TALL BUILDING COLLAPSE MECHANISMS INITIATED BY FIRE: DESIGN METHOD

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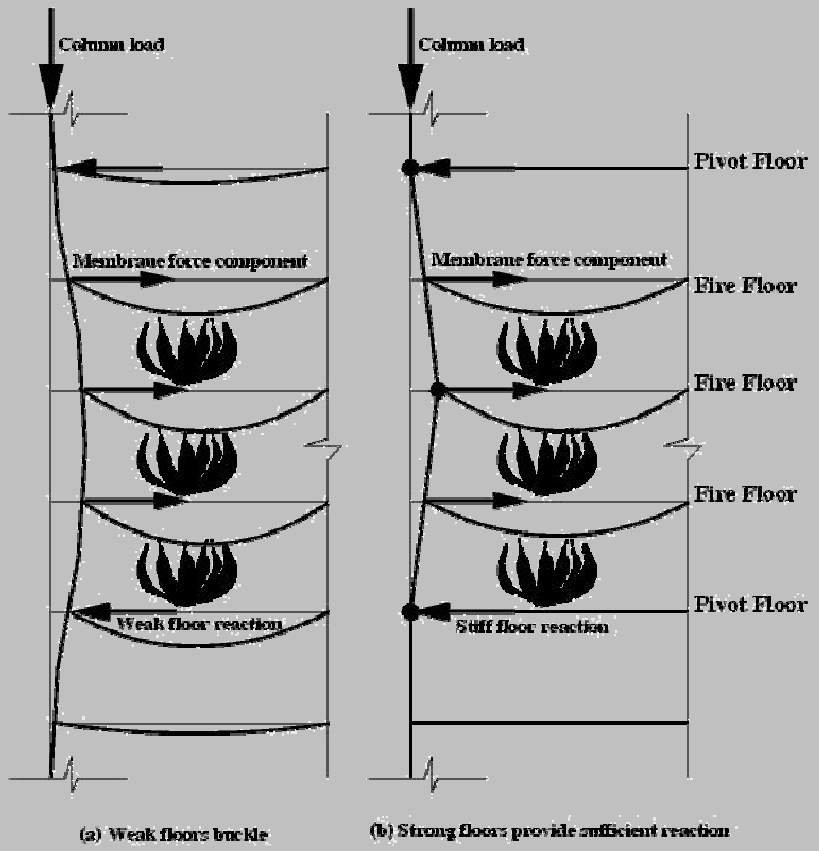
Overview

- Introduction
- Design
  - Methodology
  - Calculations
- Examples
- Conclusions

