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Course Description

July 31, 2017– Fundamental Concepts of Bracing Compression and Flexural Members

This lecture will focus on the fundamental behavior related to bracing of compression and flexural members. The dual criteria of stiffness and strength will be covered. The effects of imperfections on brace forces will be addressed, along with the impact of connection flexibility and cross-sectional distortion on the effectiveness of the bracing. An overview of the different classifications of bracing including relative, nodal, continuous, and lean-on bracing will be provided.

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Learning Objectives

- Identify various categories of bracing.
- Describe the fundamental requirements of bracing systems.
- Identify the differences between relative and nodal bracing for columns.
- Describe lean-on bracing systems for columns.

There's always a solution in steel.

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Fundamentals of Stability for Steel Design

Session 7: Fundamental Concepts of Bracing Compression and Flexural Members

July 31, 2017

Presented by
Todd A. Helwig, Ph.D., P.E.
University of Texas at Austin

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Fundamentals of Stability for Steel Design

Session 7
Fundamental Concepts of Bracing Compression and Flexural Members

Todd A. Helwig, P.E., Ph.D.

9

Bracing Fundamentals

- Categories of Bracing
- Fundamental Requirements of Bracing Systems
- Relative and Nodal Bracing Systems for Columns
- Lean-on Bracing Systems for Columns
- Torsional Buckling of Columns Braced on one Flange

10

Bracing Behavior – Column Bracing

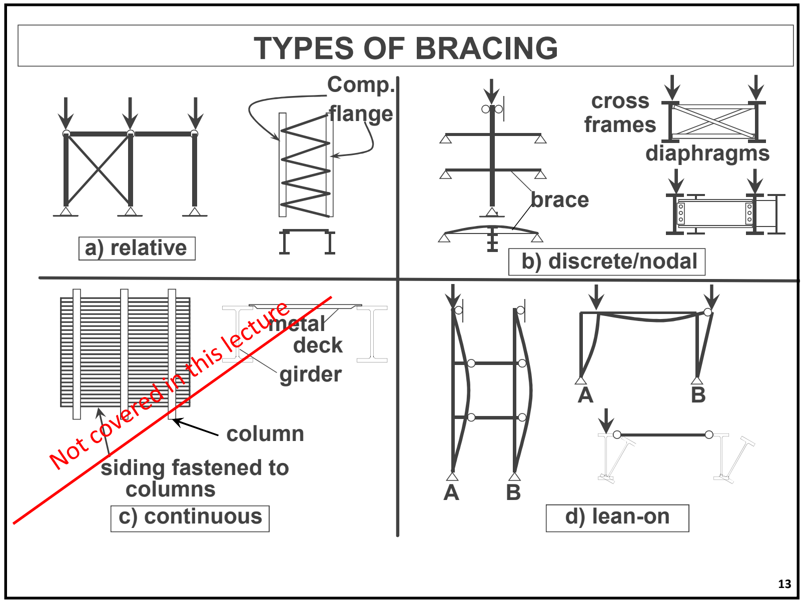
- Tonight's lecture focuses on the fundamental behavior of bracing systems.
- The lecture will focus on behavior and applications to column bracing.
- Next weeks lecture will focus on beam bracing behavior and applications.

