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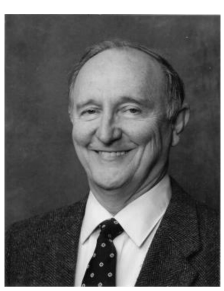
Five Useful Stability Concepts

Presented by
Joseph Yura, Ph.D., P.E.
Emeritus Professor
University of Texas, Austin, TX



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FIVE USEFUL STABILITY CONCEPTS

Joseph A. Yura
University of Texas at Austin

FIVE STABILITY CONCEPTS

- loss of stiffness as the buckling load is approached
- inelastic column behavior
- ΣP for system buckling
- importance of end connection details in built-up columns
- stiffness and strength required for braces

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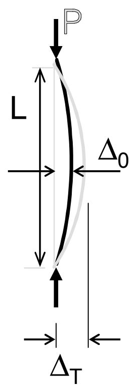
IMPERFECT MEMBERS



$$\Delta_T = \frac{\Delta_0}{1 - \dfrac{P}{P_{cr}}}$$

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

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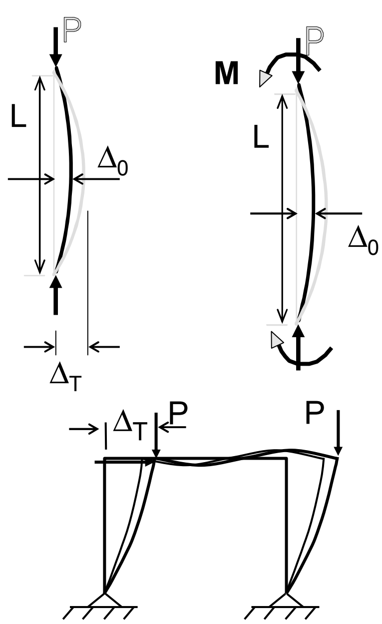
IMPERFECT MEMBERS



$$\Delta_T = \frac{\Delta_0}{1 - \dfrac{P}{P_{cr}}}$$

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

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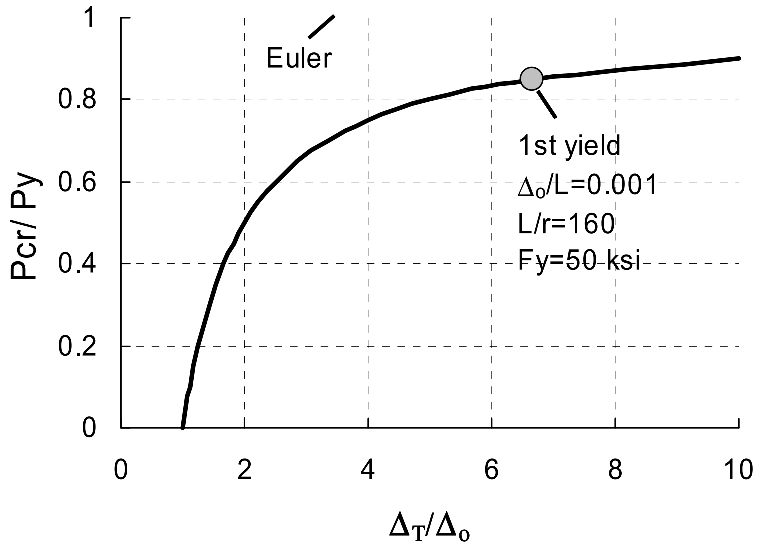
RESPONSE OF AN IMPERFECT COLUMN



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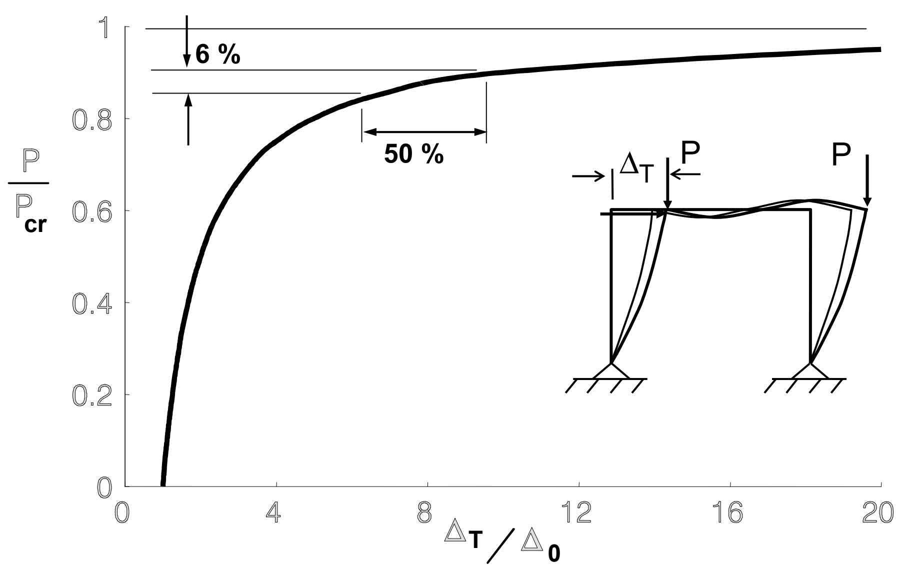

