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# Course Description

## Session 5: Crane Girder Design and Frame Analysis
## March 6, 2017

Lesson 5 includes the design of a typical 30-foot-long crane runway girder and an analysis for a typical frame in the example building. A crane girder design procedure is demonstrated, including the evaluation of strength and serviceability limit states. Examples of proper details for minimizing fatigue effects for crane runway girders are presented. Development of the frame loads, including seismic loads, and the selection of the seismic force resisting system are discussed. Second order analysis methods and calculations for estimating second order effects are presented.

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# Learning Objectives

- List the steps in the procedure for the design of a crane runway girder.
- List the key aspects in crane runway girder details to minimize fatigue effects.
- Establish the seismic loads for the building frame design based on ASCE7-10 requirements.
- Discuss the general analysis requirements per AISC 360-10 for use of the Direct Analysis Methods for analysis of frames

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# Design of Industrial Buildings

Session 5: Crane Girder Design and Frame Analysis

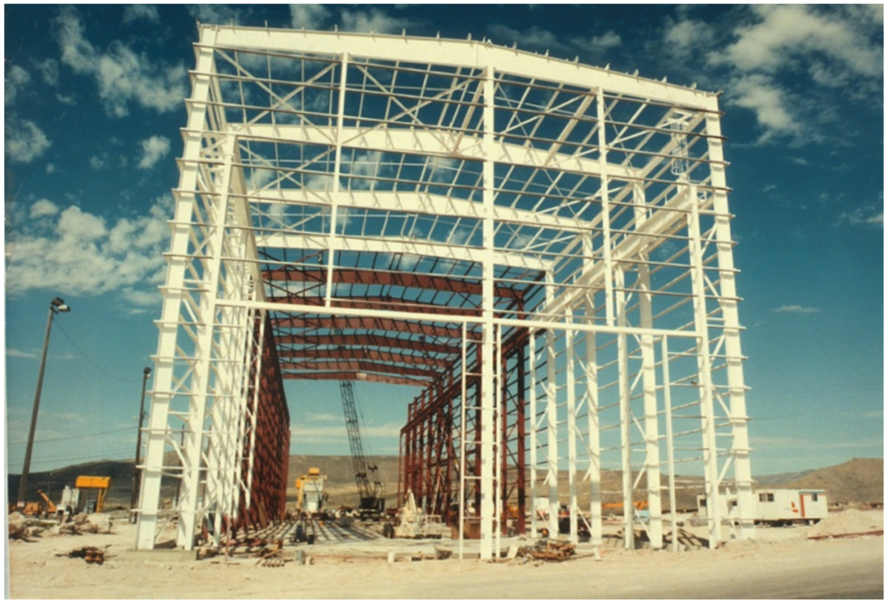
March 6, 2017

Presented by
Jules Van de Pas, SE, PE
Vice President, Computerized Structural Design

structural STEEL

# AISC Night School 13

## Design of Industrial Buildings
## Lesson 5



Presenter:
Jules Van de Pas

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# Buildings with Overhead Cranes

- **Lesson 5**
  - **30 ft. Runway Beam Design**
  - Runway Details
  - Wind load Calculations
  - Snow Load Calculations
  - Seismic Forces
  - Load Combinations
  - Frame Design using the Direct Analysis Method

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# Design of 30 ft Runway Girder

Crane capacity = 50 tons (CMAA Class D)

Bridge weight = 90.8 kips

Trolley and hoist weight = 31.2 kips

Wheel load = 78 kips

Wheel spacing = 11.0 ft.

Rail weight = 175 lbs./yard

Vertical impact = 25% of wheel loads

Lateral load= 20% of lifted load + trolley and hoist

*Lateral load = .20(100 kips + 31.2 kips)/4=6.6 kips/wheel*

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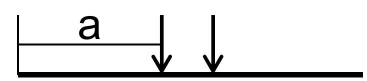
# Design of 30 ft Runway Girder

Use **ASD**

Deflection requirements: Locate wheel loads symmetrically placed about the girder centerline. a =9.5 ft. (114 in.)

Vertical: L/800 = (30 ft.)(12)/800 = 0.45 in.




Horizontal: L/400 = (30 ft.)(12)/400 = 0.9 in.

$I_{xreq'd}$: $$\Delta_{\max(x)} = \frac{P_a a}{24EI}\left(3L^2 - 4a^2\right) = \frac{(78kips)(114in.)}{(24)(29000)I}\left[3(360)^2 - 4(114in.)^2\right]$$

$$= \frac{4300}{I} \quad I = \frac{4300}{0.45in.} = 9,560in.^4$$

Try W36x160, $I_x$ = 9760 in.$^4$ Table 3-3

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# Design of 30 ft Runway Girder

$$P_{lat} = \frac{.20(100kips + 31.2kips)}{4} = 6.6\ kips$$

$$\Delta max = \frac{P_{lat}a}{24EI}(3L^2 - 4a^2)$$

$$\Delta max = \frac{(6.6kips)(114")}{(24)(29000)I}(3(360")^2 - 4(114")^2) = \frac{364}{I}$$

$$I = \frac{364}{\frac{L}{400}} = 404\ in^4$$

Try W36X231 $I_y/2$=470 $in^4$ Table 3-5

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# Design of 30 ft Runway Girder

Calculate Moments:

DL (Girder + Rail + Clamps) = 231+175/3 + 20 = 309 lbs/ft

$$M_{xDL} = \frac{wL^2}{8} = \frac{\left(.309\frac{kips}{ft}.\right)(30\ ft)^2}{8} = 35\ kip - ft$$

$$M_{xLL} = \frac{P_a}{2L}(L - \frac{a}{2})^2 = \frac{78\ kips}{2(30\ ft.)}(30\ ft. - \frac{11\ ft.}{2})^2 = 780\ kip - ft.$$

$$M_x = 1.25(780kip - ft.) + 35\ kip - ft = 1010\ kip - ft$$

$$M_y = \frac{6.6kips}{78kips}(780kip - ft) = 66\ kip - ft$$

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# Design of 30 ft Runway Girder

Check bending with impact for the W36x231:

From Table 3-10: $M_x$ = 1800 kip-ft. >1010 ok

From Table 3-4: $M_y$ = 439 kip-ft/2 = 220 > 66.0 kip-ft ok

Check biaxial bending:

$$M_{rx}/M_{cx} + M_{ry}/M_{cy} = 1010/1800 + 66/220 = 0.86 < 1.0 \text{ ok}$$

Use W36x231

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# Design of 30 ft Runway Girder

Check Shear- AISC Chapter G

$h/t_w$ = 42.2 (Table 1-1), d= 36.5 in., $t_w$ = 0.76 in.

$$\frac{h}{t_w} = 42.2 \leq 2.24\sqrt{\frac{E}{F_y}} = 54$$ (web slenderness limit for G2.1)

Nominal shear strength, $V_n = 0.6F_yA_wC_v$

$\Omega_v = 1.5,\ C_v = 1.0,\ A_w = (36.5\ in.)(0.76\ in.) = 27.7\ in.^2$

$V_n/\Omega = (0.6)(50\ ksi)(27.7\ in.^2)(1.0)/1.5 = 554\ kips$

$V_a = W_{dl}(L/2) + P_a(2 - a/L)$

$V_a = (.309 kip/ft)(30 ft/2) + (1.25*78\ kips)(2 - 11\ ft/30\ ft)$

$V_a = 164\ kips < 554\ ok$

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# Design of 30 ft Runway Girder

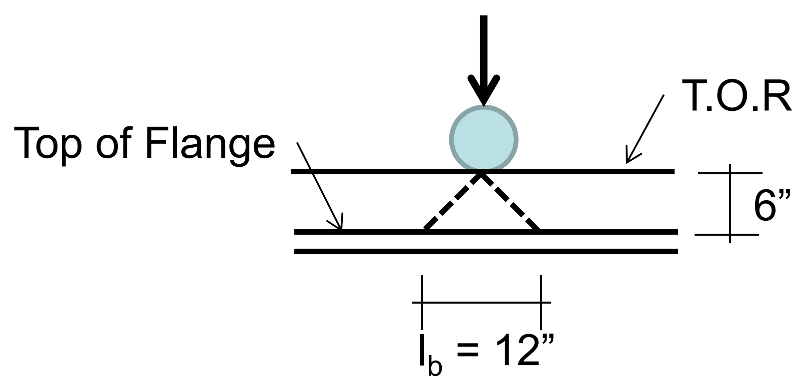
Check Web Local Yielding- AISC J10.2

$\Omega = 1.5$

$R_n/\Omega = F_{yw} t_w (5k + l_b)/1.5$ J10-2

$= (50\ \text{ksi})(0.76\ \text{in.})[(5)(2.21\ \text{in.}) + (12\ \text{in.})]/1.5 = 584\ \text{kips}$

$97.5\ \text{kips} < 584\ \text{kips}$ ok

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# Design of 30 ft Runway Girder

Check Web Local Crippling- AISC J10.3

$t_f$ =1.26 in., $t_w$ = 0.76 in., d = 36.5 in., $l_b$ = 12 in. Ω =2.0

$$\frac{R_n}{\Omega} = \frac{0.8t_w^2\left[1+3\left(\frac{l_b}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{\frac{EF_{yw}t_f}{t_w}}}{\Omega} \quad \text{J10-4}$$

$$= \frac{0.8(0.76)^2\left[1+3\left(\frac{12}{36.5}\right)\left(\frac{0.76}{1.26}\right)^{1.5}\right]\sqrt{\frac{29000(50)(1.26)}{0.76}}}{2.0} = 524 kips \geq 97.5 kips \quad \text{ok}$$

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# Design of 30 ft Runway Girder

Check Sidesway Web Buckling AISC J10.4(b)
compression flange not restrained against rotation

$h/t_w = 42.2,\ b_f = 16.5\ in.,\ L_b = 360\ in.$

$(h/t_w)/(L_b/b_f) = 42.2/(360/16.5) = 1.93 > 1.7$

Sidesway web buckling limit state does not apply

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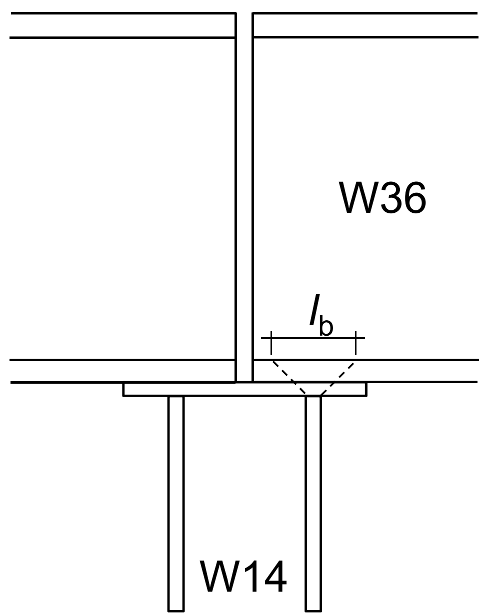
# Design of 30 ft Runway Girder

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# Design of 30 ft Runway Girder

Check if Bearing Stiffeners are Required (at column):

Check using AISC Section J10.2(b) for an end condition.

Use ¾ in. cap plate on the column.

$$R_n = F_{yw} t_w (2.5k + l_b) \qquad (J10\text{-}2)$$

$k = 2.21\ in.$ $\quad l_b = 2(0.75) + t_{fcol}$

$$l_b = 2(0.75) + 0.86 = 2.36\ in.$$

$$R_n = (50)(0.76)[(2.5)(2.21) + 2.36] = 300\ kips$$

$$R_n/\Omega = 300/1.5 = 199 > 164.\ kips\ \ ok$$

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# Design of 30 ft Runway Girder

Check Local Web Crippling AISC J10-5a

$l_b/d = 2.36\text{ in.}/36.5\text{ in.} = 0.07 < 0.2$

$$\frac{R_n}{\Omega} = \frac{.4tw^2\left[1 + \left(\frac{l_b}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{\frac{EF_{yw}t_f}{t_w}}}{\Omega}$$

$$\frac{R_n}{\Omega} = \frac{.4(.76)^2\left[1 + \left(\frac{2.36}{36.5}\right)\left(\frac{.76}{1.26}\right)^{1.5}\right]\sqrt{\frac{29000(50)1.26}{.76}}}{1.5}$$

$$\frac{Rn}{\Omega} = 213\ kips \geq 164\ kips$$

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# Design of 30 ft Runway Girder

Even though the calculations indicate that bearing stiffeners are not required, the author's opinion is that they should be provided. This is because if the rail is not precisely centered over the web, or if other eccentricities exist, the web may buckle due to combined bending and axial load.