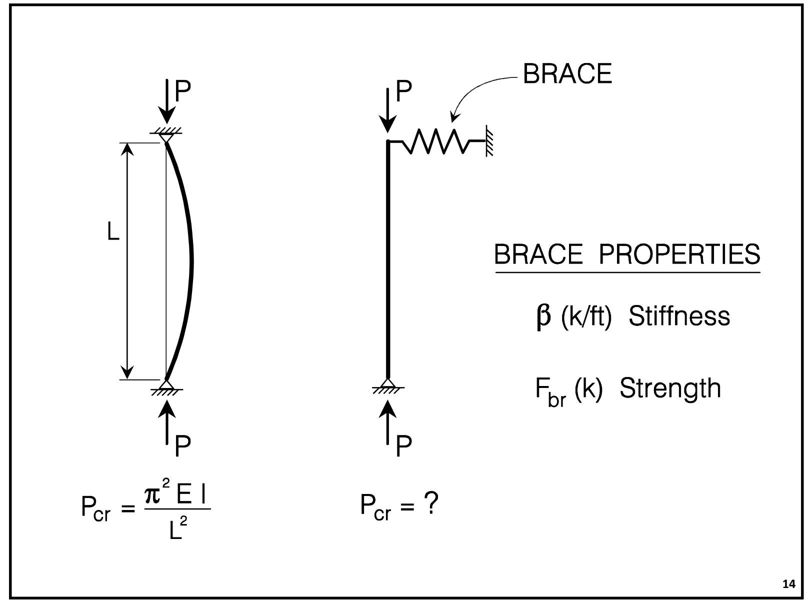
11

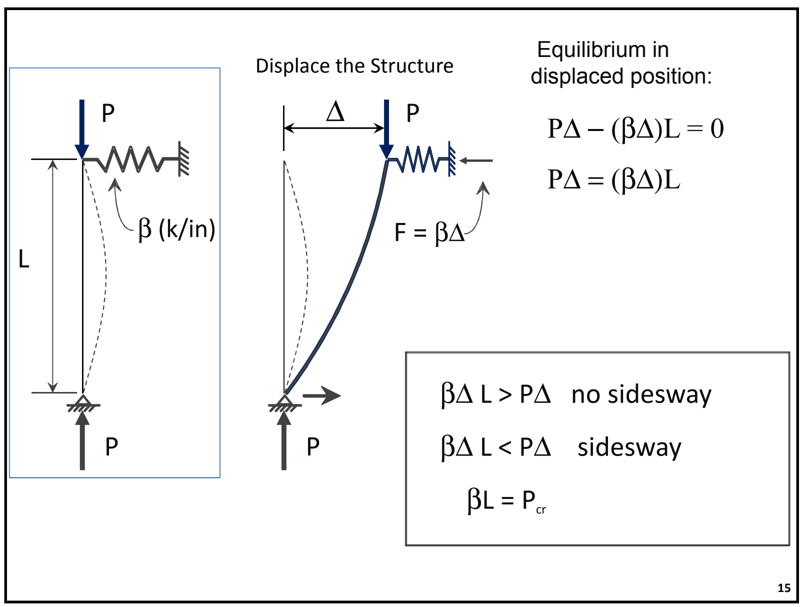
PURPOSES OF BRACING

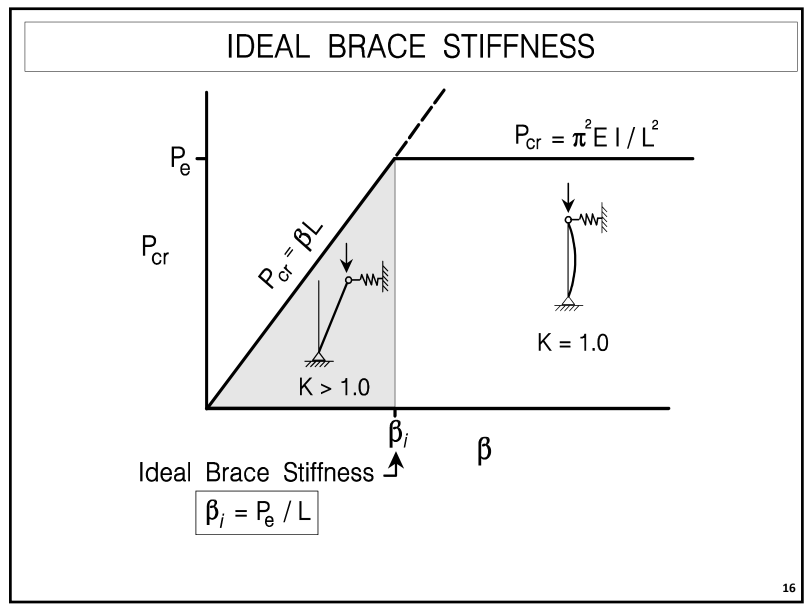
- Reduce Effective Length
- Reduce Unbraced Length
- Provide Overall Stability

12

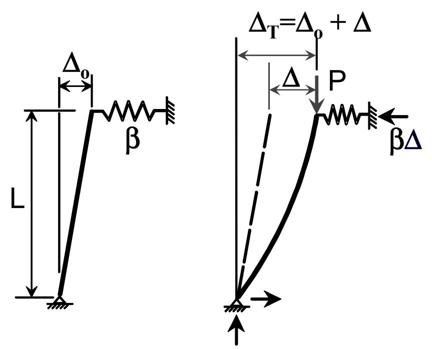

TYPES OF BRACING
Comp.
flange
a) relative
cross
frames
diaphragms
brace
b) discrete/nodal
metal
deck
girder
column
siding fastened to
columns
c) continuous
Not covered in this lecture
A
B
A
B
d) lean-on
13


P
L
P
$P_{cr} = \frac{\pi^2 E I}{L^2}$
P
BRACE
P
P_{cr} = ?
BRACE PROPERTIES
β (k/ft) Stiffness
F_{br} (k) Strength
14


P
β (k/in)
L
P
Displace the Structure
Δ
P
F = βΔ
P
Equilibrium in
displaced position:
PΔ – (βΔ)L = 0
PΔ = (βΔ)L
βΔ L > PΔ no sidesway
βΔ L < PΔ sidesway
βL = P_{cr}
15


IDEAL BRACE STIFFNESS
P_e
P_{cr}
$P_{cr} = \pi^2 E I / L^2$
$P_{cr} = \beta L$
K > 1.0
K = 1.0
β_i
β
Ideal Brace Stiffness
$\beta_i = P_e / L$
16

REAL COLUMNS - Brace Stiffness



No Axial Load | **Axial Load Applied**

Equilibrium:

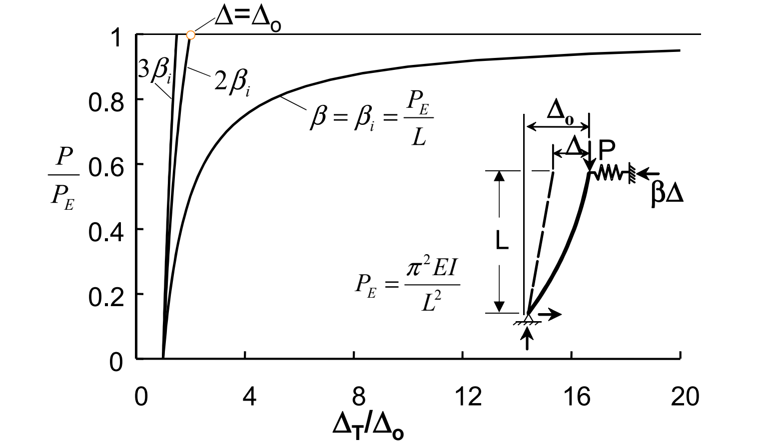
$$P\Delta_T = (\beta\Delta)L = \beta L(\Delta_T - \Delta_o)$$

$$\Delta_T = \frac{\Delta_o}{1 - \frac{P}{\beta L}}$$

Recall the ideal stiffness $\beta_i = P_E/L$:

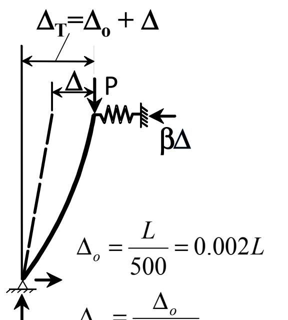
17

BRACING of IMPERFECT COLUMN (DEFORMATION)



18

REAL COLUMNS - Brace Strength



$$\Delta_o = \frac{L}{500} = 0.002L$$

$$\Delta_T = \frac{\Delta_o}{1 - \frac{P}{\beta L}}$$

$$\mathbf{F_{br}} = (\beta\Delta) = \beta(\Delta_T - \Delta_o)$$

$$F_{br} = \beta\left(\frac{\Delta_o}{1 - \frac{P}{\beta L}} - \Delta_o\right) = \beta\Delta_o\left(\frac{P/\beta L}{1 - P/\beta L}\right)$$

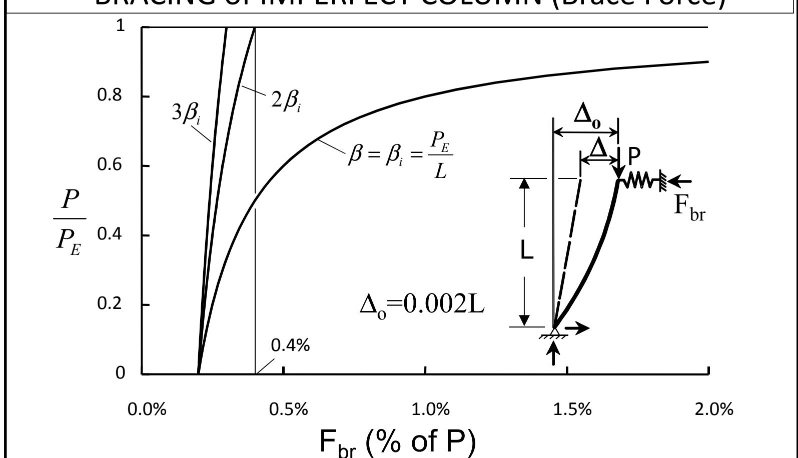
For Δ_o=0.002L:

$$\frac{F_{br}}{P} = \left(\frac{0.002}{1 - P/\beta L}\right)$$

If $\beta = 2\beta_i = 2P_E/L$: F_{br} = 0.004P at $P=P_E$

19

BRACING of IMPERFECT COLUMN (Brace Force)



20

GENERAL BRACE REQUIREMENTS

- *STIFFNESS* (Use at least twice the ideal stiffness)

  CONNECTION DETAILS CAN BE DETRIMENTAL

- *STRENGTH*

  BRACE FORCES ARE DIRECTLY RELATED TO THE MAGNITUDE OF INITIAL OUT -OF-STRAIGHTNESS

21

Appendix 6 Relative Bracing Provisions

Page 16.1-228

6.2. COLUMN BRACING

It is permitted to brace an individual *column* at end and intermediate points along the length using either relative or nodal *bracing*.

