Second-order Direct Analysis Method to Code of Practice for the Structural Use of Steel 2011

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- **What?**
- **Why?**
- **When?**
- **How?**

Commonly used analysis and design method

6.6 FIRST-ORDER LINEAR ELASTIC ANALYSIS (FIRST-ORDER INDIRECT ANALYSIS)

6.6.1 General

P-Δ and P-δ effects should be checked in the member design by the moment

6.7 SECOND-ORDER P-Δ-ONLY ELASTIC ANALYSIS (SECOND-ORDER INDIRECT ANALYSIS)

6.7.1 General

This analysis method considers the changes in nodal coordinate and sway such that the

6.8 SECOND-ORDER P-Δ-δ ELASTIC ANALYSIS (SECOND-ORDER DIRECT ANALYSIS)

6.8.1 General

Both the P-Δ and P-δ effects are accounted for in the computation of bending moment in

First-order Linear Analysis Method

When can I use first-order linear analysis method ??

Non-sway frames

Except for advanced analysis, a frame is classified as non-sway and the P-Δ effect can be ignored when

$\lambda_{cr} \geq 10$

Sway frames

Except for advanced analysis, a frame is classified as sway when

$10 > \lambda_{cr} \geq 5$

Sway ultra-sensitive frames

A frame is classified as sway ultra-sensitive when

$\lambda_{cr} < 5$

Only second order P-Δ-δ or advanced analysis can be used for sway ultra-sensitive frames.

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First-order Linear Analysis Method

- **Elastic Critical Load factor**

  - **1) Deflection method**

    - For **sway buckling mode** of a geometrically **regular** and **rectangular** frame

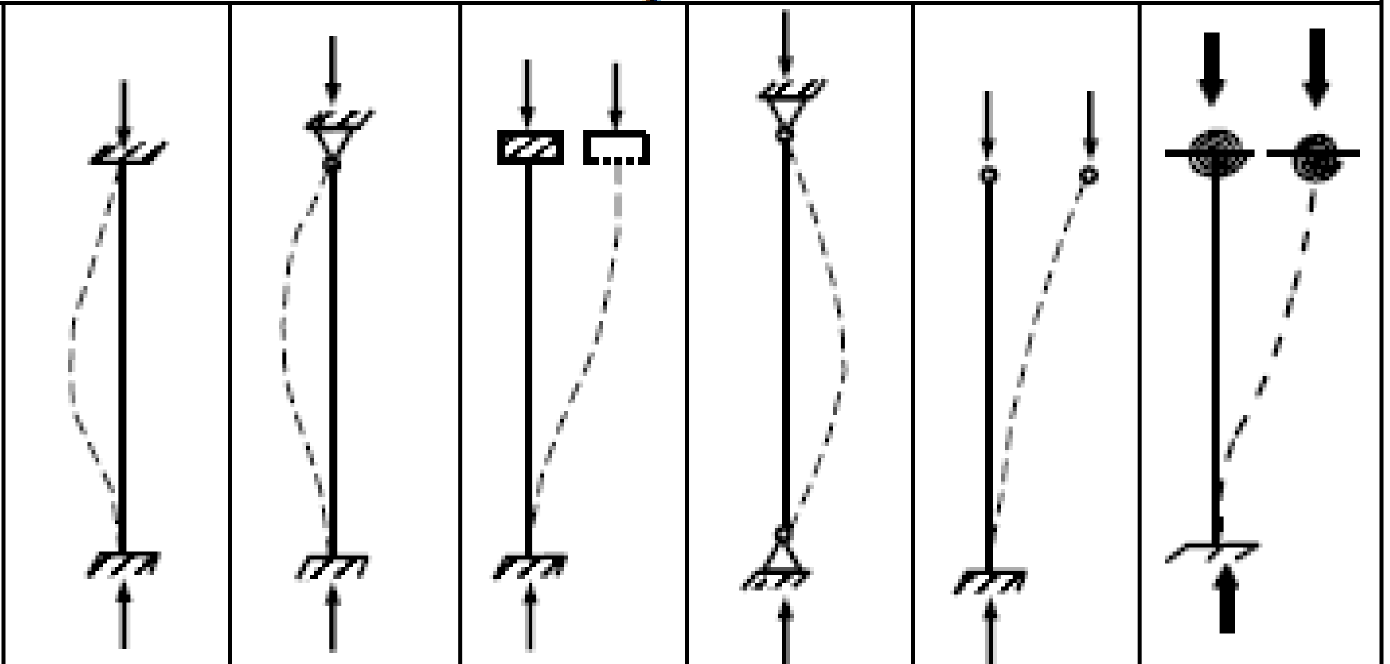
  - **2) Eigenvalue analysis**

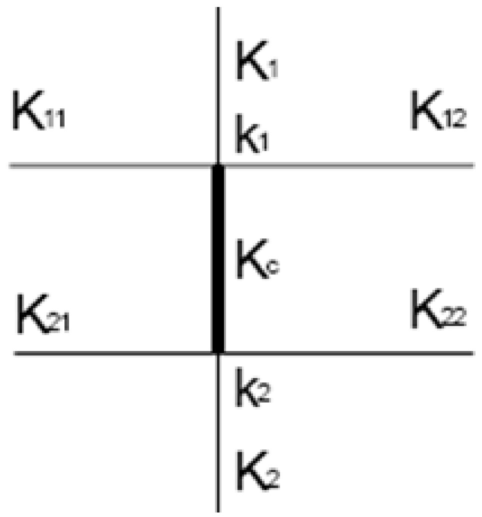
First-order Linear Analysis Method

▪ Effective Length

Effective length of idealized columns

Table 8.6 - Effective length of idealized columns

	Flexural Buckling					
Buckled shape of column shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	/
Recommended K value when ideal conditions are approximated	0.70	0.85	1.20	1.00	2.10	1.5



Distribution factors:

$$k_1 = \frac{K_c + K_1}{K_c + K_1 + K_{11} + K_{12}}$$

$$k_2 = \frac{K_c + K_2}{K_c + K_2 + K_{21} + K_{22}}$$

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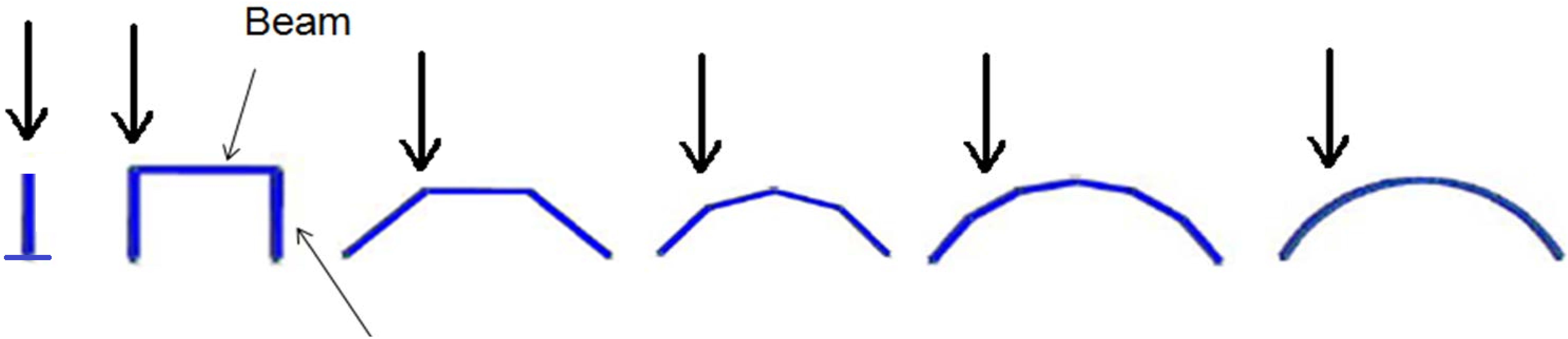
Effective Length