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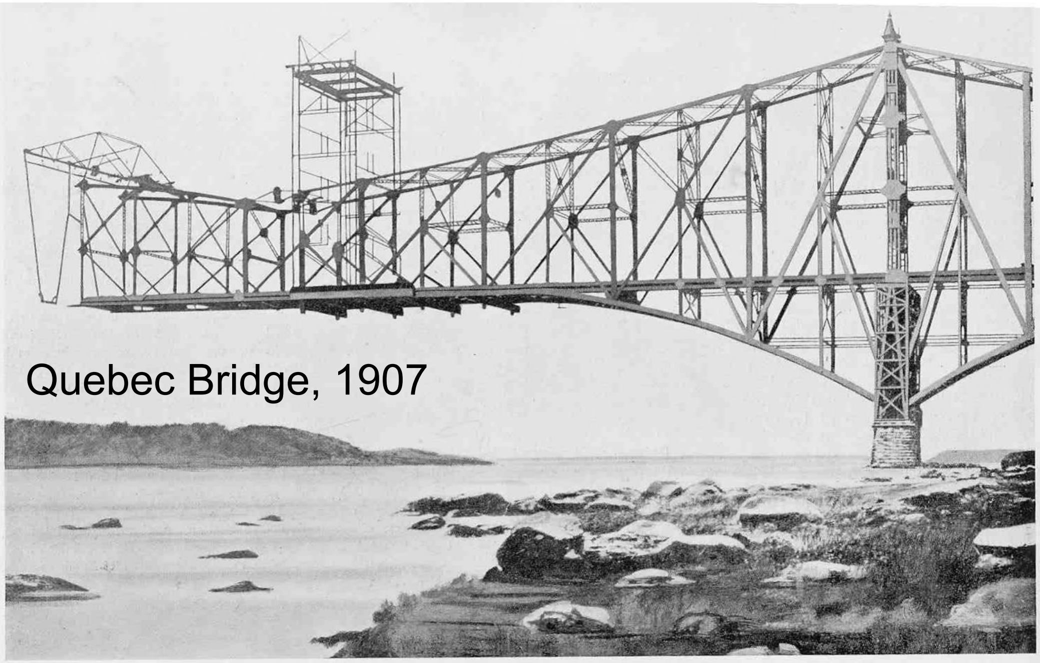
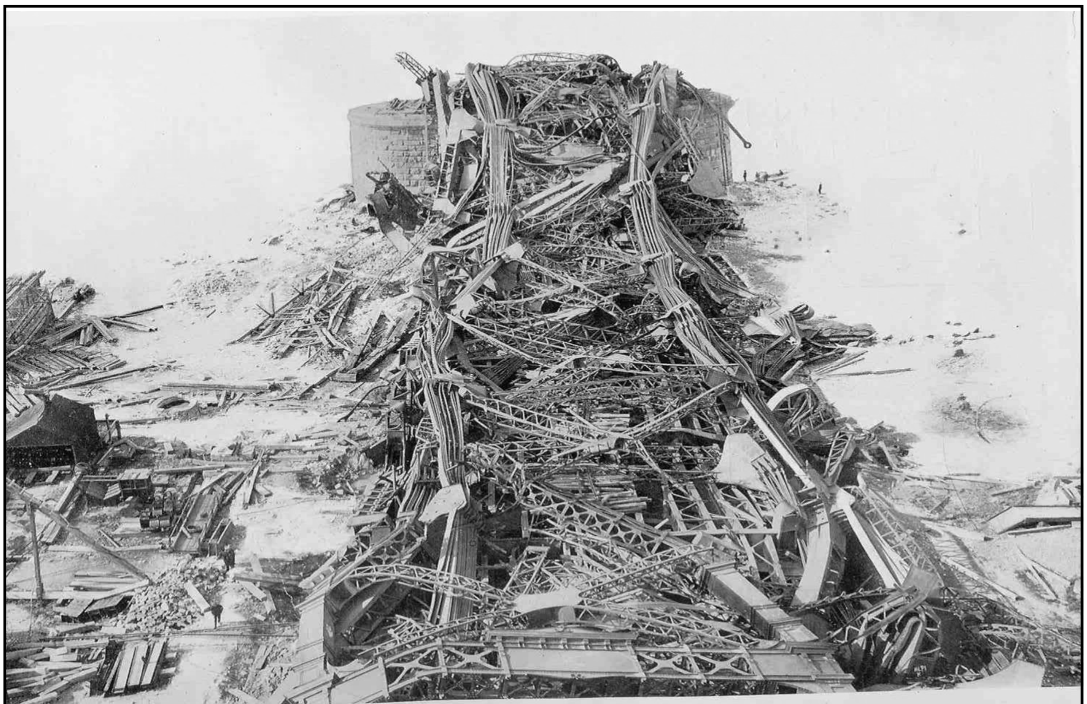


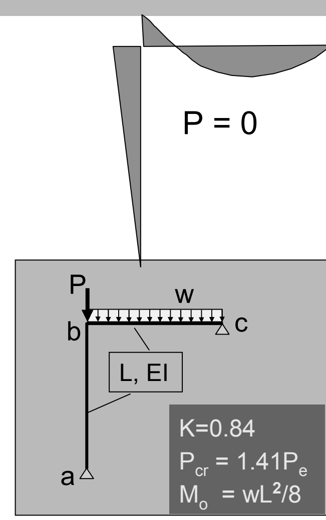
The Phoenix Co.'s Bridge immediately before the collapse, August 29th, 1907



Wreckage of old bridge, August 29th, 1907

Marcy Pedestrian Bridge, 2002

EFFECT OF COLUMN STIFFNESS ON FRAME MOMENTS



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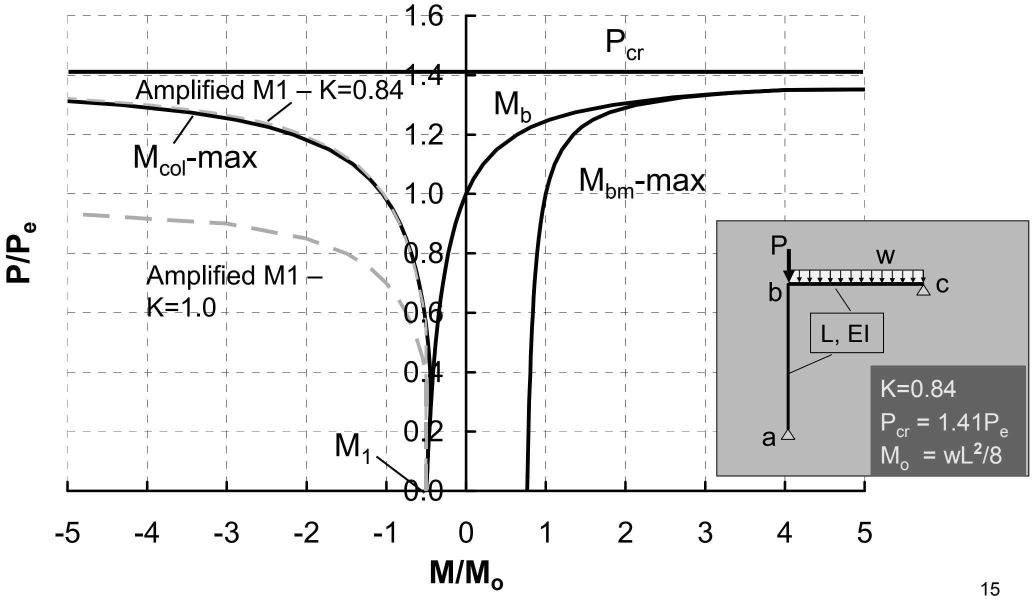
EFFECT OF COLUMN STIFFNESS ON FRAME MOMENTS



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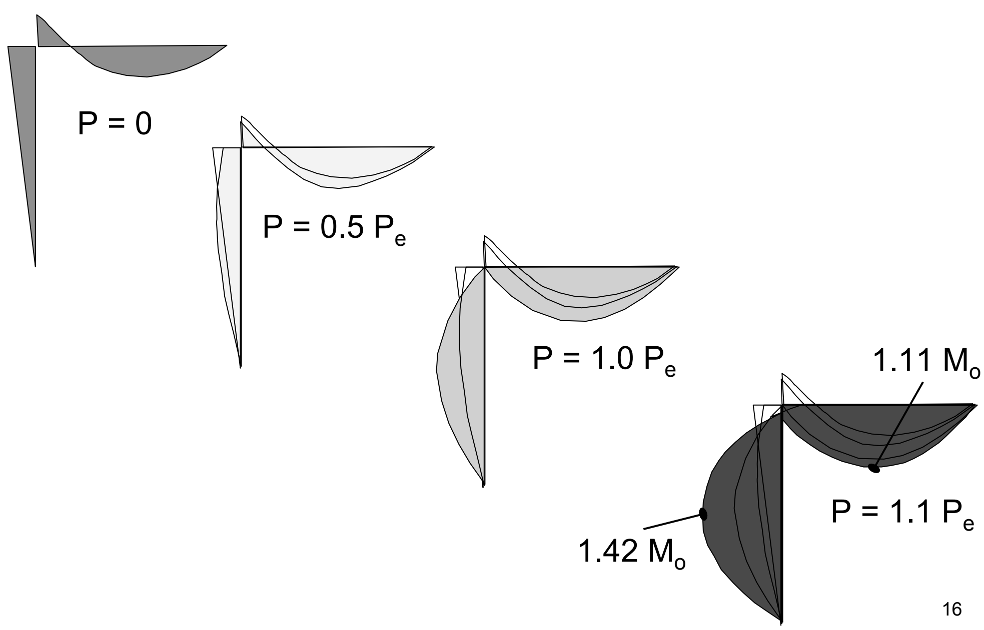
EFFECT OF COLUMN LOAD ON FRAME MOMENTS