1. Relative Bracing

The *required strength* is

$$P_{rb} = 0.004P_r \quad \text{(A-6-1)}$$

The required *stiffness* is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{2P_r}{L_b}\right) \text{ (LRFD)} \qquad \beta_{br} = \Omega\left(\frac{2P_r}{L_b}\right) \text{ (ASD)} \quad \text{(A-6-2)}$$

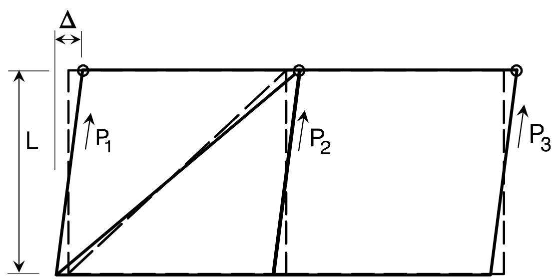
where

$\phi = 0.75$ (LRFD) $\quad \Omega = 2.00$ (ASD)

L_b = *unbraced length*, in. (mm)

22

FRAMES

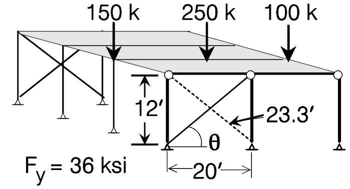


FOR STIFFNESS AND STRENGTH

USE ΣP

23

EXAMPLE - RELATIVE BRACE - TENSION SYSTEM



Typical brace must stabilize three bents . Factored load each bent = 150 + 250 + 100 = 500 kips

Design recommendations assume F_{br} and Δ are perpendicular to the column .

Brace Force : $0.004(3 \times 500)/\cos\theta = 6.99$ k

5/8 threaded rod *OK*

Brace Stiffness : $\frac{A_b E}{L_b}\cos^2\theta = \frac{2(3 \times 500 \text{ k})}{0.75(12)}$; $A_{b_{gross}} = 0.364 \text{ in}^2$

USE 3/4 ϕ , $A_g = 0.44 \text{ in}^2$

Stiffness Often Controls the Stability Bracing Requirements

24

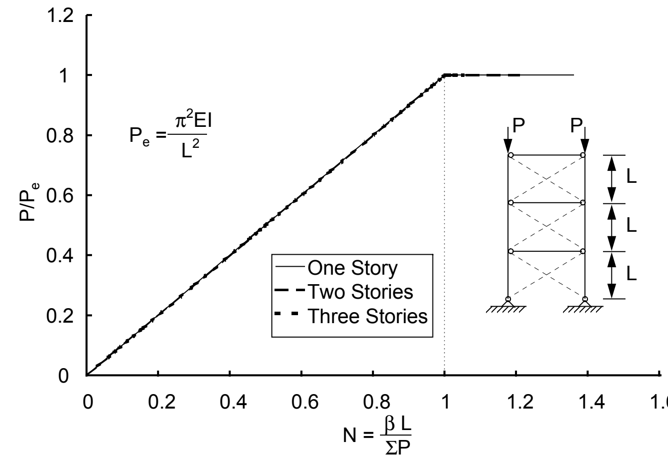
Strength versus Stiffness

- Consider two 0.5 in. diameter cables with lengths of 20 ft. and 100 ft.
- How does the tensile strength vary? ($P_y = \phi A_s F_y$).
- How does the axial stiffness of these two rods compare? $\beta_{axial} = AE/L$
- The 20 ft. long rod will be 5 times stiffer.

Watch out for long flexible braces.

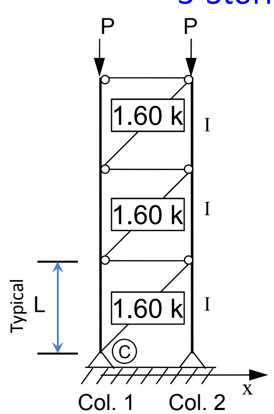
25

Stiffness Requirements For Multistory Systems



26

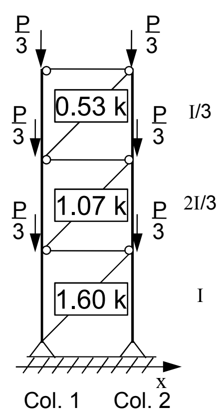
Load Path for Brace Forces For Multistory Systems
3-Stories with L = 120 inches



Frame 1

$I = 10$ in^4
L=120 in.
$\Delta_o = L/500$
P=198.8 kips
$\beta = 2\beta_i$

All brace forces are in the lateral (x) direction



Frame 2

27

BRACE STIFFNESS

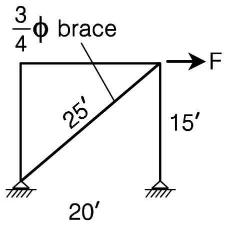
EFFECT OF CONNECTION DETAILS

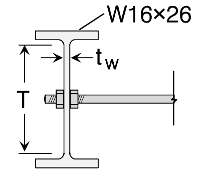
$$\frac{1}{\beta_{system}} = \frac{1}{\beta_{brace}} + \frac{1}{\beta_{connection}}$$

β_{system} will be less than or equal to the smallest of either β_{brace} or $\beta_{connection}$

28

EXAMPLE PROBLEM - System Stiffness





CONNECTION DETAIL
(at both ends of rod)

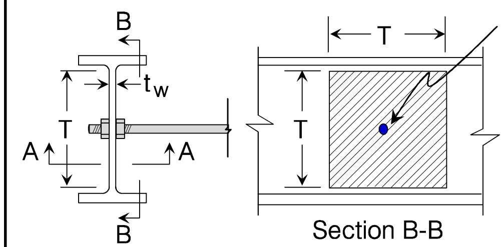
Stiffness of Rod:

$A = 0.44\ \text{in}^2;\quad \beta_{rod} = \dfrac{AE}{L_{br}}\cos^2\theta = \dfrac{0.44\,(29000)}{25\,(12)}\left(\dfrac{20}{25}\right)^2 = 27\ \text{k/in}$

Stiffness of Connection:

Idealize connection area as a square plate with dimensions T x T

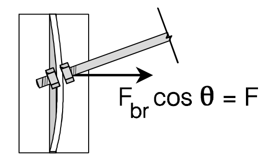
Note: This is just an academic example demonstrating the impact of connection flexibility. Proper detailing can avoid such a calculation during design.