# Buildings with Overhead Cranes

- **Lesson 5**
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# Tie Back Failure

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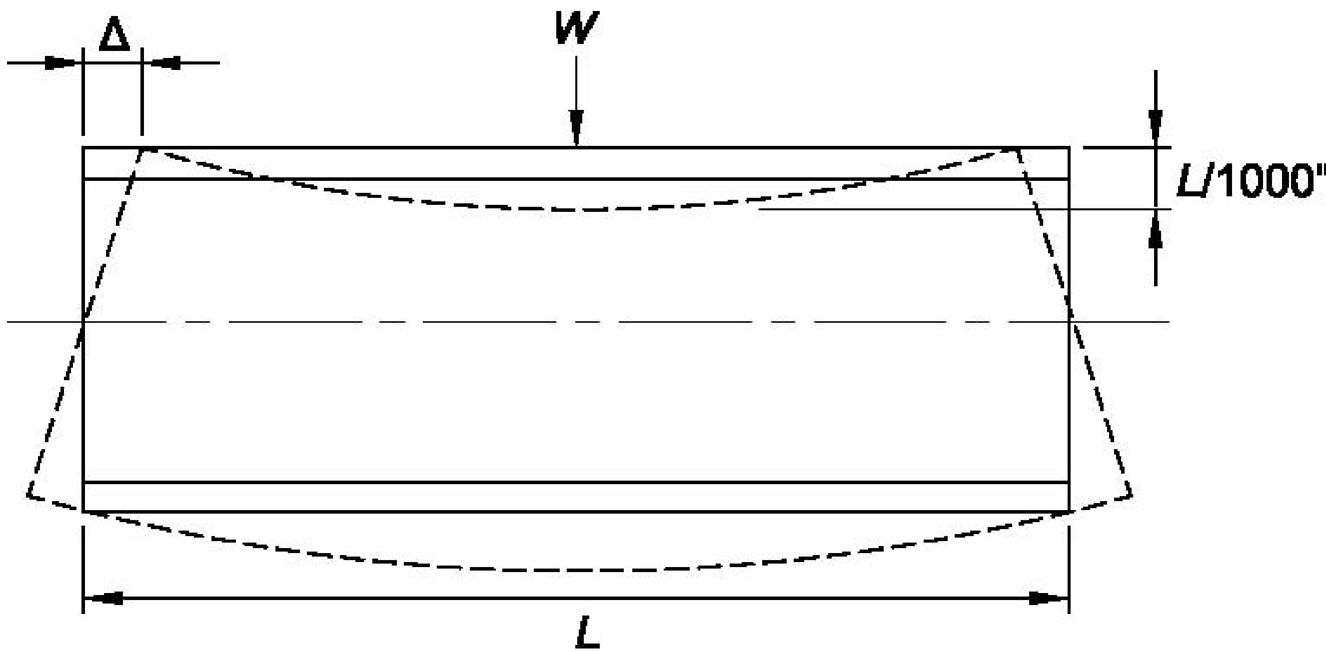
# Tie Backs

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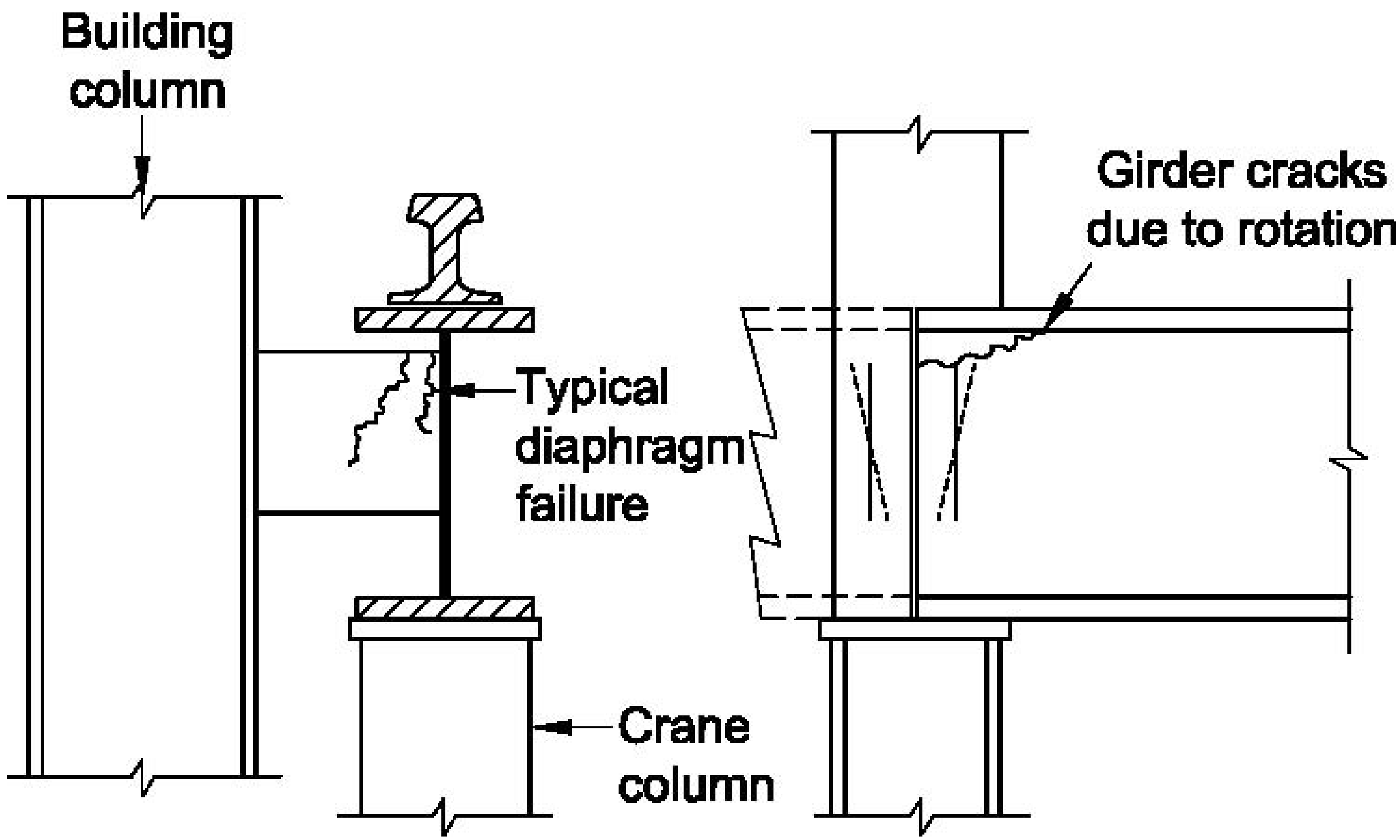
# Tie Backs

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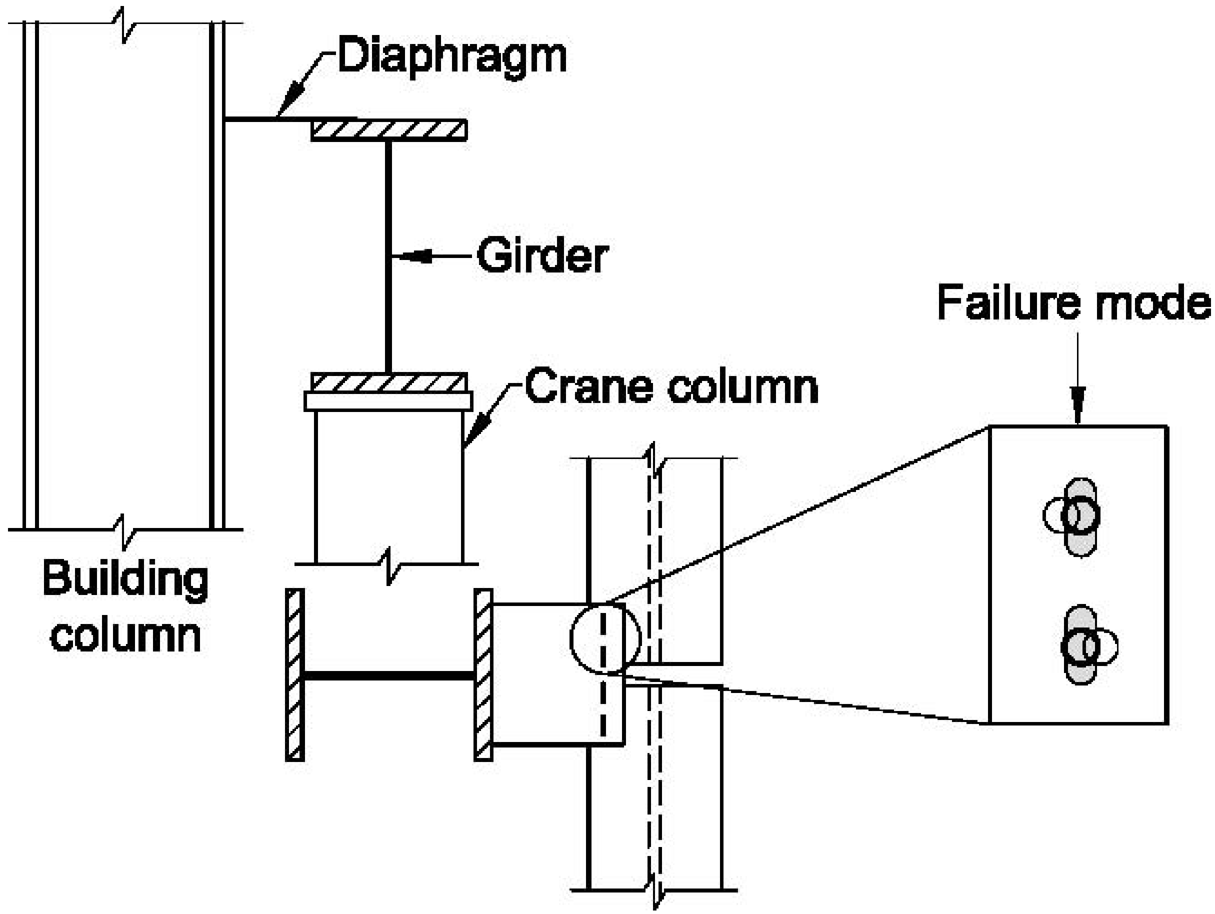
# Tie Backs

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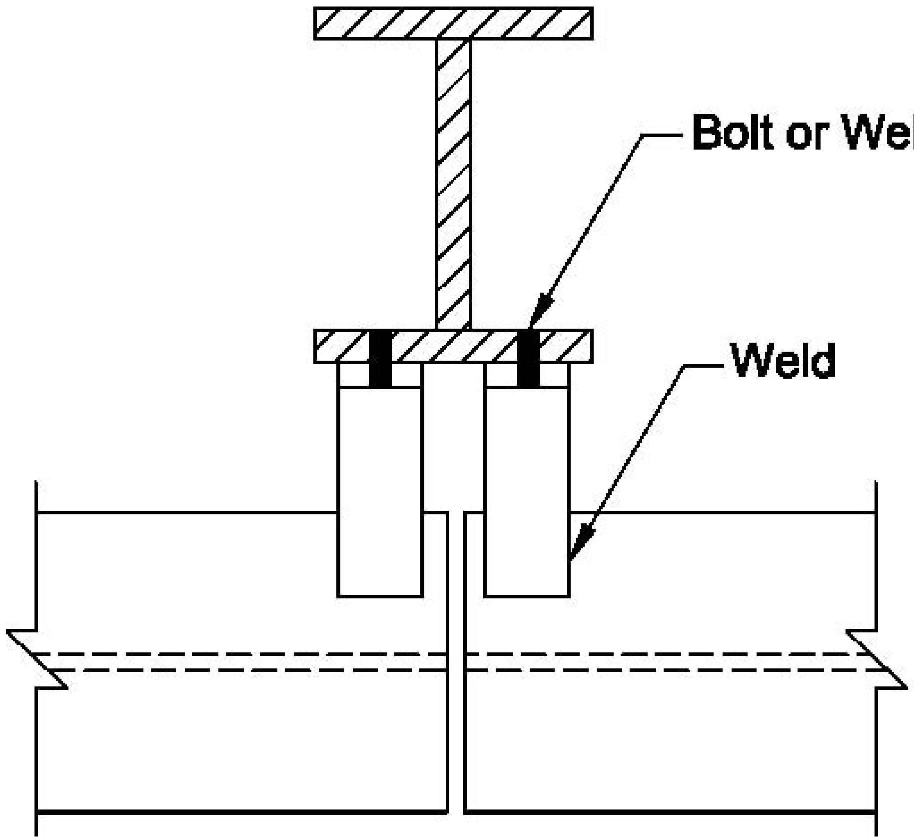
# Tie Back Design

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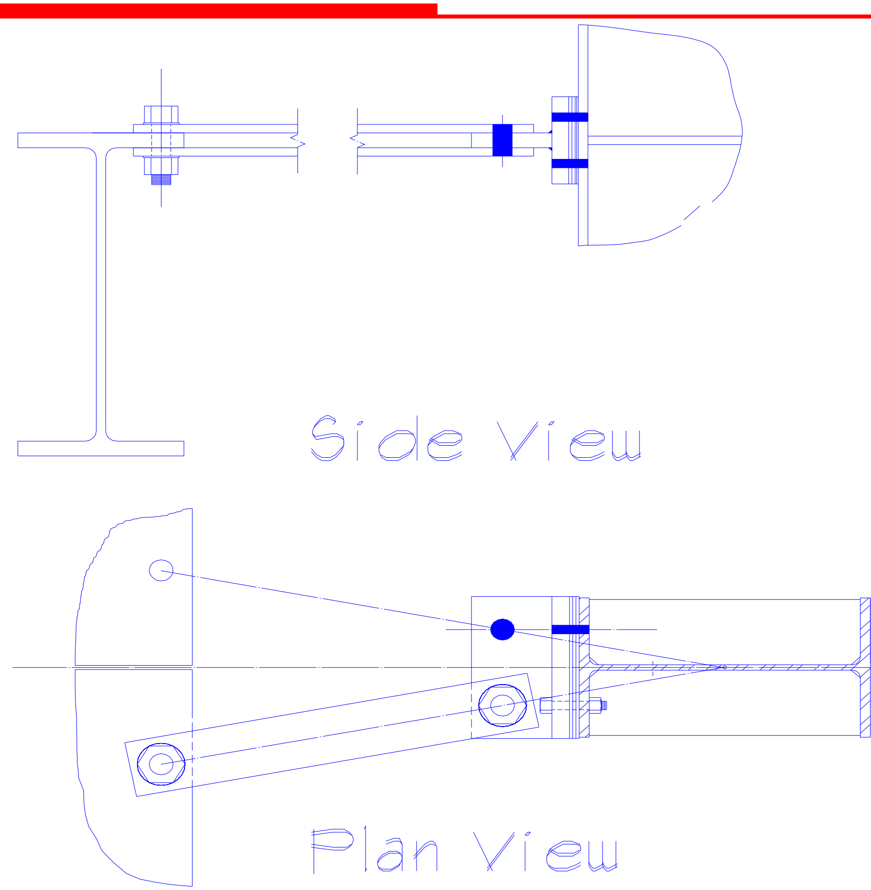
# Tie Back Design