Introduction

- Two basic collapse mechanisms for tall buildings



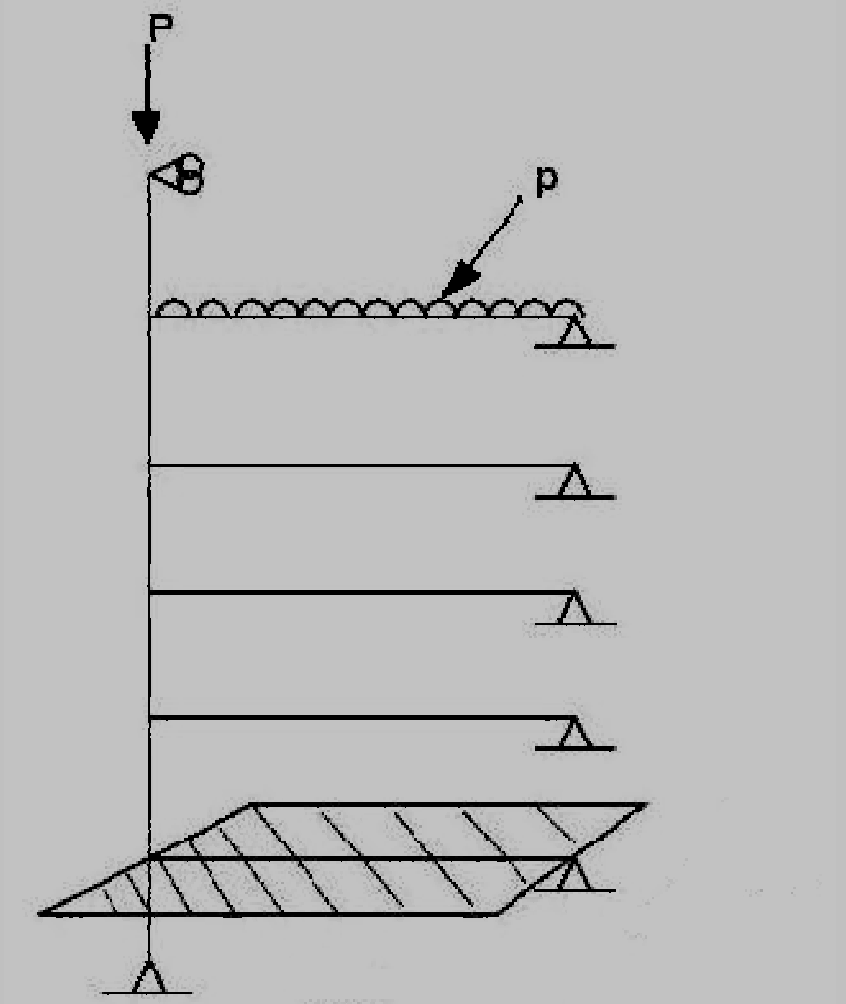
Design Methodology

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

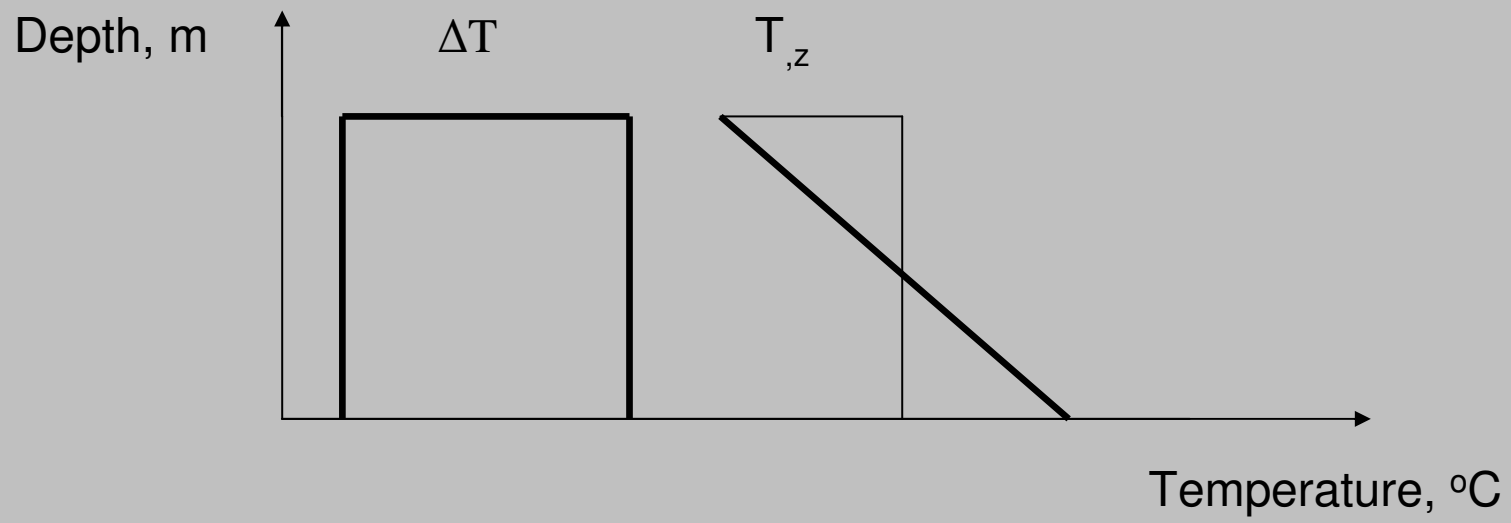
Structure and Thermal Loading

- 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

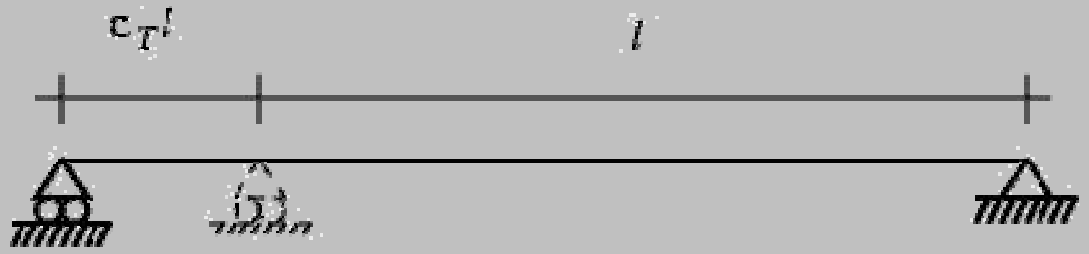
- Can the UDL be carried by Flexural Capacity?