- **How to define the buckling effective length**



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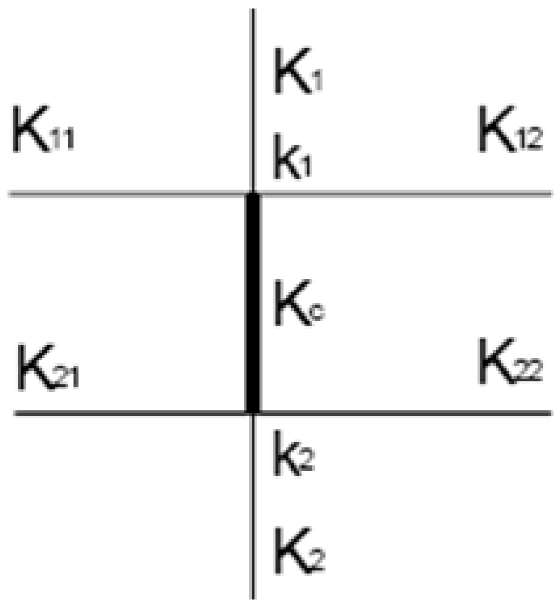

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First-order Linear Analysis Method

- **Effective Length**

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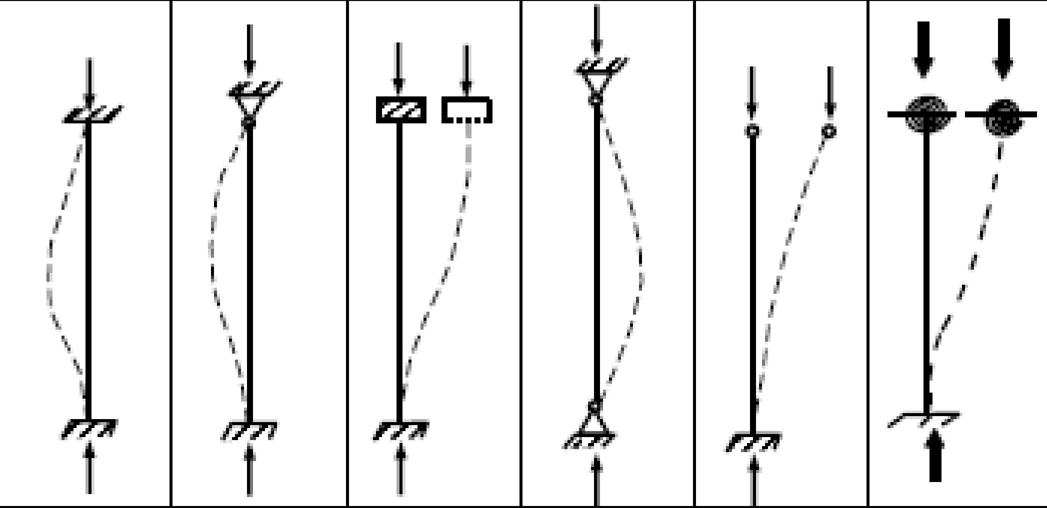
Buckled shape of column shown by dashed line						
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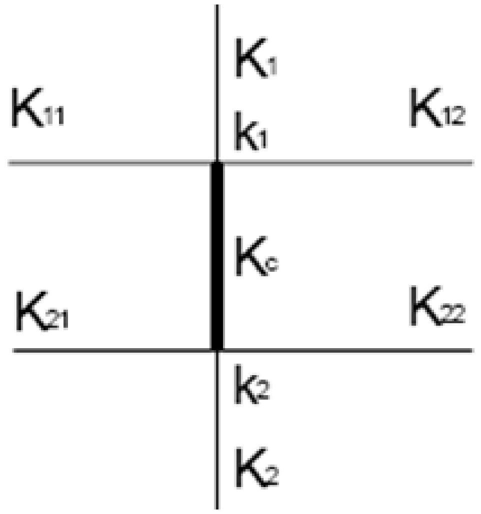

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- **Moment Amplification for sway frames**

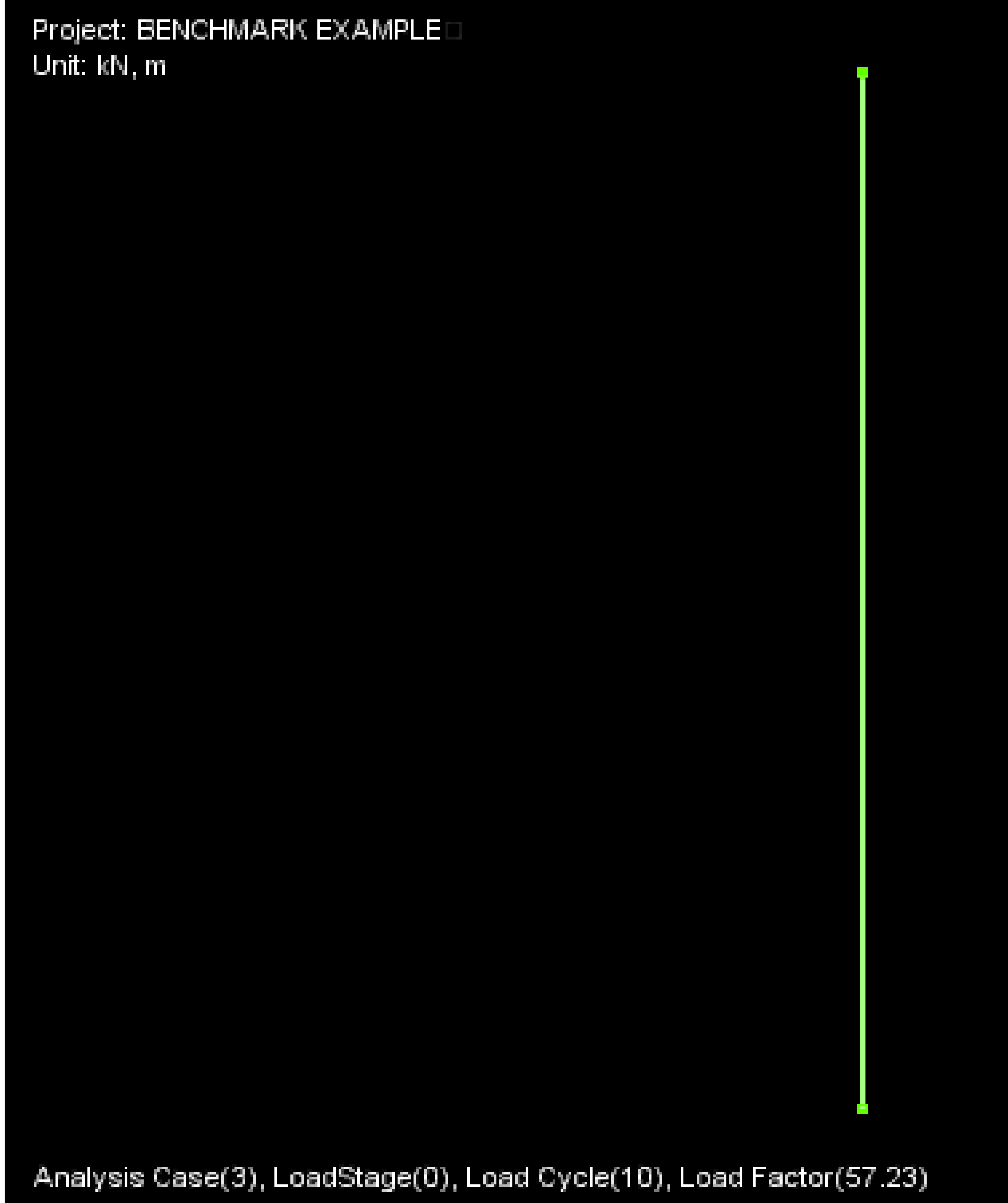
$$\frac{\lambda_{cr}}{\lambda_{cr} - 1}$$:

