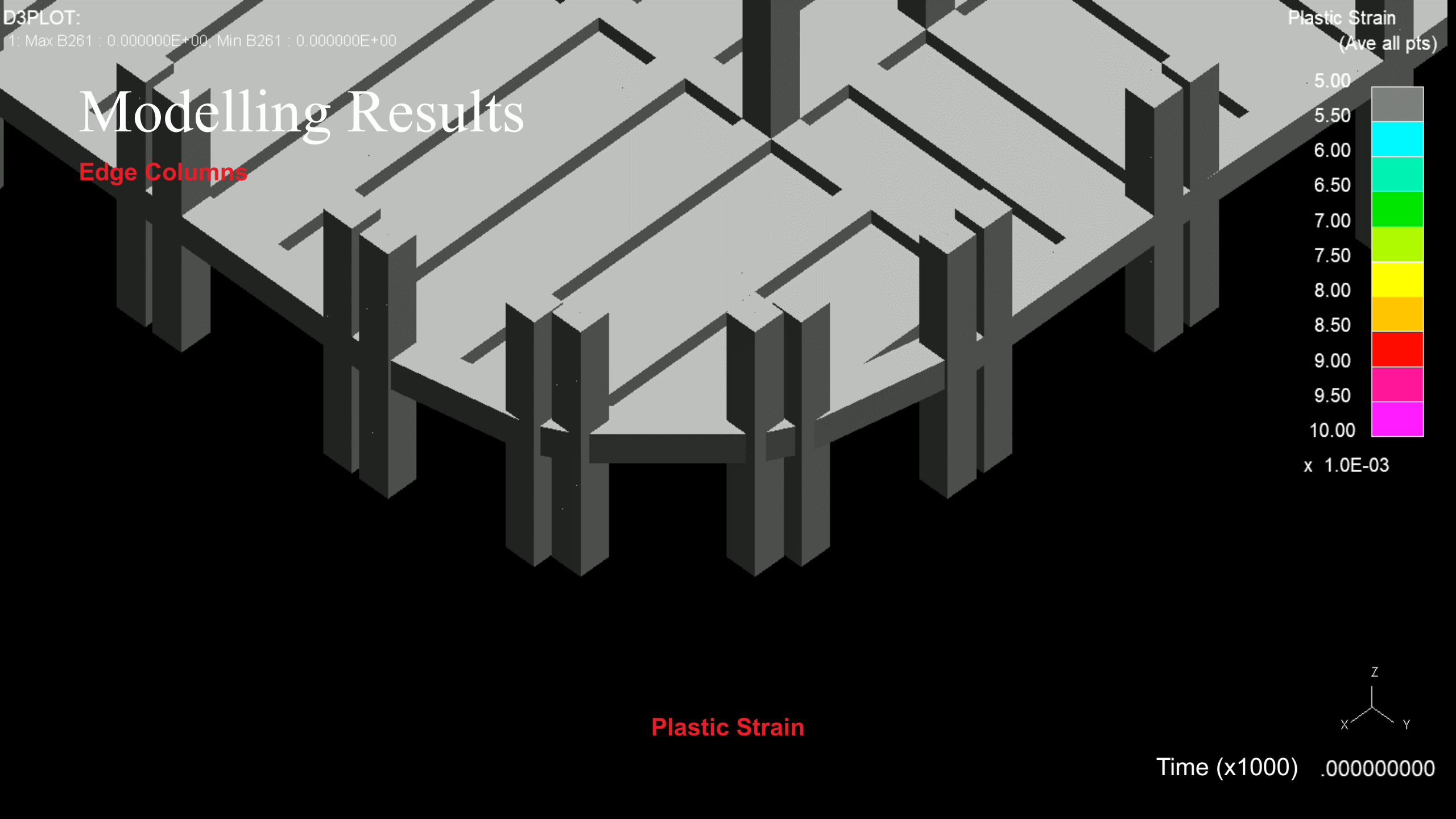


X Displacement
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
0.000
m

Horizontal Displacement

Z
X
Y

Time (x1000) .000000000



Modelling Results

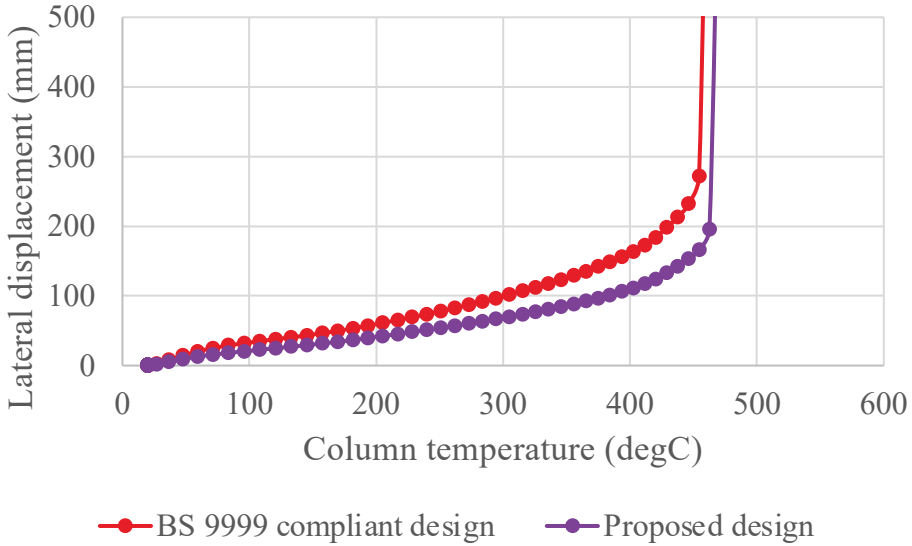
Edge Columns

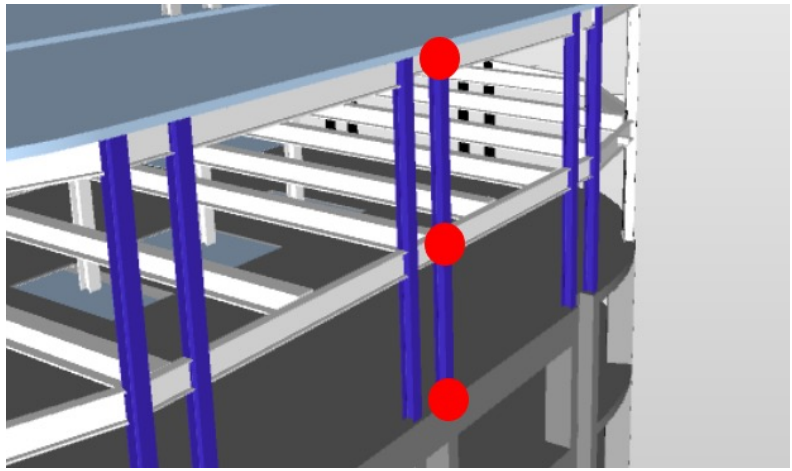
Plastic Strain

Failure mode

Edge columns

- Edge columns are free to deflect outwards
- Pinned connections of the columns do not transfer bending moments
- Large horizontal floorplate displacements causing excessive bending moment due to P-Δ effect
- Plastic hinge forming at floorslab level result in dynamic mechanism due to reduced rotational restraint