Floor Mechanical Loading

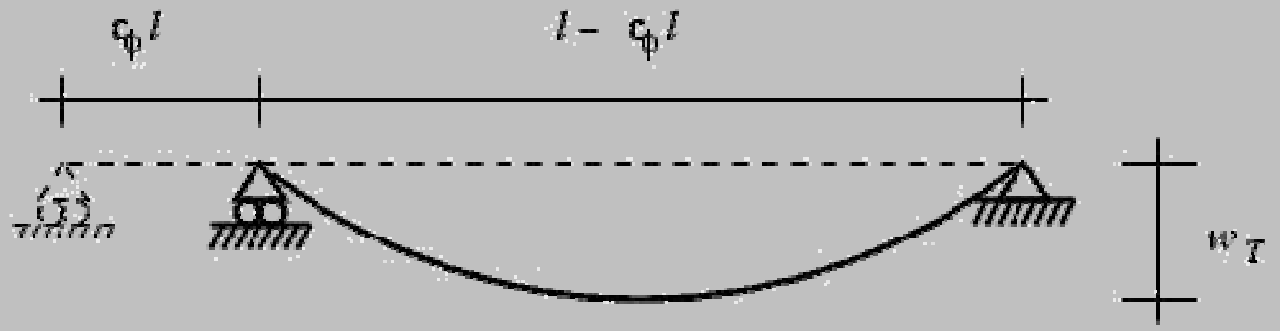
- Can the UDL be carried through Tensile Membrane Action?
- Determine the tensile “pull-in” forces applied to the column by the floors in catenary action.

Floor Mechanical Loading

- Thermal Deflections



$$\varepsilon_T = \alpha \Delta T$$



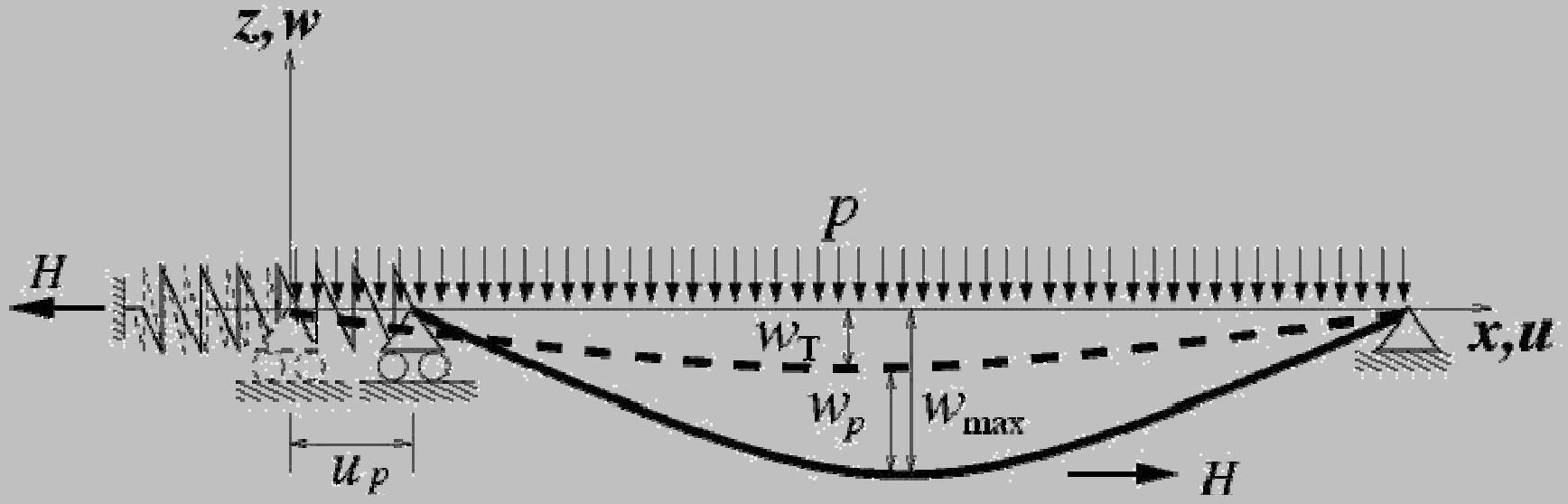
$$\varepsilon_\phi = 1 - \frac{\sin\frac{l\phi}{2}}{\frac{l\phi}{2}}$$