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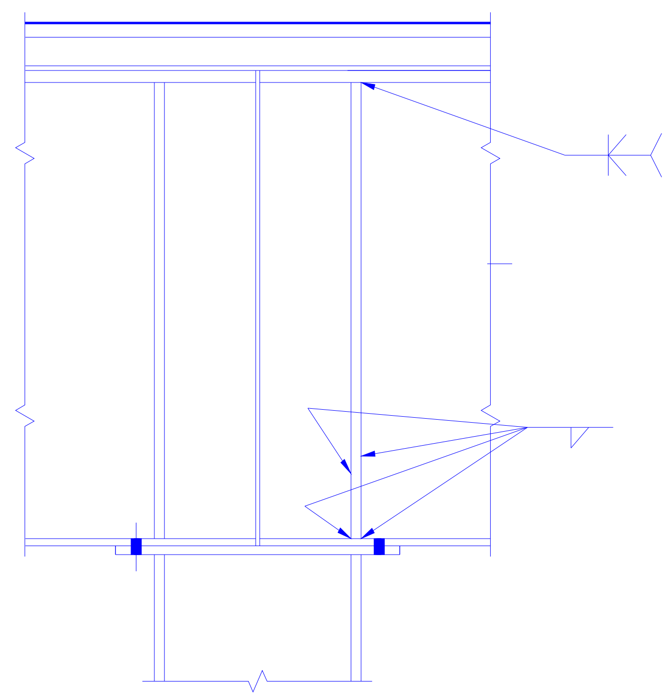
# Bearing Stiffeners

- Extend the full height of the girder
- Weld to the girder top flange with full penetration welds
- Weld to the girder web and bottom flange with properly sized continuous fillet welds.



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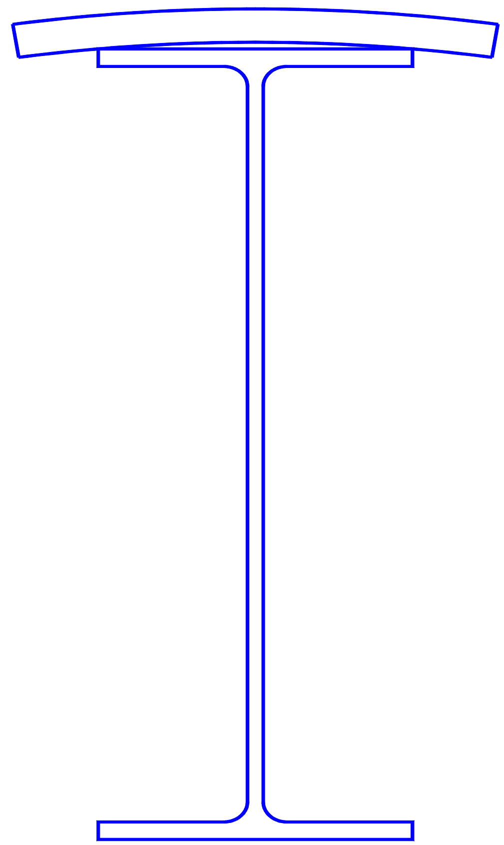
# Cap Channel and Cap Plates

- Use girder cap channels only if this saves 30 #/ft. over a wide flange member
- Avoid girder cap plates for AIST Mill Buildings Class A (500,000 cycles and above)



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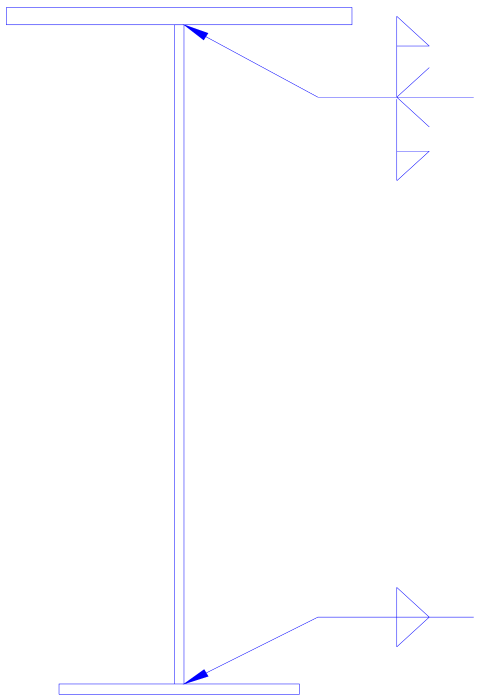
# Welded Plate Girders

- AIST Requirements
  - AWS Chapter 9 required
  - Top flange to web weld, full penetration with fillet backing
  - Bottom flange to web weld, continuous fillet welds
  - Flange and web splices, full penetration welds ground smooth in the direction of stress
  - Nondestructive testing of all welds is required



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# Laced Crane Girders

- Horizontal truss attached to the top flange of the girder and a back up girder to form a truss to stabilize the top flange of the girder
  - usually economical for spans over 40 feet
  - use bolted connections
  - account for differential deflection of the girder and back up girder
- AIST requires *bottom* flange bracing for spans over 36 feet in class A, B, and C buildings and spans over 40 feet in class D buildings.

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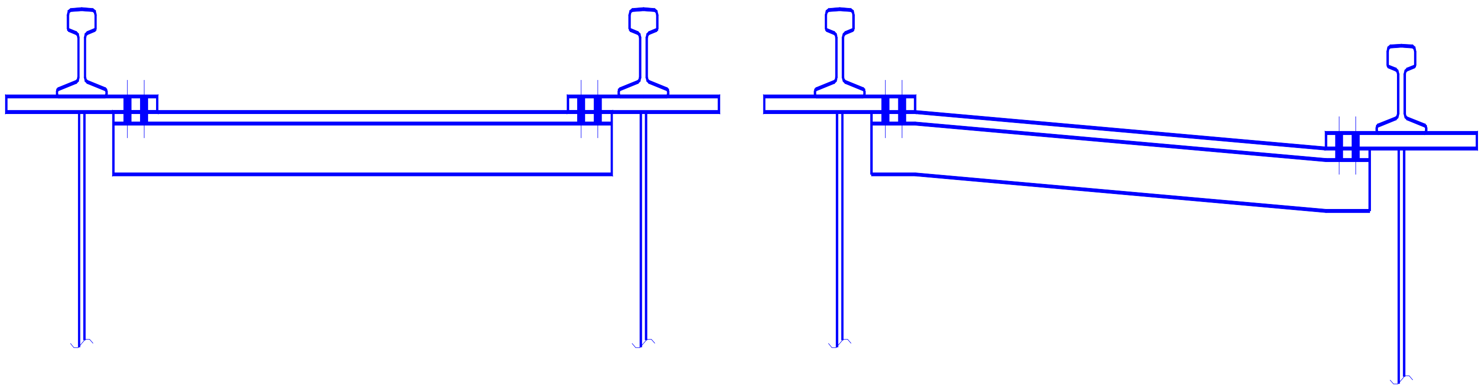
# Crane Girder Lacing



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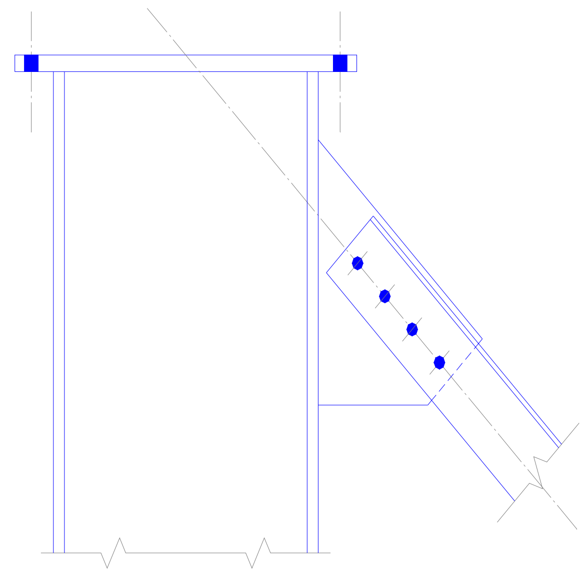
# Crane Column Cap Plates

- Allow girder end rotation
  - avoid thick cap plates
  - place the bolts outside of the column flanges.
- Transfer longitudinal forces down the runway aisle
- Allow for adjustment in placing the crane girder.
  - use slip critical bolts in oversize holes or bolts with short slots perpendicular to the girder.



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# Rail Attachments

- The rail to girder attachments must perform the following functions:
  - transfer the lateral loads from the top of the rail to the top of the girder
  - allow the rail to float longitudinally relative to the top flange of the girder
  - hold the rail in place laterally
  - allow for lateral adjustment or alignment of the rail

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# Methods of rail Attachment

- The commonly accepted methods of rail attachment are:
  - hook bolts
  - rail clips
  - rail clamps
  - patented rail clips

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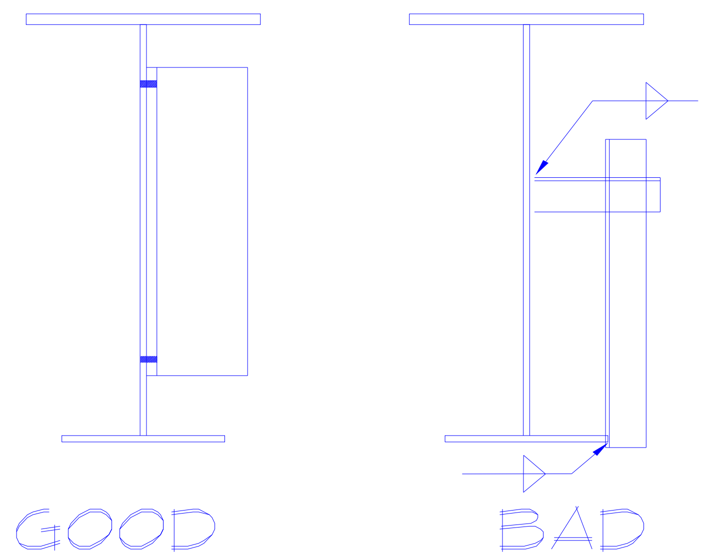
# Miscellaneous Attachments

- Coordinate attachments to the crane girder with other trades
- AIST prohibits welding attachments to the bottom flange

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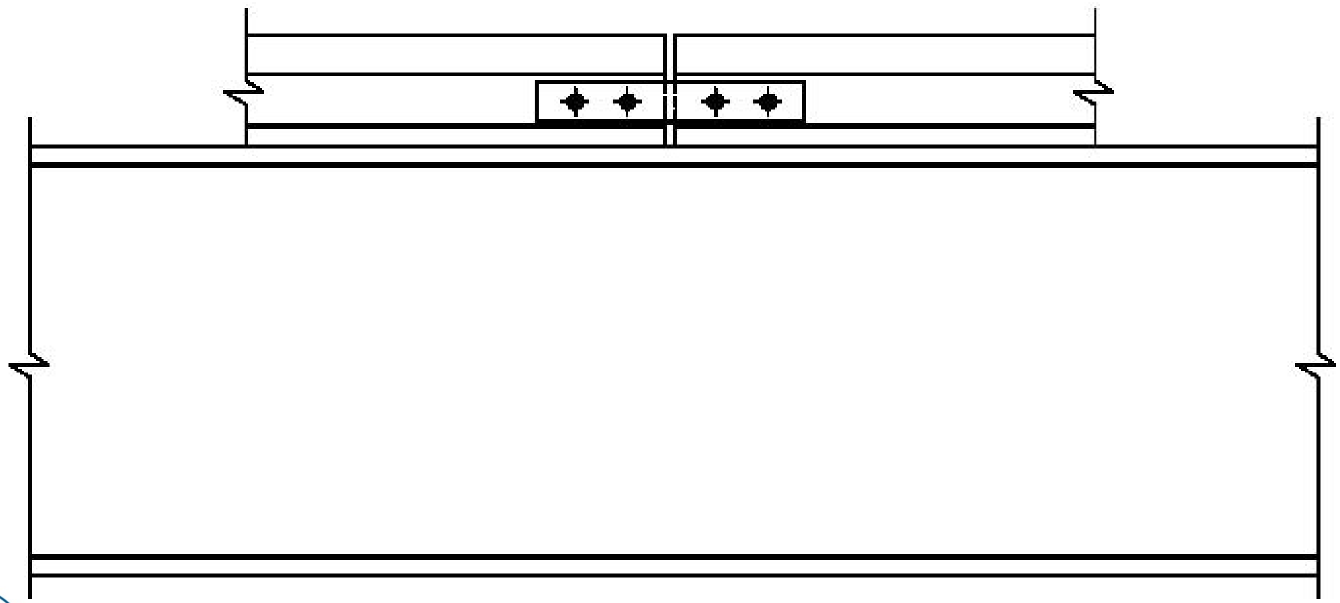
# Bolted Rail Joints