- **Maximum slenderness ratio**

  <200

What is Buckling?

Buckling behavior



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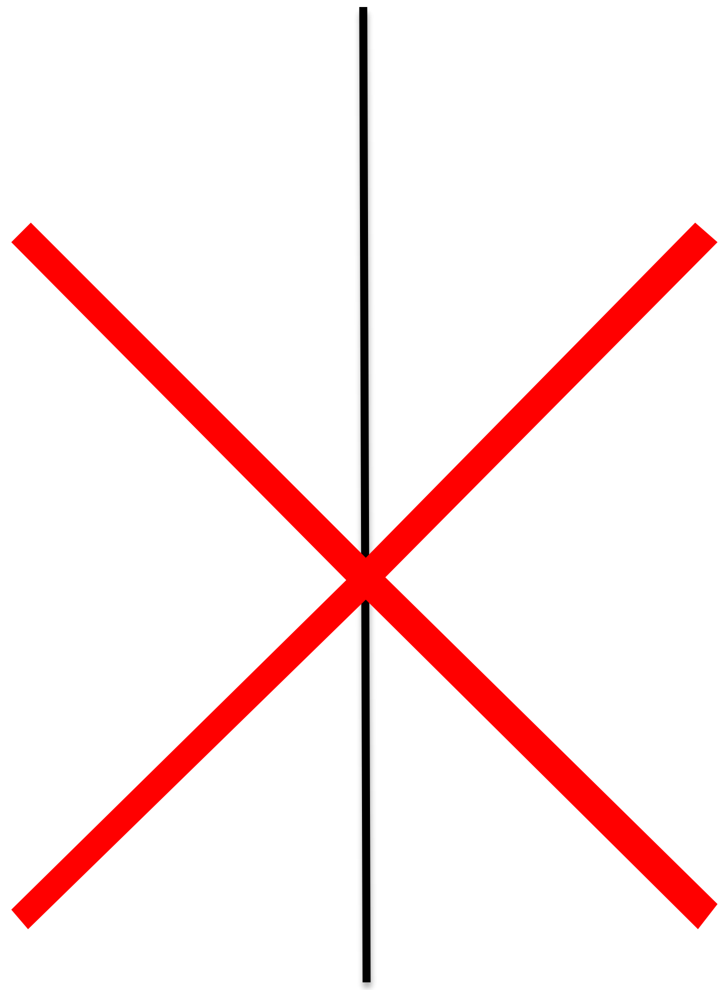
Second-order Analysis and Design Method

➢ P-δ Moment

- Member initial imperfection



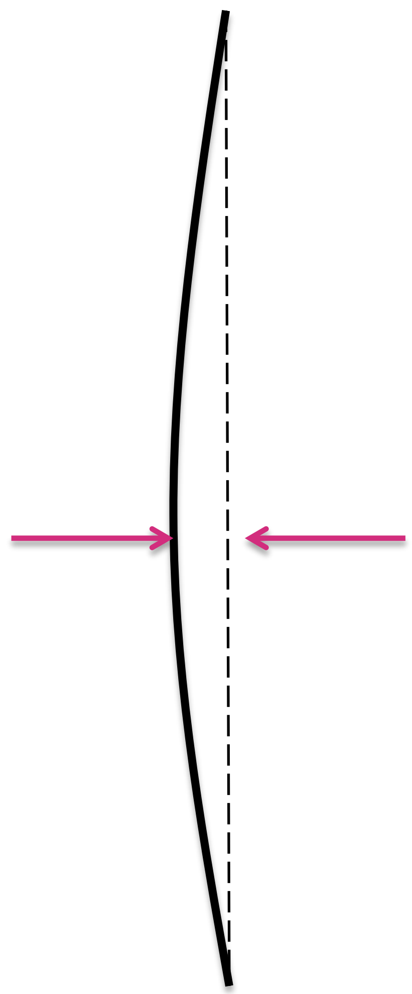
Perfect member

Second-order Analysis and Design Method

➢ P-δ Moment

- Member initial imperfection

Buckling curves referenced in Table 8.7	$\frac{e_0}{L}$ to be used in Second-order P-Δ-δ elastic analysis
a_0	1/550
a	1/500
b	1/400
c	1/300
d	1/200