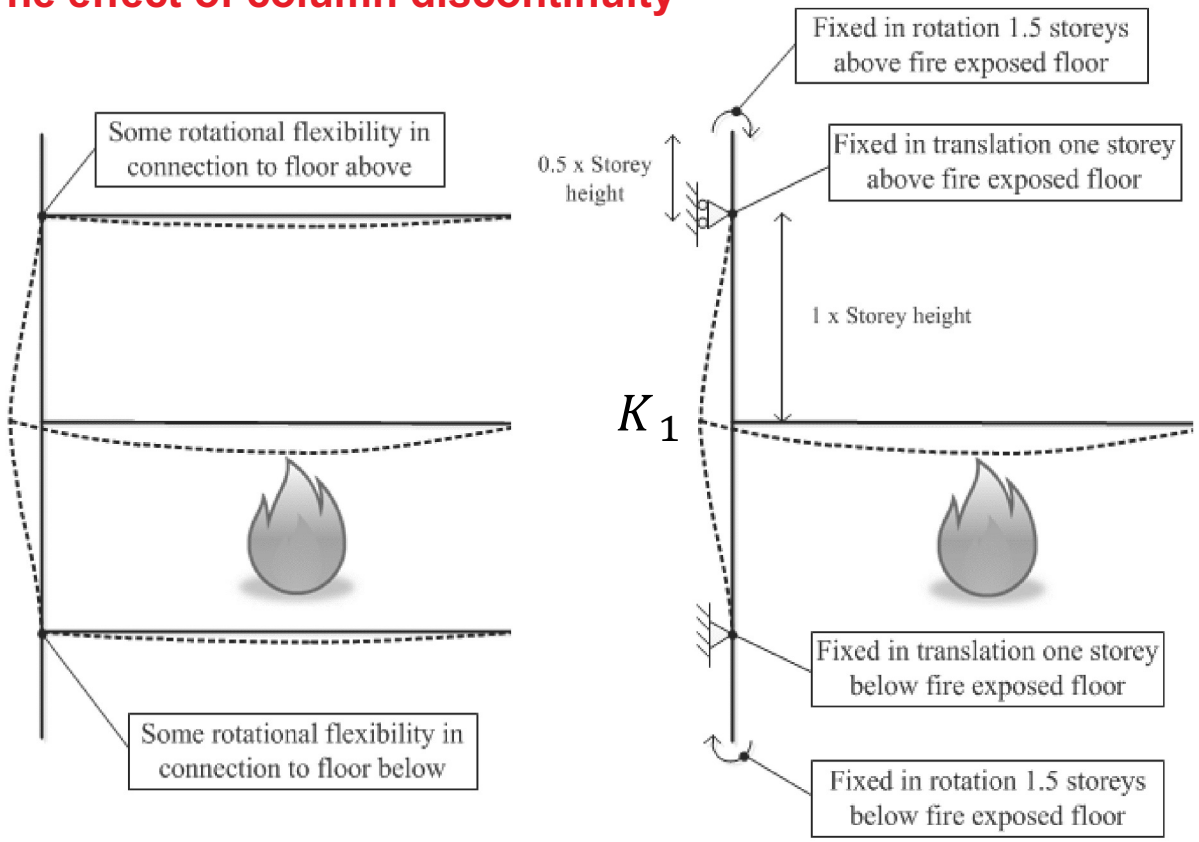




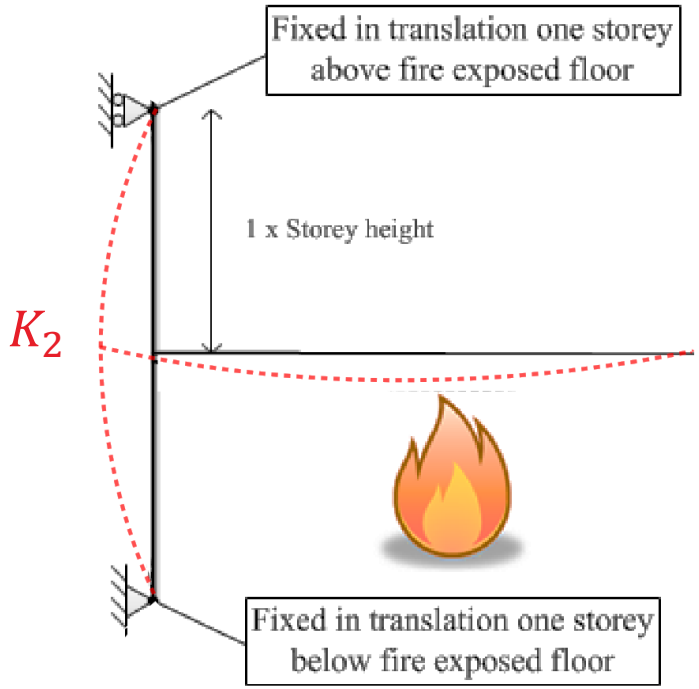
Retrofit Columns

Global Response

The effect of column discontinuity



Typical column design



Retrofit pinned columns

$$K_2 > K_1$$

ARUP

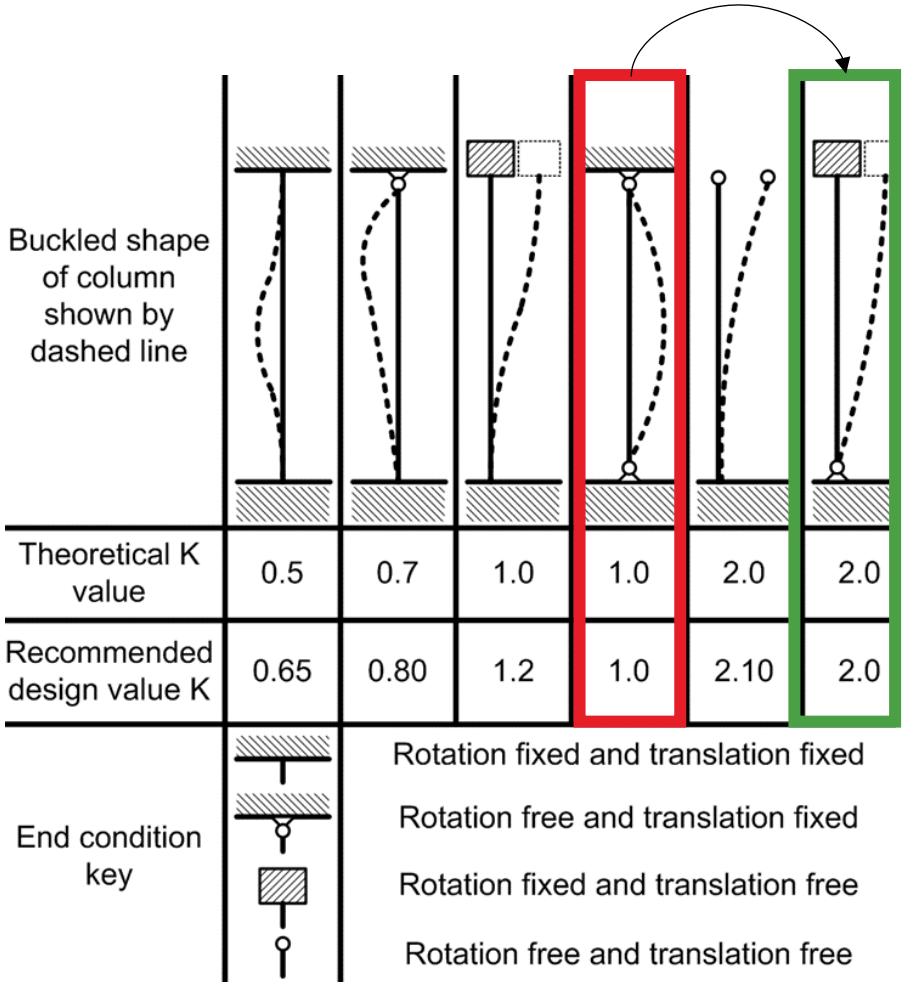
Column Fire Resistance

Eurocode Design

- Factors affecting performance of columns in fire:
  - Steel section
  - Fire protection applied
  - Column utilisation rate
  - Connection fixidity

- Could it be foreseen?
  - Eurocode 1993-1-2 with $K = 2.0$ hand calculation provided similar utilisation rate

- Rotational moment is not transferred from columns to the existing structure – can be desirable for retrofit