**CRANE RAILS**

**Bolted butt joint**



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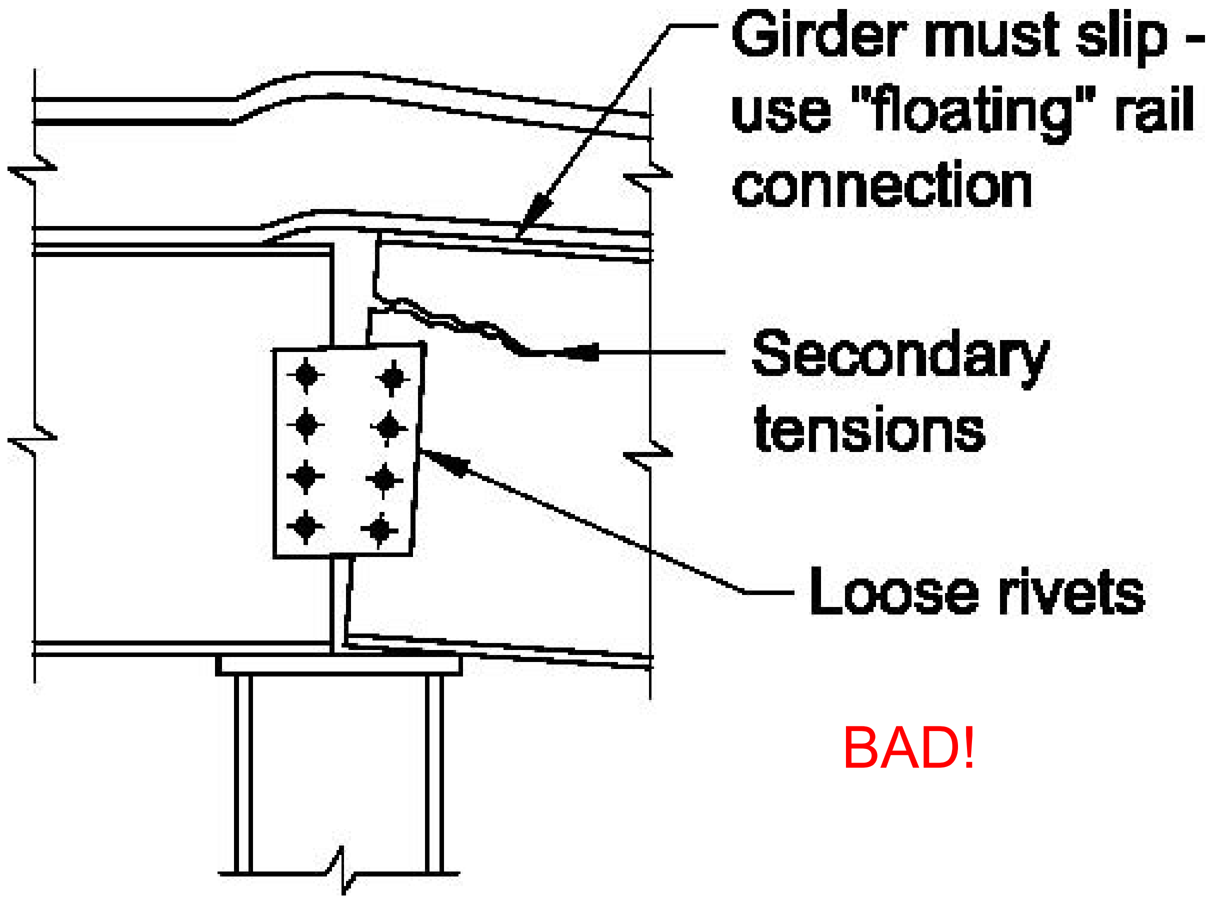
# Welded Butt Joints

- Consult rail manufacturer for welding requirements and details.
- Once welded these joints are usually maintenance free.
- Impact stresses eliminated with welded joints.

# Diaphragm Plate Failure




BAD!

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# Buildings with Overhead Cranes

- **Lesson 5**
  - **30 ft Runway Beam Design**
  - **Runway Details**
  - **Wind load Calculations**
  - **Snow Load Calculations**
  - Seismic Forces
  - Load Combinations
  - Frame Design using the Direct Analysis Method

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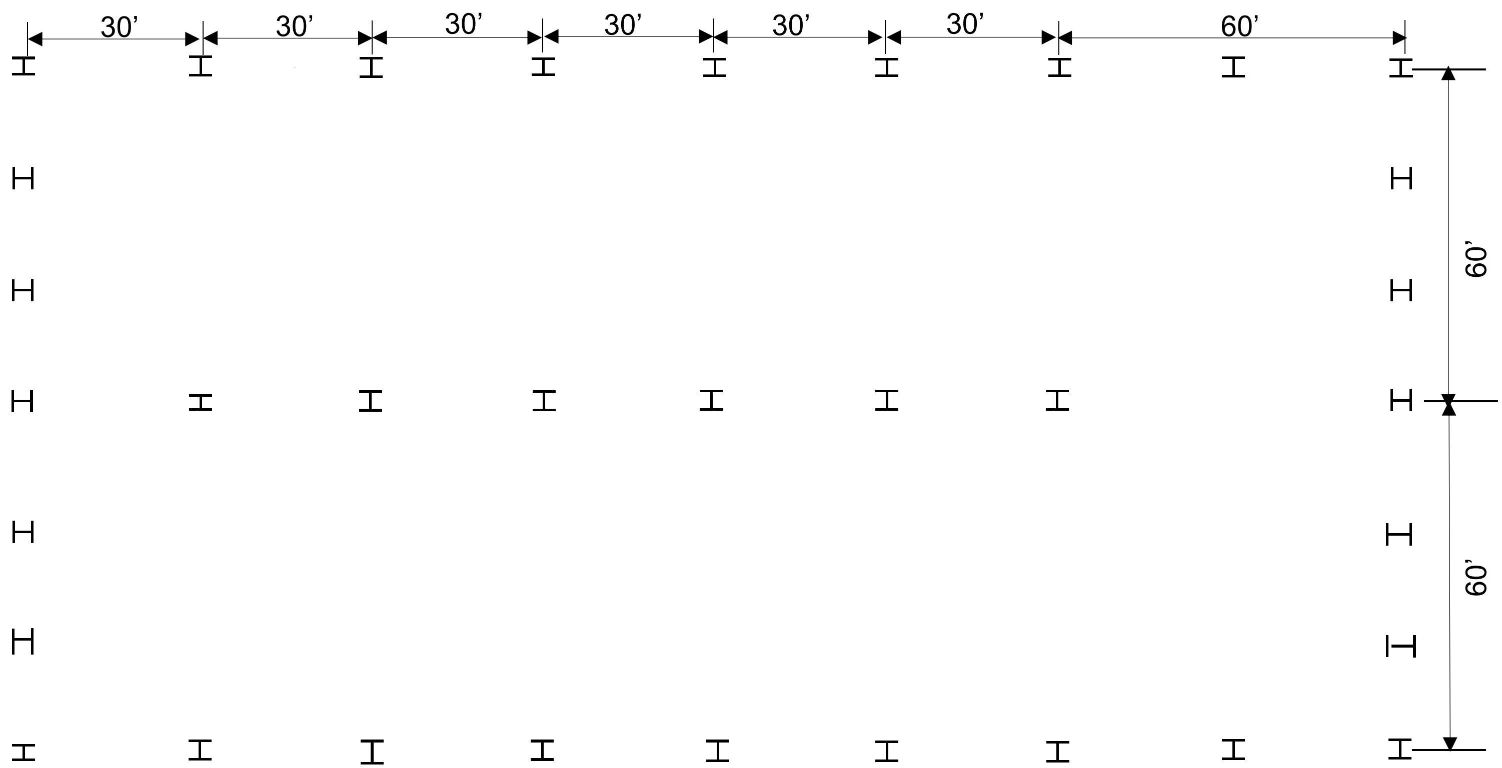
# Building Footprint

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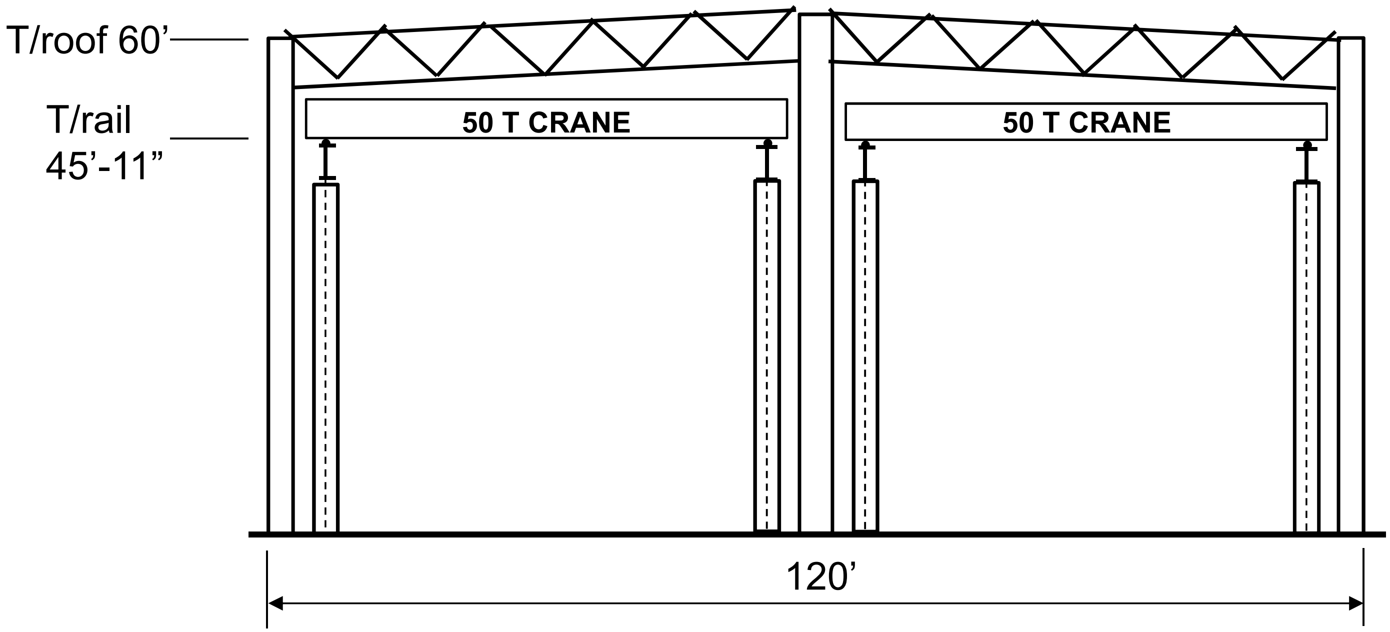
# Cross Section

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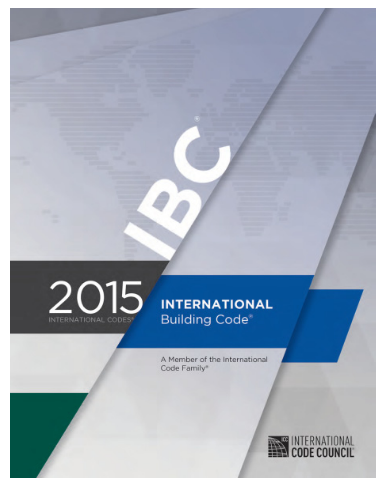
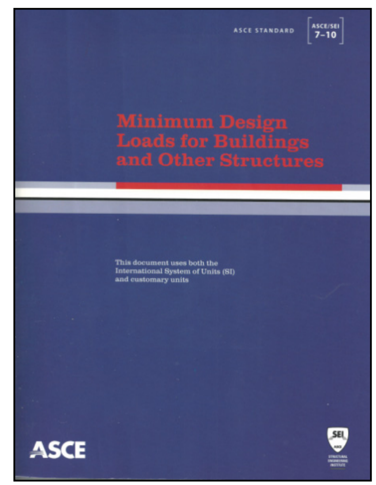
# Codes and Standards

- Building Code: IBC 2015
- Minimum Design Loads For Buildings And Other Structures (ASCE 7-10)
- Building Department Contact: John Smith
- Date: July 6, 2016
- Local Ordinances: None



# Loads

- ROOF DEAD LOAD

| | |
|---|---|
| – Roofing (SSR) | 2.0 psf |
| – Insulation | 1.0 psf |
| – Roof Bracing | 1.0 psf |
| – Joists | 3.0 psf |
| – Joist Girders | 3.0 psf |
| – Columns | 6.0 psf |
| – MEP Allowance | <u>3.0 psf</u> |
| – **Total** | **19.0 psf** |

- WALL DEAD LOAD (Includes Girts) **3.0 psf**

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# Load Calculations - Wind

- Wind Loads
- Wind Speed: 115 mph
- Wind Exposure: C
  - Using ASCE 7-10 (Directional Procedure)
  - Chapter 27 ASCE 7-10
  - Use Spreadsheet!