Member Imperfection

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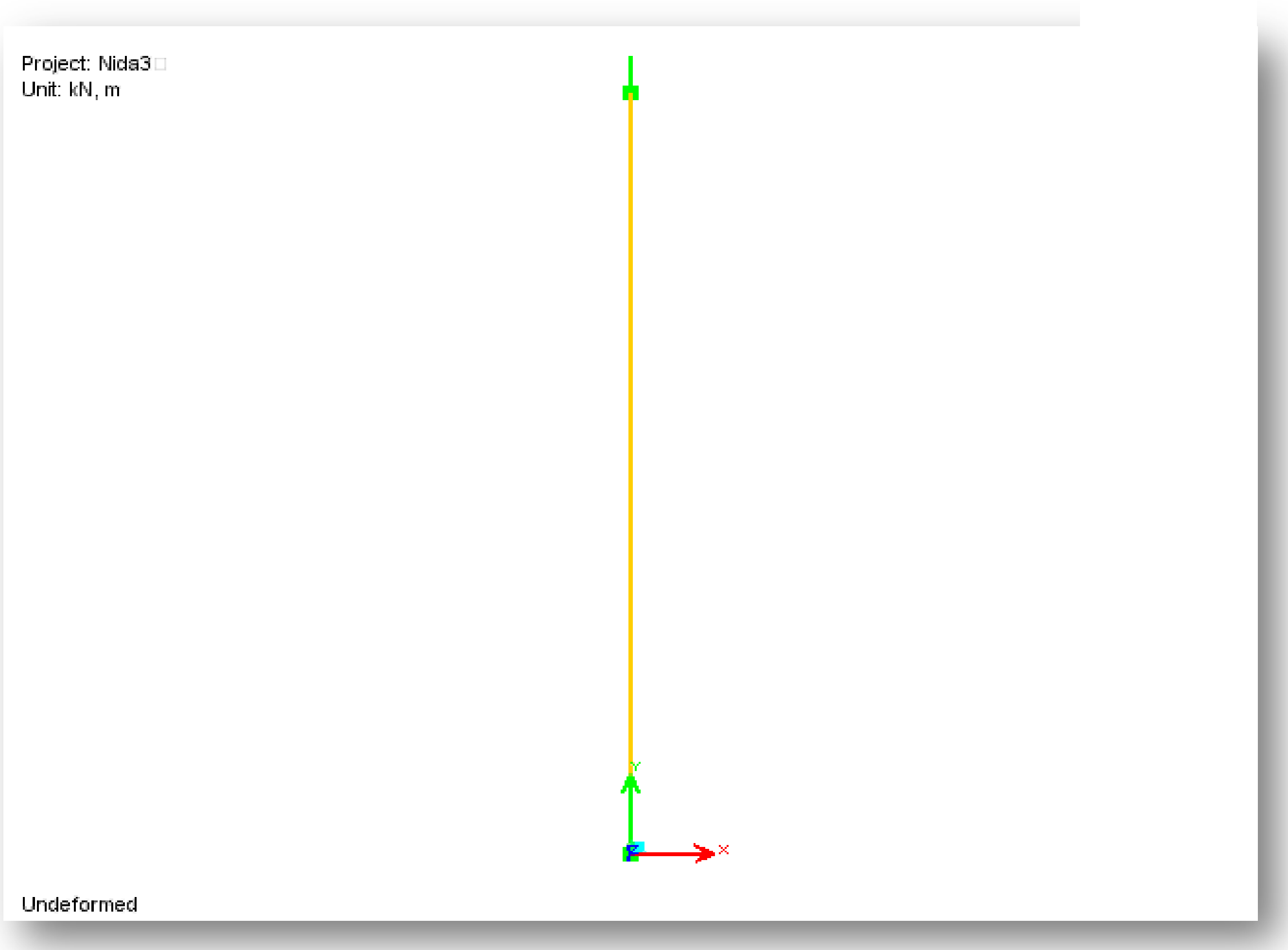
Second-order Analysis and Design Method

➢ P-δ Moment

- Member initial imperfection + Member deformation under load



Use effective length and buckling reduction factor in linear analysis

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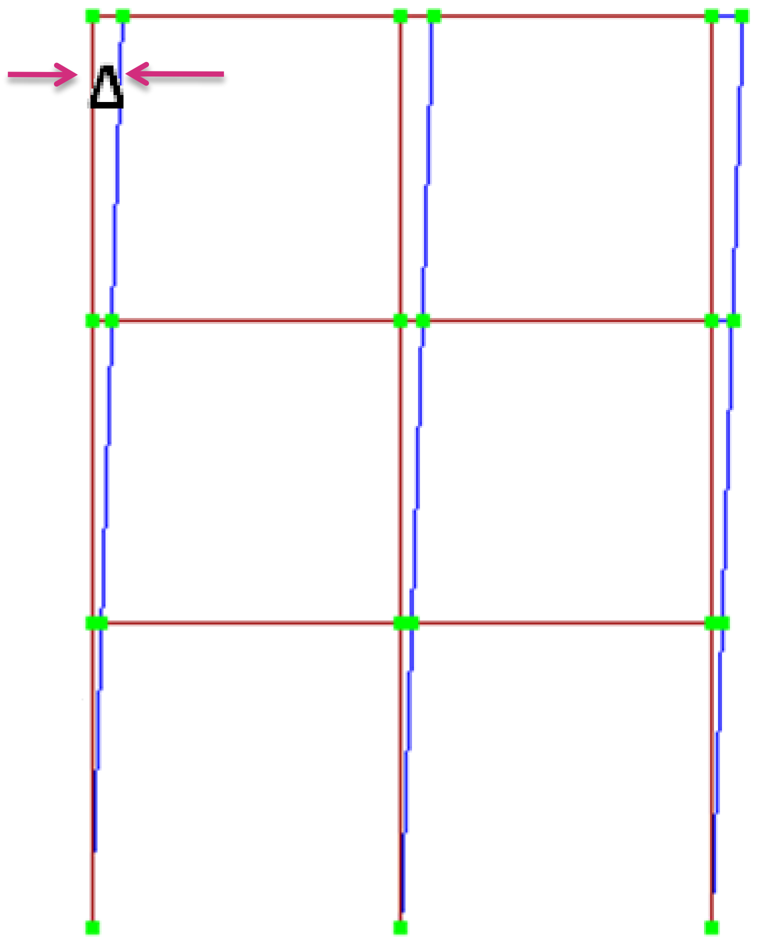
Second-order Analysis and Design Method

➢ P-Δ Moment

-Structural global imperfection



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Second-order Analysis and Design Method

