Night School 23: Topics on Industrial Building Design and Design of Non-building Structures

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Session 3 – Industrial Buildings -- Part 2

July 7, 2020

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Stronger.
Steel.

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Course Description

Industrial Buildings -- Part 2
July 7, 2020

This session takes a deep dive into various aspects of the design of industrial buildings and reviews some of the challenges including unique analysis, stability, horizontal bracing of members and torsional bracing. The session will review seismic analysis, column flange bracing, sag rods and their role, framing standing seam roofs, and more.

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Learning Objectives

- Review steel building framing systems commonly used for industrial buildings
- Investigate dynamic loads and impact factors
- Investigate unique analysis requirements for industrial buildings
- Investigate unique member stability bracing topics pertinent to industrial buildings

Night School 23: Industrial Structures

Session 3: Industrial Buildings Part 2
July 7, 2020

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Bo Dowswell, P.E., PhD, Arc International LLC


Smarter.
Stronger.
Steel.

INTRODUCTION

SESSION 1 INTRODUCTION AND CODE PROVISIONS
SESSION 2 INDUSTRIAL BUILDINGS – PART 1
SESSION 3 INDUSTRIAL BUILDINGS – PART 2
SESSION 4 CRANE SUPPORTING STRUCTURES
SESSION 5 FATIGUE DESIGN FOR INDUSTRIAL STRUCTURES
SESSION 6 HIGH & LOW TEMPERATURE DESIGN FOR INDUSTRIAL STRUCTURES
SESSION 7 NON-BUILDING STRUCTURES –PART 1
SESSION 8 NON-BUILDING STRUCTURES –PART 2

SESSION 3: INDUSTRIAL BUILDINGS - PART 2

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  - Design for high and low temperature applications
  - Design for vibrational loading

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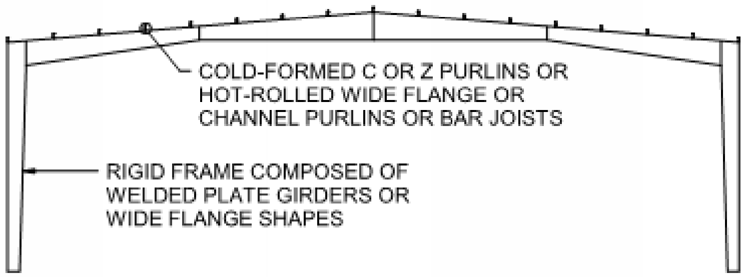
INDUSTRIAL BLDGS. – STEEL FRAMING SYSTEMS

Rigid Frame with Roof Purlins or Bar Joists:



RIGID FRAME WITH PURLINS OR BAR JOISTS

ROOF BEAM COULD ALSO BE TRUSS OR JOIST GIRDER WITH RIGID CONNECTION TO COLUMN

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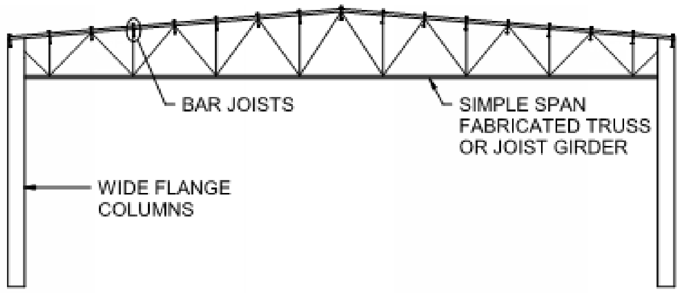
INDUSTRIAL BLDGS. – STEEL FRAMING SYSTEMS

Hot Rolled Columns – Simple Span Truss or Joist Girder – Roof Purlins or Bar Joists



HOT-ROLLED COLUMNS WITH SIMPLE SPAN TRUSS/JOIST GIRDER AND BAR JOISTS

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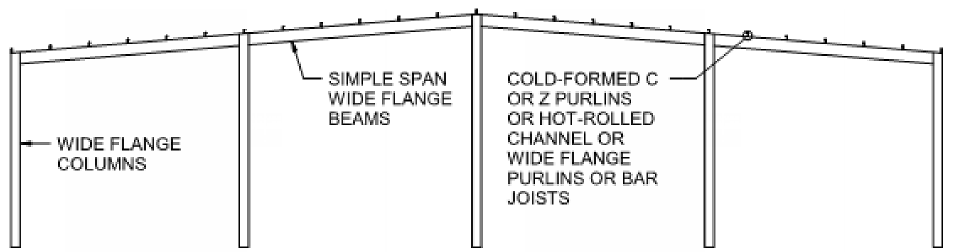
INDUSTRIAL BLDGS. – STEEL FRAMING SYSTEMS

Hot Rolled Columns – Simple Span Roof Beams – Roof Purlins or Bar Joists



HOT-ROLLED BEAMS AND COLUMNS WITH PURLINS OR BAR JOISTS

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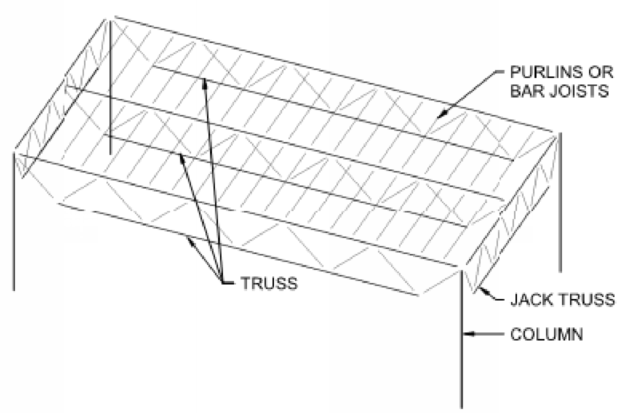
INDUSTRIAL BLDGS. – STEEL FRAMING SYSTEMS

Hot Rolled Columns – Combination of Roof Trusses and Jack Trusses – Roof Purlins or Bar Joists (Common System used in Automotive Plants)



HOT-ROLLED COLUMNS WITH ROOF TRUSSES, JACK TRUSSES, AND PURLINS OR BAR JOISTS

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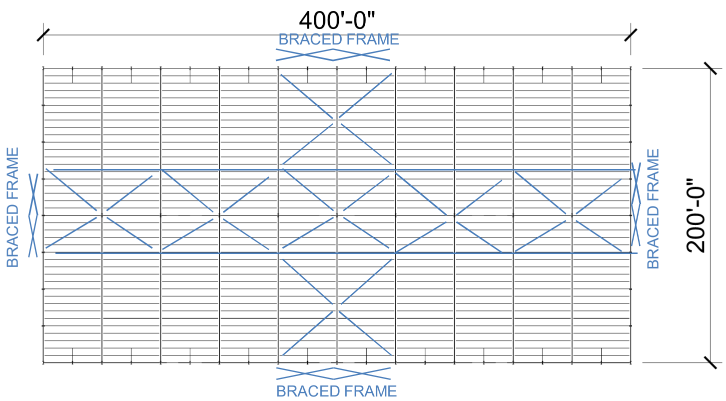
LATERAL LOAD RESISTING SYSTEM

BUILDING WITH SMALLER ASPECT RATIOS



Braced Frame Systems

- Requires roof deck diaphragm or roof horizontal truss diaphragm to distribute lateral loads to braced frames
- Generally applicable when building aspect ratio is 3:1 or less
- Provides low-cost system when roof deck diaphragm can be used with reasonable fastening
- Not recommended to use roof deck diaphragm to transfer crane lateral forces for high use cranes

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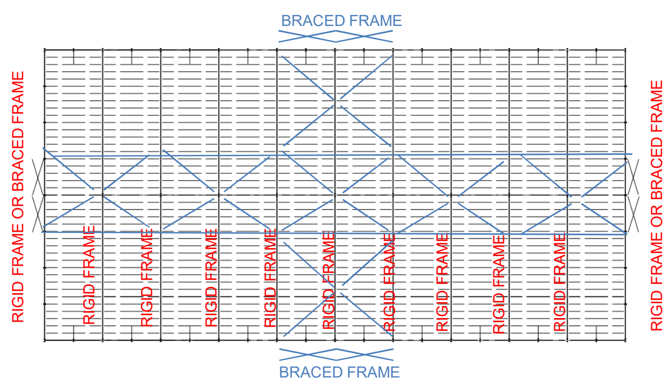
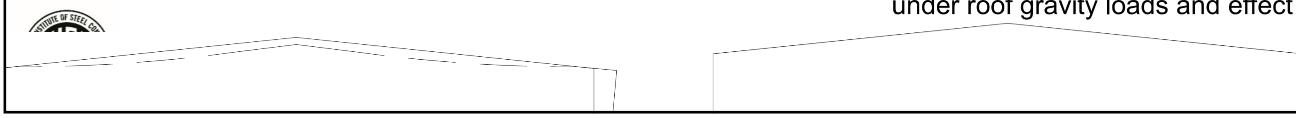
LATERAL LOAD RESISTING SYSTEM



Rigid Frame Systems

- Does not require roof deck diaphragm parallel to rigid frames
- Spreads lateral forces out to more elements of the building – less taxing on building foundations
- Applicable for buildings with smaller or larger aspect ratios
- Use of continuous horizontal truss diaphragm can be advantageous for buildings with top running cranes
- Concern regarding column spread under roof gravity loads and effect