- Use ATC website to get wind speed.

http://windspeed.atcouncil.org/

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# Load Calculations - Wind

**MWFRS WIND LOAD CALCULATIONS**

(ASCE 7-10)

Project ABC Building

Job No. SJI/AISC
By JMF
Date 4/30/16

**qz = 0.00256Kz*Kzt*Kd*V^2 (Eq. 27.3-1)**

| | | |
|---|---|---|
| Occ. = | II | risk category, Table 1.5-1 |
| V = | 115 | basic wind speed (3-second gust), mph, Figure 26.5-1A |
| Exp = | C | exposure category, Section 26.7 |
| Kd = | 0.85 | wind directionality factor, Section 26.6 & Table 26.6-1 |
| Kzt = | 1 | topographic factor, Section 26.8 & Figure 26.8-1 |
| Encl. = | E | enclosure classification, Section 26.10 |
| Ri= | 1 | large volume buildings reduction factor, Section 26.11.1.1 |
| G = | 0.85 | gust factor, Section 26.9 |
| zg = | 900 | atmospheric boundary layer, ft., Table 26.9-1 |
| $\alpha$ = | 9.5 | 3-sec gust speed power law exponent, Table 26.9-1 |

Pressure Coefficients per Table 26.11-1 & 27.4-1

| | | | Wind Pressures, psf | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | WW WL | LW WL | Total WL | Side WL | Roof WL 0 to h | Roof WL h to 2h | Roof WL > 2h | Internal WL |
| Height | Kz | qz | 0.8 | 0.5 | | -0.7 | -0.9 | -0.5 | -0.3 | 0.18 |
| 0-15 | 0.85 | 24.43 | 16.6 | 10.4 | 27.0 | -14.5 | -18.7 | -10.4 | -6.2 | 4.4 |
| 20 | 0.90 | 25.95 | 17.6 | 11.0 | 28.7 | -15.4 | -19.9 | -11.0 | -6.6 | 4.7 |
| 30 | 0.98 | 28.27 | 19.2 | 12.0 | 31.2 | -16.8 | -21.6 | -12.0 | -7.2 | 5.1 |
| 40 | 1.04 | 30.03 | 20.4 | 12.8 | 33.2 | -17.9 | -23.0 | -12.8 | -7.7 | 5.4 |
| 50 | 1.09 | 31.48 | 21.4 | 13.4 | 34.8 | -18.7 | -24.1 | -13.4 | -8.0 | 5.7 |
| 60 | 1.14 | 32.71 | 22.2 | 13.9 | 36.1 | -19.5 | -25.0 | -13.9 | -8.3 | 5.9 |

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# Load Calculations - Wind

- Wind Loads
  - Using ASCE 7-10 (Directionality Procedure)
  - Use Spreadsheet!

Wind Loads For A Specific Height, h (Used for Components & Cladding)

| | | | WW | LW | Total | Side | | Roof WL | | Int. |
|---|---|---|---|---|---|---|---|---|---|---|
| Height | Kz | q | WL | WL | WL | WL | 0 to h | h to 2h | > 2h | WL |
| 0-15 | 0.85 | 24.43 | 16.6 | | | | | | | |
| 60 | 1.14 | 32.71 | 22.2 | 13.9 | 36.1 | -19.5 | -25.0 | -13.9 | -8.3 | 5.9 |

- For a typical frame:

  16.6 psf ≤ Windward Wall Pressure ≤ 22.2 psf

  Wind at eave/frame = (36.1 psf)(30 ft)(60/2 ft) = 32.5 kips

  For ASD Factored wind = (0.6)(32.5 kips) = 19.5 kips

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# Loads

- ROOF LIVE LOADS
  - 20.0 psf (reducible)

- SNOW LOADS
  - Ground Snow Load ($P_g$): 15.0 psf
  - Building Category: II –> Importance Factor, $I_S$ = 1.0
  - Thermal Factor, $C_t$: 1.0
  - Exposure Factor, $C_{e,}$ Partially Exposed: 1.0

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# Load Calculations - Snow

- Low Slope Roof Snow Load (slope <15°):

$$P_f = 0.7 C_e C_t I P_g = 10.5 \text{ psf}$$

- Minimum Roof Snow for Low Slope Roof

$$P_m = I_S P_g = 15 \text{ psf}$$ ← controls

- Check Rain-on-Snow Surcharge, slope ¼" per ft.

$$(Slope = 1.19°) < (W/50 = 60/50 = 1.2)$$ Add Surcharge

→ $$P_f = 15\,psf + 5\,psf = 20 \text{ psf}$$

- Must consider unbalanced snow per 7.6 if slope is ½" per ft. or greater.

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# Buildings with Overhead Cranes

- **Lesson 5**
  - **30 ft Runway Beam Design**
  - **Runway Details**
  - **Wind load Calculations**
  - **Snow Load Calculations**
  - **Seismic Forces**
  - Load Combinations
  - OMF Design using the Direct Analysis Method

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# Local Code Requirements

- Ground Snow Load: 15 psf
- Seismic Spectral Acceleration:
  - $S_s$ = 1.054 g
  - $S_1$ = .40 g

(Determine from USGS Website)

http://earthquake.usgs.gov/designmaps/us/application.php

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# Loads

- SEISMIC LOADS
  - Spectral Acceleration, $S_s$: 1.054 G
  - Spectral Acceleration, $S_1$: 0.400 G
  - Occupancy Category: II
  - Site Class: D
    - Average Soil shear wave velocity, $\overline{v}_s$ 800 ft/sec
    - Average Standard penetration resistance, $\overline{N}$ 15 blows
    - Average Soil undrained shear strength, $\overline{s}_u$ 1500 psf
  - Importance Factor, I: 1.0
  - Seismic Design Category: TBD

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# Load Calculations - Seismic

Determine Seismic Design Category

- Adjusted MCE Spectral Response Acceleration

$$S_{MS} = F_a S_s = (1.1)(1.054) = 1.16g$$

$$S_{M1} = F_v S_1 = (1.6)(0.400) = 0.640g$$

- Design Spectral Acceleration

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3}(1.16) = 0.77g$$

$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3}(0.64) = 0.43g$$

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# Load Calculations - Seismic

Determine SDC (Cont.)

Since $S_1 < 0.75$,

Use Tables 11.6-1 and 11.6-2

From Table 11.6-1: Seismic Design Cat. = D

From Table 11.6-2: Seismic Design Cat. = D

Seismic Design Category = D

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# Load Calculations - Seismic

Impact of Seismic Design Category D

ASCE 7-10 Chapter 12 Seismic Design Requirements for Building Structures

- Cannot use R=3.0 + AISC 360 (table 12.2-1)

Transverse Direction: OMF?

- Not permitted in SDC D except single story buildings up to 65 ft. tall with roof dead load of less than 20 psf …

Longitudinal Direction: OCBF?

- Not permitted in SDC D except single story buildings up to 60 ft. tall with roof dead load of less than 20 psf …

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# Load Calculations - Seismic

Including the mass of the crane in the dead load results in dead load exceeding the Chapter 12 limits for the use of OMF and OCBF systems per Chapter 12.

- Consider Structure as a "Nonbuilding Structure Similar to Buildings" per Chapter 15 of ASCE 7-10
- Refer to ASCE 7-10 Chapter 11 definitions and Chapter 15 for "Nonbuilding Structure Similar to Buildings"

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# Load Calculations - Seismic

- Transverse Direction from Table 15.4-1

  OMF – Ordinary Moment Frame

  With permitted height increase

  $R = 2.5$

  $\Omega_0 = 2$

  $C_d = 2.5$

  Height limit of 100 feet.

  Detailing Requirements per AISC 341

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# Load Calculations - Seismic

- Longitudinal Direction from Table 15.4-1

  OCBF – Ordinary Concentrically Braced Frame

  With permitted height increase

  $R = 2.5$
  $\Omega_0 = 2$
  $C_d = 2.5$

Height limit of 160 ft.

Detailing Requirements per AISC 341

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# Load Calculations - Seismic

- See ASCE 7-10 Chapter 15 15.4.4
- Calculate the Elastic Fundamental Period
  - From 1st Order Frame Analysis (Crane Lateral)

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{21.6\,\text{kips}/2.00\,\text{in.}}{255\,\text{kips}}\left(\frac{386\,\text{in.}}{\text{sec}^2}\right)} = \frac{4.04\,\text{rads}}{\text{sec}}$$

$$T = \frac{2\pi}{\omega} = \left(\frac{2\pi\,\text{rads}}{\text{cycle}}\right)\left(\frac{\text{sec}}{4.04\,\text{rads}}\right) = 1.55\,\text{sec/cycle}$$

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# Load Calculations - Seismic

- Limit the calculated period to the product of the "coefficient for upper limit on calculated period" and the approximate fundamental period (ASCE 7-10 12.8.2)

$$T_a = C_t h_n^x = (0.028)(60)^{0.8} = 0.74\,\text{sec/cycle}$$

$$T \le C_u T_a = 1.4(0.74) = 1.04\ \text{sec}$$ (Limit)

# Load Calculations - Seismic

- Equivalent Lateral Force Procedure

$$V = C_s W$$

where

$$C_s = \frac{S_{DS}}{R/I_e} \leq \frac{S_{D1}}{T\left(R/I_e\right)} \geq .044 S_{DS} * I_e$$

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# Load Calculations - Seismic

- Determine the seismic coefficient $C_s$

$$\frac{S_{DS}}{R/I_e} = \frac{0.77}{2.5/1.0} = 0.31$$

  - using $T_a$ from ASCE-7

$$\frac{S_{D1}}{T(R/I_e)} = \frac{0.427}{0.74(2.5/1.0)} = 0.23$$

  - using 1.4 $T_a$

$$\frac{S_{D1}}{T(R/I_e)} = \frac{.427}{1.04(2.5/1.0)} = 0.16$$

>29%

$C_s$= .16 transverse direction

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# Lateral Frame Loads

- Crane Thrust = 21.6 kips
- Wind at Eave = 19.5 kips
- Seismic Strength Check
  - Seismic at Roof: $0.7\rho Q_E$ = 10.9 kips
  - Seismic at TOR: $0.7\rho Q_E$ = 22.3 kips

    32.4 kips
- Seismic Drift Evaluation and P-Delta Limit per ASCE*
  - Seismic at Roof: $Q_E$ =(1.04/1.55)(1/.7)10.9=10.4 kips
  - Seismic at TOR: $Q_E$ = (1.04/1.55)(1/.7)22.3=21.4 kips
- *Strength level adjusted without the limit on the period

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# Vertical Frame Loads

- Roof Dead Load = (13)(30)/1000 = 0.39 kips/ft
- Roof Live or Snow = (20)(30)/1000 = 0.60 kips/ft
- Wind Uplift (windward, W)
  = (25.0 + 5.9)(30)/1000 = 0.927 kips/ft
- Wind Uplift (leeward)
  = (8.5 + 5.9)(30)/1000 = 0.36 kips/ft
- Maximum Roof Downward Seismic Load
  $= [1.0 + (0.14)S_{DS}]D = [1.0 + (0.14)(0.77)](0.39)$
  = 0.43 kips/ft.
- Minimum Roof Upward Seismic Load
  $= [.60- (0.14)S_{DS}]D = [.60 - (0.14)(0.77)](0.39)$
  = 0.19 kips/ft.

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# Buildings with Overhead Cranes

- **Lesson 5**
  - **30 ft. Runway Beam Design**
  - **Runway Details**
  - **Wind load Calculations**
  - **Snow Load Calculations**
  - **Seismic Forces**
  - **Load Combinations**
  - Frame Design using the Direct Analysis Method

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# Load Combinations - ASD

1) D
2) D + L
3) D + S
4) D + 0.75L + 0.75S
5) 5) D + 0.6W
5a) D + 0.7E
6a) D + 0.75L + 0.75(0.6W) + 0.75(S)
6b) D + 0.75L + 0.75(0.7E) + 0.75(S)
7) 0.6D + 0.6W
8) 0.6D + 0.7E

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# Load Combinations - Seismic

Substituting $E = \rho Q_E$ and including $(0.14S_{DS})D$:

1) $D$
2) $D + L$
3) $D + S$
4) $D + 0.75L + 0.75S$
5) $D + 0.6W$
5a) $(1.0 + 0.14S_{DS})D + 0.7\rho Q_E$
6) $D + 0.75L + 0.45W + 0.75S$
6a) $(1.0 +0.14S_{Ds})D + 0.75L + 0.525\rho Q_E + 0.75S$
7) $0.6D + 0.6W$
8) $(0.6 - 0.14S_{DS})D + 0.7\rho Q_E$

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# Load Combinations - Cranes

- The following designations are used for the crane loads. This is the same nomenclature as used by AISE in Technical Report No. 13:
  - $C_{vs}$ – Vertical loads due to a single crane in one aisle only.
  - $C_{ss}$ – Side thrust due to a single crane in one aisle only.
  - $C_d$ – Dead load of cranes.

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# Load Combinations - Cranes

1) $D + C_d$
2) $D + C_d + C_{vs} + C_{ss}$
3) $D + C_d + S$
4) $D + C_d + 0.75(C_{vs} + C_{ss}) + 0.75 S$
5) $D + C_d + 0.6W$

5a) $(1.11)(D + C_d) + 0.7\rho Q_E$

6) $D + C_d + 0.75W + 0.75L + 0.75 S$

6a) $(1.11)(D + C_d) + 0.525\rho Q_E + 0.75C_{VS} + 0.75 S$

7) $0.6(D) + 0.6W$
8) $(0.49)(D + C_d) + 0.7\rho Q_E$

By observation, combinations 5a and/or 6a will control the design of the frame. Use combination 5a for the analysis / example.