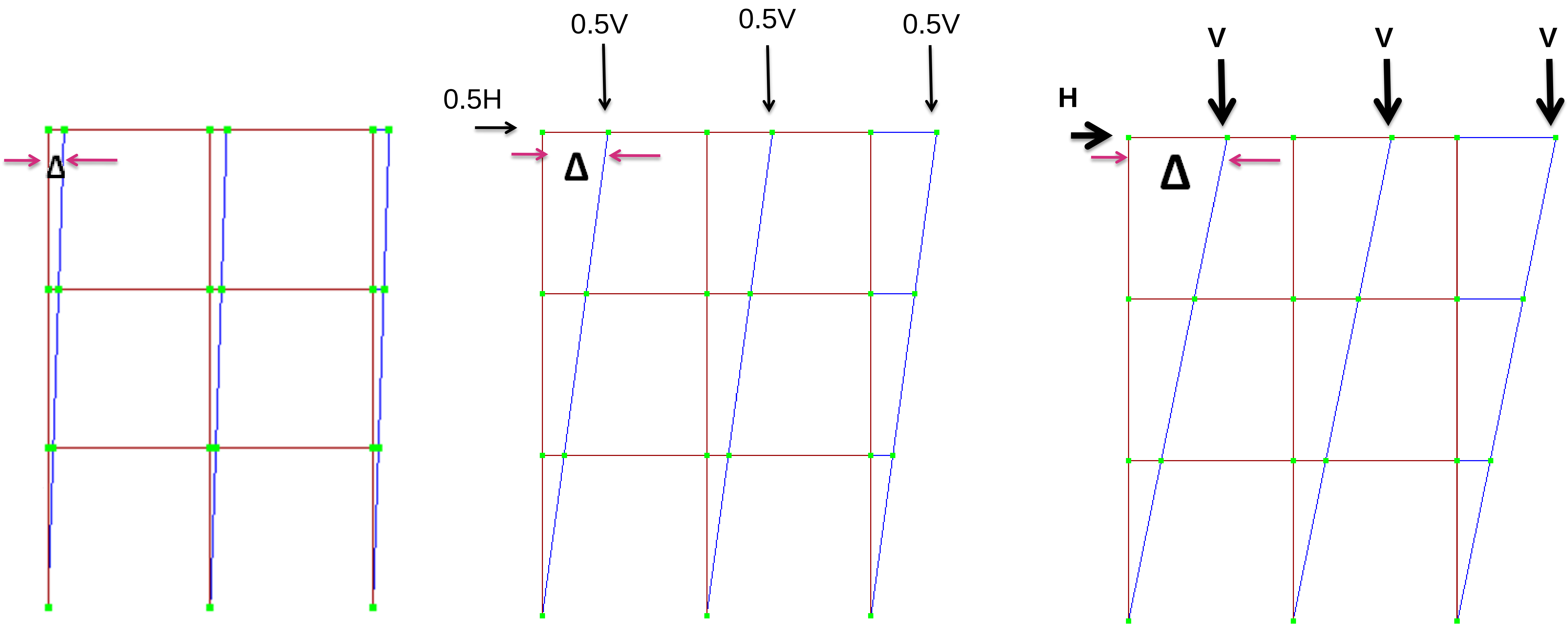
- **Structural global imperfection**

  - **Shape of imperfection**
    - **1) Notional horizontal force method**
      - Suitable for regular structures
    - **2) Elastic buckling mode**
      - Applicable for all structures

  - **Value of imperfection**
    - **Storey height/200**

➢ P-Δ Moment

-Structural global imperfection + *Nodal geometric change*



Use in Moment Amplification factor in linear analysis

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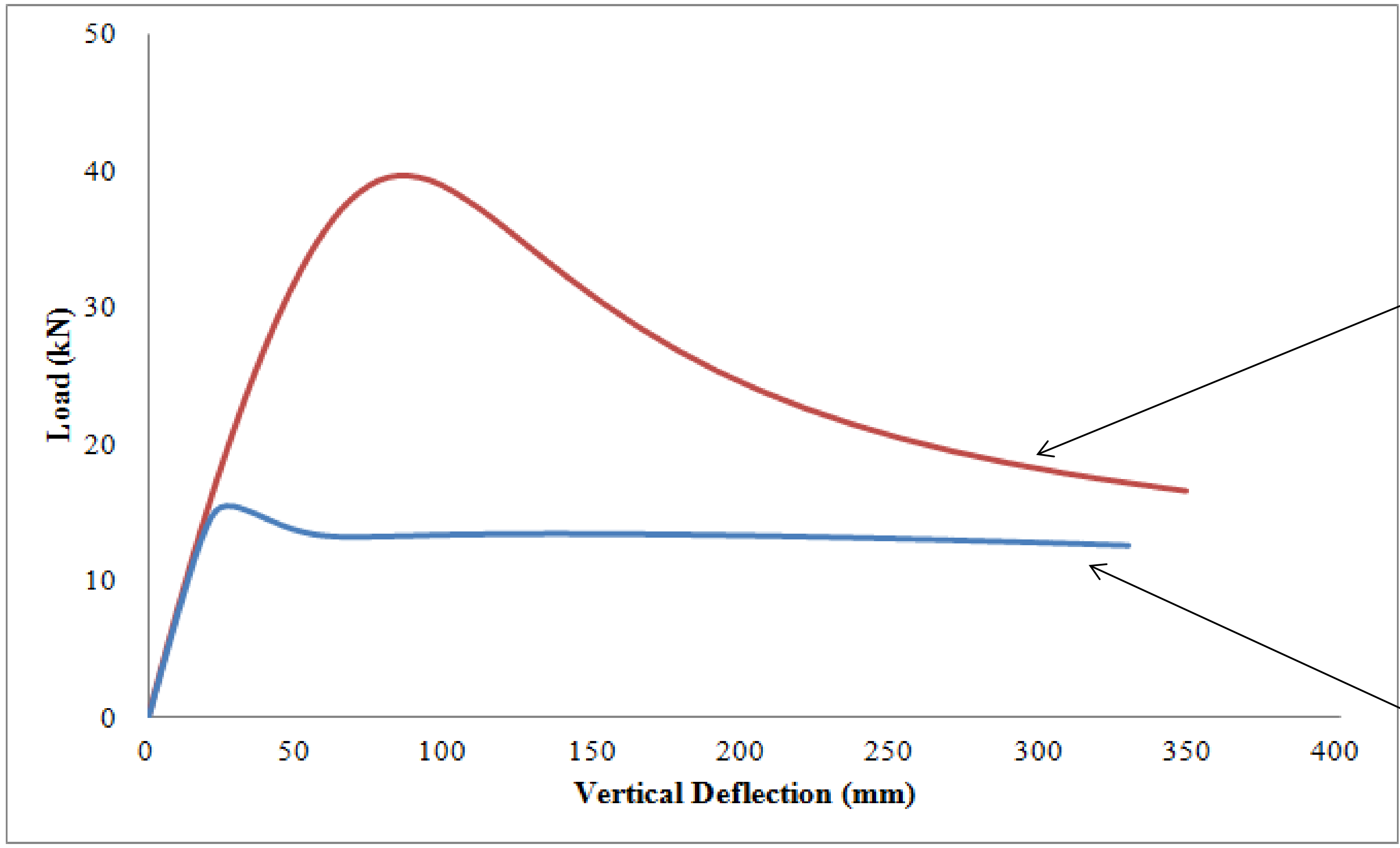
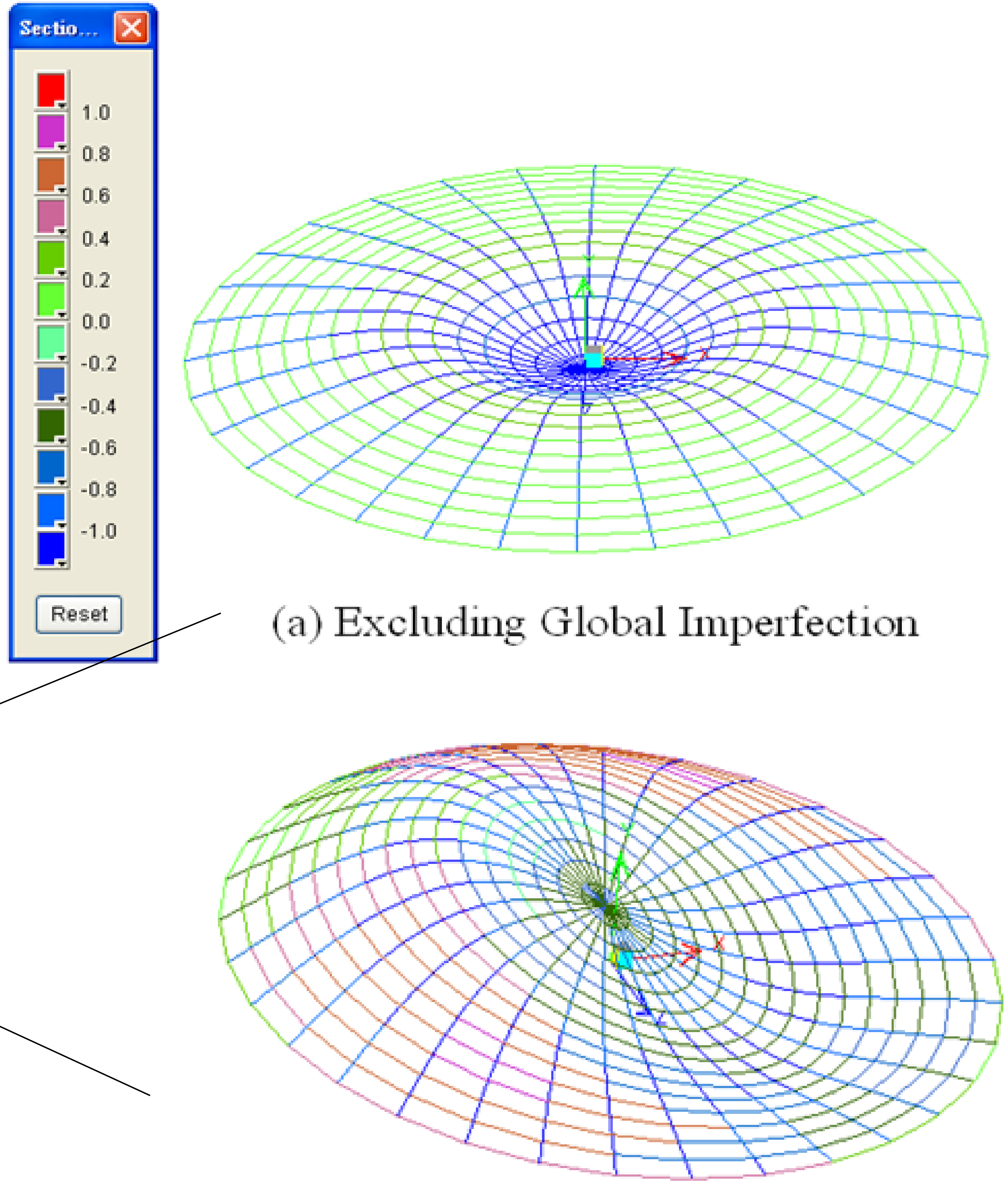
Second-order Analysis and Design Method