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FIVE STABILITY CONCEPTS

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STRENGTH OF AN IMPERFECT COLUMN

$$\frac{P}{A} + \frac{Mc}{I} = F_y$$

where $M = P\Delta_T = \dfrac{P\Delta_0}{1 - P/P_{cr}}$

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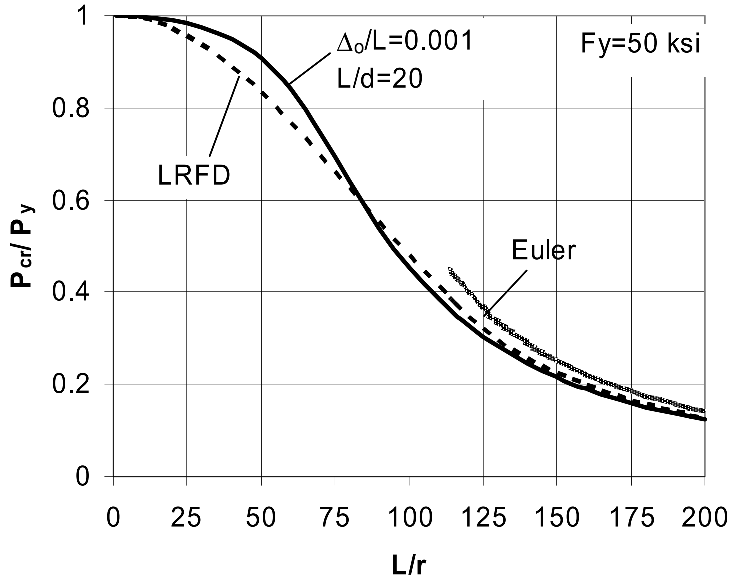
YIELD LIMIT FOR AN OUT-OF-STRAIGHT COLUMN



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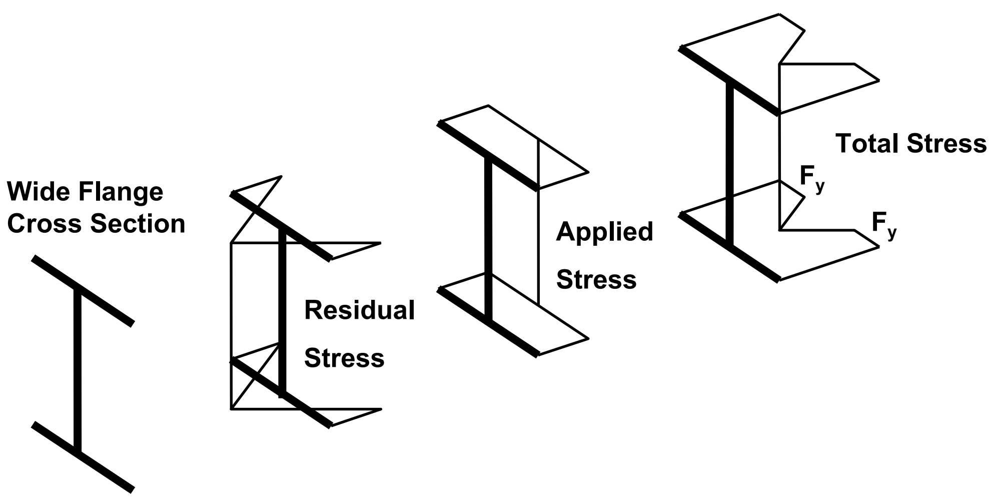
EFFECT OF RESIDUAL STRESS



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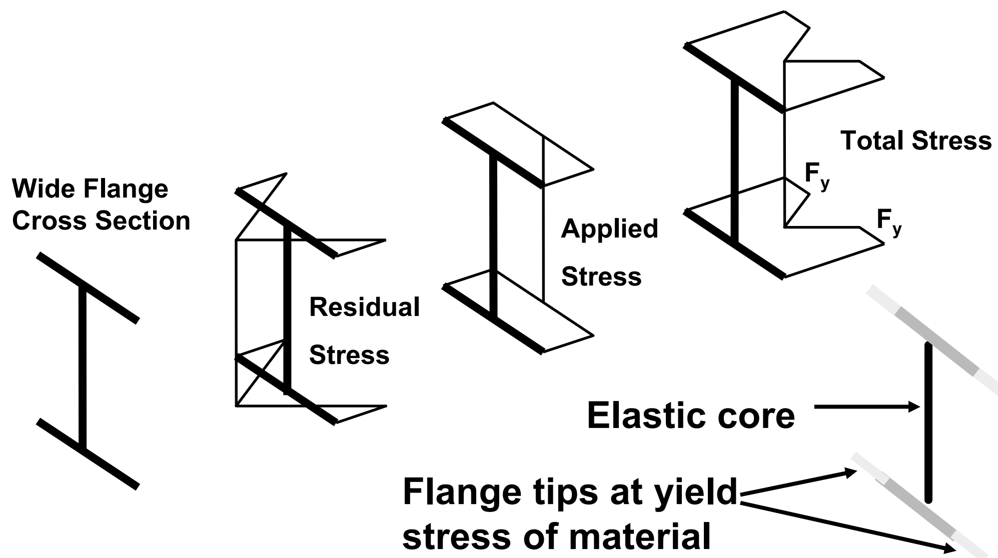
EFFECT OF RESIDUAL STRESS



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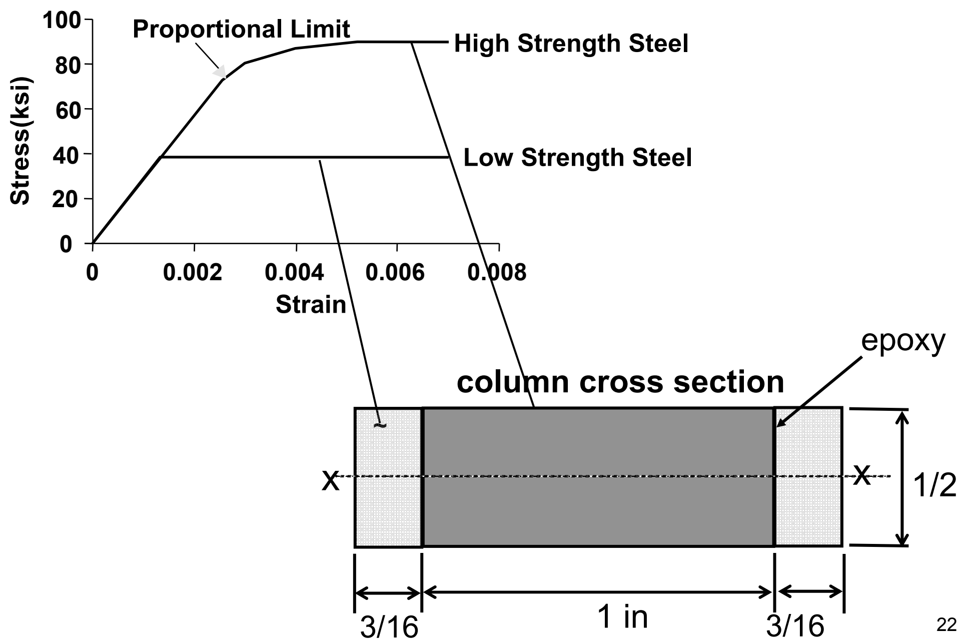