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# Load Combinations - Seismic

Load Cases Including the Overstrength Factor (ASD):

5b) $(1.11)(D + C_d) + 0.7\Omega_o Q_E$

6b) $(1.11)(D + C_d) + 0.5\Omega_o Q_E + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$

8b) $(0.6 - 0.14S_{DS})D + 0.7\Omega_o Q_E$

Load Case For Story Drift Determination

5c) $(1.35)(D + C_d) + Q_E^* + .2S$

$\theta$ limit per 12.8.7 (ASCE 7-10) $D + Q_E^* + S$

*Strength Level, adjusted for actual T, $\rho = 1.0$

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# Buildings with Overhead Cranes

- Lesson 5
  - 30 ft Runway Beam Design
  - Runway Details
  - Wind load Calculations
  - Snow Load Calculations
  - Seismic Forces
  - Load Combinations
  - Frame Design using the Direct Analysis Method

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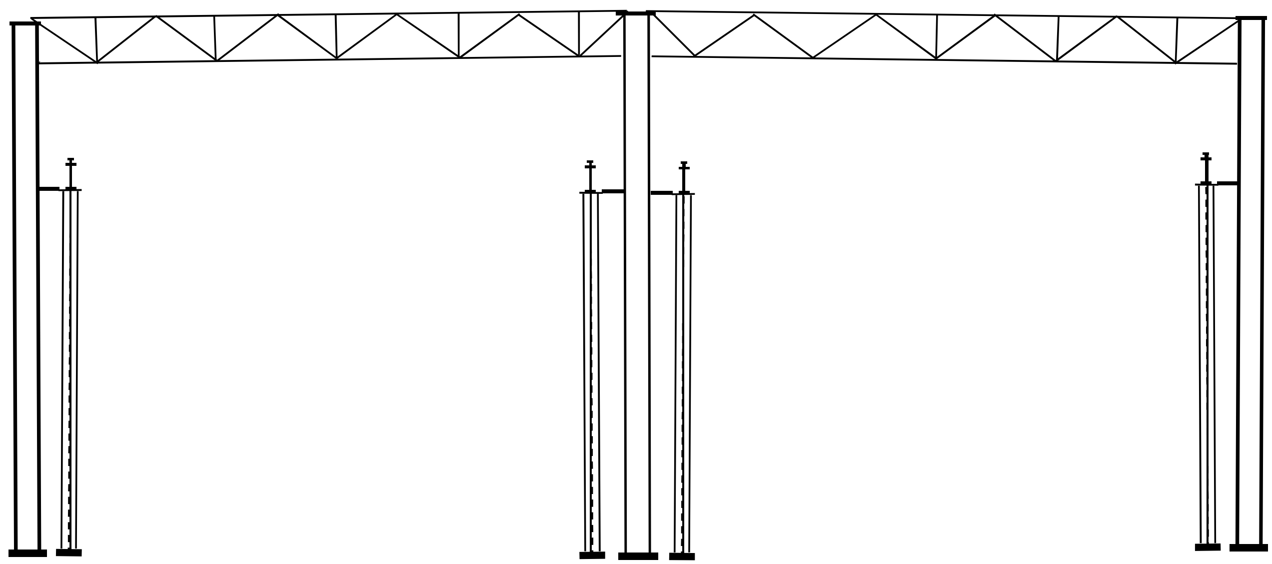
# Analysis of the Frame



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# Analysis of the Frame

First a review of the AISC Specification requirements for analysis and design.

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# AISC Specification General Stability Requirements

Chapter C DESIGN FOR STABILITY

- Use any method of *analysis and design* that considers:
  1. Member deformations (flexural, axial, shear)
  2. P-Δ effects and P-δ effects
  3. Geometric imperfections
  4. Stiffness Reduction due to inelasticity
  5. Uncertainty in stiffness and strength

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# 2010 Analysis for Stability

- Three prescriptive analysis and design approaches are provided in the Specification:
  - Section C1.1: Direct Analysis Method of Design
  - Section C1.2: Alternative Methods of Design
    - Effective Length Method (Appendix 7)
    - First-Order Analysis Method (Appendix 7)

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# Analysis and Design Methods

- All 3 methods involve a direct or indirect $2^{nd}$ order analysis.
- All 3 methods require addition of "notional" loads.
- If $\frac{\Delta_{2nd-order}}{\Delta_{1st-order}} > 1.5$, only "direct analysis" is permitted.

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# Analysis and Design Methods

- First-Order Method is usually conservative
  - Assumes $B_2 = 1.5$
- Effective Length Method
  - Uses nominal stiffness in model
  - Requires stability analysis to calc. K factors unless $B_2 \leq 1.1$
- Direct Analysis Method
  - Uses reduced stiffness in model
  - K=1 (no further stability analysis required)

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# Direct Analysis Method

- Chapter C in 2010 *Specification*
  - Applicable to all types of structures
  - 2nd Order Analysis uses Reduced Stiffness
  - Applicable to All Structural Systems
    - Braced frames
    - Moment frames
    - Shear wall systems
    - Any combination of systems

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# Notional Loads

- *Notional loads*, $N_i$, are fictitious lateral loads, where

$$N_i = 0.002Y_i$$

$Y_i$ = the total gravity load on $\text{story}_i$

The notional loads account for an initial out-of-plumbness at the maximum of 1/500 as defined in the AISC COSP. If a lesser out-of-plumbness can be justified, $N_i$ can be reduced.

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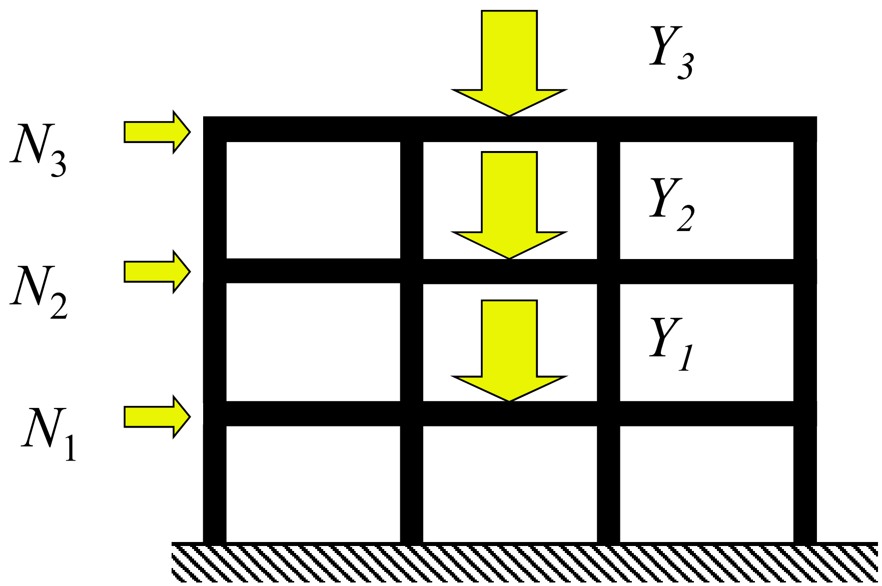
# Direct Analysis Method




$$N_i = 0.002Y_i$$

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# Direct Analysis Method

- If the second-order effects are limited,

$$\frac{\Delta_{2nd-order}}{\Delta_{1st-order}} \leq 1.5$$

notional loads are only required for the gravity-only load combinations.

Note:

- For most buildings, this will be the case.

# Direct Analysis Method

- If $\dfrac{\Delta_{2nd-order}}{\Delta_{1st-order}} > 1.5$

  the notional loads are added to the other lateral loads in the load combinations.

- Apply notional loads in the direction of sway!

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# Notional Loads -Example

- Summation of the notional loads:

Where 276 kips is the summation of the vertical service loads in Combination 1 (D including $C_d$).

$C_d$=99kips/aisle   D=78 kips

$$\sum N_i = 0.002 \sum Y_i = 0.002(276\,\text{kips}) = 0.55\,\text{kips}$$

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# Direct Analysis Method

- Use a reduced flexural and axial stiffness

$$EI^* = 0.8\tau_b EI$$

$$EA^* = 0.8EA$$

to account for influence of inelasticity on second-order effects (stiffness loss).

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# Direct Analysis Method

- $\tau_b$ accounts for loss of flexural stiffness under high compression loads ($\alpha P_r > 0.5P_y$).
- For Mid-Rise and Low-Rise structures, $\tau_b$ will usually be 1.0.

Rather than using $\tau_b < 1$, an additional notional load equal to $0.001Y_i$ can be conservatively added to **all** load combinations. (Section C2.3(3))

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# Direct Analysis Method

- Inelastic flexural response due to axial force
  - Depends on the level of axial stress in the member

$$\text{when } \alpha P_r \leq 0.5 P_y; \quad \tau_b = 1.0$$

$$\text{when } \alpha P_r > 0.5 P_y; \quad \tau_b = 4\left[\frac{\alpha P_r}{P_y}\left(1 - \frac{\alpha P_r}{P_y}\right)\right]$$

$$\alpha = 1.0 \ \ \text{(LRFD)} \qquad \alpha = 1.6 \ \text{(ASD)}$$

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# Direct Analysis Method

- For LRFD
  - Conduct analysis using LRFD combinations
- For ASD
  - Conduct analysis using 1.6 * ASD combinations
  - Divide final forces and moments by 1.6

(Accounts for nonlinearity of 2nd order analysis)

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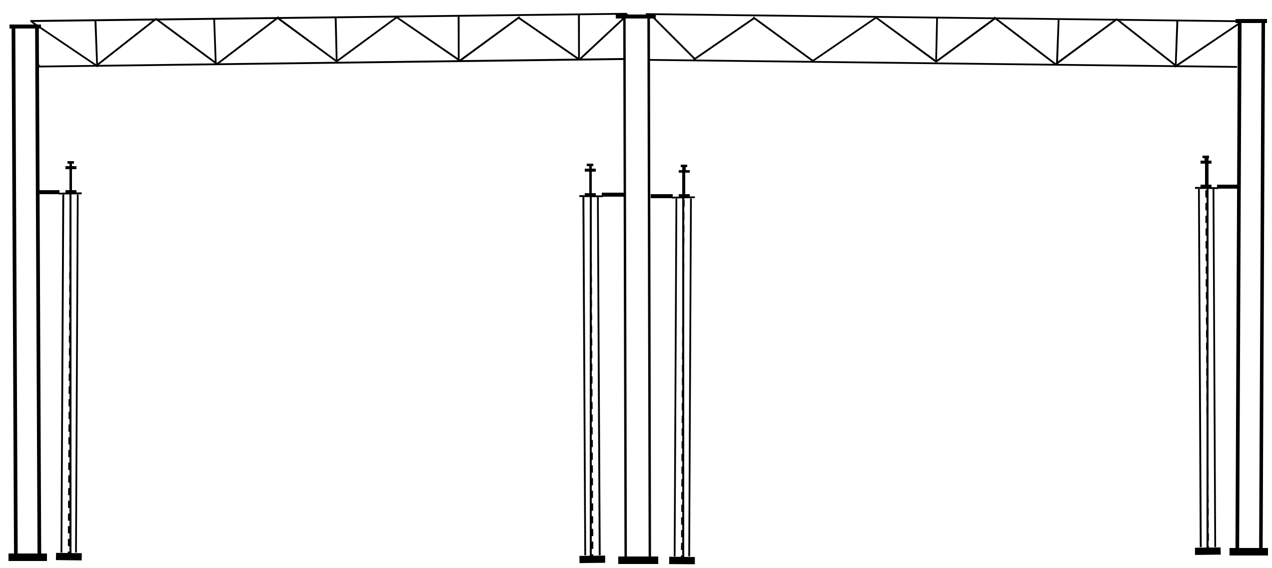
# Actual Frame



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# Model Details

- Model Joist Girder or Truss as a beam element at centerline of the truss
  - JG moment of inertia from SJI DG #11
  - Or estimate from the truss preliminary design
  - ΣAd ^2 of the chords (*.85)
- Include the crane columns
  - Necessary for $2^{nd}$ order analysis
  - Leaners increase $2^{nd}$ order effects

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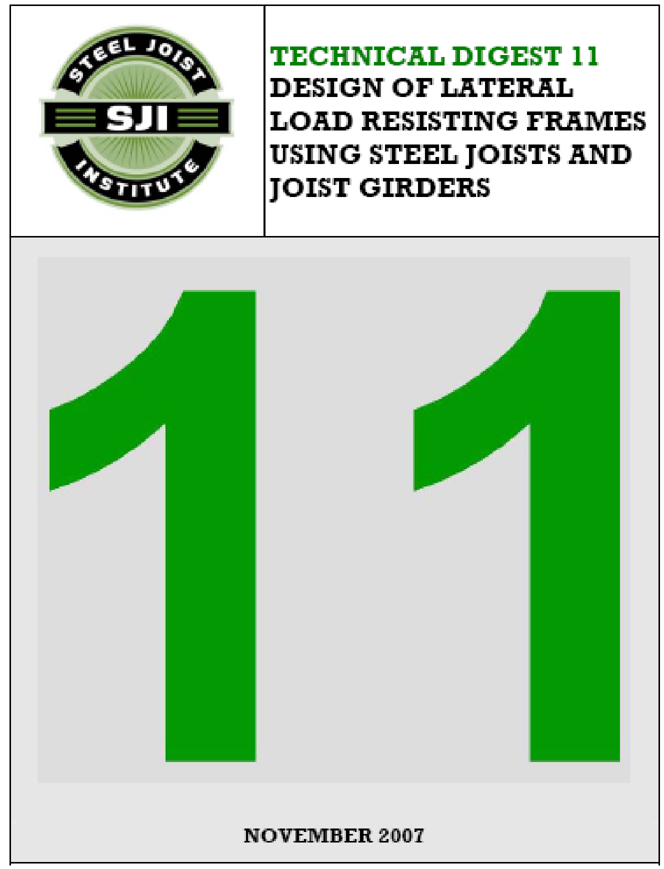
# Reference