➢ **Structural global imperfection**





(a) Excluding Global Imperfection

(b) Including Global Imperfection

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Commonly Used Analysis and Design Method

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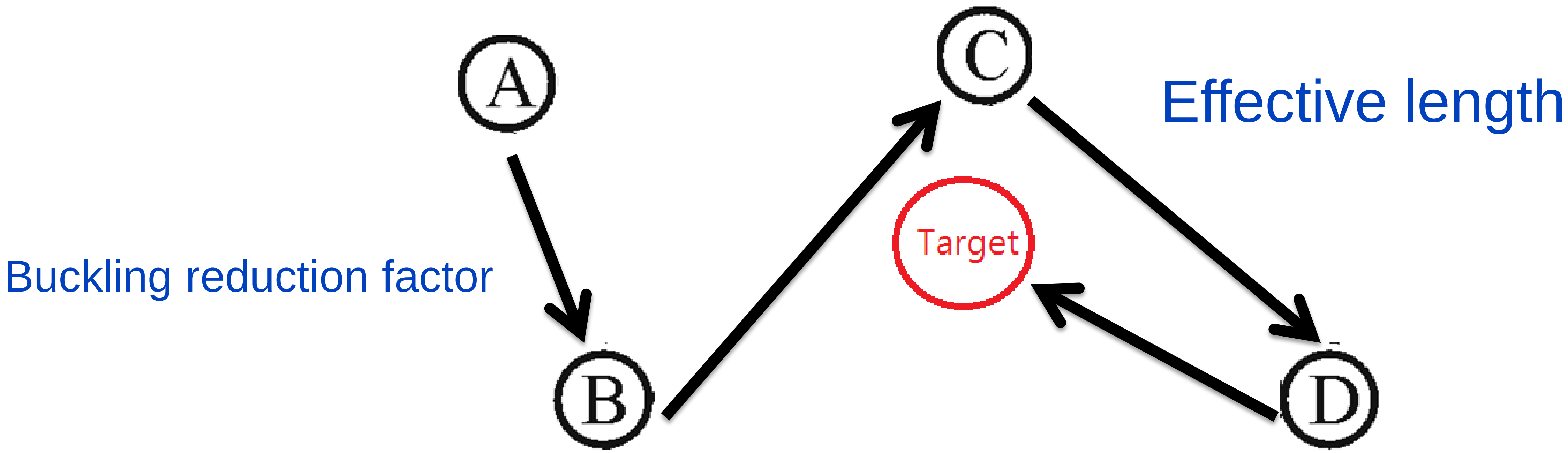
Second-order Analysis and Design Method

- ***What's second-order*** ***INDIRECT*** ***(P-Δ) analysis?***



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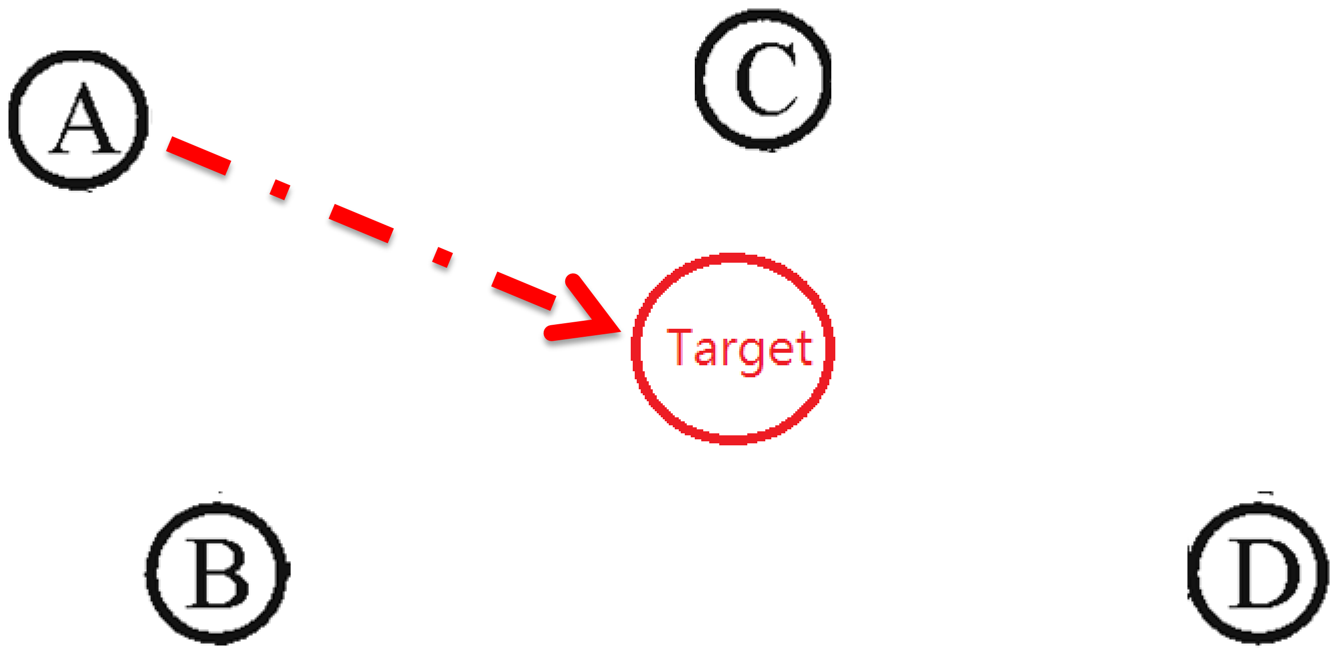
Second-order Analysis and Design Method