$$\phi = \alpha T_{,z}$$

$$w_T = \frac{2l}{\pi}\sqrt{\left|\varepsilon_\phi - \varepsilon_T\right|}$$

Floor Mechanical Loading

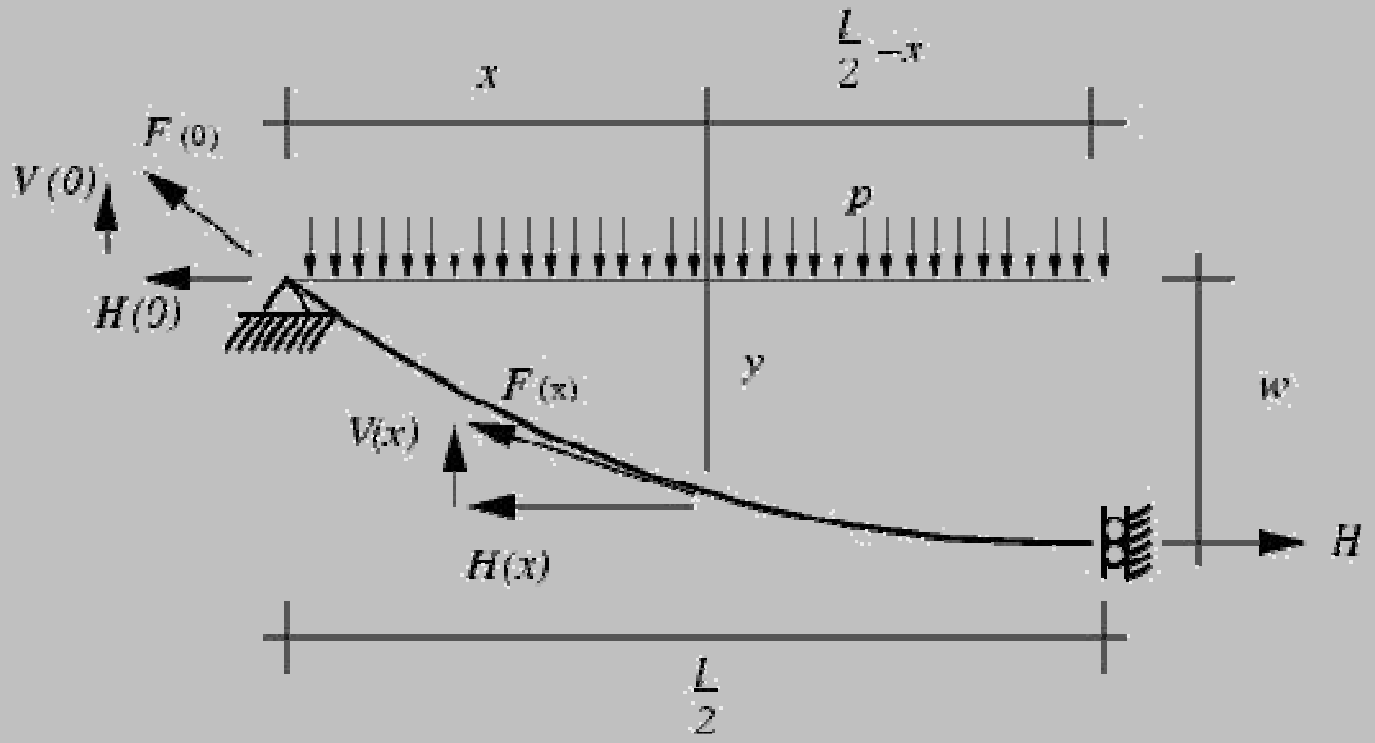
- Mechanical Deflections



$$H = F(0)\cos\theta$$

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

Floor Mechanical Loading



$$F(x) = \sqrt{H(x)^2 + V(x)^2} \qquad H(0) = H(x) = H$$

$$V(x) = p\left(\frac{l}{2} - x\right)$$

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

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

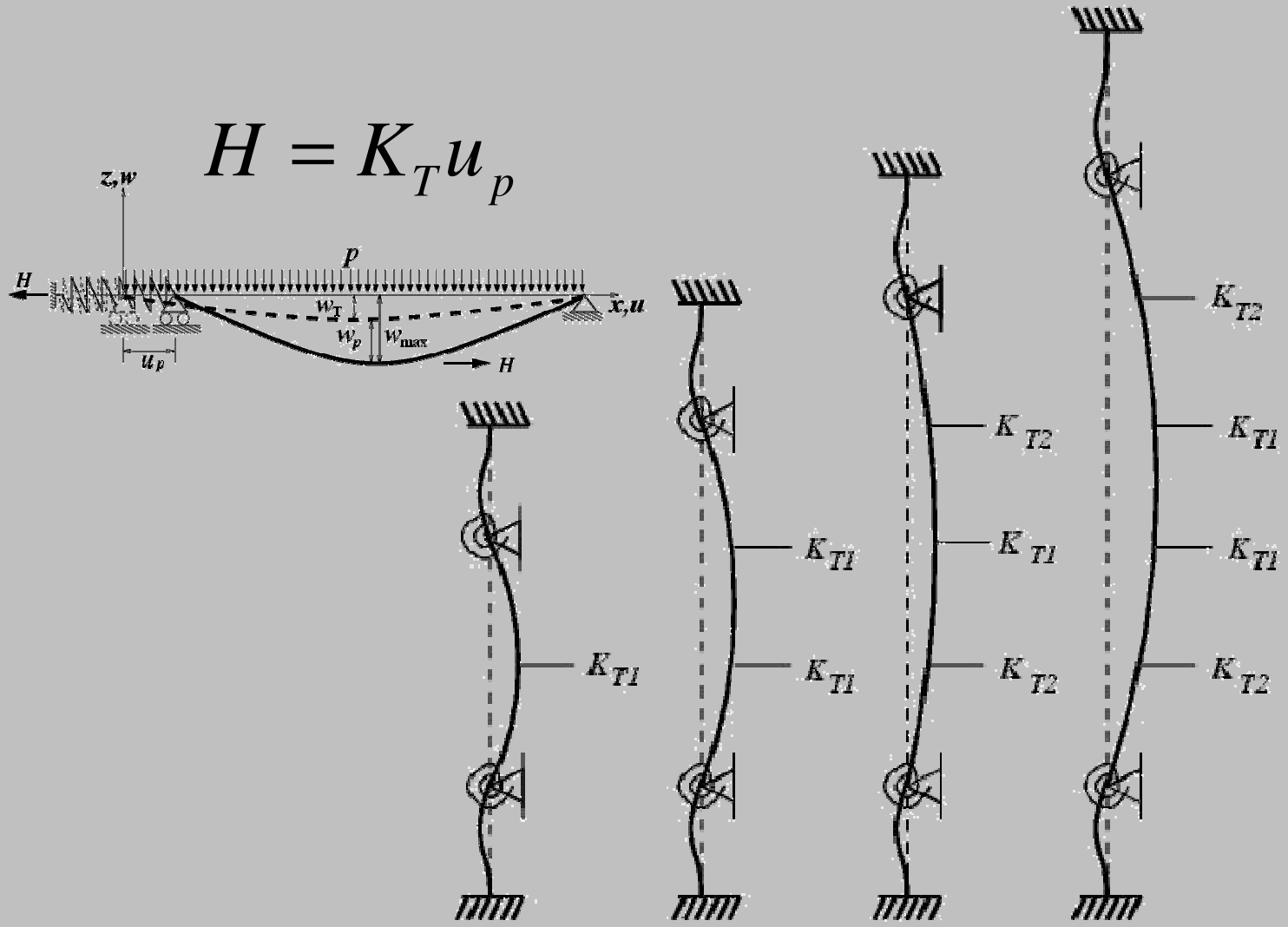
$$\frac{\Delta L}{2} = \frac{1}{A_s E_s(T)} \left[\frac{2p^2x^2 - p^2 l}{4p^2} \left(H^2 + p^2 \left(\frac{l}{2} - x \right)^2 \right)^{1/2} + 4p^2 \left(H^2 + p^2 \frac{l^2}{4} \right) - \right.$$

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

$$\frac{A_b \sigma_{yb}(T) l}{2 A_s E_s(T)}$$

Floor Mechanical Loading

$$H = K_T u_p$$



Floor Mechanical Loading

- In Summary:

$$H = K_T u_p$$

$$H = F(0)\cos\theta \qquad H = \frac{F\pi w}{l}$$

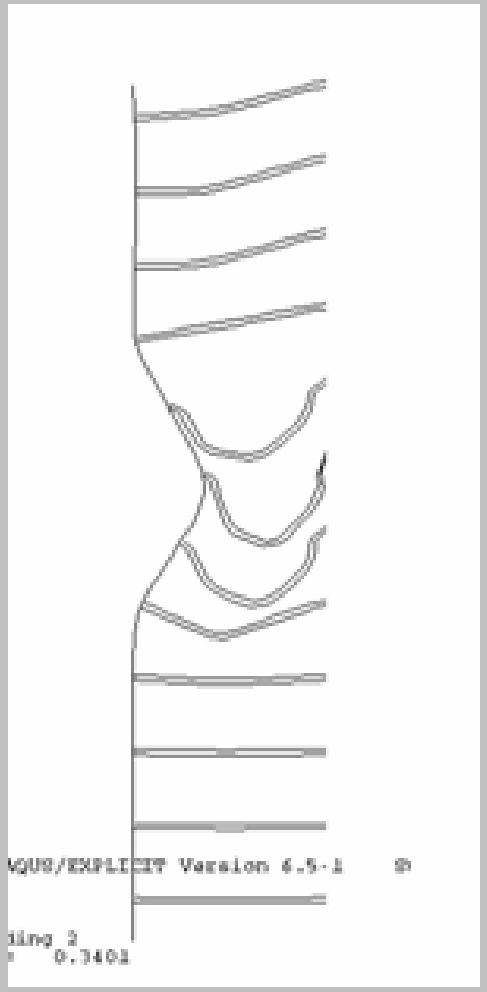
- These can be solved for H, using the increase in length, ΔL to link w and u_p

Column Mechanical Loading

- obtain the moments induced in the column
  - P-δ moments, and
  - Moments from Pull-in forces

