Structural Fire Response of Tall Buildings with Inclined and Bi-linear Columns

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Tall building collapse in fire

WTC Towers, NY, 2001

Windsor Tower, Madrid, 2005
Background

- The collapses of the WTC complex and other buildings posed questions on the stability of tall buildings in fire
- Tall buildings are becoming more and more complex and innovative
- Prescriptive guidance and standard fire testing may be inadequate to consider the effects of fire for these structures
- Understanding of the global structural fire behaviour is required to identify potential vulnerabilities
- Perimeter columns are an integral component for the stability of tall buildings
- Failure can be due to buckling or by combined compression and bending caused by thermally induced pull-in forces
- Frames with orthogonality between beams and columns have been typically considered
What about inclined columns in fire?

VS

Would these buildings have a similar structural fire response?
Effect of angled and bi-linear columns

- Structural design of a proposed tall building in London
- Comparative study with several forms of inclination

(a) Plan view of floorplate (b) various possible arrangements for perimeter columns
The provision of inclined linear columns did not significantly affect the fire performance of the structural frame compared to vertical columns.

The provision of bi-linear columns had a significant impact on the performance of the structural frame compared to vertical columns.

Failure was observed in both analysis with bi-linear columns.
Ambient Mechanics

- The difference in the behaviour is due to the difference in the load paths at ambient, and the subsequent changes at high temperature.
- In vertical or inclined columns the load from upper stories is transferred directly down the columns.
- In the case of the bi-linear arrangement, an additional force is required at the bifurcation point to maintain equilibrium.
- The force is tensile or compressive depending on the angle direction.
- A moment also develops in the column, below the bifurcation point.

(a) Outwards angled bi-linear column (b) Inwards angled bi-linear column
Effects at High Temperature

- The outwards and inwards inclined bi-linear columns are under combined compression and bending (beam-columns)
- Failure occurs when a plastic hinge is formed in the column when the applied moments reach the plastic moment capacity of the column
- The form of failure resembles that presented previously when considering the stability of tall buildings under multiple floor fires
Parametric study on angle of inclination

- Columns with a greater angle of inclination fail earlier than the columns with a smaller angle of inclination.
- During the early stages of a fire, the utilisation in the bi-linear outwards is lower than the bi-linear inwards columns.
- As temperatures increase, the utilisations in the bi-linear outwards column begin to increase more rapidly.
- Bi-linear outwards columns are more sensitive to change in angle of inclination than the bi-linear inwards columns (P-delta effect).
Parametric study on applied axial load

- Bi-linear inwards columns are at a higher utilisation for most of the analysis
- Bi-linear inwards columns are less sensitive to both change of temperature, and change in applied axial load
- Sensitivity of the bi-linear outwards columns is due to the P-delta effect
- The utilisation is approximately a linear/quadratic function of applied axial load in the bi-linear inwards/outwards columns
Discussion of the parametric study

- Failure mechanisms are analogous to the collapse mechanisms identified due to multiple floor fires (strong floor)

- Outwards bi-linear columns are more sensitive to both axial load and angle of inclination than the bi-linear inwards columns

- The P-delta feedback that occurs in the bi-linear outwards columns is the cause of the failure of these assemblies

- The behaviour for bilinear inwards columns is more analogous to a linear vertical column where the horizontal translation of the floorplate is increased by the action of the axial load from above

- Mitigation measures would need to be introduced when considering bi-linear columns
Conclusions

- Buildings with linearly inclined columns show similar structural fire behaviour to buildings with vertical columns.

- Bi-linear columns that undergo a change in inclination over their height induce compressive or tensile axial forces into the floorplate.

- Bi-linear outwards columns are more vulnerable to the effects of fire than bi-linear inwards columns due to the P-delta effect on the adjoining beams.

- Bi-linear columns that are designed to achieve a fire resistance based on the factored ambient design loads are unlikely to achieve the specified fire resistance period.
Any questions

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