- ***What's second-order DIRECT (P-Δ-δ) analysis?***



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Second-order Analysis and Design Method

- *What do I* ***NEED*** *for second-order direct analysis?*

- ***Member imperfection***

Buckling curves referenced in Table 8.7	$\frac{e_0}{L}$ to be used in Second-order P-Δ-δ elastic analysis
a_0	1/550
a	1/500
b	1/400
c	1/300
d	1/200

- ***Frame imperfect***

Frame imperfections

The effects of imperfections for typical structures shall be incorporated in frame analysis using an equivalent geometric imperfection in Equation 6.7 as an alternative to the notional horizontal force in clause 2.5.8,

$\Delta = h / 200$

Second-order Analysis and Design Method

- **Section capacity check**

$$\frac{F_c}{A_g p_y}+\frac{M_x}{M_{cx}}+\frac{M_y}{M_{cy}}=\frac{F_c}{A_g p_y}+\frac{\overline{M}_x+F_c(\Delta_x+\delta_x)}{M_{cx}}+\frac{\overline{M}_y+F_c(\Delta_y+\delta_y)}{M_{cy}}\leq 1$$

$$\left(\frac{M_x}{M_{rx}}\right)^{z_1}+\left(\frac{M_y}{M_{ry}}\right)^{z_2}=\left(\frac{\overline{M}_x+F_c(\Delta_x+\delta_x)}{M_{rx}}\right)^{z_1}+\left(\frac{\overline{M}_y+F_c(\Delta_y+\delta_y)}{M_{ry}}\right)^{z_2}\leq 1$$