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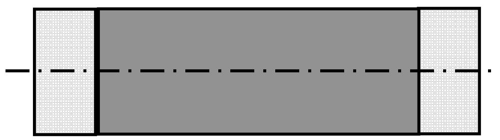
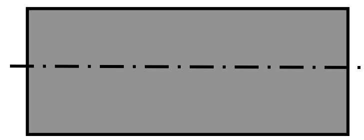
COLUMN TESTS WERE CONDUCTED WITH EACH OF THE CROSS SECTIONS SHOWN. FOR A COLUMN LENGTH OF 9.5 IN., THE BUCKLING LOAD WAS THE SAME EVEN THOUGH SECTION A IS 38% LARGER THAN SECTION B. AT L = 19 IN. THE BUCKLING LOAD FOR COLUMN A WAS 40% HIGHER THAN B.



cross section A



cross section B

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Any yielded portion of a steel column contributes nothing to the buckling strength of that member even though the entire cross section supports the load

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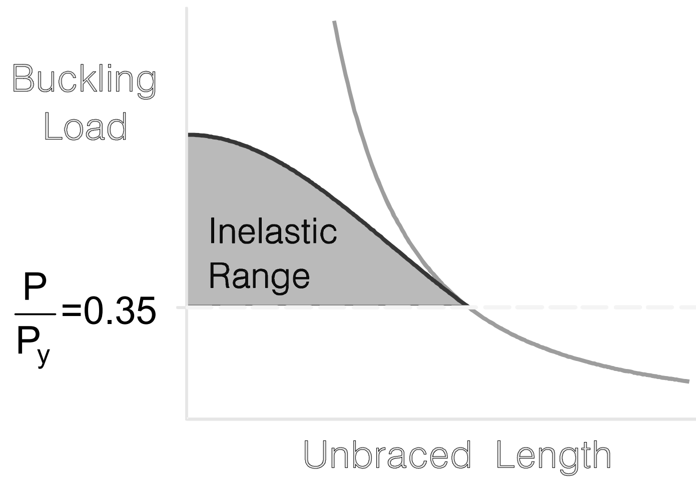
COLUMNS IN THE INELASTIC RANGE



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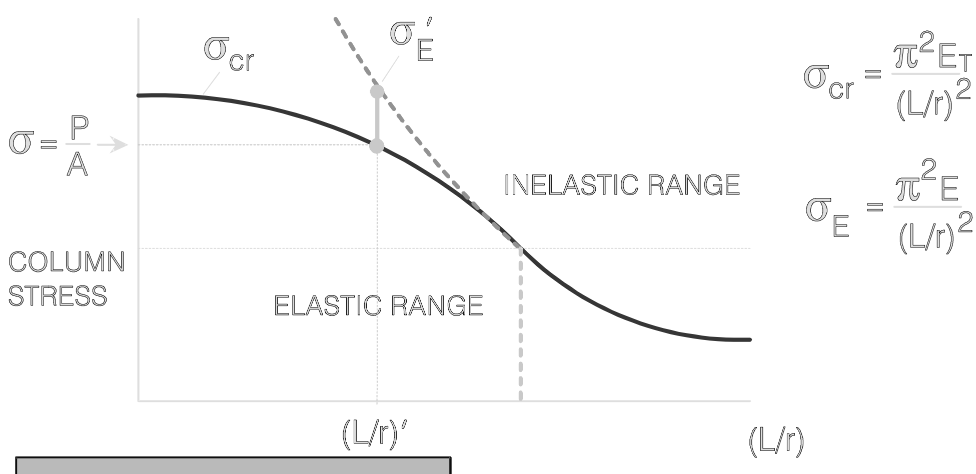
STIFFNESS REDUCTION FACTOR, τ



$$\tau = \frac{E_T}{E} = \frac{(P/A)}{\sigma_E @ (L/r)'} = \frac{\sigma}{\sigma_E'}$$

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CURRENT LRFD METHOD

$$\phi P_n = 0.90 F_{cr} A$$

where $F_{cr} = 0.877 F_e = 0.877\left(\frac{\pi^2 EI}{(KL/r)^2}\right)$ when $F_e \le 0.44 F_y$

and

$$F_{cr} = 0.658^{\left(\frac{F_y}{F_e}\right)} F_y \quad \text{when } F_e > 0.44 F_y$$

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LRFD EQUIVALENT METHOD

$$\phi P_n = 0.90(0.877)\frac{\pi^2 EI}{(KL)^2}\tau = 226000\frac{I}{(KL)^2}\tau$$

$$\tau = 1.0 \text{ for } \frac{P}{P_y} \le 0.35$$

$$\text{and } \tau = -6.97\left(\frac{P}{P_y}\right)\log\left(\frac{P}{0.9P_y}\right) \text{ if } \frac{P}{P_y} > 0.35$$

$$P_y = F_y A$$

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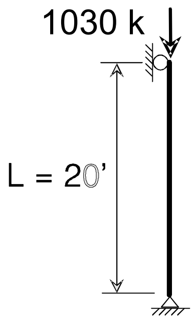
ALTERNATIVE COLUMN DESIGN



What column size is required?

Try a W12x120 (F_y = 50 ksi) : $A = 35.3\ in^2$
$I_y = 345\ in^4$

$$\frac{P_u}{P_y} = \frac{1030}{(35.3\,in^2 \times 50\,ksi)} = 0.584 > 0.35 \text{(inelastic)}$$

$$\tau = -6.97(0.584)\log\left(\frac{0.584}{0.9}\right) = 0.764$$

$$\phi P_n = 226000\frac{345}{(20\times12)^2}0.764 = 1034\ k$$

(1030 in tables)

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FIVE STABILITY CONCEPTS

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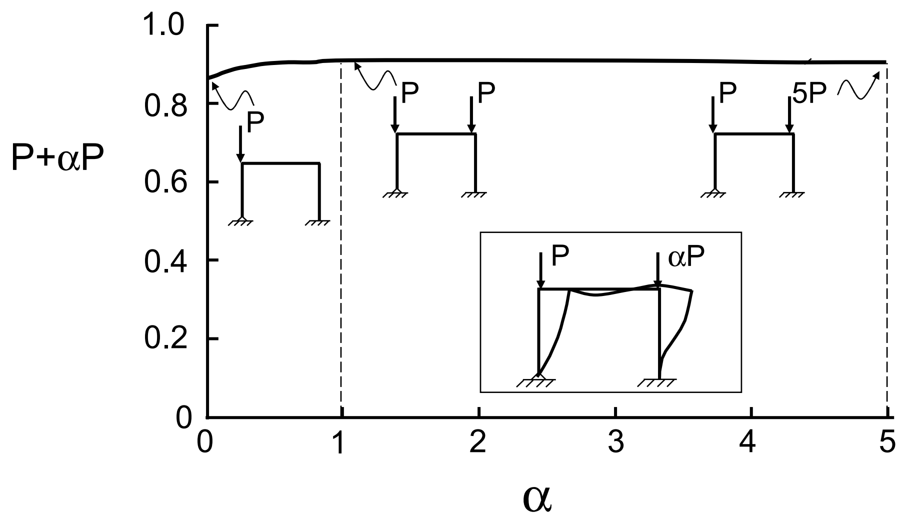
EXACT BUCKLING SOLUTIONS



