TALL BUILDING COLLAPSE MECHANISMS INITIATED BY FIRE: DESIGN METHOD

David Lange
Overview

• Introduction
• Design
  – Methodology
  – Calculations
• Examples
• Conclusions
Introduction

- Two basic collapse mechanisms for tall buildings
Design Methodology

5 Main Stages:
1. Structure and Thermal Loading
2. Floor Mechanical Loading
3. Column Mechanical Loading
4. Check for Weak Floor Collapse Mechanism
5. Check for Strong Floor Collapse Mechanism
Structure and Thermal Loading

- two-dimensional representation of the structural frame,
  - exterior columns and the adjacent structure,
  - restrained on the other side by a stiff core;
Structure and Thermal Loading

- The number of floors involved in the fire; and the temperature time curve of the fire
- The temperature distribution in the structural members of the frame
Floor Mechanical Loading

- Can the UDL be carried by Flexural Capacity?
Floor Mechanical Loading

• Can the UDL be carried through Tensile Membrane Action?
• Determine the tensile “pull-in” forces applied to the column by the floors in catenary action.
Floor Mechanical Loading

- Thermal Deflections

\[ \varepsilon_T = \alpha \Delta T \]

\[ \varepsilon_\phi = 1 - \sin \frac{l \phi}{2} \varepsilon_\phi^l \]

\[ \phi = \alpha T_z \]

\[ w_T = \frac{2l}{\pi} \sqrt{\varepsilon_\phi - \varepsilon_T} \]
Floor Mechanical Loading

- Mechanical Deflections

\[ H = F(0) \cos \theta \]

\[ F(x) = A_s E_s(T) \varepsilon_s(x) + A_b \sigma_{yb}(T) \]
Floor Mechanical Loading

\[ F(x) = \sqrt{H(x)^2 + V(x)^2} \quad H(0) = H(x) = H \]

\[ V(x) = p \left( \frac{l}{2} - x \right) \]
Floor Mechanical Loading

\[ F(x) = A_s E_s(T) \varepsilon_s(x) + A_b \sigma_{yb}(T) \]

\[ \varepsilon_s(x) = \frac{\sqrt{H^2 + p^2 \left( \frac{l}{2} - x \right)^2}}{A_s E_s(T)} - \frac{A_b \sigma_{yb}(T)}{A_s E_s(T)} \]
Floor Mechanical Loading

\[ \frac{\Delta L}{2} = \frac{1}{2} \int_0^{L/2} \varepsilon_s(x) \, dx = \left\{ \frac{1}{A_s E_s(T)} \right\}^{\frac{1}{2}} \left[ H^2 + p^2 \left( \frac{l}{2} - x \right)^2 \right]^{\frac{1}{2}} \int_0^{L/2} dx - \frac{A_b \sigma_{yb}(T)}{A_s E_s(T)} \]

\[ \frac{\Delta L}{2} = \frac{1}{A_s E_s(T)} \left[ \frac{2p^2x^2 - p^2l}{4p^2} \left( H^2 + p^2 \left( \frac{l}{2} - x \right)^2 \right) \right]^{\frac{1}{2}} + 4p^2 \left( H^2 + p^2 \frac{l^2}{4} \right) - \]

\[ \frac{p^4l^2}{8p^2} \ln \left[ 2 \left( p^2 \left( H^2 + p^2 \left( \frac{l}{2} - x \right)^2 \right) \right)^{\frac{1}{2}} + 2p^2x - p^2l \right]_0^{\frac{L}{2}} - \]

\[ \frac{A_b \sigma_{yb}(T)}{2A_s E_s(T)} \]
Floor Mechanical Loading

\[ H = K_T u_p \]
Floor Mechanical Loading

- In Summary:

\[ H = K_T u_p \]

\[ H = F(0) \cos \theta \quad H = \frac{F \pi w}{l} \]

- These can be solved for \( H \), using the increase in length, \( \Delta L \) to link \( w \) and \( u_p \)
Column Mechanical Loading

- obtain the moments induced in the column
  - $P-\delta$ moments, and
  - Moments from Pull-in forces
Weak Floor Collapse Mechanism

- Combined pull-in force from each fire floor gives the required axial resistance of the pivot floors.

- Where the pivot floors do not provide the necessary axial resistance, a weak floor failure mechanism can develop.
Strong Floor Collapse Mechanism

- The column should be checked for the 3-hinge mechanism
- Using a temperature dependent interaction diagram,
Example: Weak Floor Collapse Mechanism

Steel Column = 305 x 305 x 198
Steel Beam = 305 x 102 x 28
  309mm deep
  A_{sb} = 36.3cm^2
  I_{sb} = 5420cm^4
  E_{sb} = 210000N/mm^2
Concrete Slab = 0.1m deep
  A_c = 0.6 m^2
  E_{c} = 14000N/mm^2
  A_{sr} = 142mm^2/m
p=45kN/m^2, P=6900N
Example: Weak Floor Collapse Mechanism

<table>
<thead>
<tr>
<th>No. of fire floors</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>$K_1$, kN/m</td>
<td>6031.3</td>
<td>4247.5</td>
<td>941.29</td>
<td>682.06</td>
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<tr>
<td>$K_2$, kN/m</td>
<td></td>
<td>4237.3</td>
<td>4200.7</td>
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<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Capacity</th>
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<tbody>
<tr>
<td>0</td>
<td>2.32 MNm</td>
</tr>
<tr>
<td>600</td>
<td>2.68 kNm</td>
</tr>
<tr>
<td>800</td>
<td>2.68 kNm</td>
</tr>
<tr>
<td>1400</td>
<td>2.68 kNm</td>
</tr>
</tbody>
</table>
Example: Weak Floor Collapse Mechanism
Example: Weak Floor Collapse Mechanism

Buckling load = 4.7MN
Example: Weak Floor Collapse Mechanism
Example: Strong Floor Collapse Mechanism

Column = 305 x 305 x 198
Beam = 533 x 210 x 92
  533mm deep
  Asb= 1173cm²
  Isb = 55230cm⁴
  Esb = 210000N/mm²
Concrete Slab = 0.1m deep
  Ac = 0.6 m²
  Ec = 14000N/mm²
  Asr = 142mm²/m
p=45kN/m², P=6900N
Example: Strong Floor Collapse Mechanism

\[ Mp = 2.1 \times 10^9 \]
Example: Strong Floor Collapse Mechanism
Conclusions

• a simple stability assessment methodology for tall buildings in fire was proposed.
• The method qualitatively predicts the failure mechanisms described
• Time to failure is less accurately predicted, although the question of whether or not failure occurs is addressed.
Thank You!

Questions?