Comment questions

- **Second-order direct analysis ONLY used in HK Steel Code?**

Comment questions

Recommended by many design codes

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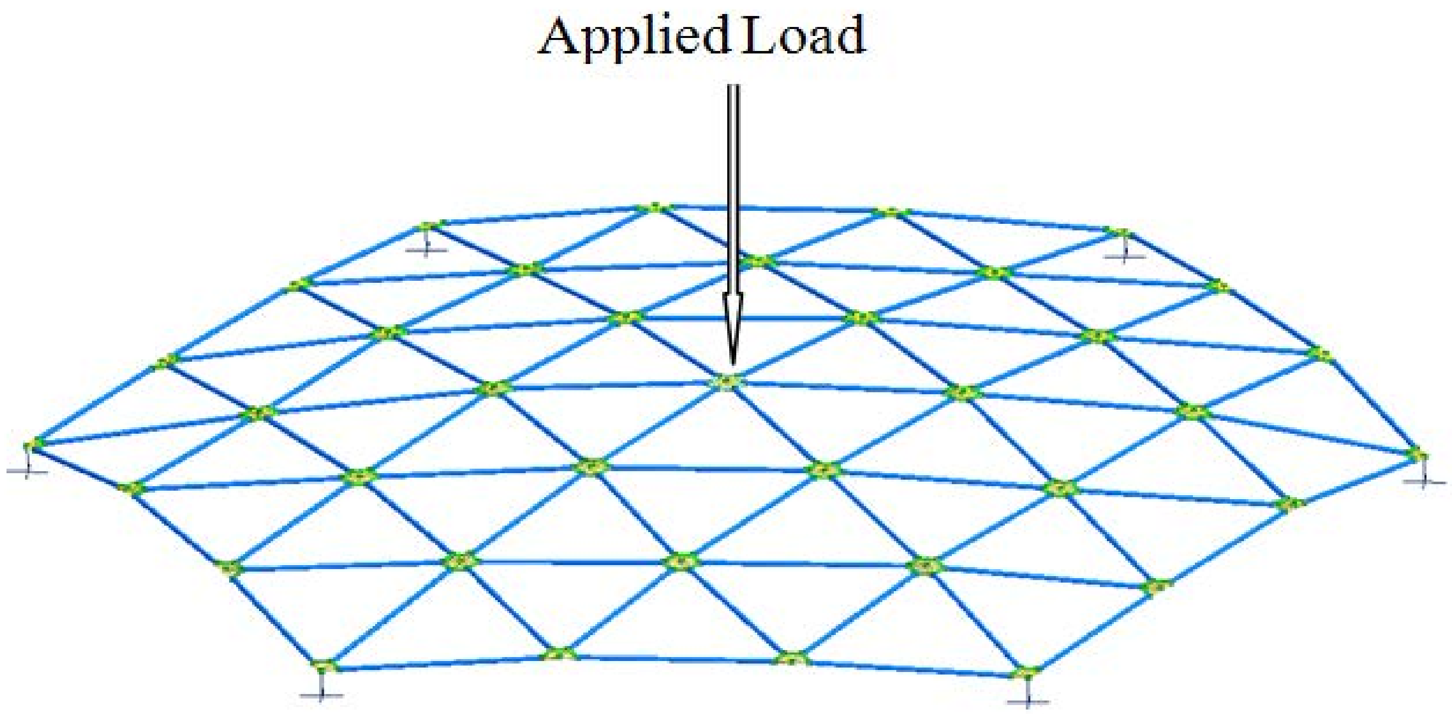
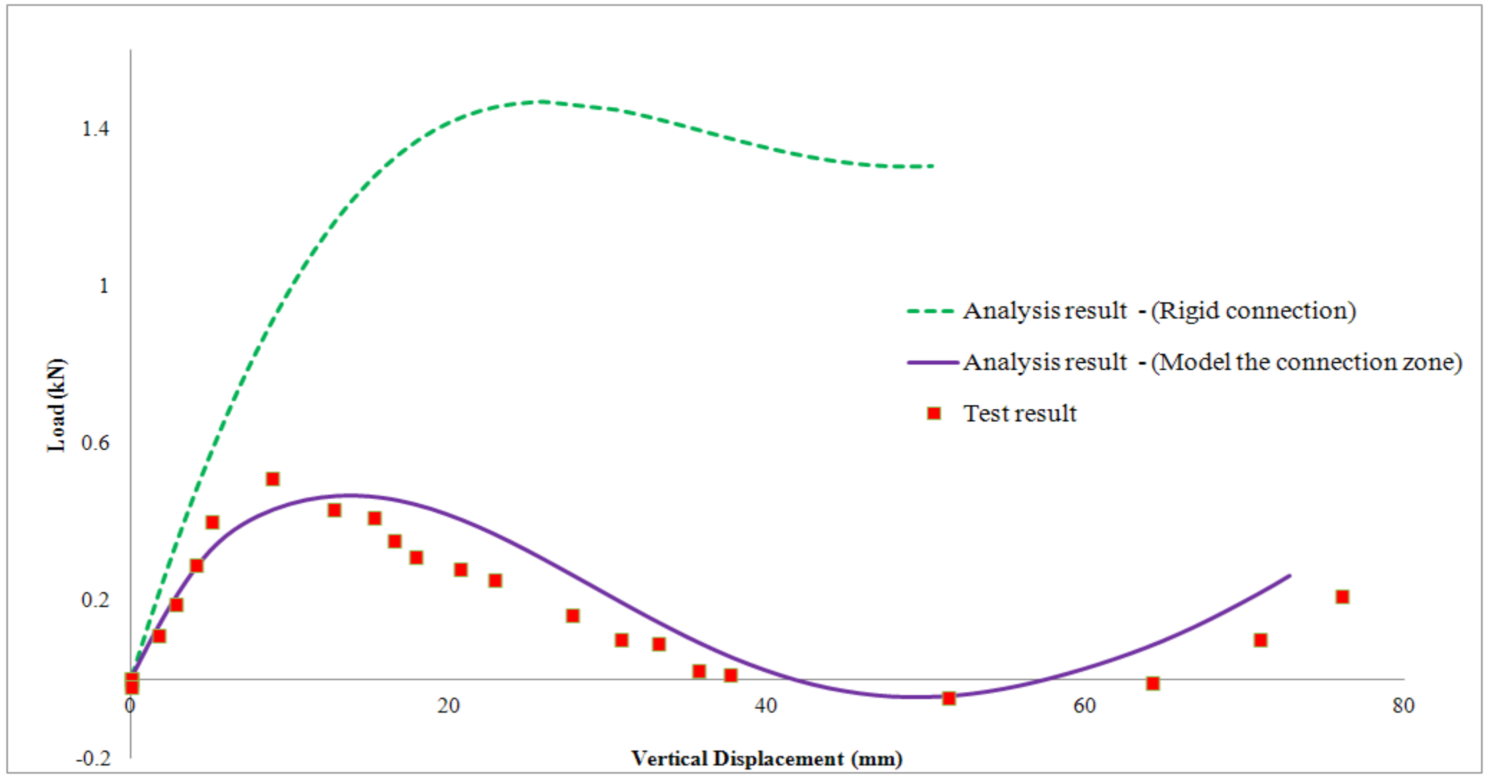
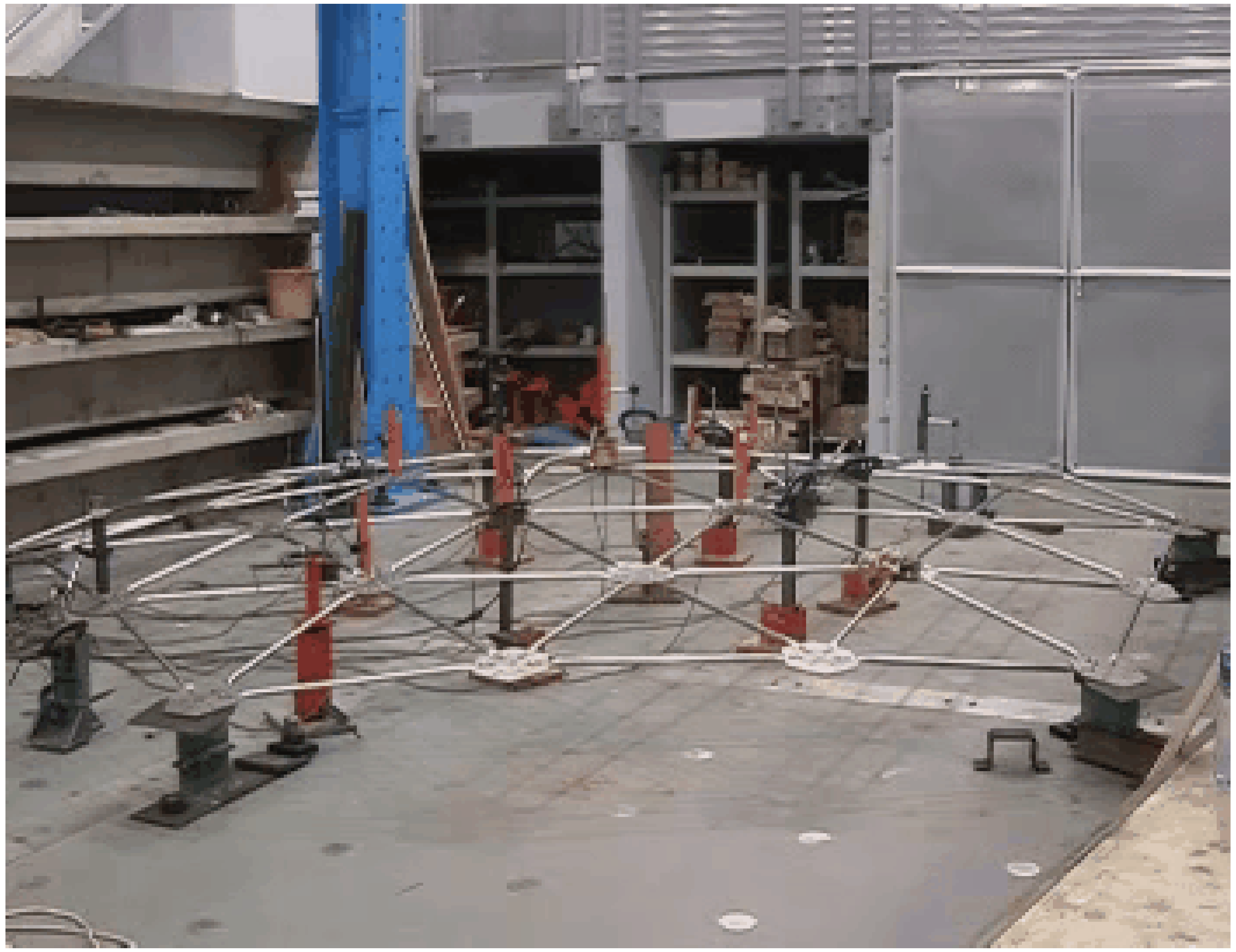
Comment questions

- Second-order direct analysis ONLY used in HK Steel Code?
- Second-order analysis gives a more economic/conservative design?
- Can I add the reaction forces from each load cases?
- Anything miss in linear analysis?

Snap-through buckling problem







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Conclusion

- **What?**
- **Why?**
- **When?**
- **How?**

Thank you

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