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Course Description

Session 6: Frame Member and Connection Design
March 13, 2017

Lesson 7 begins with the design of a 60-foot-long crane runway girder, the backup girder, and the horizontal lacing which connects the backup beam to the runway girder. The design of the longitudinal bracing system is then presented including the roof longitudinal bracing, and the building longitudinal bracing. The loads and forces acting on the bracing members and struts are developed, the members selected, and typical details are discussed. The crane bumper force calculation is provided and the crane longitudinal bracing design is shown. The design of the end wall bracing is also provided. Connection details for the braces are provided.

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Learning Objectives

- List the steps in the procedure for the design of a 60' bay crane runway girder.
- Calculate the lateral deflection of the crane runway girder and design a backup girder to resist the horizontal movement.
- List the recommendations for efficient design of vertical bracing connections.
- List the key characteristics of economical bracing connection details.

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Design of Industrial Buildings
Session 7: Transfer Crane Girder and Longitudinal Building Bracing
March 27, 2017

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

structural STEEL

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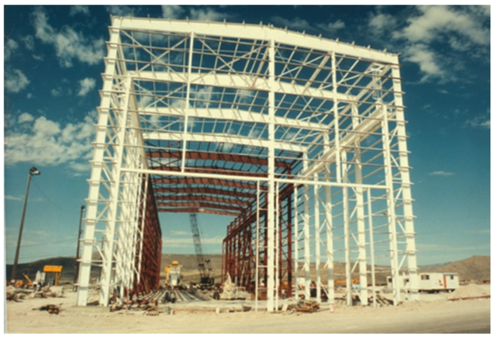
Design of Industrial Buildings Lesson 7



Presenter:
Jules Van de Pas

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Design of an Industrial Crane Building

Lesson 7

- Sixty Foot Runway Girders
  - Perimeter Girder
  - Interior Girder
- Roof Longitudinal Bracing
- Longitudinal Building Bracing
- Longitudinal Crane Bracing
- End Wall Bracing

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Review of Design Criteria

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Project Description

- 50 ton, top running crane, Class D
- Quantity: 1 per aisle
- Hook height: 45 ft
- Roof type: Standing Seam on Joists
- Wall type: R- panel with continuous Zees

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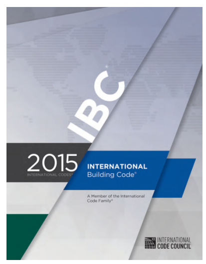
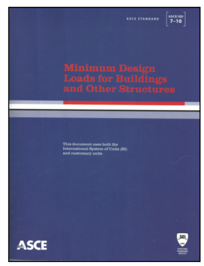
Codes and Standards

- Building Code: IBC 2012
- Minimum Design Loads For Buildings And Other Structures (ASCE 7-10)
- Building Department Contact: John Smith
- Date: July 6, 2016
- Local Ordinances: None
- Wind Speed: 115 mph
- Wind Exposure: C
- Building Category: II





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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 3.0 psf
  - **Total** **19.0 psf**
- WALL DEAD LOAD **3.0 psf**

  (Includes Girts)

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Local Code Requirements

- Frost Depth: 24 in.
- Rain Intensity:
  - 4.0 in. per hr (5 min/5yr)
  - 6.0 in. per hr (5 min/25yr)
- ROOF LIVE LOADS
  - 20.0 psf (reducible per building code not reducible per AISE tech report #13)
- Ground Snow Load: 15 psf

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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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Loads

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

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Load

- Structure is considered to be a "Nonbuilding Structure Similar to Buildings" per Chapter 15 of ASCE 7-10
- Transverse Direction from Table 15.4-1 OMF – Ordinary Moment Frame with permitted height increase

  R = 2.5 Ω_o = 2.0 C_d = 2.5

  Detailing per AISC 341 Height limit =100 feet.
- Longitudinal Direction from Table 15.4-1 OCBF – Ordinary Concentrically Braced Frame with permitted height increase

  R = 2.5 Ω_o = 2.0 C_d = 2.5

  Detailing per AISC 341 Height limit of 160 ft.