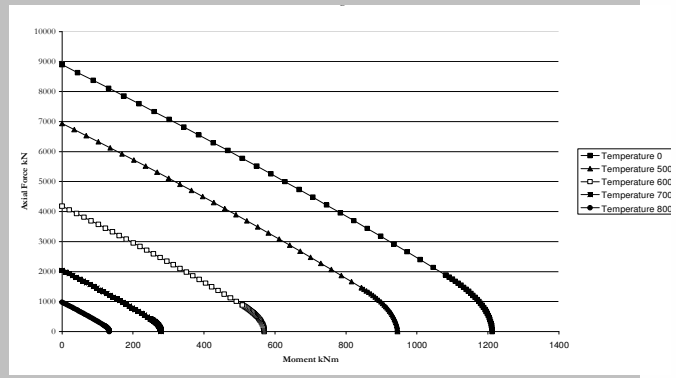
Weak Floor Collapse Mechanism

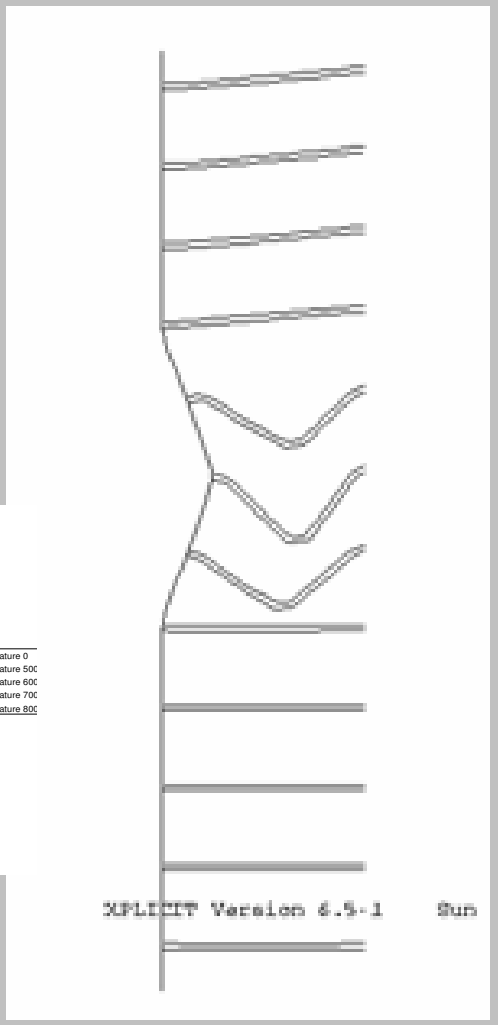
- Combined pull-in force from each fire floor gives the required axial resistance of the pivot floors
- Where the pivot floors do not provide the necessary axial resistance, a weak floor failure mechanism can develop.