Section B-B

$$\Delta_{℄} = C\,(1-\mu^2)\,\frac{F\,T^2}{E\,t_w^3}$$

C = .138 for S.S. ← use
= .067 for fixed



Section A-A

$$\Delta_{℄} = 0.138\,(0.91)\,\frac{F\,(13.625)^2}{29000\,(0.25)^3}$$

$F/\Delta = 19.4$ k/in each end

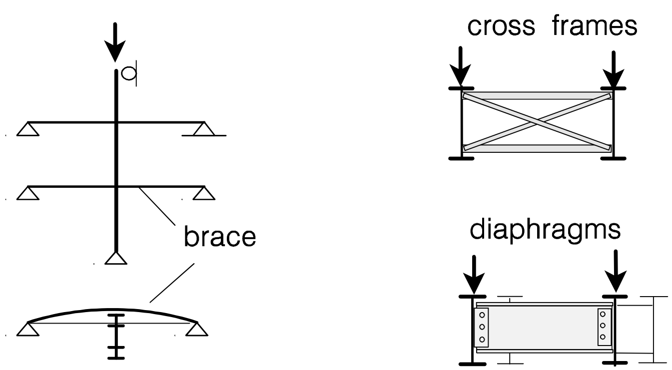
$$\frac{1}{\beta} = \frac{1}{19.4} + \frac{1}{19.4} + \frac{1}{27} \quad \therefore \quad \beta = 7.1\ \text{k/in}$$

System Stiffness is only 26% of rod stiffness !!

Fixture For Inclined Braces

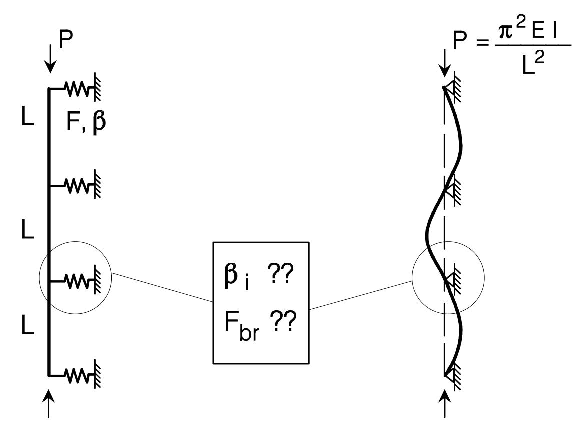
34

DISCRETE (NODAL) BRACING



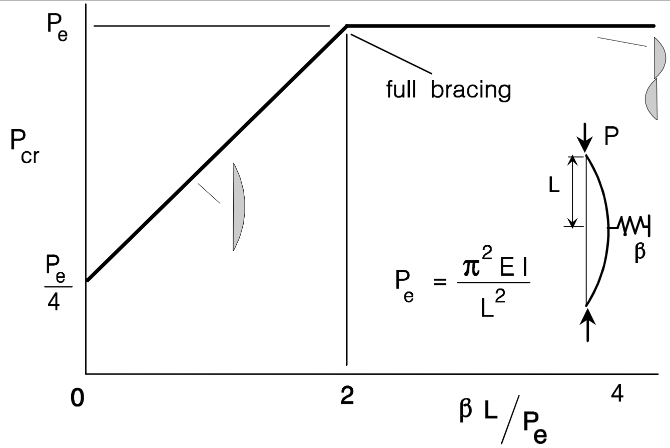
35

DISCRETE BRACES



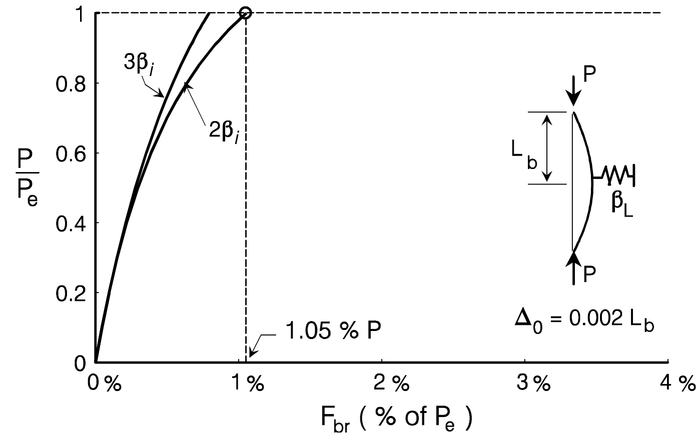
36

BRACING FUNDAMENTALS



37

IMPERFECT COLUMN BRACE FORCES (FEM)



AISC Appendix 6 Uses $P_{br} = 0.01\ P_r$

38

Nodal Bracing – Ideal Stiffness

Depending on the number of intermediate braces, the ideal stiffness (β_i) for a nodal bracing system is somewhere between 2P/L and 4P/L.

Timoshenko provided the exact ideal stiffness for a column restrained by intermediate braces: $\beta_i = \frac{\alpha P}{L}$

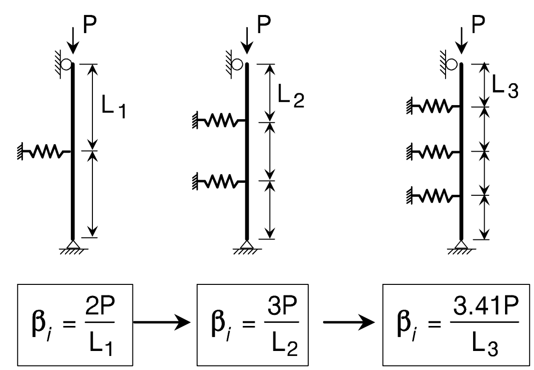
# of braces, n	1	2	3	4	Lots
α	2	3	3.41	3.62	4
$N_i = 4 - \frac{2}{n}$	2	3	3.33	3.5	4

Approximation: $\beta_i = \frac{N_i P}{L}$

The Appendix 6 Provisions Assume "lots" of braces. The N_i expression is in Commentary

39

IDEAL BRACE STIFFNESS REQUIREMENTS

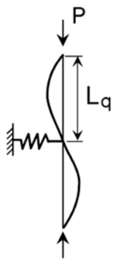


More braces require more stiffness ?!

40

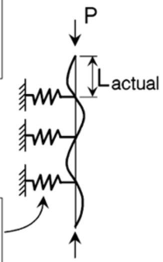
IS THE IDEAL BRACE STIFFNESS REQUIRED?

REQUIRED BRACING



$$P = \frac{\pi^2 EI}{(L_q)^2}$$

ACTUAL BRACING



$$\beta_i = \frac{3.41P}{L_{actual}}$$

$$\beta_{req} = \frac{3.41P}{L_q}$$

Page 16.1-229

In Equation A-6-4, L_b need not be taken less than the maximum *effective length*, *KL*, permitted for the column based upon the required axial strength, P_r.