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SESSION 3: INDUSTRIAL BUILDINGS - PART 2

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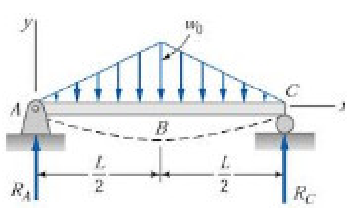
STATIC LOADS AND EVALUATION USING PRINCIPLES OF STATICS

- Structures designed to carry their own weight and other superimposed loads which are essentially unvarying with time (static loads) can be analyzed and designed using principles of Statics.
- Statics is the branch of structural mechanics concerned with bodies at rest and forces in equilibrium



$\Sigma F_x=0$

$\Sigma F_y=0$

$\Sigma M_A=0$

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DYNAMIC LOADS AND EVALUATION USING PRINCIPLES OF STRUCTURAL DYNAMICS

- Dynamic Loads are loads that are either moving or vary with time
- Effect of dynamic loading is pertinent in structural analysis when the time increment associated with the change in load is not significantly higher than the natural frequency of the structure
- Requires consideration of principles of dynamics to determine maximum response in the supporting structure
- Use Energy Methods or Newtons 2nd Law of Motion (Conservation of Momentum) and associated differential equations to determine the maximum load effect on the supporting structure
- Maximum response in structure is commonly determined by applying a dynamic magnification factor or impact factor to the response of the structure calculated based on static load assumption

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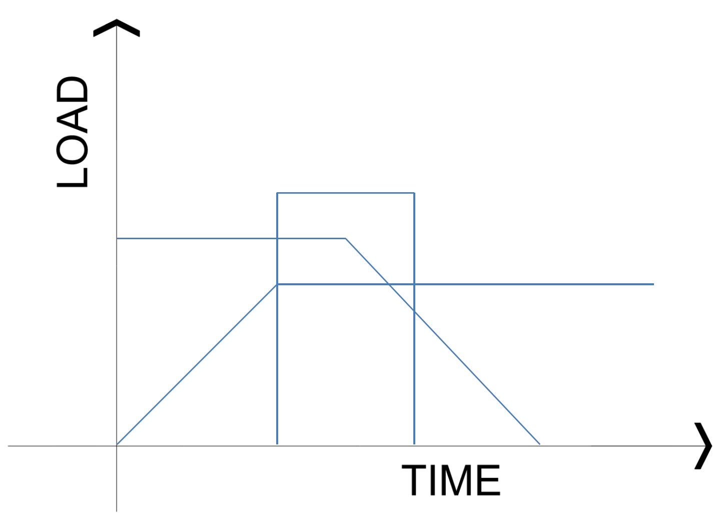
DYNAMIC PULSE LOADS



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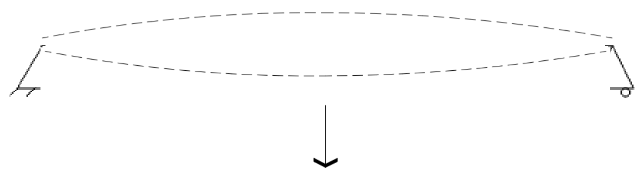
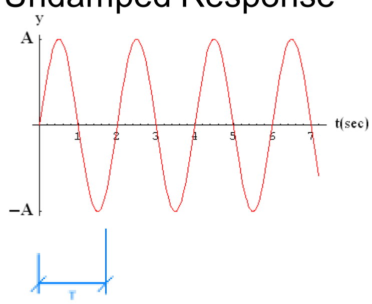
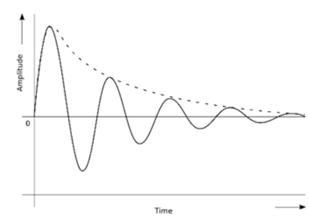
RESPONSE TO PULSE LOAD



Undamped Response



Damped Response



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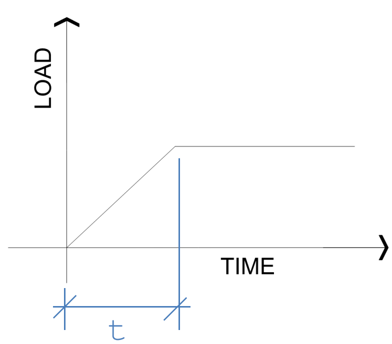
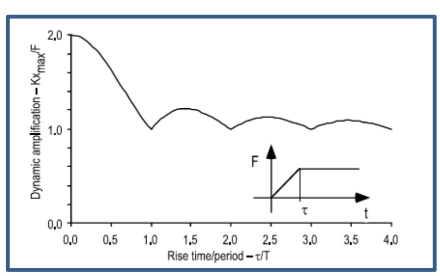
Calculation of Impact Factor for Ramped Stepped Pulse Load



$$Impact\ Factor = 1 + Abs.Value\left[\frac{T}{\pi\tau} sin\left(\frac{\pi\tau}{T}\right)\right]$$

T = Natural Period of Structure



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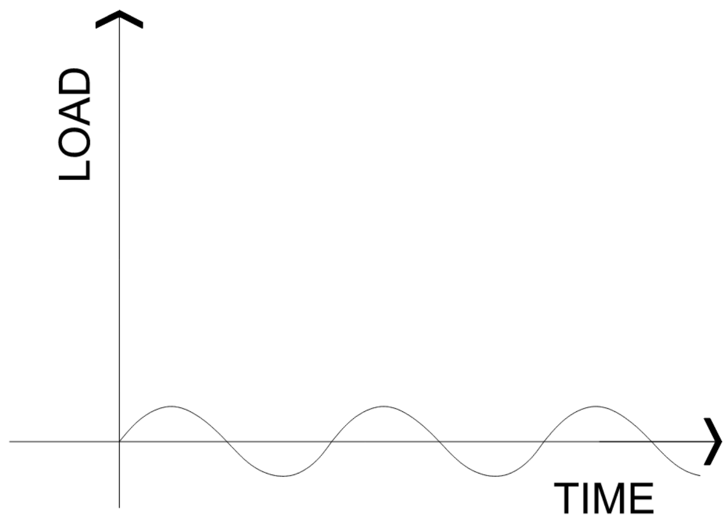
HARMONIC LOADS



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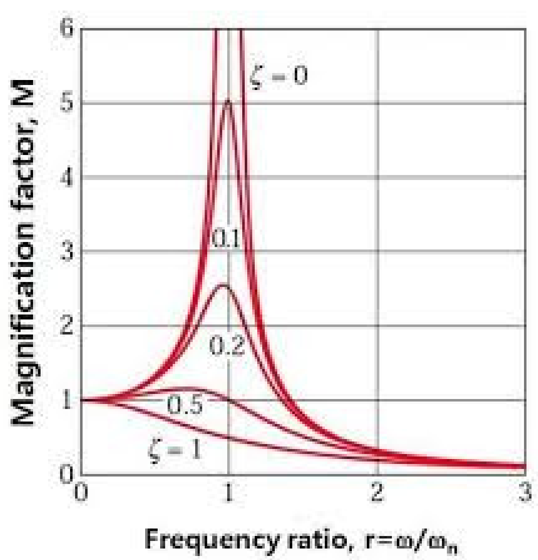
RESPONSE TO HARMONIC LOAD



Frequency Analysis

ω = Natural Frequency of structure
ω_n = Frequency of harmonic load
ς = Damping ratio as a percentage of critical damping

Can also perform a time-history analysis to determine the maximum response at any point in the structure at a specific time

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ANALYSIS TOPICS – INDUSTRIAL BUILDINGS

AISC Specification Requirements

- Chapter C – Design for Stability
- Appendix 6 – Member Stability Bracing
- Appendix 7 – Alternative Methods of Design for Stability
- Appendix 8 – Approximate Second-Order Analysis

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Chapter C Requirements

General Stability Requirements

Must consider:

a. Member flexural, shear and axial deformations and connection deformations that contribute to displacements in structure
b. Second order effects
c. Geometric imperfections
d. Stiffness reductions due to inelasticity (including residual stress effects)
e. Uncertainties in system, member and connection strength and stiffness

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DESIGN FOR STABILITY

Methodologies

1. Direct Analysis – Chapter C
2. Effective Length Method – Appendix 7
3. First-Order Analysis Method – Appendix 7

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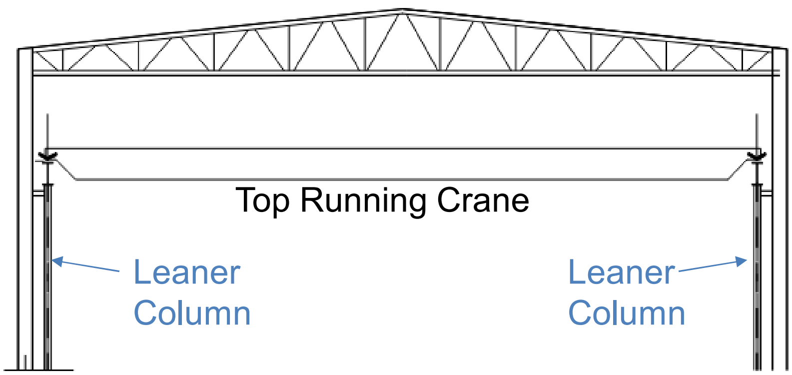
CONSIDERATIONS FOR INDUSTRIAL BUILDINGS