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= 36.3cm2

Isb = 5420cm4

Esb = 210000N/mm2

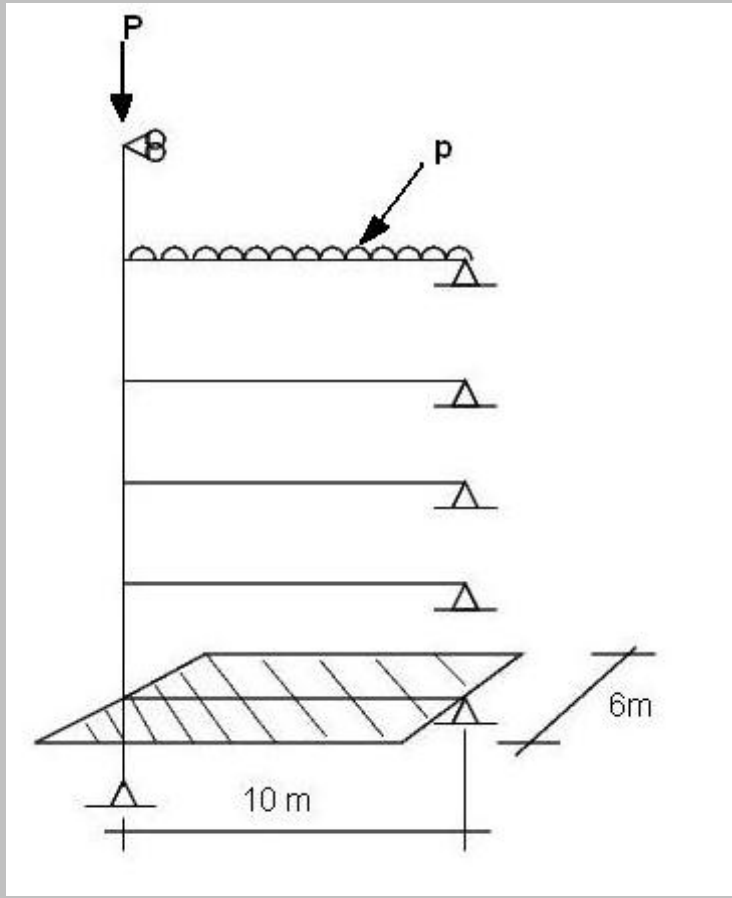
Concrete Slab = 0.1m deep

Ac = 0.6 m2

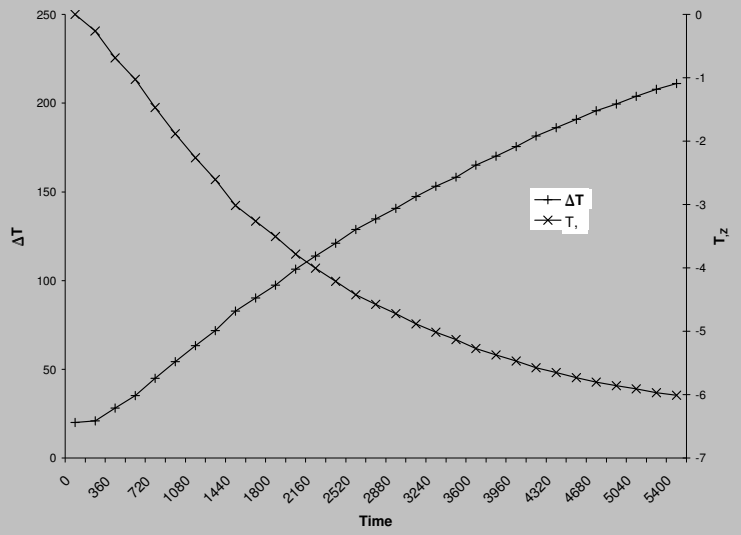
Ec = 14000N/mm2

Asr = 142mm2/m

p=45kN/m2, P=6900N



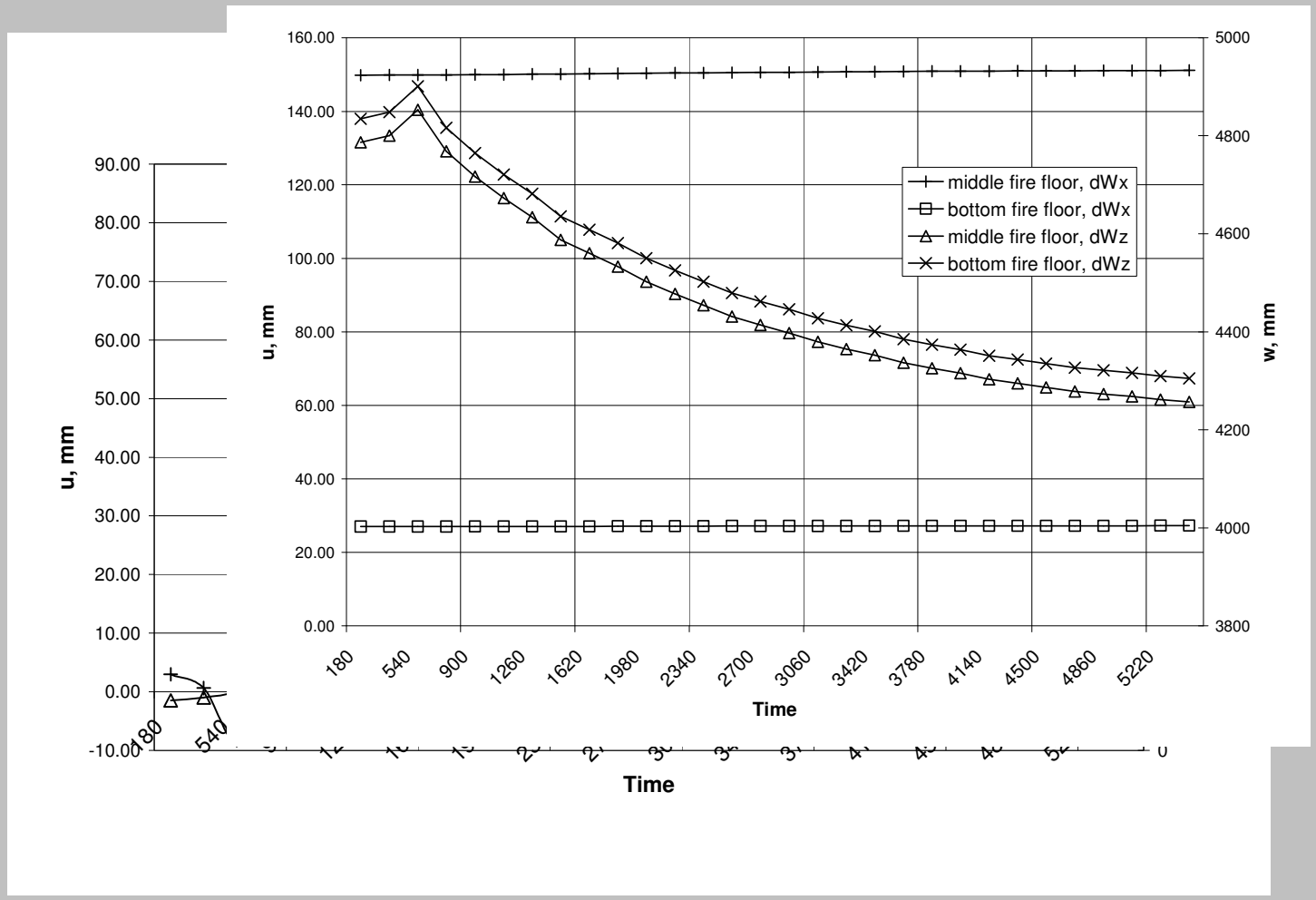
Example: Weak Floor Collapse Mechanism



No. of fire floors	1	2	3	4
K_1, kN/m	6031.3	4247.5	941.29	682.06
K_2, kN/m			4237.3	4200.7