41

Appendix 6 Nodal Bracing Provisions (Columns)

Page 16.1-228

2. **Nodal Bracing**

The *required strength* is

$$P_{rb} = 0.01P_r \quad \text{(A-6-3)}$$

The required *stiffness* is

$$\beta_{br} = \frac{1}{\phi}\left(\frac{8P_r}{L_b}\right) \text{ (LRFD)} \qquad \beta_{br} = \Omega\left(\frac{8P_r}{L_b}\right) \text{ (ASD)} \quad \text{(A-6-4)}$$

User Note: These equations correspond to the assumption that *nodal braces* are equally spaced along the *column*.

where

$\phi = 0.75$ (LRFD) $\quad \Omega = 2.00$ (ASD)

For design according to Section B3.3 (LRFD)

P_r = required strength in axial compression using *LRFD load combinations*, kips (N)

For design according to Section B3.4 (ASD)

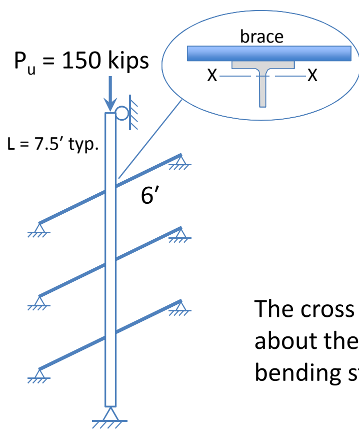
P_r = required strength in axial compression using *ASD load combinations*, kips (N)

Page 16.1-229

In Equation A-6-4, L_b need not be taken less than the maximum *effective length*, *KL*, permitted for the column based upon the required axial strength, P_r.

42

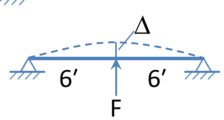
COLUMN NODAL BRACING EXAMPLE



Consider the 30 ft. long WT7x34 that is braced by three 12 ft. long cross members spaced along the length. Buckling about the X-X axis controls. Size the members to provide adequate bracing.
Brace F_y = 36 ksi

The cross members will brace the column about the X-X axis based upon their bending stiffness:

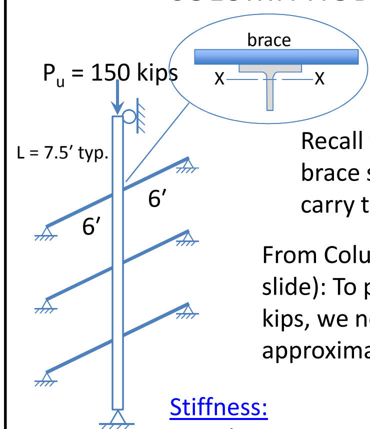
$$\Delta = \frac{FL_{br}^3}{48EI}$$



$$\beta = \frac{F}{\Delta} = \frac{48EI}{L_{br}^3}$$

43

COLUMN NODAL BRACING EXAMPLE



Recall that we do not need to use a larger brace spacing than is actually needed to carry the 150 kip load.

From Column Load Tables on Pg. 4-113 (see next slide): To possess a load capacity larger than 150 kips, we need an unbraced length of approximately 18 ft.

Stiffness:

With n=3 intermediate braces: N_i = 4-2/n = 3.33

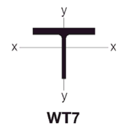
$$\beta_{req'd} = \frac{2x3.33(150)}{0.75(18\;x\;12)} = 6.1\;k/in$$

44

AISC Manual – Page 4-113

F_y = 50 ksi

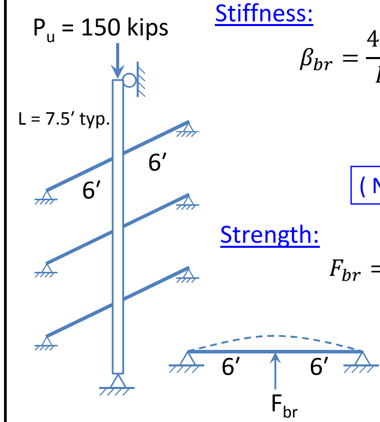
Table 4-7 (continued)
Available Strength in Axial Compression, kips
WT-Shapes



Shape		WT7×											
lb/ft		37		34		30.5[c]		26.5[c]		24[c]		21.5[c]	
Design		P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
…ect to indicated axis, X-X Axis	0	326	491	299	450	260	392	223	336	186	280	146	219
	10	237	357	217	326	190	286	168	252	143	215	115	173
	12	206	310	188	283	165	249	148	223	128	192	104	156
	14	175	263	159	240	140	211	128	192	111	167	92.1	138
	16	145	217	132	198	116	175	108	162	95.2	143	80.0	120
	18	116	175	106	159	93.5	141	88.7	133	79.7	120	68.1	102
	20	94.2	142	85.5	128	75.8	114	71.9	108	65.2	98.0	57.0	85.6
	22	77.9	117	70.7	106	62.6	94.1	59.5	89.4	53.9	81.0	47.1	70.8
	24	65.4	98.3	59.4	89.2	52.6	79.1	50.0	75.1	45.3	68.1	39.6	59.5
	26	55.7	83.8	50.6	76.0	44.8	67.4	42.6	64.0	38.6	58.0	33.7	50.7
	28	48.1	72.02	43.6	65.6	38.7	58.1	36.7	55.2	33.3	50.0	29.1	43.7
	30	41.9	62.9	38.0	57.1	33.7	50.6	32.0	48.1	29.0	43.6	25.3	38.1

45

ADJUSTMENT FOR EXTRA BRACES



Stiffness:

$$\beta_{br} = \frac{48EI}{L_{br}^3} = \frac{48(29000)I}{(12\ x\ 12)^3} \geq 6.1\frac{k}{in} = \beta_{req'd}$$

$$I_{br} \geq 13.1\ in^4$$

(Note: I_{br} = 31.7 in^4 if L_{br} = 7.5′)

Strength:

$$F_{br} = 0.01x150\ k = 1.5\ k$$

$$M_{br} = \frac{1.5k(12x12)}{4} = 54\ k - in$$

$$S_{br} = \frac{54\ k - in}{(0.9\ x\ 36\ ksi)} = 1.7\ in^3$$

Use M8x6.2: $I_x = 17.6\ in^4 > 13.1 in^4$, $S_x = 4.39\ in^3 > 1.7 in^3$

46

Knowledge Check

Select the answer from the list below that best answers the question:

The most important quality for effective stability bracing is:

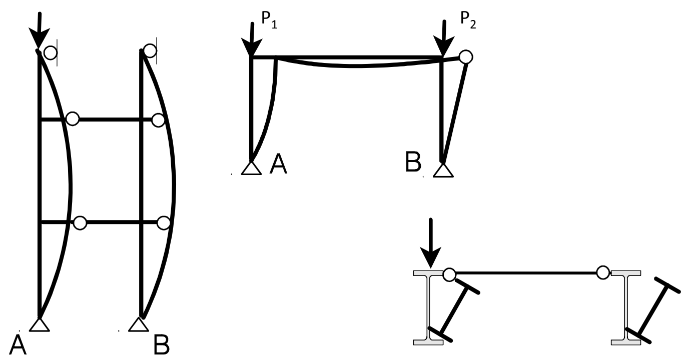
A) Stiffness
B) Strength
C) Both A) and B)
D) Either A) or B)