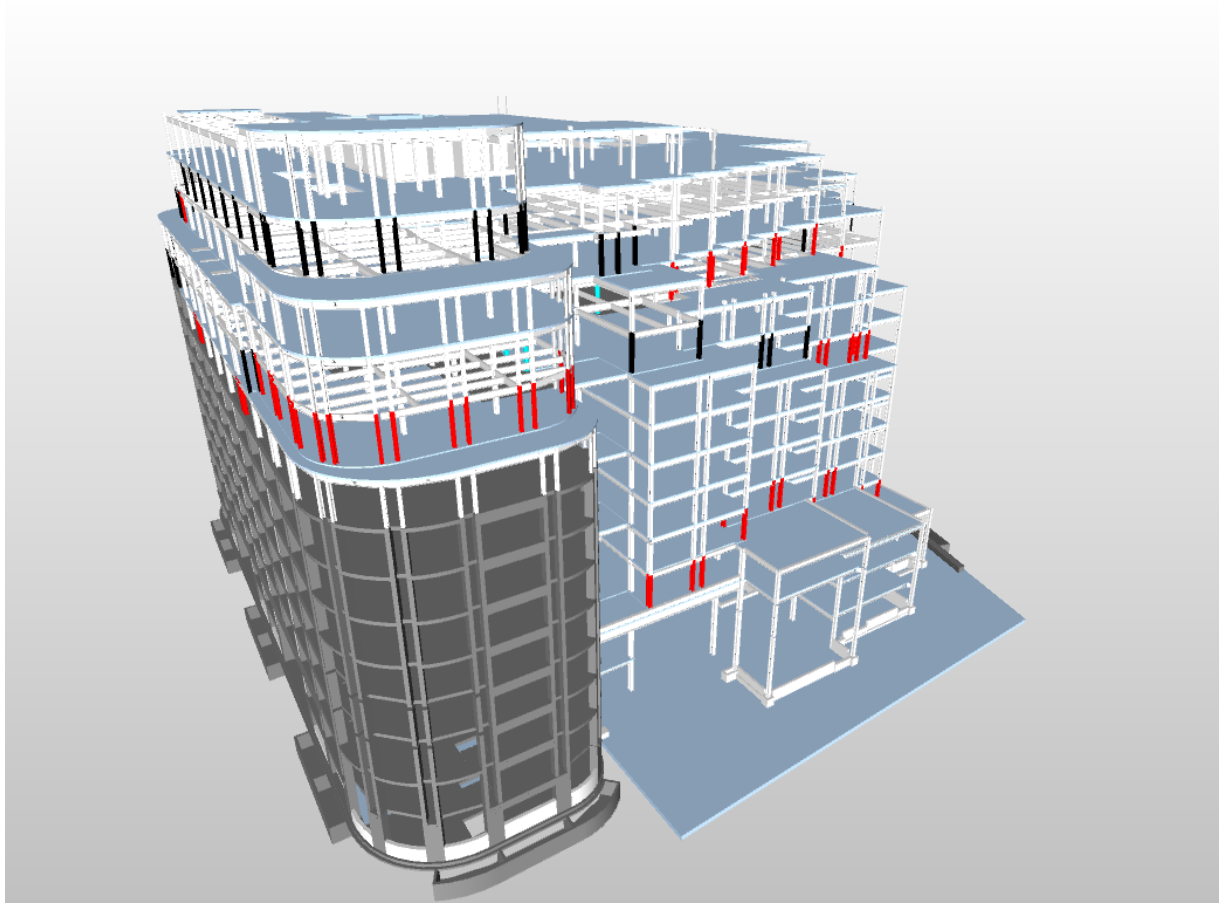
Equivalent Lengths of Columns for Various End Conditions

ARUP

Project Outcomes

Fire Protection Design

- Determined required fire protection for structural steel elements
- Critical columns identified throughout the structure
- Structural designer advised to revise utilisation rates and connection details
- Steelwork to be updated if the columns are not able to achieve required FR



3D Markup showing critical columns

ARUP

Concluding Remarks

Fire Resistance of Retrofit Structures

- Structural features to watch-out for:
  - Pinned column connections
  - Members with inherently reduced stiffness (e.g. edge columns)
  - Additional design specifics (transfers, eccentric columns, etc)

- Eurocode 1993-1-2 check with buckling length of 2.0 showed early column failure without extensive FEM modelling

- Early involvement of fire engineers & close collaboration between disciplines is very important

ARUP