Second Order Analysis – Leaning Column Effect



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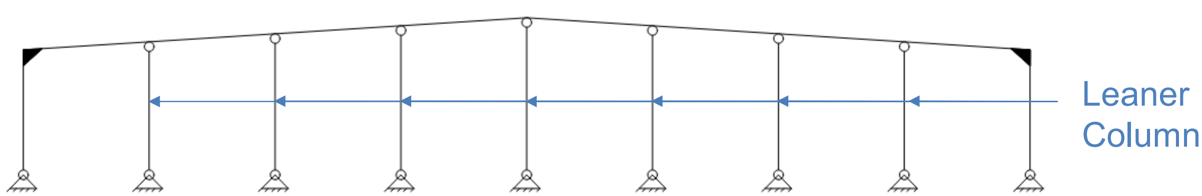
CONSIDERATIONS FOR INDUSTRIAL BUILDINGS

Second Order Analysis – Leaning Column Effect



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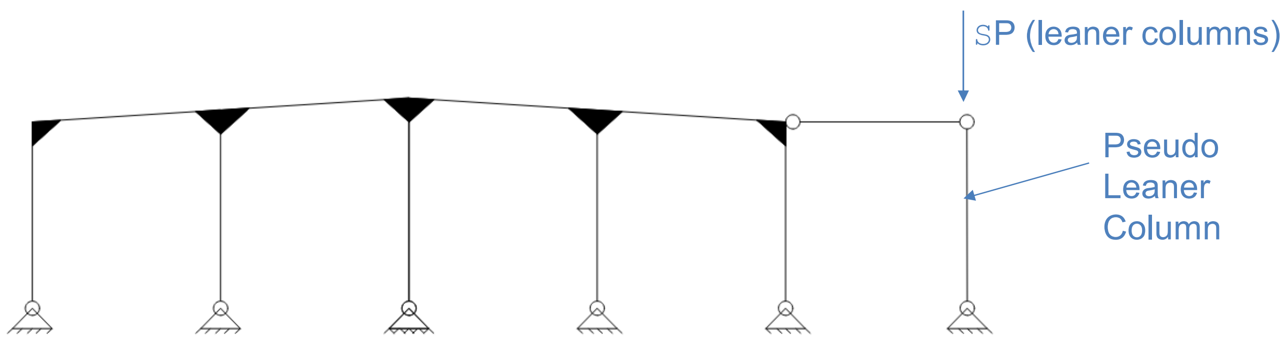
CONSIDERATIONS FOR INDUSTRIAL BUILDINGS

Second Order Analysis – Simplified Modeling for Multiple Leaner Column Effect



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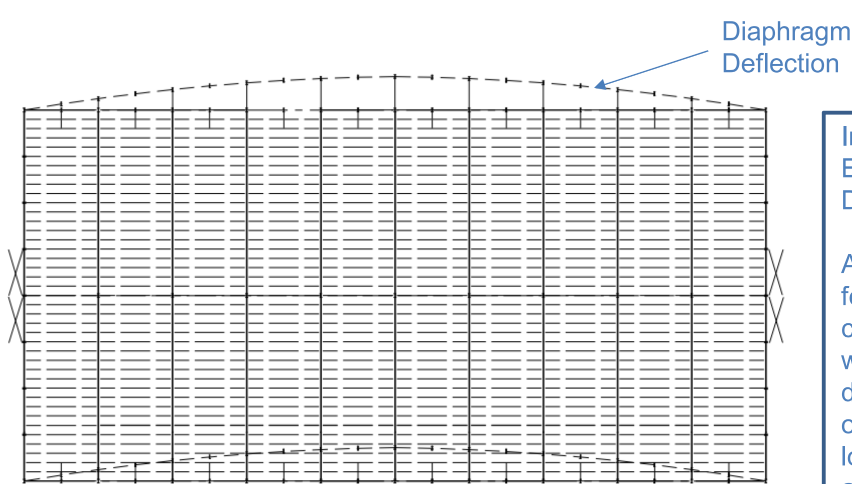
CONSIDERATIONS FOR INDUSTRIAL BUILDINGS

Second Order Analysis – Contribution of Diaphragm Displacements



Incorporate 2nd Order Effects from Diaphragm Deflection

Added Horiz. Load (H) for each leaner column = P Δ/h where Δ = relative diaphragm deflection of diaphragm to lateral load resisting frame and h = roof height

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CONSIDERATIONS FOR INDUSTRIAL BUILDINGS

Member Stability Bracing – Appendix 6

Considerations:

- Does a purlin, girt or other secondary framing element have sufficient strength, stiffness, and load path to qualify as a brace for the primary framing member it is connected to?
- What is the likelihood that future changes or alterations to the building will compromise the bracing "system" for the structure
  - Example – Recognize that girts may be removed in the future to accommodate material flow or process changes. In recognition of this, should you use girts and wall panel system to brace columns?
  - Example – Recognize that vertical bracing may need to be relocated or removed in the future to accommodate material flow or process changes. May want to consider providing redundancy for bracing system and/or column and foundation capacity in non-braced bays to allow for potential changes.

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Member Stability

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Member Stability

Compression Members

- Flexural buckling
- Torsional buckling
- Constrained-axis buckling
- Loads within the unbraced length

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Member Stability

Bracing Members

- Horizontal bracing
- X-bracing

Flexural Members: Lateral-Torsional Buckling

- Load height
- Brace height

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Member Stability

Compression Members

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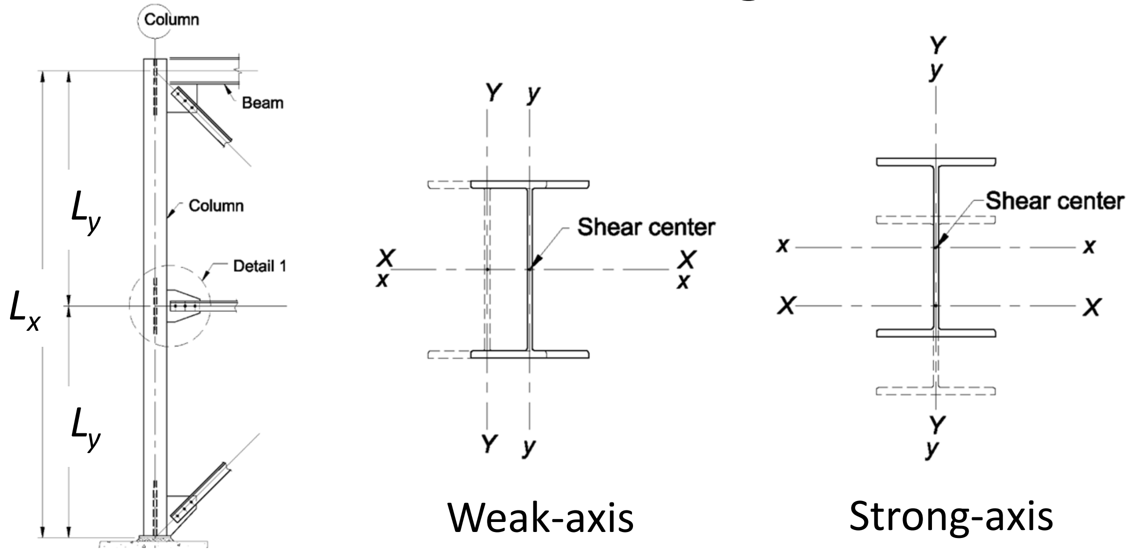
Flexural Buckling



Weak-axis Strong-axis

Elevation Cross-Section

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Flexural Buckling

AISC *Specification* Section E3

$$F_e = \frac{\pi^2 E}{\left(\frac{L_c}{r}\right)^2} \qquad \text{(\textit{Spec.} Eqn. E3-4)}$$

L_c = KL = effective length for flexural buckling

For weak-axis buckling: $L_{cy} = K_y L_y$

For strong-axis buckling: $L_{cx} = K_x L_x$

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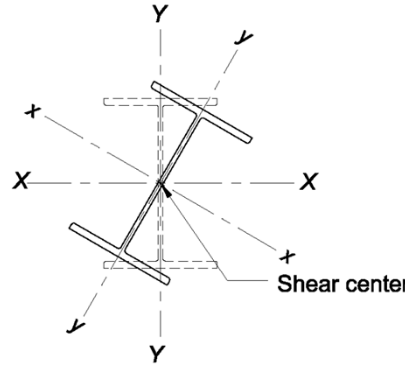
Torsional Buckling

AISC *Specification* Section E4

Doubly-symmetric members

$$F_e = \left[\frac{\pi^2 E C_w}{L_{cz}^2} + GJ \right] \frac{1}{I_x + I_y}$$

(*Spec.* Eqn. E4-2)



Cross-Section

$L_{cz} = K_z L_z$ = effective length for torsional buckling

L_z = distance between restraints against torsional rotation

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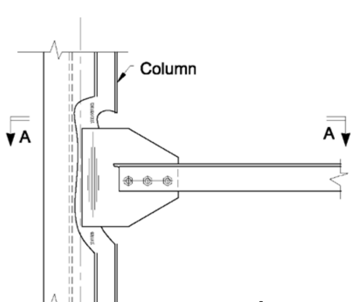
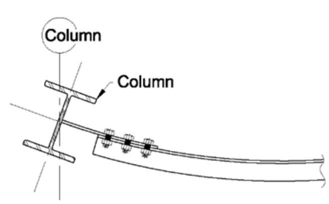
Torsional Buckling