TECHNICAL DIGEST 11
DESIGN OF LATERAL LOAD RESISTING FRAMES USING STEEL JOISTS AND JOIST GIRDERS

11

NOVEMBER 2007

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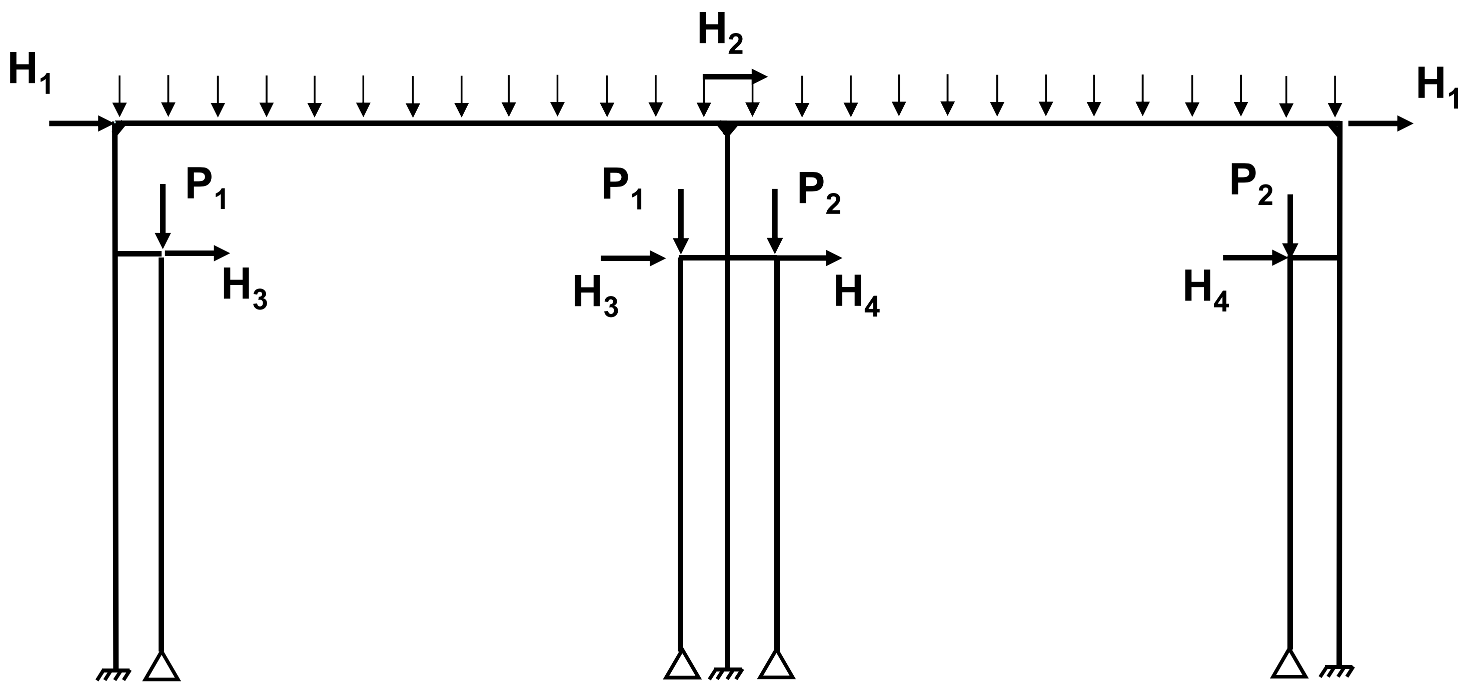
# Frame Model

The Model

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# Direct Analysis Method

- Design process
  - Establish desired serviceability drift index.
  - Perform a preliminary design to determine member sizes.
  - Perform a first-order analysis to check drift index.
  - Estimate the ratio of second-order to first-order effects.
  - Adjust design as necessary to get reasonable drifts and 2nd-order magnifiers.
  - Perform second-order analysis
    - Use reduced stiffness, EI* and EA*
    - Apply notional loads, $N_i = 0.002Y_i$ to the required load combinations
    - Conduct analysis using load combinations, not load cases, because second-order analysis is a non-linear problem.
    - If ASD, multiply forces by 1.6 before analysis
  - Determine forces and moments.
    - If ASD, divide forces by 1.6 after analysis

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# Estimate 2nd Order Effects

- Use AISC App. 8 "APPROXIMATE SECOND ORDER ANALYSIS" Eq. A-8-6 to estimate 2nd order effects to:
  - Identify acceptable analysis methods
  - Get a handle on magnitude of 2nd order effects
  - Identify stability problems before 2nd order computer analysis

$$\frac{\Delta_{2nd}}{\Delta_{1st}} \approx B_2 = \frac{1}{1-\frac{\alpha \sum P_{nt}}{\sum P_{e2}}}$$

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# Estimate 2nd Order Effects

Calculate $\sum P_{e2}$ from AISC Eq. A-8-7

- From 1st-order crane lateral analysis:

$$\sum H = 21.6\,\text{kips} \quad \Delta_H = 2.0\,\text{in.}/0.8 = 2.5\,\text{in.}$$

- For a moment frame

$$R_M = 0.85 \quad \text{(conservative)}$$

- Elastic buckling load from Eq. C2-6b

$$\sum P_{e2} = R_M \frac{\sum HL}{\Delta_H} = 0.85\frac{(21.6)(551)}{2.5} = 4{,}050\,\text{kips}$$

(lateral load, at crane ht. Δ at crane ht. =551”)

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# Estimate 2nd Order Effects

- Summation of Supported Gravity Load
  - Different for each load combination!

$$\alpha \sum P_{nt} = 1.6(255) = 409 \text{ kips}$$

- 2nd Order P-Δ multiplier from Eq. C2-3

$$B_2 = \frac{1}{1 - \frac{\alpha \sum P_{nt}}{\sum P_{e2}}} = \frac{1}{1 - \frac{409}{4{,}050}} = 1.11$$

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# Estimate 2nd-Order Effects

- Small Effects

$$1.0 \leq B_2 \leq 1.1$$

  – Any prescriptive method OK, K=1
- Moderate Effects

$$1.1 < B_2 \leq 1.5$$

  – Any method OK, K>1 for Effective Length
- Large Effects

$$B_2 > 1.5$$

  – Must use Direct Analysis, K=1

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# Perform 2nd-Order Analysis!

Structural Instability Detected!

Joint 14 Degree of Freedom MX

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# 2nd Order Model Instability

- Possible Causes
  - Gross Errors / Modeling Errors
    - Units
    - Modulus of Elasticity
  - Local Instabilities
    - Buckling of individual members
    - Buckling of groups of members
  - Overall Instability
    - $B_2 >> 1.5$ (usually due to leaners)

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# Identifying 2nd Order Errors

- Check 1st Order Results First!
  - Are reactions and deflections reasonable?
  - (Cannot use unit stiffnesses or loads)
- Manually calculate $B_2$
  - If $B_2$ is large, sidesway instability is possible
  - If $B_2$ is small, sidesway instability is not likely
- Perform Elastic Buckling Analysis
  - Review Buckled Shape and Load Ratio

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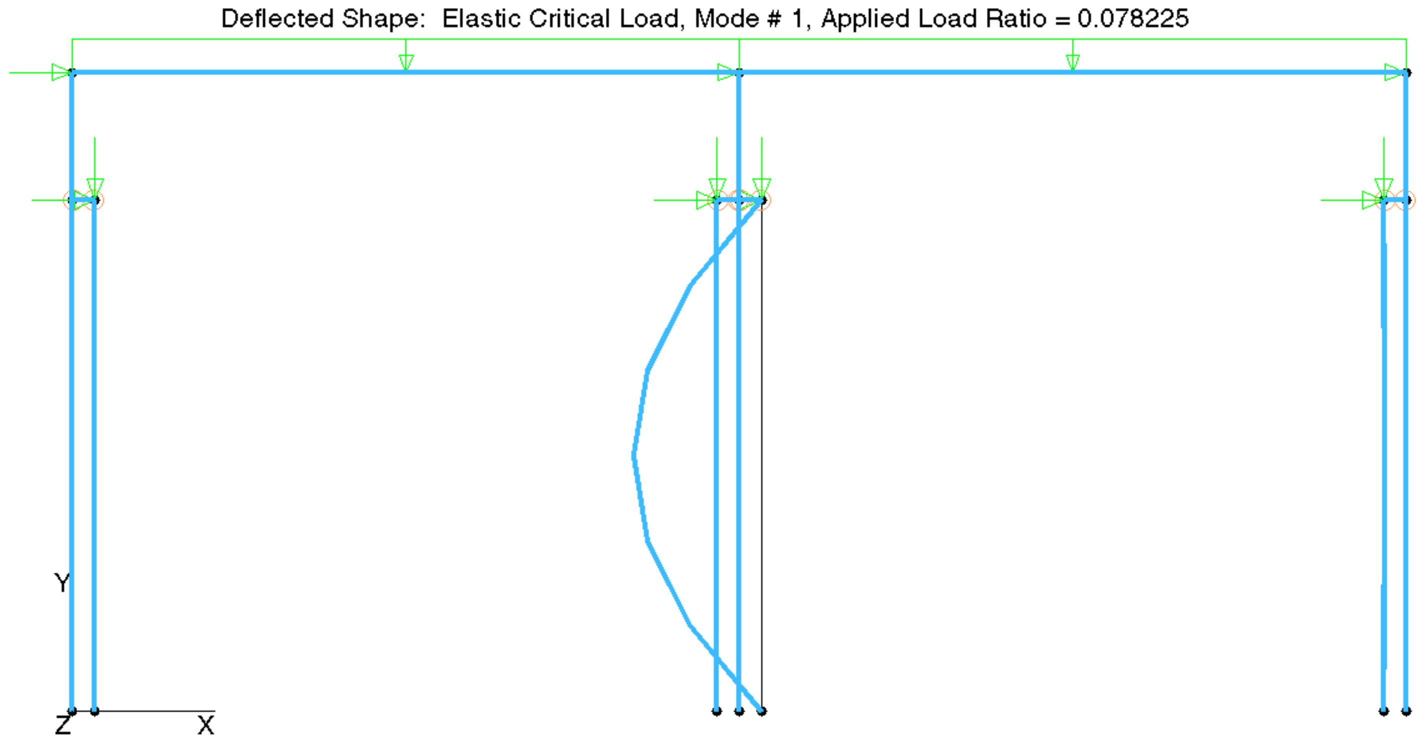
# Element Instability

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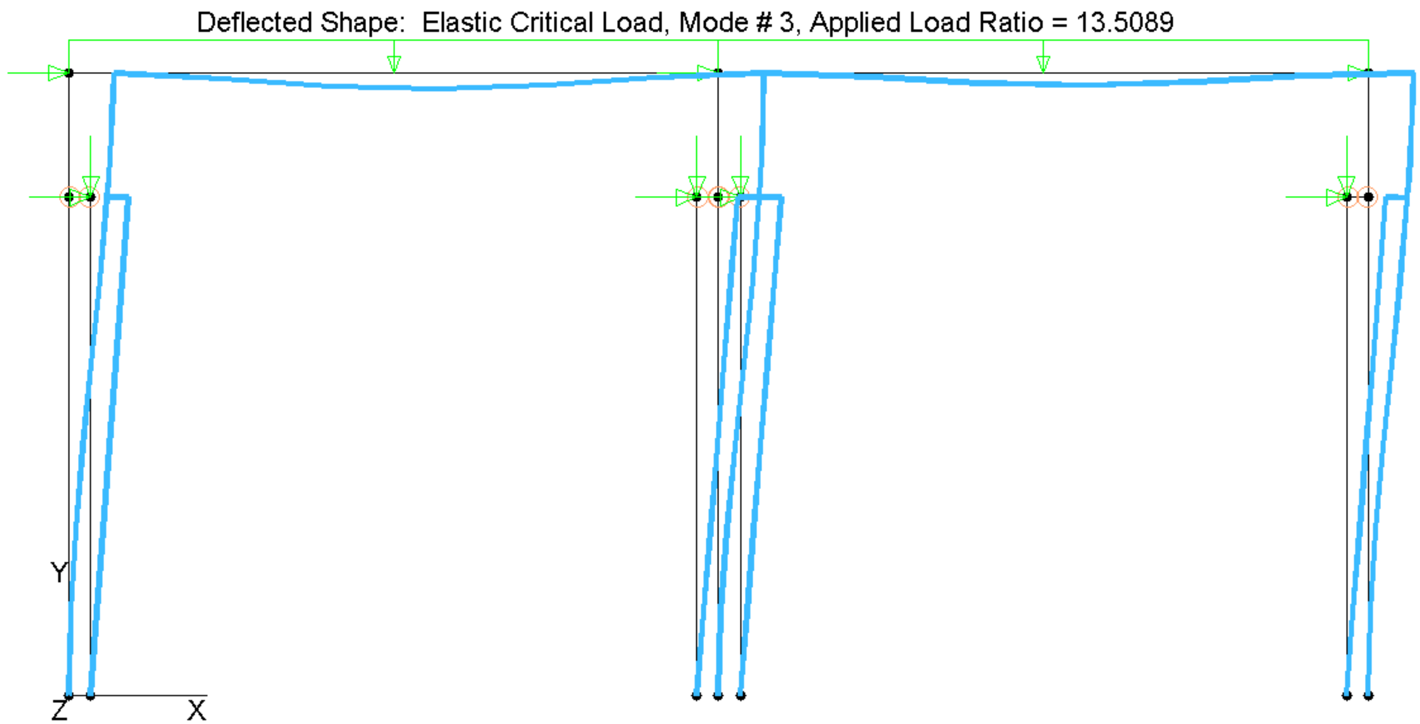
# Sidesway Instability

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# Analysis Input

- From Lesson 4 start with W24x84 exterior columns and W 24x146 interior columns.
- After some iteration select W30x99 exterior columns and W 24x146 interior columns.