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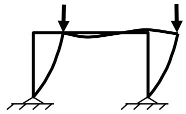
ΣP CONCEPT

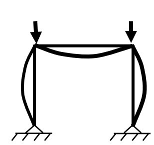
- **FOR SWAY BUCKLING OF A STORY:**



$$\Sigma P_{\substack{Story\ \ Column\\ Loads}} \leq \Sigma P_{cr\ i}$$

Sway Buckling Load of each column using Alignment Chart K-Factor

- **<u>EACH</u> COLUMN MUST SUPPORT ITS OWN LOAD IN THE NO-SWAY MODE (ie. WITH K=1.0)**



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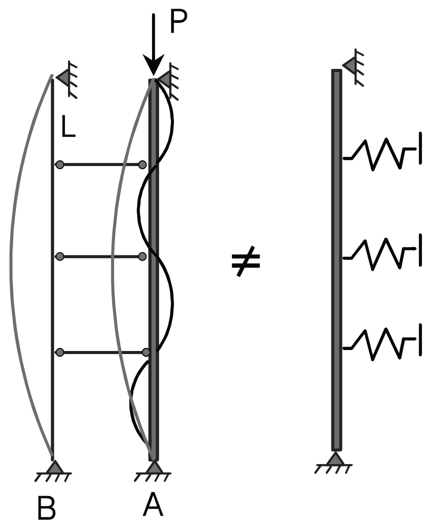
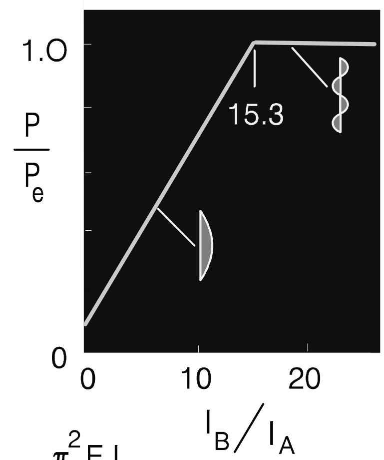
LEAN - ON SYSTEMS





$$P_e = \frac{\pi^2 E I_A}{L^2}$$

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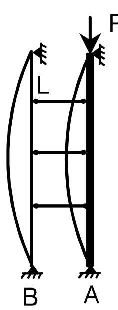
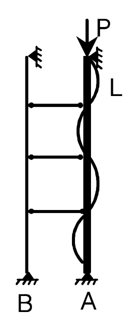


USE Σ P CONCEPT



$$\frac{\pi^2 E I_A}{(4L)^2} + \frac{\pi^2 E I_B}{(4L)^2} = \frac{\pi^2 E I_A}{L^2}$$

$$I_B = 15\ I_A$$

($15.3\ I_A$ exact)

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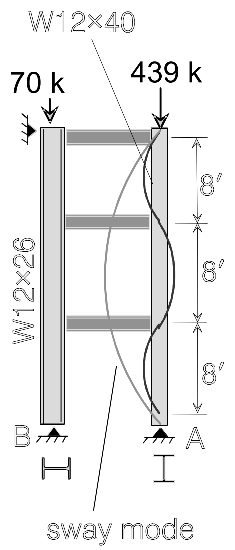
LEAN-ON SYSTEM EXAMPLE



AISC-LRFD Spec., F_y = 50 ksi, factored loads
Is the W12×26 capable of bracing the W12×40 ?

From the AISC Manual, ϕP_n = 439 k for L = 8 ft
ΣP concept: W12×40, A = 11.7 in^2, I_y = 44.1 in.^{2}
W12×26, A = 7.65 in^2, I_x = 204 in.^{2}

Col A: P_A/F_yA = 439/(50x11.7) = 0.75>0.35 $\therefore$ inelastic

τ = -6.97(0.750)log(1.111x0.750)=0.414

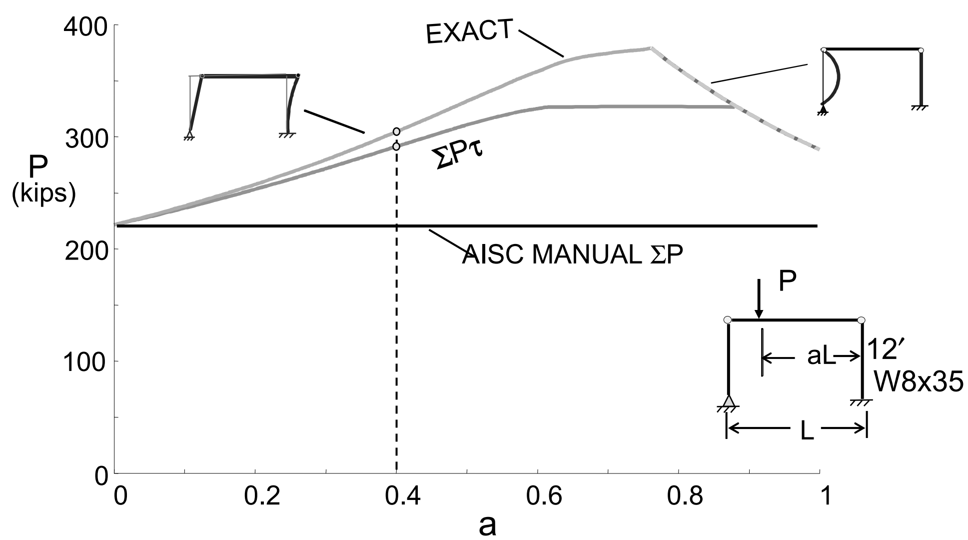
ϕP_A = 0.414 (226000) 44.1 / 288^2 = 49.7 k

Col B: P_B/F_yA = 70/(50x7.65) = 0.183<0.35 $\therefore$ τ = 1.0

ϕP_B = 1.0 (226000) 204 / 288^2 = 556 k

ΣP_{cr} = 50 + 556 = 606 > ΣP = 439 + 70 = 509 k *OK* 35

INELASTIC STORY STIFFNESS



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The "capacity" of an individual column in an unbraced frame determined from an alignment chart K-factor should be viewed only as a <u>contribution</u> to the story buckling stiffness, not as a load limit on that particular column.