Time (s)	Capacity
0	2.32 MNm
600	2.68 kNm
800	2.68 kNm
1400	2.68 kNm

Example: Weak Floor Collapse Mechanism



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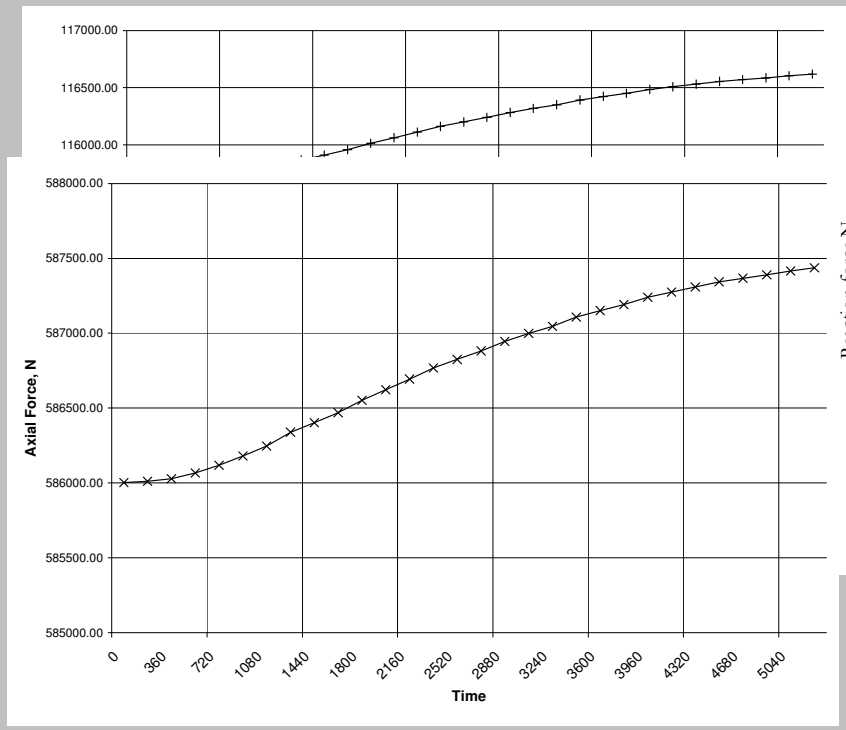
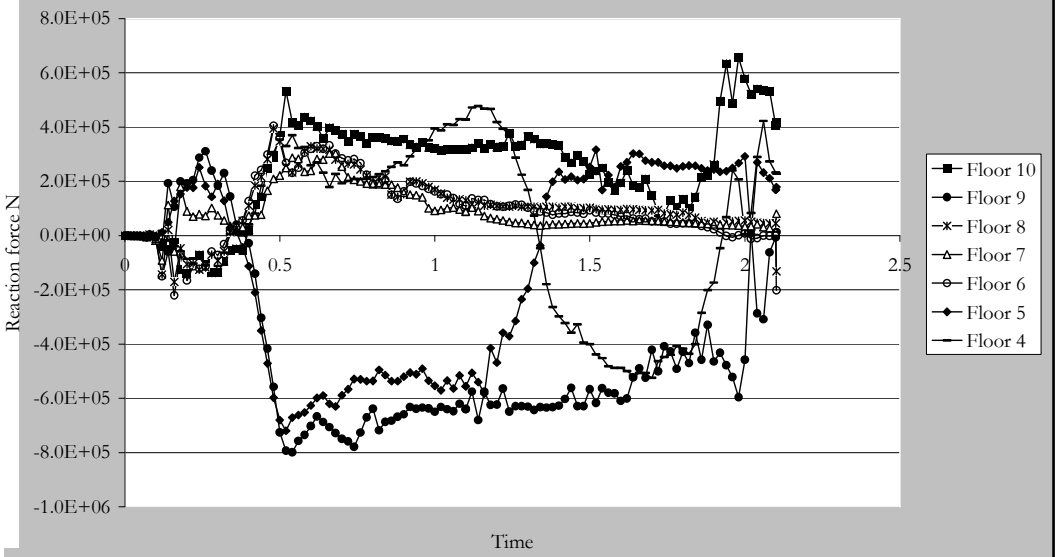
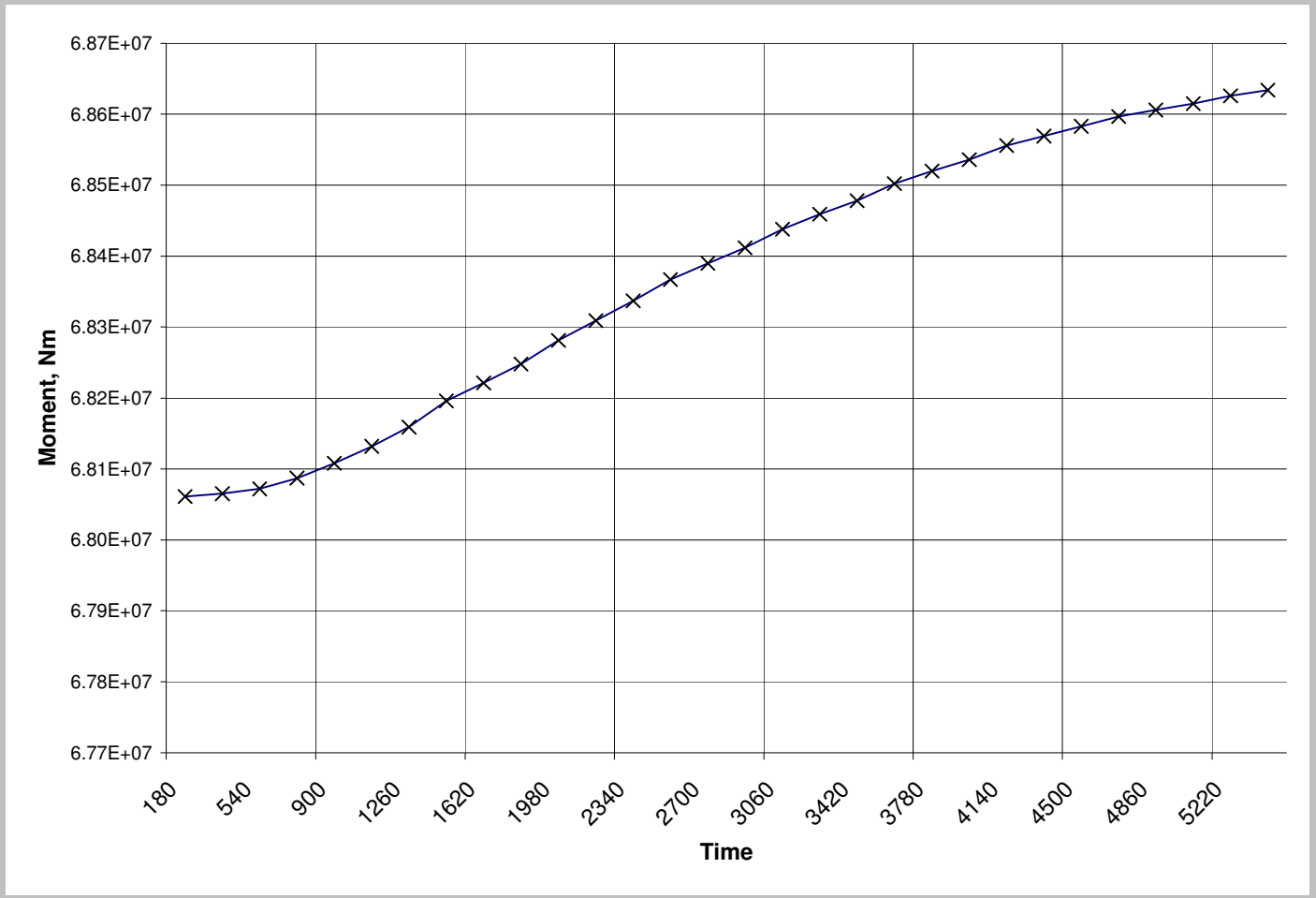