47

Video demonstrating brace stiffness and strength requirements

48

LEAN - ON BRACING



49

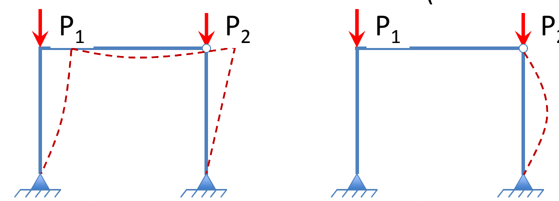
ΣP Concept - Elastic

A)FOR SWAY BUCKLING OF A STORY

$$\Sigma P_{\text{Story Column Loads}} \leq \Sigma P_{cr_i}$$

Sway buckling load of columns using Sway K

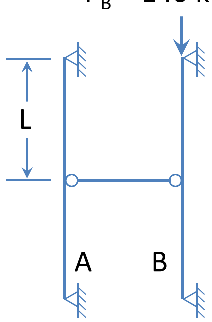
B) EACH COLUMN MUST SUPPORT ITS OWN COLUMN LOAD IN THE NO-SWAY MODE (ie. with K=1.0)



$P_1 + P_2 \leq P_{cr1} + P_{cr2}$

50

Lean-On Bracing Example



Consider the two columns that are linked together at midheight by the pin-ended strut.

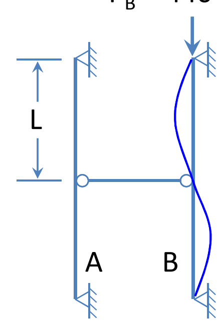
Column B has an applied load P=140 k, while Column A is unloaded.

L = 180 in.
I_B = 50 in^4

How large of a moment of inertia (I_A) is required for Column A to have a safe system?

51

Lean-On Bracing Example



Column B:

First, make sure that Column B will not buckle between the brace points (ie. the link member).

L = 180 in. ; I_B = 50 in^4

$$P_{cr-KL=180"} = \frac{\pi^2(29000)50}{(180)^2}$$

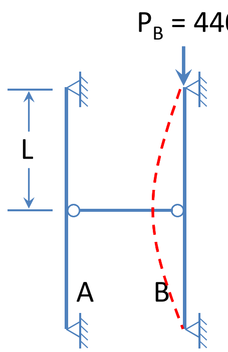
$$P_{cr-KL=180"} = 442\ kips > 440\ kips$$

OK

52

Lean-On Bracing Example

P_B = 440 k



With no bracing, Column B contributes the Euler Load with a length of 2L = 360 in.

2L = 360 in. ; I_B = 50 in^4

$$P_{cr\ B-KL=360"} = \frac{\pi^2(29000)50}{(360)^2}$$

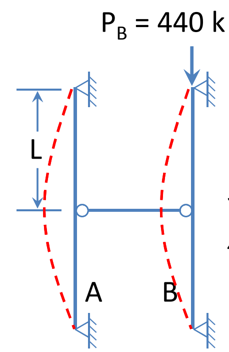
$$P_{cr\ B-KL=360"} = 110\ kips < 440\ kips$$

With no help from Column A, we would have to increase the moment of inertia of Column B to 200 in^4 to support the 440 kip load

53

Lean-On Bracing Example

P_B = 440 k



However, because of the strut, both columns A and B will displace as shown and we can use the summation of P concept:

$$\sum P_{cr} = P_{cr\ A} + P_{cr\ B} \geq 0k + 440k = \sum P$$

$$\sum P_{cr} = \frac{\pi^2(29000)I_A}{(2x180)^2} + \frac{\pi^2(29000)50}{(2x180)^2} \geq 440k$$

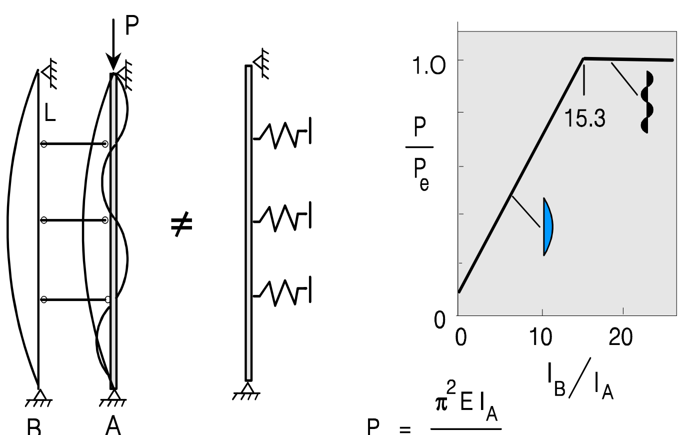
$I_A \geq 150\ in^4$

Exact solution is 165 in^4 – treating as nodal brace

Note: The total moment of inertia is 150 in^4 + 50 in^4 = 200 in^4 which is the same moment of inertia we would have had to increase Column B with no bracing from Column A.

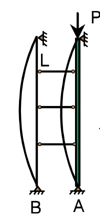
54

LEAN - ON SYSTEMS



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

LEAN - ON SYSTEMS

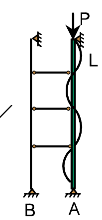


USE Σ P CONCEPT

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

$$I_B = 15\ I_A$$

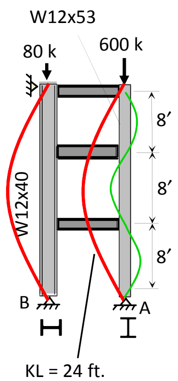
($15.3\ I_A$ exact)



Again, the load corresponding to column A buckling in 4 waves as shown on the right is 16 times the load for Column A buckling in the half-sine curve on the left. Therefore we could simply provide $16I_A$ – or make I_B=$15I_A$ for a total moment of inertial of $16I_A$.

56

LEAN-ON SYSTEM EXAMPLE (Use Column Load Tables)



Consider the two columns with orientations and factored loads shown (LRFD). Is the W12x40 capable of bracing the W12x53? Check the combined contribution of the two columns depicted in red (KL = 24 ft.). LRFD Example – Factored Loads, F_y = 50 ksi

Make sure Col. B won't buckle between brace points (sketched in green):

From the AISC Manual – Page 4-20: (W12x53)

ϕP_n = 629 k for L = 8 ft – "Link" spacing is adequate for W12x53

Both columns contribute P_{cr} based upon a 24 ft. unbraced length:

Find the contribution of both columns for mode sketched in red.