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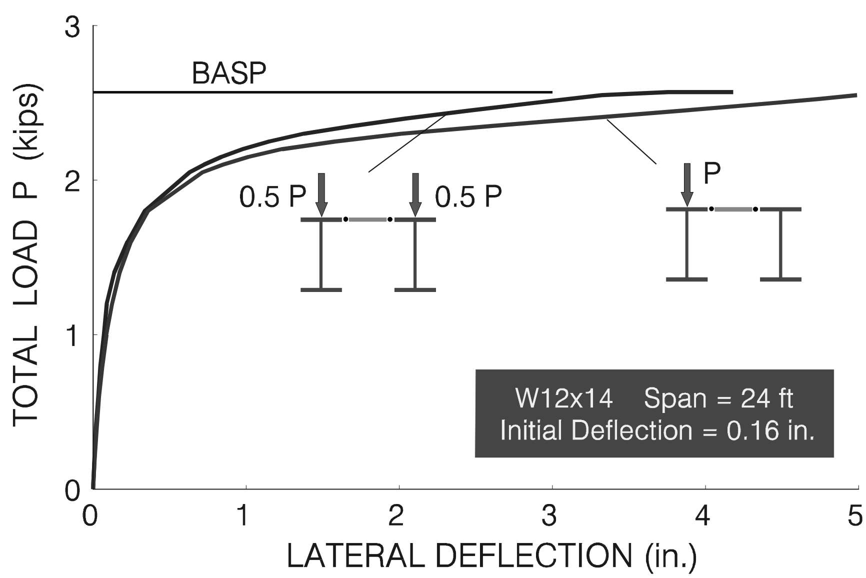
TWIN GIRDER LATERAL BUCKLING



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FIVE STABILITY CONCEPTS

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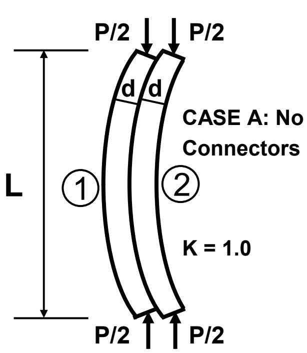
EFFECT OF SLIP ON BUILT-UP COLUMNS

Consider Three Cases:



$$\frac{P_{cr}}{2} = \frac{\pi^2 E\left(\frac{1}{12} bd^3\right)}{L^2}$$

$$P_{cr} = \frac{\pi^2 E\, bd^3}{6L^2}$$

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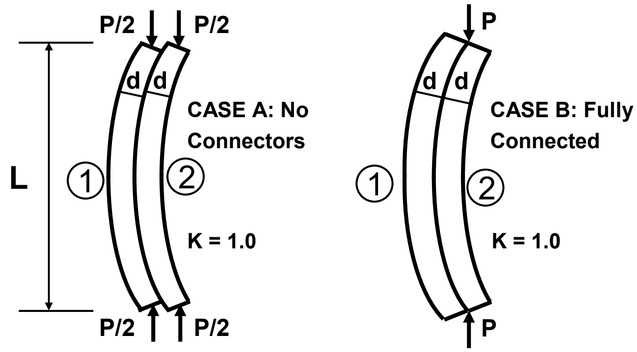
EFFECT OF SLIP ON BUILT-UP COLUMNS

Consider Three Cases:



$$\frac{P_{cr}}{2} = \frac{\pi^2 E\left(\frac{1}{12} bd^3\right)}{L^2} \qquad P_{cr} = \frac{\pi^2 E\left(\frac{1}{12} b(2d)^3\right)}{L^2}$$

$$P_{cr} = \frac{\pi^2 E bd^3}{6L^2} \qquad P_{cr} = \frac{4}{6}\frac{\pi^2 E bd^3}{L^2}$$

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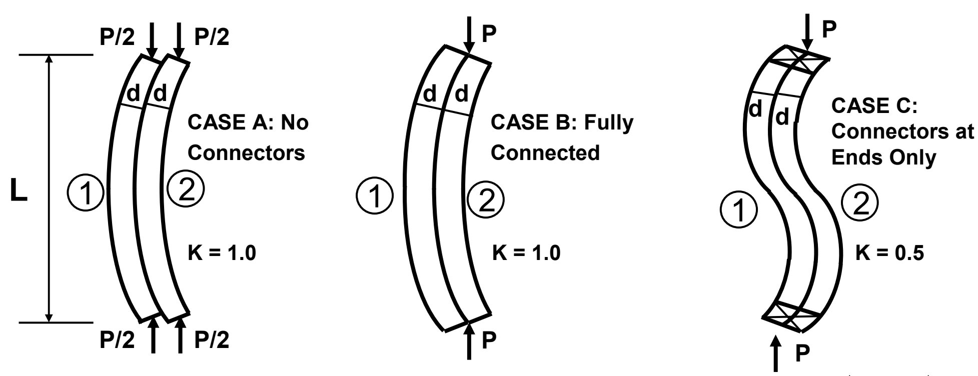
EFFECT OF SLIP ON BUILT-UP COLUMNS

Consider Three Cases:



$$\frac{P_{cr}}{2} = \frac{\pi^2 E\left(\frac{1}{12} bd^3\right)}{L^2} \qquad P_{cr} = \frac{\pi^2 E\left(\frac{1}{12} b(2d)^3\right)}{L^2} \qquad \frac{P_{cr}}{2} = \frac{\pi^2 E\left(\frac{1}{12} bd^3\right)}{(0.5L)^2}$$

$$P_{cr} = \frac{\pi^2 E bd^3}{6L^2} \qquad P_{cr} = \frac{4}{6}\frac{\pi^2 E bd^3}{L^2} \qquad P_{cr} = \frac{4}{6}\frac{\pi^2 E bd^3}{L^2}$$

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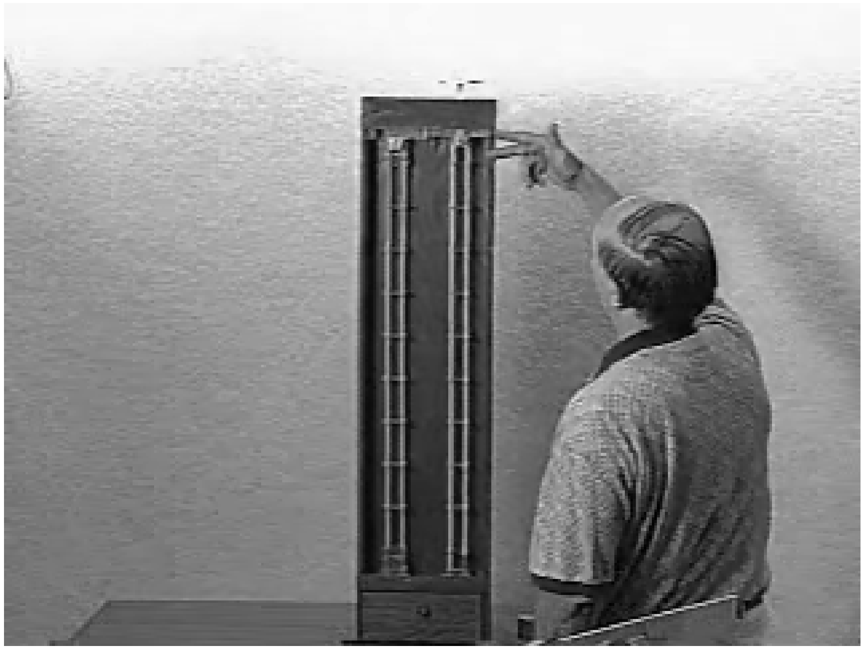
DESIGN OF BUILT-UP COLUMNS



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2L 5 x 3 x ¼ LLBB

F_y = 36 ksi L = 150 in.