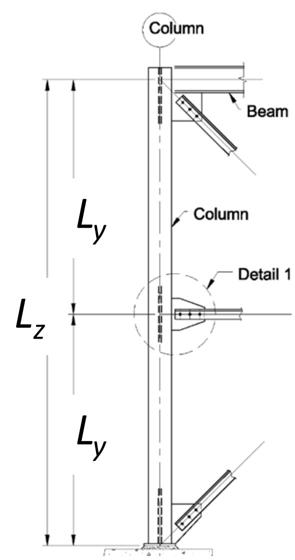
The torsional buckling strength can be less than the weak-axis flexural buckling strength only when $L_{cz} > L_{cy}$



Detail 1



Section A-A



Elevation

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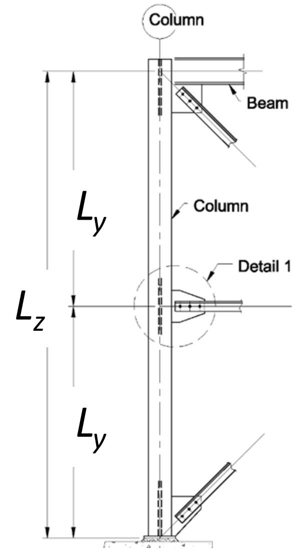
Torsional Buckling

Some commercial FE design programs do not consider torsional buckling. In this case, an equivalent effective length can be used for weak-axis flexural buckling.

$$L'_{cy} = K_{yz} L_z \geq K_y L_y \qquad K_{yz} = \sqrt{\frac{I_y\left(r_x^2 + r_y^2\right)}{C_w + \frac{GJL_{cz}^2}{\pi^2 E}}}$$



Elevation

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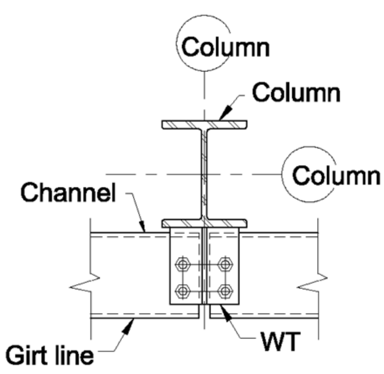
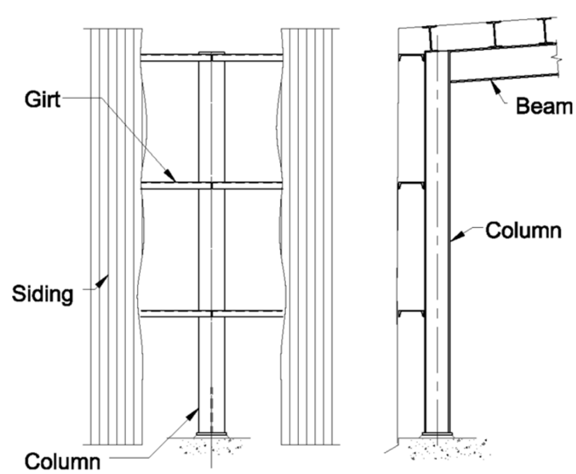
Constrained-Axis Buckling

Do the girts brace the column?



Girt-to-Column Detail



Wall Elevation

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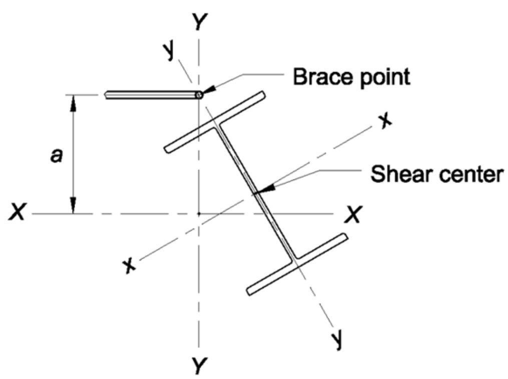
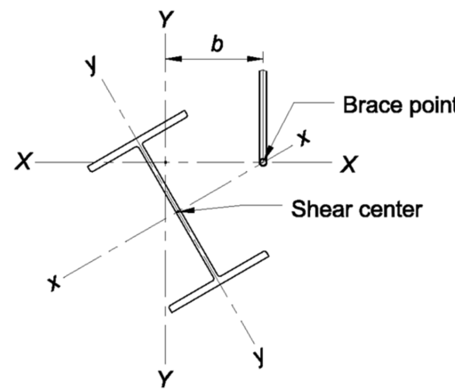
Constrained-Axis Buckling

Constrained-axis buckling: flexural-torsional buckling about an enforced axis of rotation when lateral bracing is offset from the shear center.





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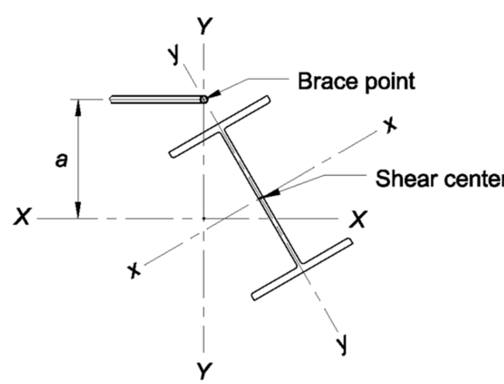
Constrained-Axis Buckling

When the brace is offset a distance *a* along the y-axis, the critical stress is

$$F_e = \frac{\omega}{A r_0^2}\left[\frac{\pi^2 E I_y}{L_{cz}^2}\left(\frac{h_o^2}{4} + a^2\right) + GJ\right]$$

(Comm. Eqn. C-E4-1)

$$\omega = 0.9$$



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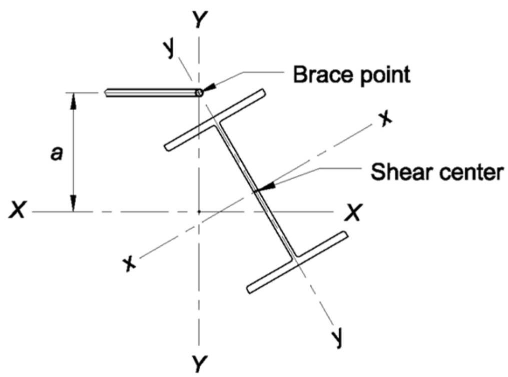
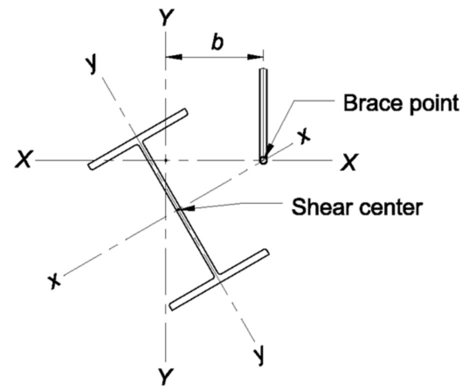
Constrained-Axis Buckling

Commentary to AISC *Specification* Section E4

$$r_o^2 = r_x^2 + r_y^2 + a^2 + b^2 \qquad \text{(Comm. Eqn. C-E4-3)}$$





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Constrained-Axis Buckling

For input into commercial FE design programs, an equivalent effective length can be used for weak-axis flexural buckling.

$$L'_{cy} = K_{yz} L_{yz} \geq L_{yo} \qquad K_{yz} = \sqrt{\frac{I_y\left(a^2 + r_x^2 + r_y^2\right)}{C_w + a^2 I_y + \dfrac{GJL_{yz}^2}{\pi^2 E}}}$$

L_{yo} = distance between offset braces that restrain lateral translation

L_{yz} = distance between restraints against both torsional rotation and lateral translation

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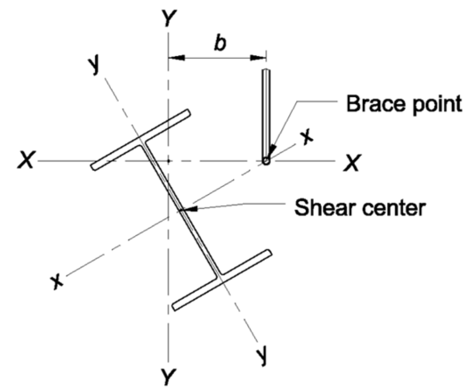
Constrained-Axis Buckling

When the brace is offset a distance *b* along the x-axis, the critical stress is

$$F_e = \frac{\omega}{Ar_0^2}\left[\frac{\pi^2 EI_y}{L_{cz}^2}\left(\frac{h_o^2}{4}+\frac{I_x}{I_y}b^2\right)+GJ\right]$$

(Comm. Eqn. C-E4-2)



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Constrained-Axis Buckling

For input into commercial FE design programs, an equivalent effective length can be used for strong-axis flexural buckling.

$$L'_{cx} = K_{xz}L_{xz} \geq L_{xo}$$

$$K_{xz} = \sqrt{\frac{I_x\left(b^2 + r_x^2 + r_y^2\right)}{C_w + b^2 I_x + \frac{GJL_{xz}^2}{\pi^2 E}}}$$

L_{xo} = distance between offset braces that restrain lateral translation

L_{xz} = distance between restraints against both torsional rotation and lateral translation

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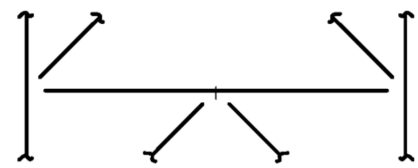
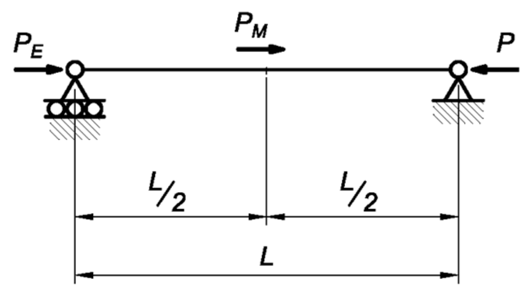
Loads Within the Unbraced Length

The effect of axial loads within the unbraced length can be calculated with a reduced effective length factor.