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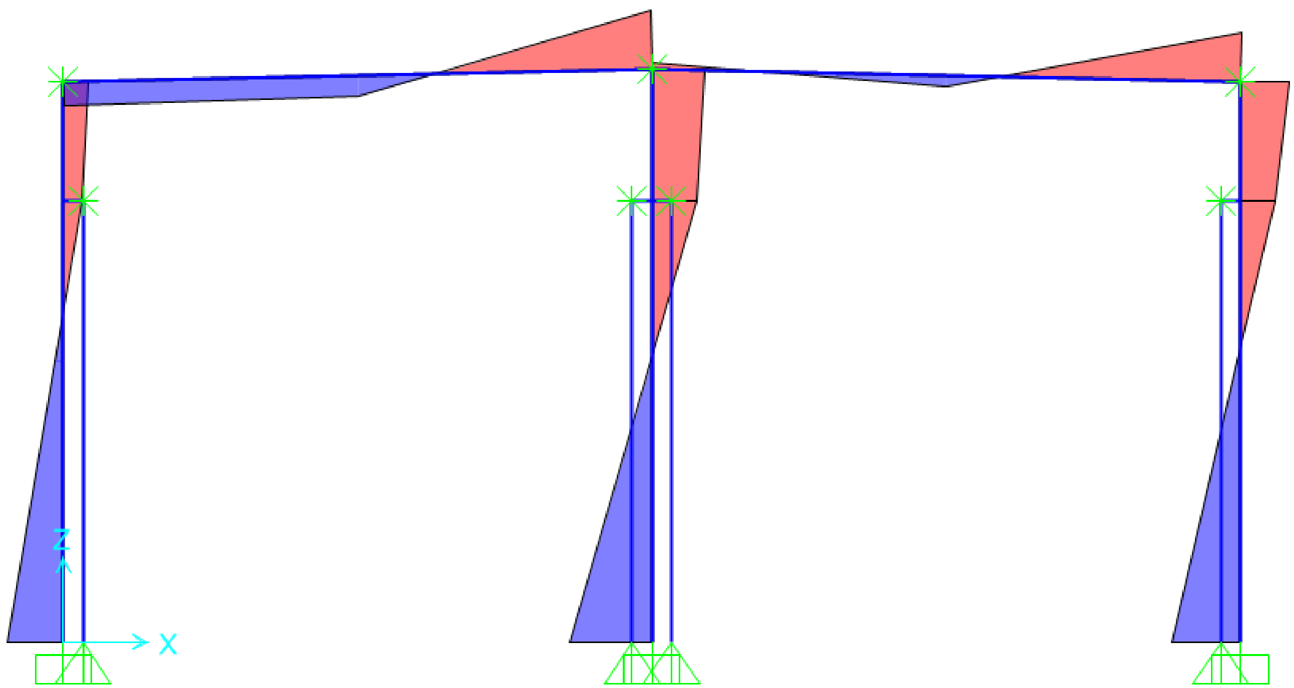
# Analysis Results - ASD

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# Analysis Results – ASD (5a)

| | | 1st Order | 2nd Order | 2nd/1st |
|---|---|---|---|---|
| Ext. Cols. | | | | |
| | $P_a$ | 16.8 kips | 16.9 kips | 1.01 |
| Top | $M_a$ | 251 kip-ft. | 256 kip-ft. | 1.02 |
| Base | $M_a$ | 350 kip-ft. | 359 kip-ft. | 1.03 |
| Int. Cols: | | | | |
| | $P_a$ | 29.2 kips | 29.3 kips | 1.00 |
| Top | $M_a$ | 268 kip-ft. | 275 kip-ft. | 1.03 |
| Base | $M_a$ | 419 kip-ft. | 430 kip-ft. | 1.03 |
| Sidesway: | | 3.15 in. | 3.23 in. | 1.03 |

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# Reference: Seismic Analysis

AISC Engineering Journal/Third Quarter 2011

Design of Steel Buildings for Earthquake and Stability by Application of ASCE 7 and AISC 360.

By: Shankar Nair, James O. Malley, and John D. Hooper

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# Buildings with Overhead Cranes

- **Lesson 5**
  - 30 ft. Runway Beam Design
  - Runway Details
  - Wind load Calculations
  - Snow Load Calculations
  - Seismic Forces
  - Load Combinations
  - Frame Design using the Direct Analysis Method

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# End of Lesson 5

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# Individual Webinar Registrants

PDH Certificates

Within 2 business days…

- 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!

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# Individual Webinar Registrants

## PDH Certificates

Within 2 business days…

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

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# 8-Session Registrants

## PDH Certificates

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

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# 8-Session Registrants

## QUIZZES

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

Quiz and Attendance records: Posted Tuesday mornings. www.aisc.org/nightschool - scroll down to Quiz and Attendance Records.

Reasons for quiz:

EEU – must take all quizzes and final to receive EEU
PDHS – If you watch a recorded session you must take quiz for PDHs.
REINFORCEMENT – Reinforce what you learned 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.

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# 8-Session Registrants

## RECORDINGS

Access to the recording: Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available for two weeks. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

PDHS – If you watch a recorded session you must take AND PASS the quiz for PDHs.

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# Night School Resources for 8-session package Registrants

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

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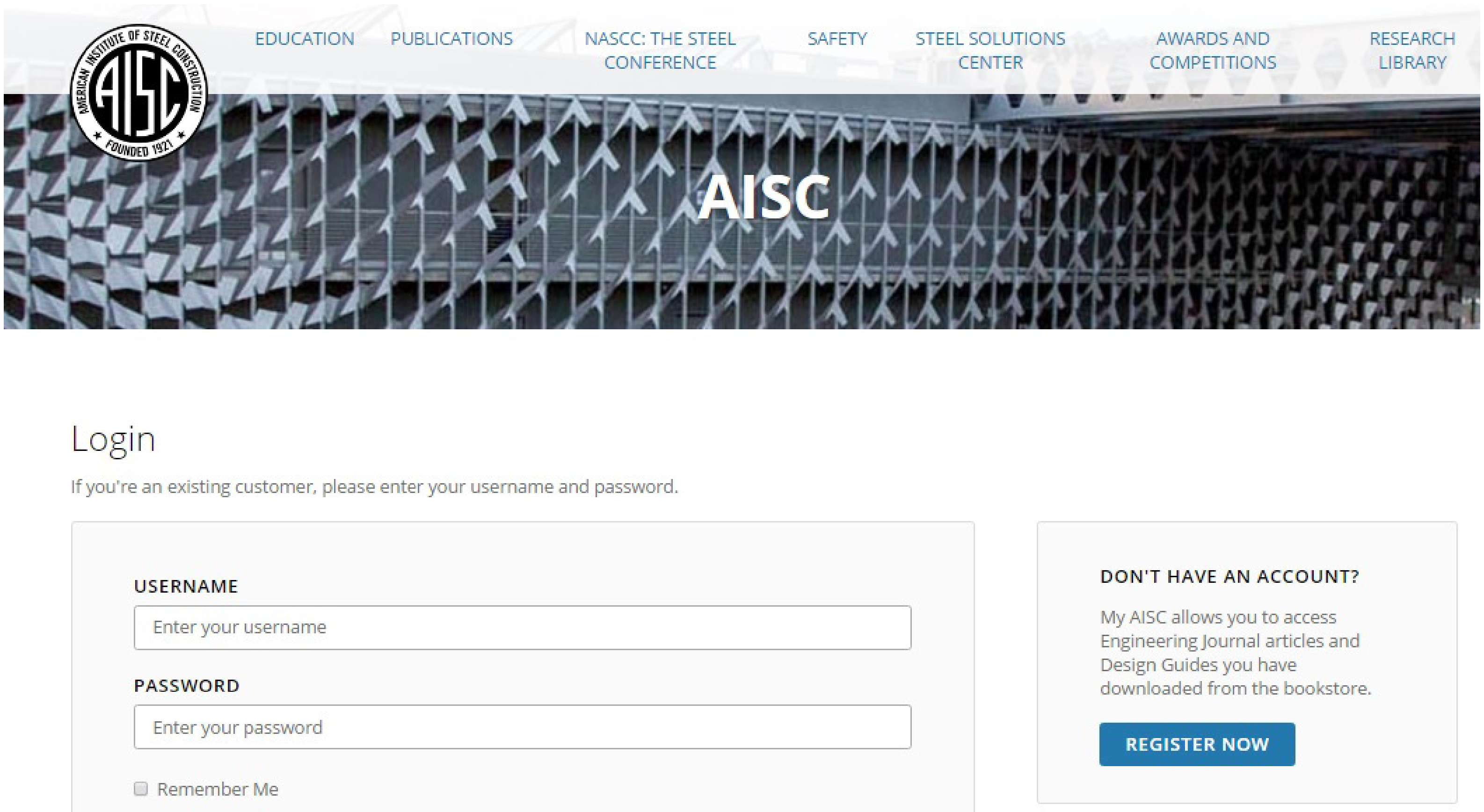
# Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.



# Night School Resources for 8-session package Registrants

**IN THIS SECTION**

- Edit Profile
- My Downloads
- My Pending Quizzes
- My Events
- Order History
- Course History
- Night School Resources

## MyAISC

### MY PROFILE

Update your contact and address information.

EDIT PROFILE

### MY PURCHASED DOWNLOADS

Access articles and documents that you have purchased.

### MY ORDER HISTORY

View your past orders.

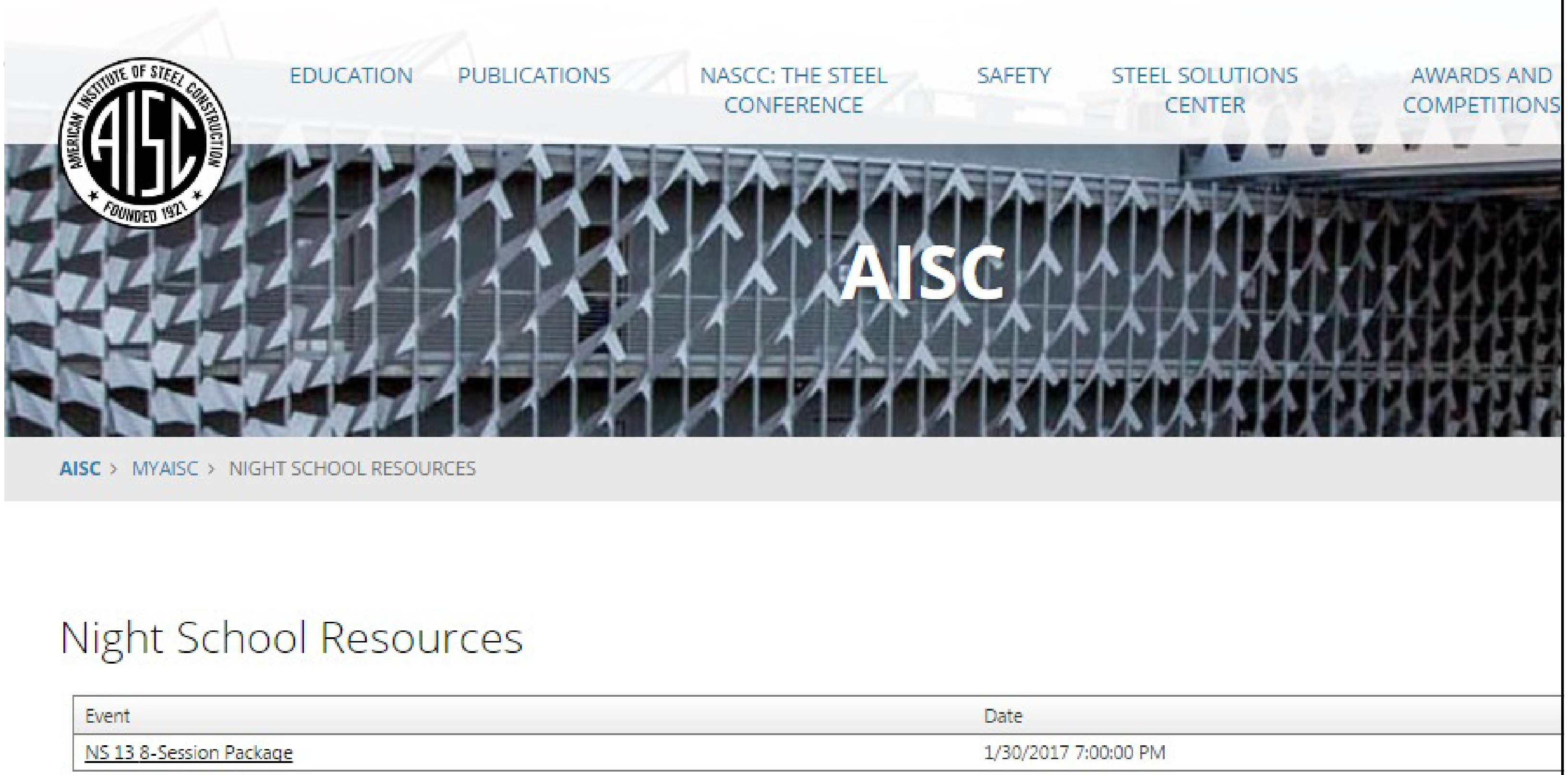
VIEW ORDERS

### MY NIGHT SCHOOL RESOURCES

View online resources for Night School courses, available for 8-Session Package registrants. See www.aisc.org/nightschool f
information on Night School including registration.

VIEW RESOURCES

# Night School Resources for 8-session package Registrants

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# Night School Resources for 8-session package Registrants

EDUCATION | PUBLICATIONS | NASCC: THE STEEL CONFERENCE | SAFETY | STEEL SOLUTIONS CENTER | AWARDS AND COMPETITIONS | RESEARCH LIBRARY


AISC › MYAISC › NIGHT SCHOOL RESOURCES › NS13 8-SESSION PACKAGE 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<br>Passcode: NS13DSN | Pass<br>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 | |

# Night School Resources for 8-session package Registrants

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

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# Night School Resources for 8-session package Registrants

- Webinar connection information:
  - Found in your registration confirmation/receipt.
  - Reminder email sent out Monday mornings.
- Link to handouts also found here.

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# Thank You

Please give us your feedback!
*Survey at conclusion of webinar.*

structural
STEEL