$^3/_8$ in. separation

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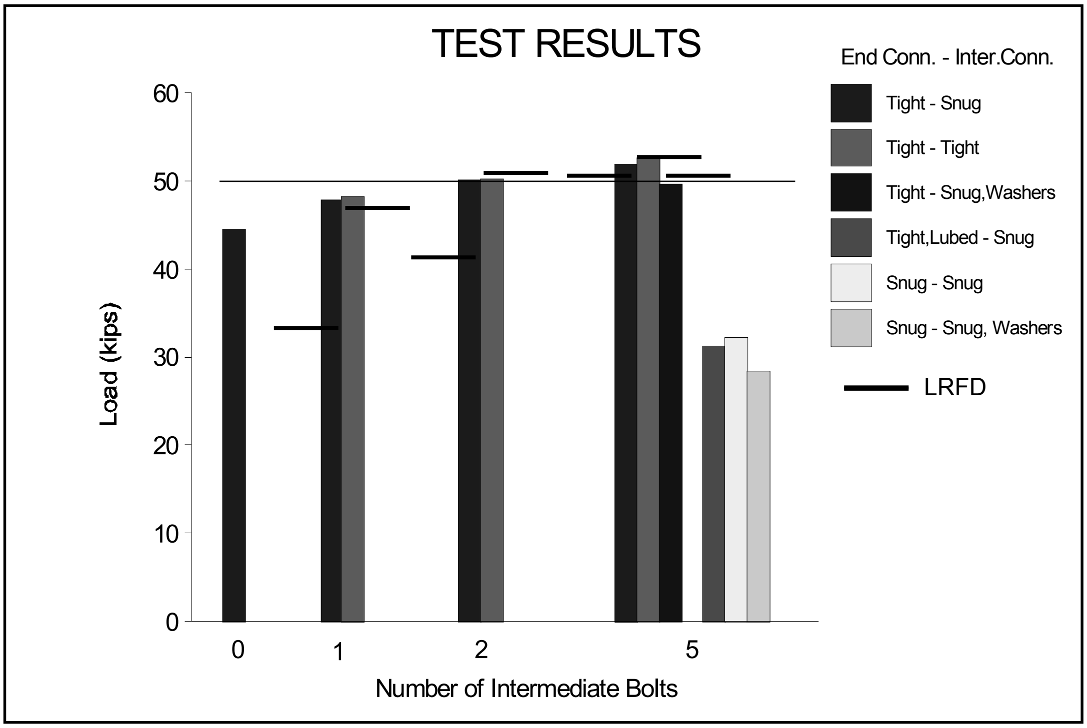

COMPRESSION MEMBERS - LRFD

(a) For intermediate connectors that are snug-tight bolted the modified column slenderness of the built-up member is:

$$\left(\frac{Kl}{r}\right)_m = \sqrt{\left(\frac{Kl}{r}\right)_0^2 + \left(\frac{a}{r_i}\right)^2} \qquad \textbf{(E6 – 1)}$$

(b) For intermediate connectors that are welded or fully tensioned bolted the modified column slenderness of the built-up member is :

$$\left(\frac{Kl}{r}\right)_m = \sqrt{\left(\frac{Kl}{r}\right)_0^2 + 0.82\frac{\alpha^2}{\left(1+\alpha^2\right)}\left(\frac{a}{r_{ib}}\right)^2} \qquad \textbf{(E6 – 2)}$$

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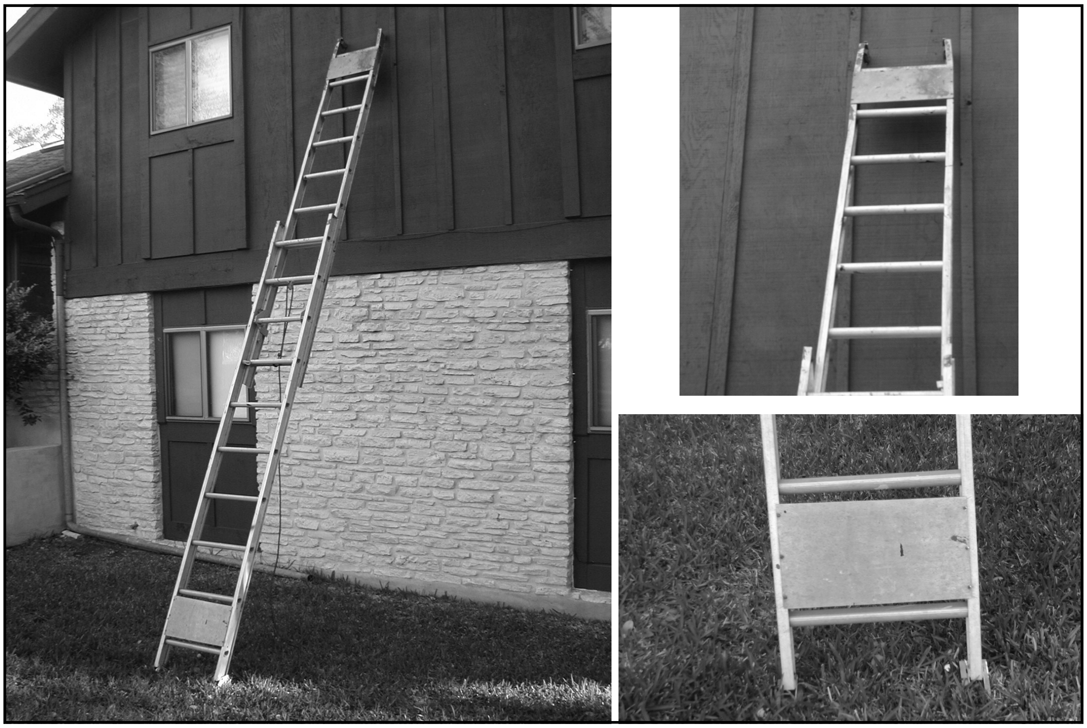