Chevron Bracing: Elevation

For pinned-end compression members, $K \leq 1.0$.



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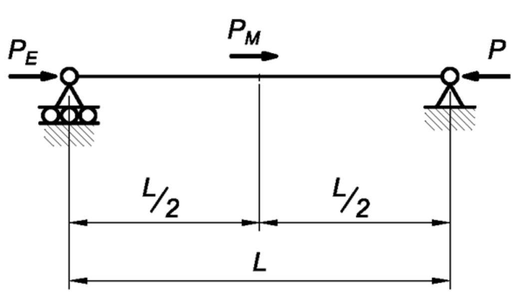
Loads Within the Unbraced Length

Load at mid-length



$$K = 0.75 + 0.25\left(\frac{P_E}{P}\right)$$

Use with a required load, $P_r = P$

$K = 0.50$ if $P = P_M/2 = -P_E$

P_E = smaller of the two end forces (+ for compression, – for tension)

$P = P_E + P_M$ = larger of the two end forces (always compression)

Vinnakota, S. (2006), *Steel Structures, Behavior and LRFD*, McGraw Hill.

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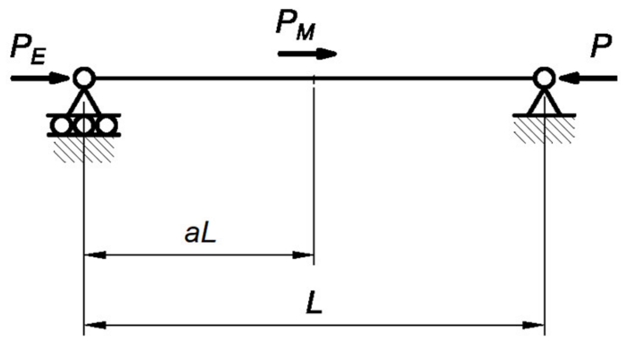
Loads Within the Unbraced Length

Load anywhere within the span



Loads Within the Unbraced Length

Table 1. Effective Length Factors K for a pin-ended column with an intermediate axial load P at height aL and a load P_1 at the top

a	P_E/P_M	0.10	0.25	0.50	0.75	1.0	2.0	3.0	4.0
	Effective Length Factor K								
0.25		0.715	0.750	0.795	0.840	0.863	0.903	0.927	0.940
0.50		0.745	0.775	0.825	0.860	0.875	0.915	0.935	0.955
0.75		0.815	0.835	0.860	0.890	0.895	0.930	0.950	0.965
0.85		0.880	0.905	0.910	0.920	0.930	0.955	0.965	0.975
0.95		0.950	0.955	0.965	0.970	0.975	0.980	0.985	0.985
1.00		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

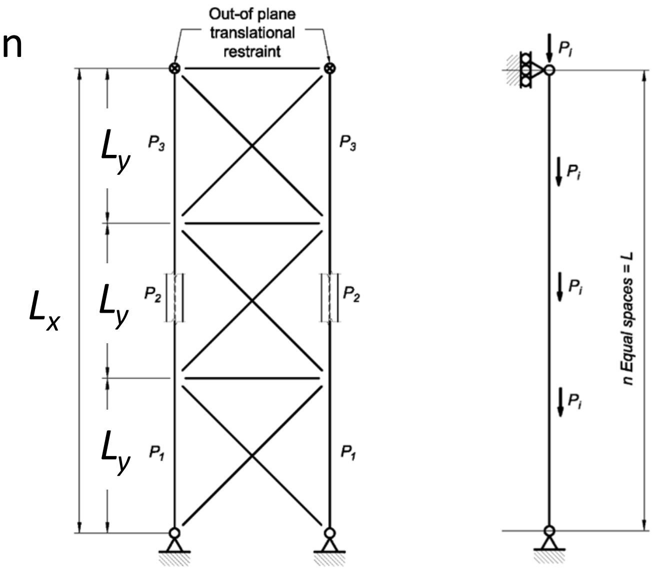
Sandhu, B.S. (1972), "Effective Length of Columns with Intermediate Axial Load," *Engineering Journal*, American Institute of Steel Construction, October.

Loads Within the Unbraced Length

Multiple loads within the span

$K_y = 1.0$

$K_x = ?$



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Loads Within the Unbraced Length

For members with n equal loads, P_i, at n equal spaces

$$K = 0.75 + 0.25\left(\frac{1}{n}\right)$$

Use with a required load, $P_r = \Sigma P_i$

This equation is sufficiently accurate when the loads and spaces are be within ≈ 20% of average

56

Loads Within the Unbraced Length

For any combination of load magnitudes, load directions (tension or compression) and spacings:

Shrivastava, S.C. (1980), “Elastic Buckling of a Column Under Varying Axial Force,” *Engineering Journal*, AISC, First Quarter.

57

Member Stability

Bracing Members

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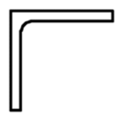
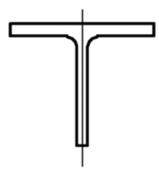
Horizontal Bracing

Common Shapes

Single angle 

WT 

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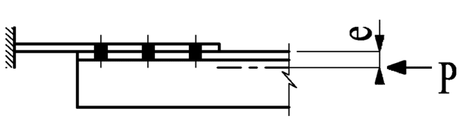
Horizontal Bracing

Connection Eccentricity

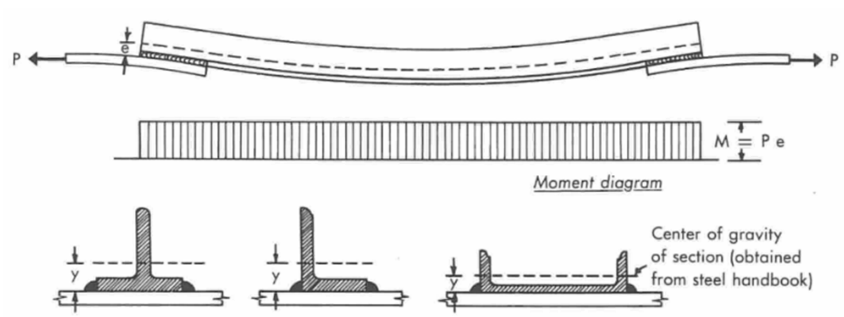
Gusset plate end connections are typically offset from the brace centroid

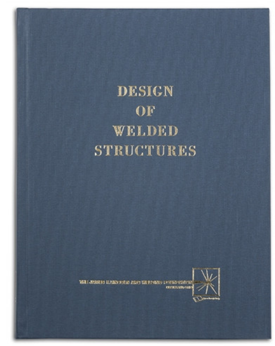


60

Horizontal Bracing

Blodgett (1966): If the gusset plate is flexible relative to the member, the member is designed for the full moment, $M = Pe$.





Blodgett, O.W. (1966), *Design of Welded Structures*, The James F. Lincoln Arc Welding Foundation.

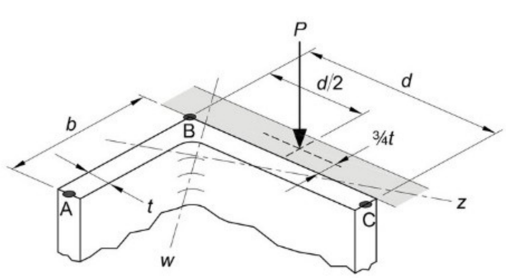
61

Horizontal Bracing

Single Angles

Axial compression + flexure

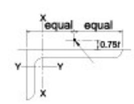
AISC *Manual* Table 4-12



F_y = 36 ksi

Table 4-12 (continued)
Available Strength in Axial Compression, kips
Eccentrically Loaded Single Angles

L3



Shape		L3×3×											
		1/2		7/16		3/8		5/16		1/4		3/16[c,f]	
lb/ft		9.40		8.30		7.20		6.10		4.90		3.71	
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
radius of gyration, r_z	0	25.3	38.1	24.3	36.5	23.2	34.9	21.7	32.6	19.4	29.2	12.7	19.1
	1	24.8	37.3	23.8	35.7	22.7	34.1	21.2	31.9	19.1	28.7	12.6	18.9
	2	23.2	35.0	22.2	33.5	21.1	31.8	19.7	29.7	17.7	26.7	12.2	18.3
	3	21.0	31.7	19.9	30.2	18.9	28.5	17.5	26.5	15.7	23.7	11.2	16.7
	4	18.3	27.8	17.3	26.3	16.3	24.7	15.0	22.8	13.4	20.3	10.0	15.0
	5	15.7	23.8	14.7	22.4	13.7	20.9	12.5	19.1	11.1	16.9	8.95	13.3
	6	13.1	20.0	12.2	18.7	11.3	17.3	10.3	15.7	8.97	13.7	7.29	11.1
	7	10.8	16.5	10.0	15.3	9.19	14.1	8.27	12.7	7.17	11.0	5.83	8.92
	8	8.99	13.7	8.27	12.6	7.55	11.5	6.75	10.3	5.80	8.88	4.68	7.16
	9	7.58	11.6	6.93	10.6	6.30	9.64	5.60	8.57	4.79	7.32	3.84	5.86

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Horizontal Bracing

For single angle compression members connected through one leg, the eccentricity can be neglected if an effective slenderness ratio is used.