Col A: With a 24′ unbraced length about weak axis:

W12x53: ϕP_n = 261 k for L = 24 ft

Col B: With a 24′ unbraced length about strong axis (r_x/r_y = 2.64):

KL_{eqv} = 24′/2.64 = 9′ - ϕP_n = 420 k

ΣP_{cr} = 261k + 420k = 681k > 680k = 80k+600k = ΣP *OK*

Yes, the W12x40 can brace the W12x53

57

Column Load Tables (Page 4-20)

W12

Table 4-1 (continued)
Available Strength in Axial Compression, kips
W-Shapes

F_y = 50 ksi

Shape	W12×									
lb/ft	58		53		50		45		40	
Design	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$	P_n/Ω_c	$\phi_c P_n$
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
0	509	765	467	702	437	657	392	589	350	526
6	479	720	439	660	396	595	355	534	317	476
7	469	705	429	646	382	574	342	515	305	459
8	457	687	419	629	367	551	329	494	293	440
9	445	668	407	611	350	526	313	471	279	420
10	431	647	394	592	332	500	297	447	265	398
11	416	625	380	571	314	472	281	422	250	375
12	400	601	365	549	295	443	263	396	234	352
13	384	577	350	526	275	413	246	369	218	328
14	367	551	334	502	255	384	228	343	202	304
15	349	525	318	478	236	355	210	316	187	281
16	332	499	301	453	217	326	193	290	171	257
17	314	472	285	428	198	298	176	265	156	235
18	296	445	268	403	180	270	160	240	142	213
19	278	418	252	378	162	244	144	216	127	191
20	261	392	235	354	146	220	130	195	115	173
22	227	341	204	307	121	182	107	161	95.0	143
24	194	292	174	261	102	153	90.3	136	79.8	120
26	165	249	148	223	86.6	130	76.9	116	68.0	102
28	143	214	128	192	74.7	112	66.3	99.7	58.6	88.1

...th, KL (ft), with respect to least radius of gyration, r_y

Properties at bottom of table give r_x/r_y = 2.64

58

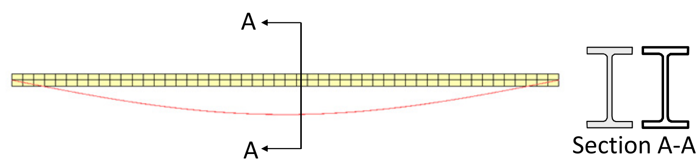
Torsional Buckling of Columns

A) Columns braced at centroid

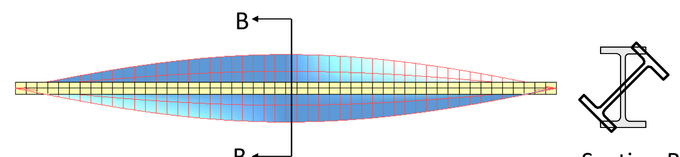
B) Columns braced on one flange (constrained axis buckling)

59

POTENTIAL BUCKLING MODES



1) Flexural Buckling



2) Torsional Buckling

60

AISC Provisions for Torsional Buckling

Page 16.1-33

E3. FLEXURAL BUCKLING OF MEMBERS WITHOUT SLENDER ELEMENTS

This section applies to nonslender element compression members as defined in Section B4.1 for elements in uniform compression.

User Note: When the torsional *unbraced length* is larger than the lateral unbraced length, Section E4 may control the design of wide flange and similarly shaped *columns*.

Page 16.1-34

E4. TORSIONAL AND FLEXURAL-TORSIONAL BUCKLING OF MEMBERS WITHOUT SLENDER ELEMENTS

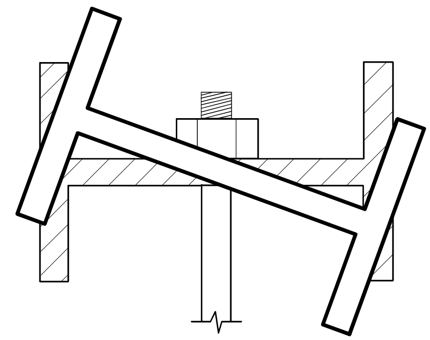
(b) For all other cases, F_{cr} shall be determined according to Equation E3-2 or E3-3, using the torsional or flexural-torsional elastic *buckling* stress, F_e, determined as follows:

(i) For doubly symmetric members:

$$F_e = \left[\frac{\pi^2 EC_w}{(K_z L)^2} + GJ\right]\frac{1}{I_x + I_y} \quad \text{(E4-4)}$$

61

INEFFECTIVE TORSIONAL BRACE



62

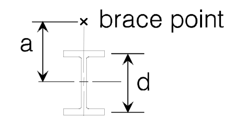
Elastic Torsional Buckling Expression

$$P_T = \frac{\dfrac{\pi^2 EI_y}{(L_T)^2}\left(\dfrac{h_o^2}{4}\right) + GJ}{(r_x)^2 + (r_y)^2}$$

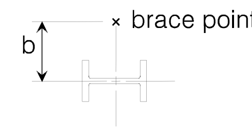
L_T = spacing between points where twist is restrained
E = modulus of elasticity of column material
I_y = weak-axis moment of inertia
J = torsional constant
G = shear modulus
$r_{x,y}$ = radius of gyration about x or y axis
h_o = distance between flange centroids

63

BUCKLING ABOUT A RESTRAINED AXIS



$$P_T = \frac{P_{ey}\left(\dfrac{d^2}{4} + a^2\right) + GJ}{a^2 + r_x^2 + r_y^2}$$

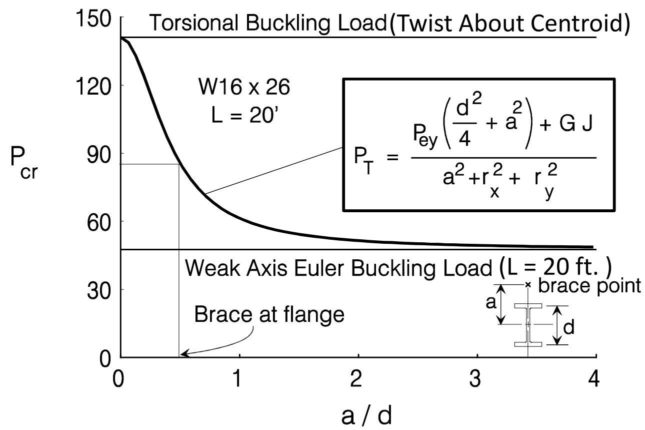


$$P_T = \frac{P_{ey}\left(\dfrac{d^2}{4} + \dfrac{I_x}{I_y}b^2\right) + GJ}{b^2 + r_x^2 + r_y^2}$$