FIVE STABILITY CONCEPTS

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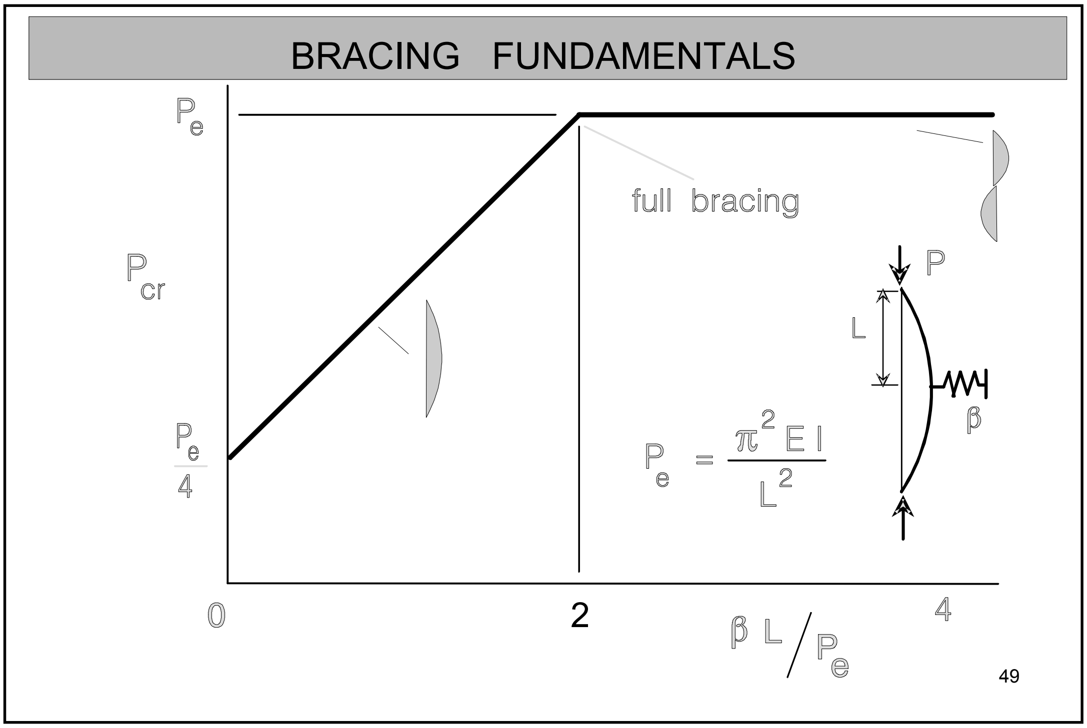

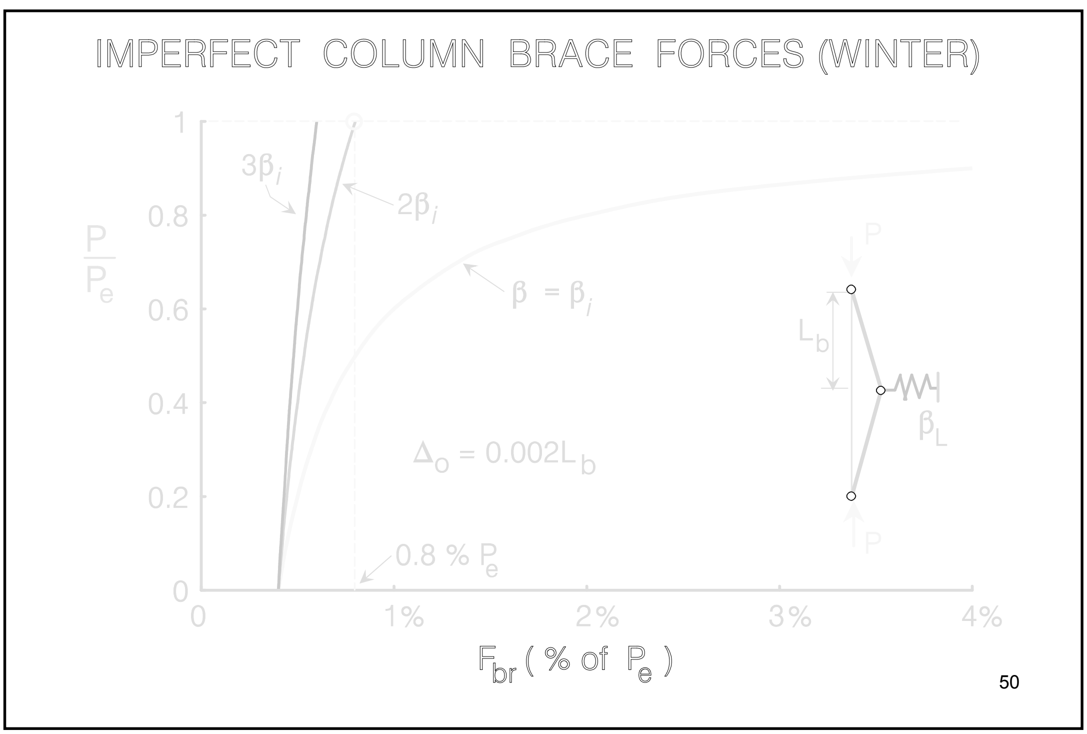

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SIMPLE RULE

- USE BRACE SYSTEM STIFFNESS AT LEAST TWICE THE IDEAL VALUE
- BRACE FORCE IS DIRECTLY RELATED TO THE MAGNITUDE OF THE INITIAL OUT-OF-STRAIGHTNESS
- DESIGN THE BRACE AND ITS CONNECTIONS FOR 1% OF THE COMPRESSIVE FORCE (Δ_1 = 0.002L)

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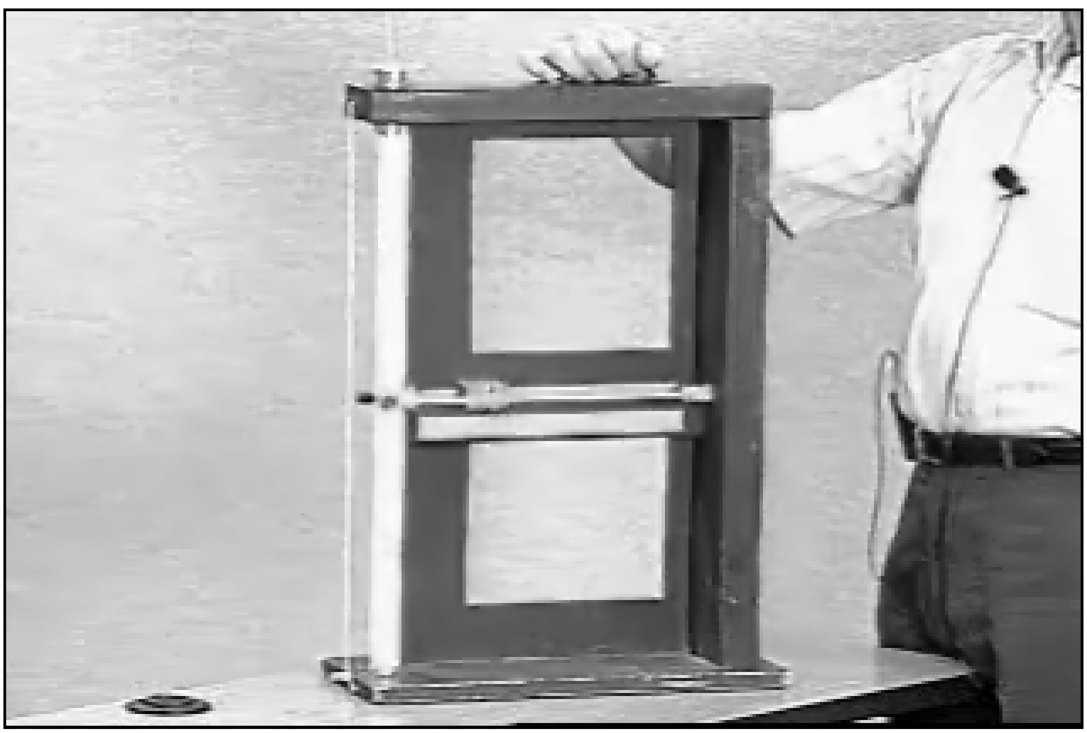

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SUMMARY

- loss of stiffness as the buckling load is approached
- inelastic column behavior
- ΣP for system buckling
- importance of end connection details in built-up columns
- stiffness and strength required for braces

REMAIN STABLE

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