The effective slenderness ratio accounts for:

- Connection eccentricity
- Buckling is primarily about the geometric axis rather than the minor principal axis

For background information see Lutz (2006)

Lutz, L.A. (2006), "Evaluating Single-Angle Compression Struts Using an Effective Slenderness Approach," *Engineering Journal*, AISC, 4th Quarter.

Horizontal Bracing

The following requirements are from AISC *Specification* Section E5:

1. The angle must be loaded through the same leg at both ends
2. Bolted connections must have a minimum of two bolts
3. There are no intermediate transverse loads
4. $L_c/r \leq 200$
5. For unequal leg angles, the leg width ratio must be less than 1.7

Horizontal Bracing

AISC *Specification* Section E5(a)(1): For equal-leg angles or unequal-leg angles connected through the longer leg

$\frac{L}{r_a} \leq 80$ $\qquad \frac{L_c}{r} = 72 + 0.75\frac{L}{r_a}$ $\qquad$ (*Spec.* Eqn. E5-1)

$80 < \frac{L}{r_a} \leq 134$ $\qquad \frac{L_c}{r} = 32 + 1.25\frac{L}{r_a}$ $\qquad$ (*Spec.* Eqn. E5-2)

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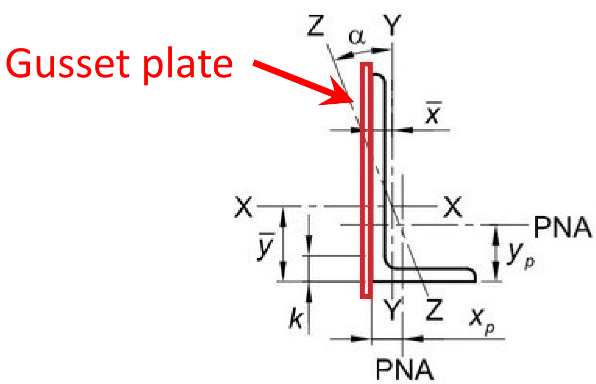
Horizontal Bracing

$r_a = r_y$



r_a = radius of gyration about the geometric axis parallel to the connected leg (eccentric moment is about this axis)

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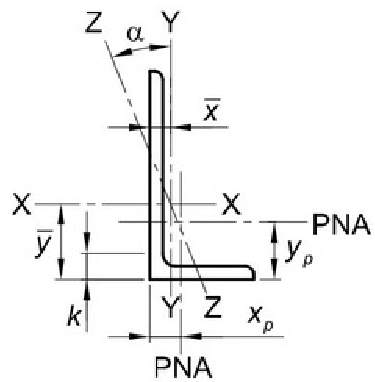
Horizontal Bracing

Commercial FE design programs typically use the minimum radius of gyration, r_z, for flexural buckling calculations. Rewriting *Specification* Equations E5-1 and E5-2 results in:



$$\frac{L}{r_a} \le 80 \qquad K_z = r_z\left(\frac{72}{L} + \frac{0.75}{r_a}\right)$$

$$80 < \frac{L}{r_a} \le 134 \qquad K_z = r_z\left(\frac{32}{L} + \frac{1.25}{r_a}\right)$$

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Horizontal Bracing

For equal-leg angles, $r_a \approx 1.56r_z$. For this case, the equations can be simplified to:

$$\frac{L}{r_z} \le 125 \qquad K_z = 0.482 + \frac{72}{L/r_z}$$

$$125 < \frac{L}{r_z} \le 209 \qquad K_z = 0.803 + \frac{32}{L/r_z}$$

The minimum value for K_z is 0.482 at L/r_z = 0
The maximum value for K_z is 1.06 at L/r_z = 125

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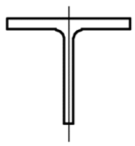
Horizontal Bracing

WTs



Axial compression + flexure

Load tables (Gordon, 2010)

Table 2 (LRFD)

Horizontal WT Shapes
Available Strength ($\phi_c P_n$) for Compression Loads* with Connection Eccentricity (kips)

Shape	Span Length (ft)										
	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5
WT4×9	40.8	36.3	30.3	23.6	17.7	13.5	10.4				
WT5×11	47.7	45.3	40.6	34.5	28.1	22.1	17.5	14.1			
WT5×13	57.8	54.5	48.3	40.7	33.1	26.0	20.7	16.6	13.4		
WT5×15	70.9	65.2	57.1	47.9	38.8	30.5	24.2	19.5	15.8		
WT6×11	45.1	41.1	33.5	24.4	17.5						
WT6×13	47.5	46.3	43.9	40.0	35.3	30.4	25.5	20.9	17.2	14.2	
WT6×15	61.6	59.6	55.7	49.8	43.2	36.3	29.8	24.3	19.9	16.5	
WT6×17.5	79.2	76.2	70.2	61.9	52.9	43.8	35.5	28.9	23.8	19.7	
WT6×20	87.4	84.1	77.5	67.3	56.9	46.9	37.8	30.7	25.1	20.6	
WT6×22.5	103	99.0	90.2	78.0	65.5	53.6	43.2	35.1	28.7	23.7	
WT6×25	117	111	99.3	86.1	72.5	59.6	48.1	39.1	32.1	26.5	

Gordon, M. (2010), "Tables for Eccentrically Loaded WT shapes in Compression," *Engineering Journal*, 2nd Quarter.

Horizontal Bracing

Ratio tables (Gordon, 2010)

$P_{ce} = R \times P_{cc}$

P_c = available axial load
P_{cc} = P_c for concentric load
P_{ce} = P_c for eccentric load
R = Load ratio

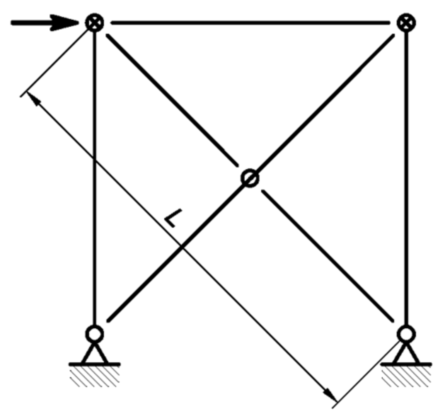
Table 4 (LRFD)

Horizontal WT Shapes
Reduction Factor for Compression Loads* with Connection Eccentricity $P_u/(\phi_c P_n)$

Shape	Span Length (ft)									
	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
WT4×9	0.391	0.392	0.404	0.448	0.515	0.564	0.594			
WT5×11	0.479	0.470	0.470	0.488	0.523	0.573	0.612	0.637		
WT5×13	0.435	0.427	0.432	0.452	0.490	0.542	0.581	0.607	0.621	
WT5×15	0.390	0.396	0.410	0.435	0.478	0.534	0.575	0.603	0.618	
WT6×11	0.539	0.564	0.626	0.713	0.781					
WT6×13	0.582	0.574	0.566	0.564	0.570	0.584	0.605	0.632	0.652	0.663
WT6×15	0.520	0.512	0.507	0.513	0.529	0.554	0.590	0.623	0.644	0.656
WT6×17.5	0.463	0.456	0.457	0.471	0.496	0.532	0.578	0.612	0.634	0.647
WT6×20	0.437	0.423	0.412	0.422	0.441	0.472	0.513	0.543	0.562	0.571
WT6×22.5	0.403	0.390	0.387	0.401	0.426	0.464	0.508	0.539	0.559	0.569
WT6×25	0.376	0.373	0.381	0.395	0.420	0.457	0.502	0.534	0.555	0.565

X-Bracing

Can the tension diagonal be used to brace out-of-plane buckling of the compression diagonal?



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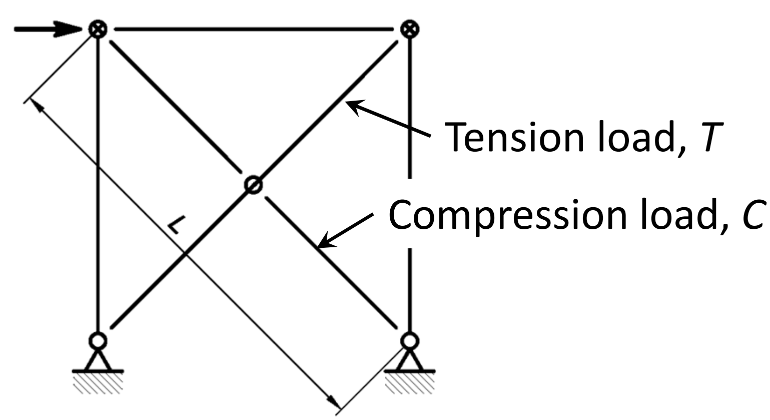
X-Bracing

For equal-length braces that are connected at the intersection, the tension diagonal braces the compression diagonal when $T/C \geq 0.65$

$L_c = 0.5L$ for $T/C \geq 0.65$

L = overall brace length



Picard, A. and Beaulieu, D. (1987), "Design of Diagonal Cross Bracings Part 1: Theoretical Study," *Engineering Journal*, AISC, 3rd Quarter.