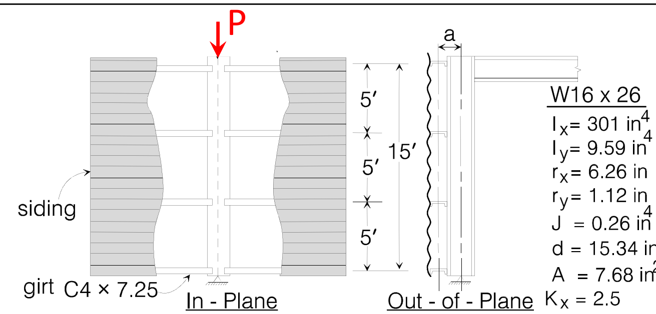
$$P_{ey} = \frac{\pi^2 EI_y}{L_T^2}$$

Design for 90% of P_T

BUCKLING ABOUT A RESTRAINED AXIS



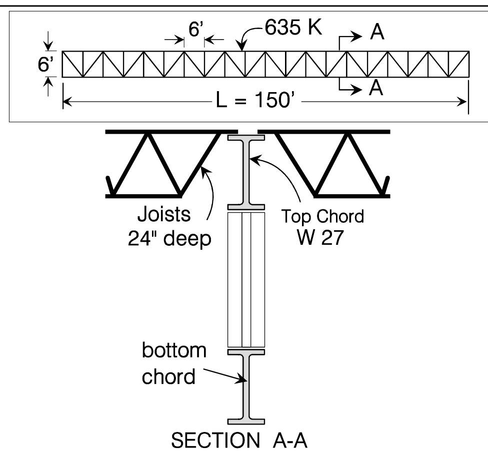
Buckling Modes to Consider

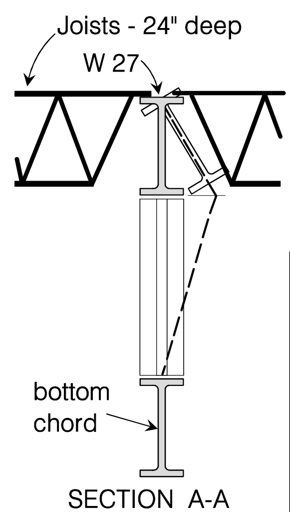


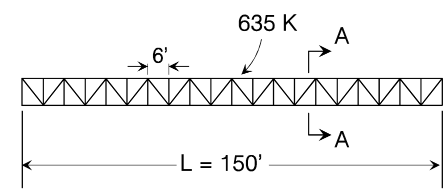
Check three types of buckling:

1) Strong axis flexural buckling (L = 15 ft. and K_x=2.5) $\phi P_{nx} = 335k$
2) Weak axis flexural buckling (L = 5 ft. and K_y=1.0) $\phi P_{ny} = 600k$
3) Torsional buckling about a restrained axis. $\phi P_{nT} = 85k$
   L_T = 15', Offset = a = d/2+4"/2

TORSIONAL BUCKLING CASE STUDY



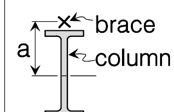




L = distance between braces that prevent twist

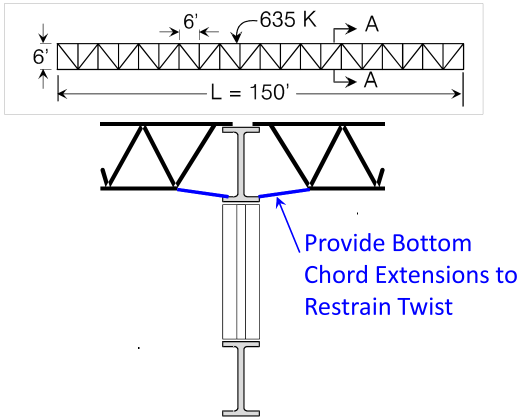
TORSIONAL BUCKLING

$$P_{cr} = \frac{P_{ey}\left(\frac{d^2}{4} + a^2\right) + GJ}{a^2 + r_x^2 + r_y^2} = 180\text{ k}$$



where $P_{ey} = \dfrac{\pi^2 E I_y}{L^2}$

TORSIONAL BUCKLING CASE STUDY



69

Knowledge Check

Torsional buckling can control the capacity of a column over weak axis flexural buckling when the unbraced length for torsional buckling is greater than the unbraced length for flexural buckling.

A) True

B) False

70

Summary

- There are 4 different categories of bracing: relative, nodal, continuous, and lean-on.
- Bracing must satisfy both stiffness and strength requirements.
- Brace strength requirements are a direct function of the magnitude of the imperfection.
- Correction (L_q) for problems when more nodal braces are provided than necessary.

71

Summary

- Lean-on bracing concepts can offer an efficient method of stabilizing a column without adding specific bracing to the structure.
- Torsional buckling (twisting about the centroid) may control the design when the unbraced length for torsional buckling exceeds that for flexural buckling.
- Constrained axis buckling can result in lower buckling capacities relative to twisting about the shear center and should be considered when columns (or truss chords) are braced on one flange.

72

Up Next…

Session 8: August 7, 2017
Design of Bracing for Beams by J. Yura, PE, PhD
This lecture will emphasize the design requirements for beam systems. Several design examples will be provided that demonstrate the effective use of the AISC Specification Appendix 6 provisions. These examples will include relative, nodal, and lean-on applications. The uses of the provisions covered in the specification appendix as well as modifications covered in the specification commentary will be addressed.

73

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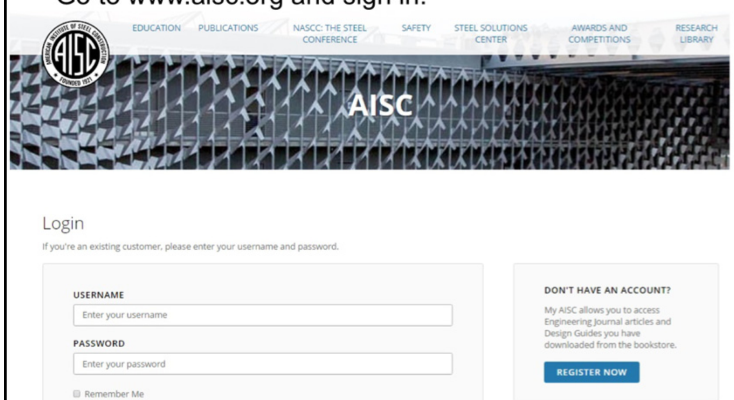

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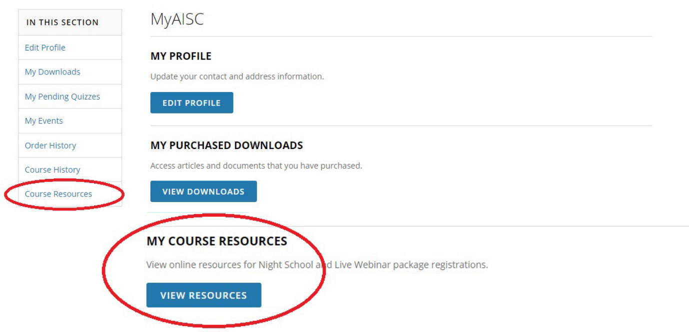

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Course Resources

Event	Start Date
NS 13 8-Session Package-Night School 13 - Design of Industrial Buildings	1/30/2017 7:00:00 PM
NS 14 8-Session Package-Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM

Night School Resources for 8-session package Registrants

Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dsn	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	Handouts	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending
NS13 - Final Exam	4/10/2017 7:00:00 PM			Available 04/12/2017 5pm EST	

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