Buckling load=4.7MN

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

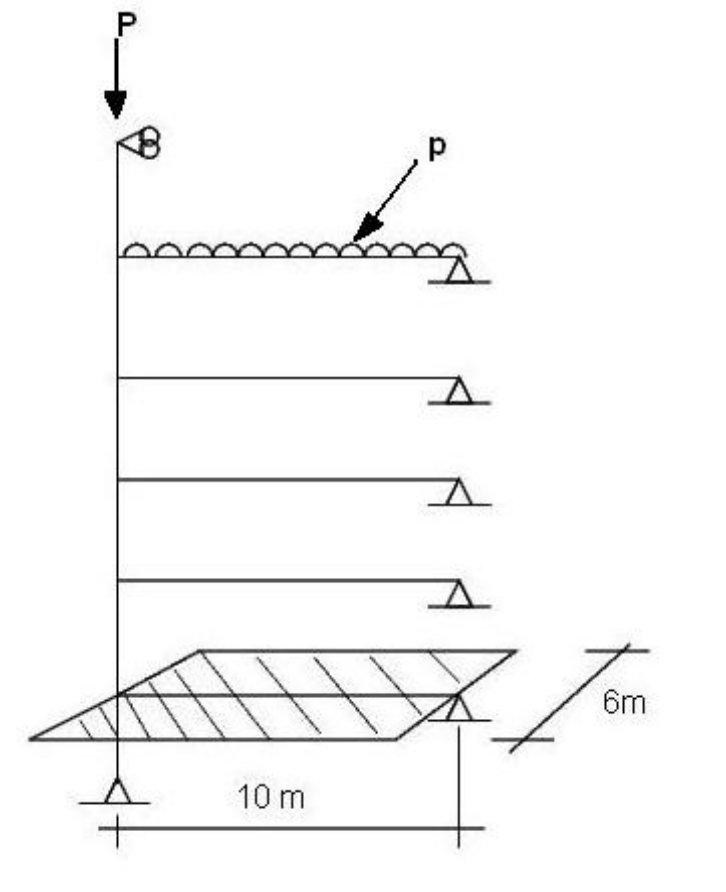
Concrete Slab = 0.1m deep

Ac = 0.6 m2

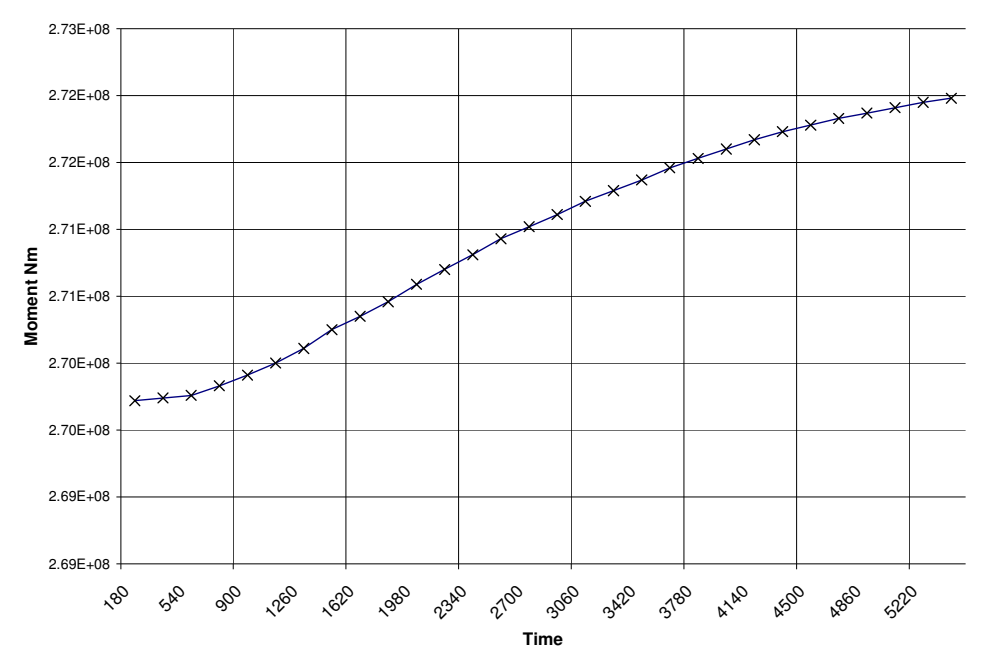
Ec = 14000N/mm2

Asr = 142mm2/m

p=45kN/m2, P=6900N

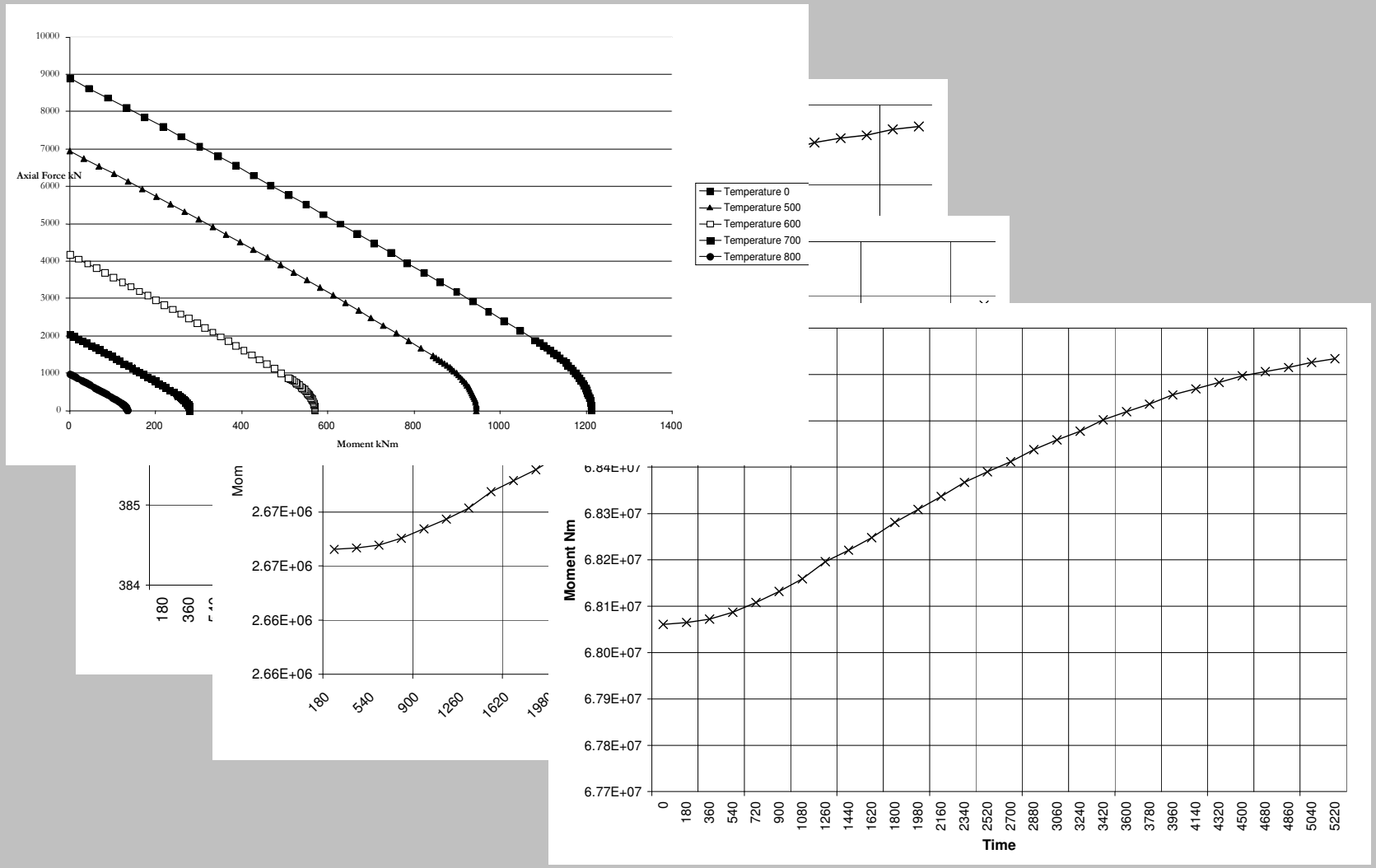


Example: Strong Floor Collapse Mechanism



$Mp=2.1 \times 10^9$

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?