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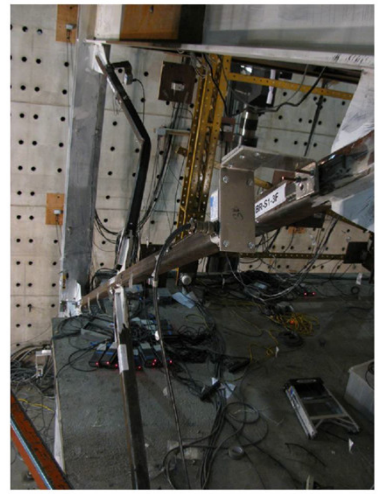
X-Bracing



Palmer, K,D. (2012), *Seismic Behavior, Performance and Design of Steel Concentrically Braced Frame Systems*, Ph.D. Dissertation, University of Washington.

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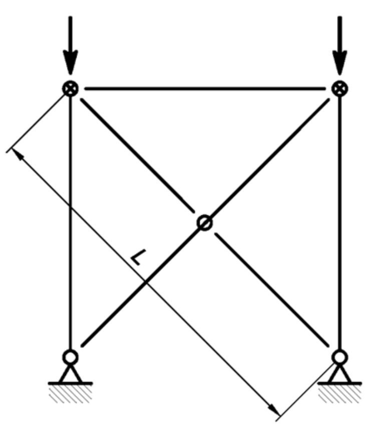
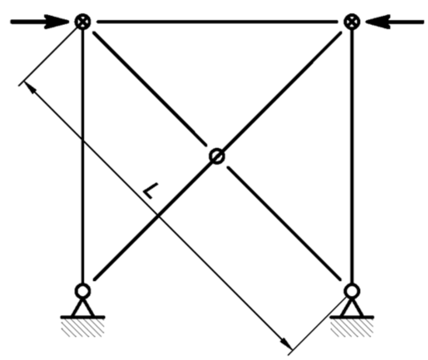
X-Bracing

Other loads in the bracing system can cause $T/C < 0.65$



Gravity Loads



Thermal Loads

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X-Bracing

For $T/C < 0.65$, a conservative approach is to use $L_c = L$

Alternatively, the effective length factor can be calculated based on the T/C ratio. For example, Picard and Beaulieu (1987) Equation 20 results in $L_c = 0.66L$ for $T/C = 0.20$.

Picard, A. and Beaulieu, D. (1987), "Design of Diagonal Cross Bracings Part 1: Theoretical Study," *Engineering Journal*, AISC, 3rd Quarter.

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Member Stability

Flexural Members

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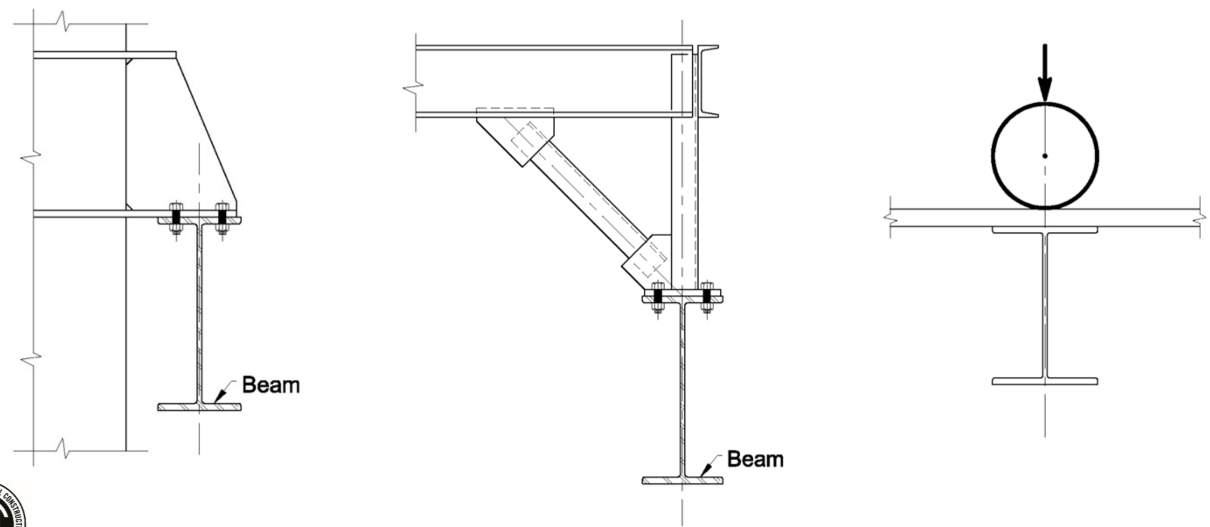
Lateral-Torsional Buckling: Load Height



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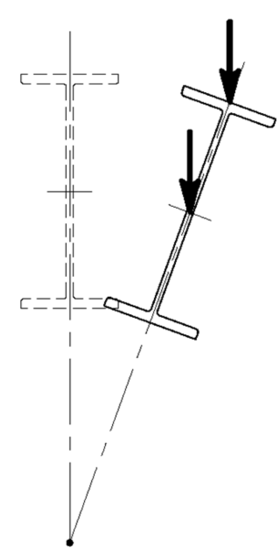
Lateral-Torsional Buckling: Load Height

The equations in AISC *Specification* Chapter F are based on the assumption that the loads are applied at the level of the shear center.

- If the load is applied above the shear center, the buckling strength is reduced
- If the load is applied below the shear center, the buckling strength increases



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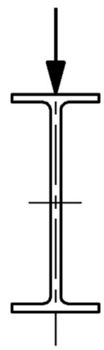
Lateral-Torsional Buckling: Load Height

For top flange loading of doubly-symmetric members in single or double curvature:

$$C_b' = \frac{C_b}{1.4}$$



Helwig, T.A., Frank, K.H. and Yura, J.H. (1997), "Lateral-Torsional Buckling of Singly Symmetric I-Beams," *Journal of Structural Engineering*, ASCE, Vol. 123, No. 9, pp.1172-1179.

Ziemian, R.D. (2010), *Guide to Stability Design Criteria for Metal Structures*, Sixth Edition, John Wiley & Sons.

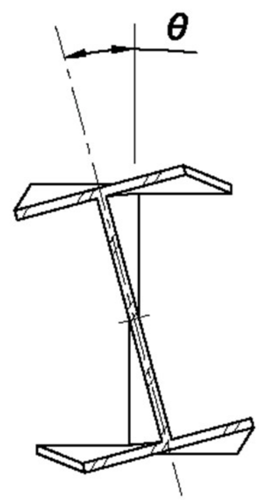
79

Lateral-Torsional Buckling: Brace Height

What is beam bracing?

- To brace a beam against lateral-torsional buckling (LTB), torsional rotation must be prevented
- AISC *Specification* Section F2.2:

  L_b = length between points that are either braced against lateral displacement of the compression flange or twist of the cross section



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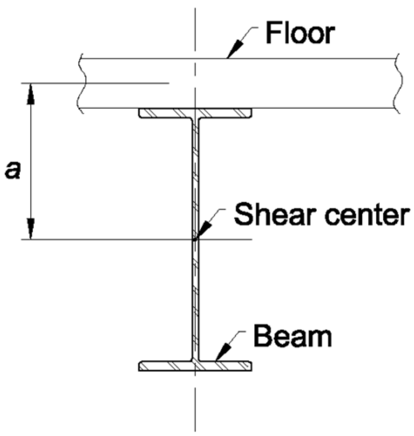
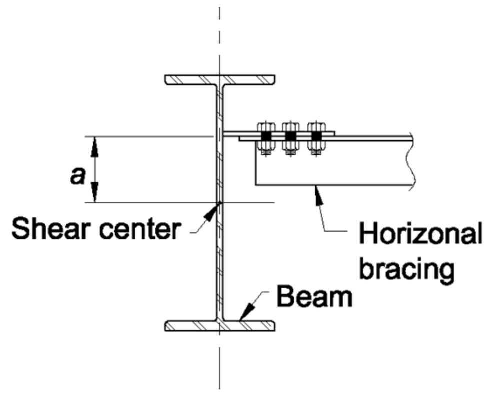
Lateral-Torsional Buckling: Brace Height

What is the lowest acceptable position for effective lateral bracing?





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Lateral-Torsional Buckling: Brace Height

The brace position limit is dependent on the load height.

For doubly-symmetric I-shaped beams with the top flange in compression:

- For top flange loading, the brace must be in the top 15% of the beam depth
- For loading in the top half of the beam web, the brace must be at the load level or higher
- For uniform moments and loading below the shear center, the brace must be at the shear center or higher

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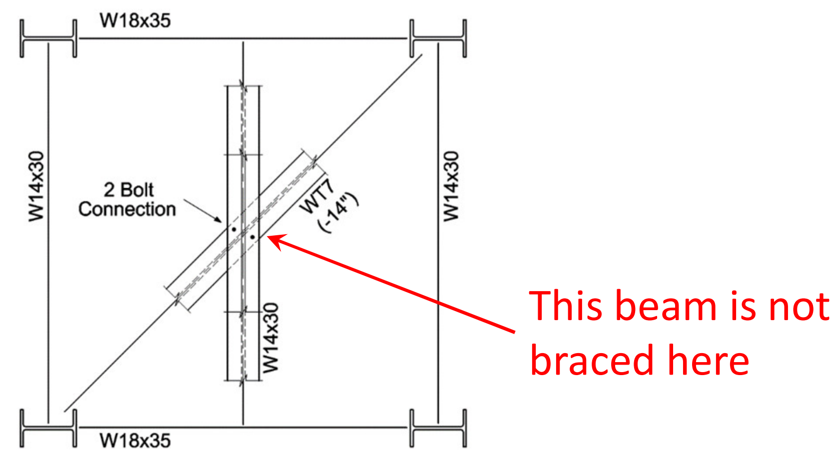
Lateral-Torsional Buckling: Brace Height



Plan View

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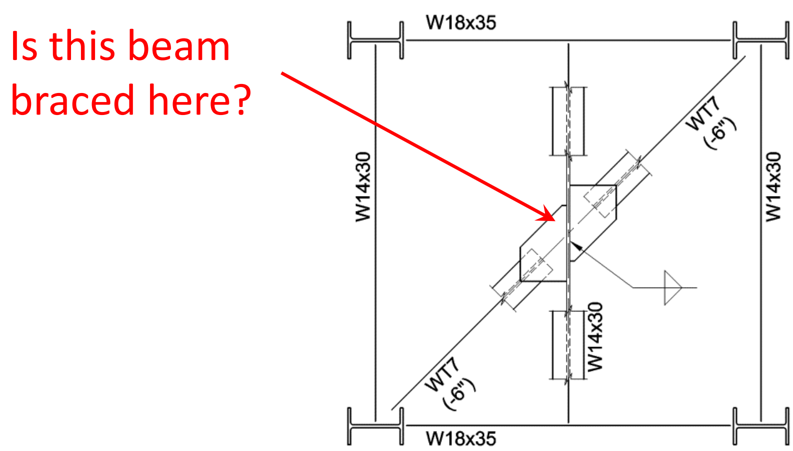
Lateral-Torsional Buckling: Brace Height



Plan View

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Session 3
the End

Thank you!

AISC | Questions?

Smarter.
Stronger.
Steel.

Individual Session Registrants

PDH Certificates

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

Individual Session Registrants

PDH Certificates

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

Individual Session Registrants

PDH Certificates

- Accommodations for Work-From-Home situations:
- AISC will provide the list of attendees from your company to report attendance. These are the only individuals that you should report for attending this session.
- The lists will be send out within 3 business days.

8-Session Registrants

PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.

8-Session Registrants

Access to the quiz

Information for accessing the quiz will be emailed to you by Thursday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

Quiz and attendance records

Posted Thursday mornings. www.aisc.org/nightschool -- Click on Current Course Details.

Reasons for quiz

- EEU – You must take all quizzes and the final exam to receive EEU.
- PDHs – If you watch a recorded session, you must pass quiz for PDHs.
- REINFORCEMENT – Reinforce what you learn tonight. Get more out of the course.

Note: If you attend the live presentation, you do not have to take the quizzes to receive PDHs

8-Session Registrants

Access to the recording

Information for accessing the recording will be emailed to you by Thursday. The recording will be available for four weeks. (For 8-session registrants only.) EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

PDHs via recording

If you watch a recorded session, you must take *and pass* the quiz for PDHs.

8-Session Registrants

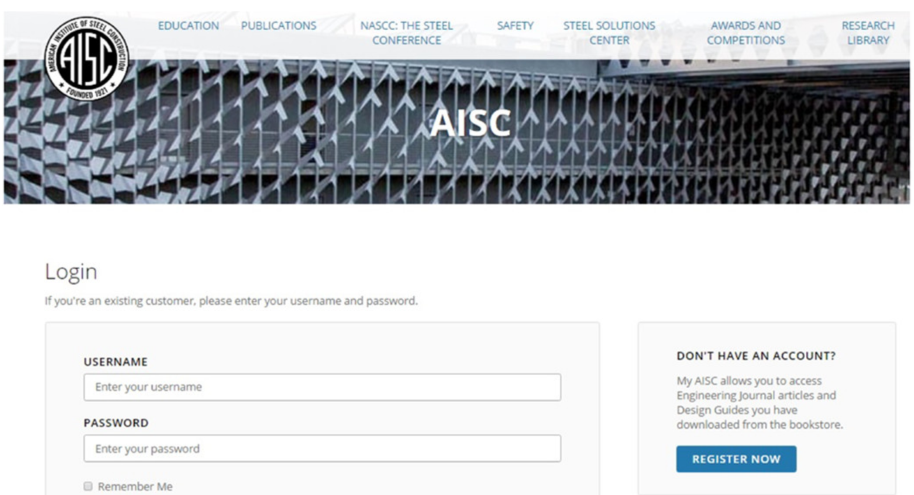
Night School Resources

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

8-Session Registrants

Night School Resources

Go to www.aisc.org and sign in.



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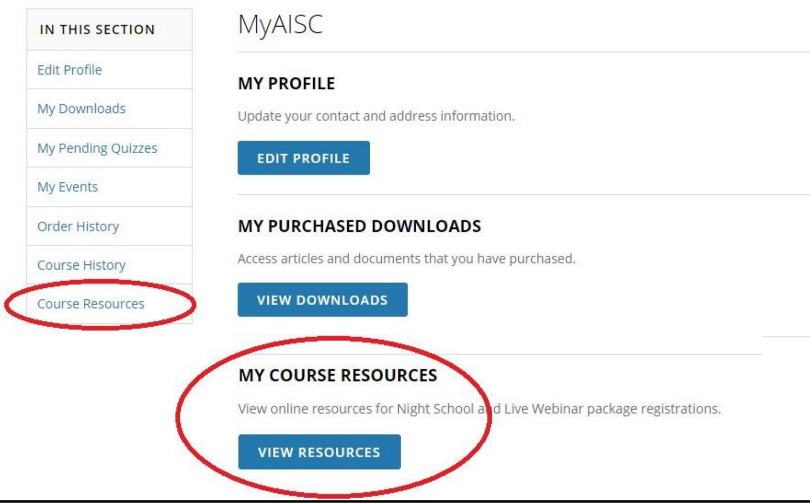
Night School Resources

Go to www.aisc.org and sign in.



8-Session Registrants

Night School Resources

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

8-Session Registrants

Night School Resources

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

8-Session Registrants

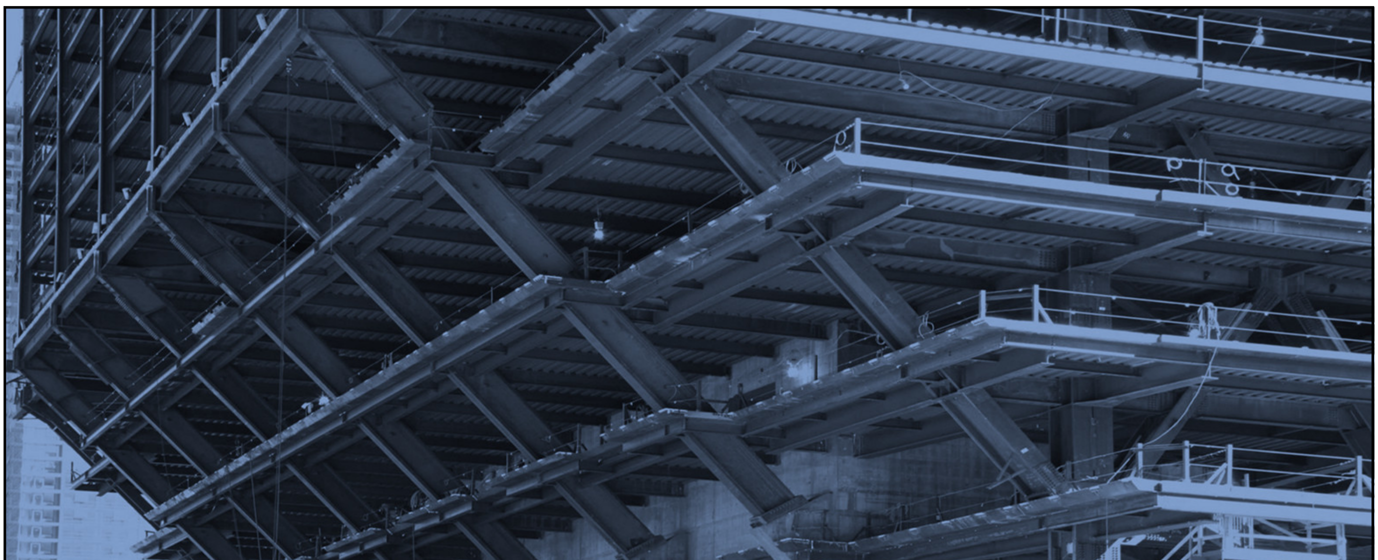
Night School Resources

- Weekly "quiz and recording" email.
- Weekly updates of the master quiz and attendance record, found at www.aisc.org/nightschool23. Scroll down to Quiz and Attendance records.
  - Updated on Thursday mornings.

8-Session Registrants

Night School Resources

- Webinar connection information
  - Reminder email sent out Tuesday mornings
- Links to handouts also found here



AISC | Thank you

Smarter.
Stronger.
Steel.