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Load

Structure is considered to be a "Nonbuilding Structure Similar to Buildings"

- Refer to ASCE 7-10 Section 11.1.3

"Buildings whose purpose is to enclose equipment or machinery and whose occupants are engaged in maintenance or monitoring of that equipment, machinery or their associated processes shall be permitted to be classified as nonbuilding structures designed and detailed in accordance with Section 15.5 of this standard."

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Design of 60 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 lifted load + trolley and hoist

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Design of an Industrial Crane Building

Lesson 7

- Sixty Foot Runway Girders
  - **Perimeter Girder**
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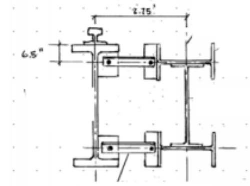
Design of the 60 ft Crane Girders

Bracing is required for the 60' Girders

- Form a horizontal truss with the center girders and bracing
- Provide back-up beams for sidewall girders

These choices are based on building configuration.



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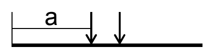
ASD Design of 60 ft Crane Girder

Deflection requirements: Locate wheel loads symmetrically placed about the girder centerline. a =24.5 ft (294 in.)

Vertical: L/800 = (60 ft.)(12)/800 = 0.9 in.

Horizontal: L/400 = (60 ft.)(12)/400 = 1.8 in.



I_{xreqd}: $\Delta_{max} = \frac{P_a a}{24EI}(3L^2 - 4a^2)$

$$\Delta_{max} = \frac{(78)(294)}{24(29000)I}(3(720)^2 - 4(294)^2) = \frac{39849}{I}$$

$$I_{xreqd} = \frac{39849}{\Delta_{max}} = \frac{39849}{.9} = 44277 \quad W40x593\ Ix = 50{,}400in^4$$

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Design of 60 ft Runway Girder

Horizontal stiffness requirement:

$$\Delta_{max} = \frac{(6.6)(294)}{24(29000)I}(3(720)^2 - 4(294)^2) = \frac{3372}{I}$$

$$I_{yreqd} = \frac{3372}{\Delta_{max}} = \frac{3372}{1.8} = 1873$$

$$W40x593 \quad {}^{I_y}/_2 = 2520\ {}^{in^4}/_2 = 1260\ in^4 < 1873\ in^4 \quad NG$$

Bottom flange must be laterally braced per AIST #13 when L > 36 ft. provide a backup beam.

Try W21x44, I_x = 843 in.^{4} Total I provided = 2103 in.^{4}

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Design of 60 ft Runway Girder

Calculate Moments:

DL (Girder + Rail + Clamps) = 593+175/3 + 20 = 671 lbs/ft

$M_{DL} = (1/8)wL^2 = (1/8)(0.67\ kips/ft)(60\ ft)^2 = 302\ kip\text{-}ft$

M_{LL} *:See table 3-23 case 44*

$$M_{LL} = \frac{78}{2(60)}(60 - 11/2)^2 = 1931\ kip\text{–}ft. \quad without\ impact$$

$$M_x = M_{DL} + M_{LL} = 302 + 1.25(1931) = 2716\ kip\text{-}ft.$$

$$M_y = \frac{6.6}{2(60)}(60 - 11/2)^2 = 163\ kip\text{–}ft.\ \ (total)$$

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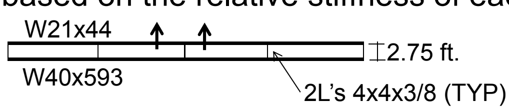
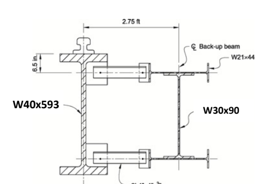
Design of 60 ft Runway Girder

Analysis with backup beam: Simply allocate lateral load based on the relative stiffness of each beam.



Plan View



W40 M_y: *From relative stiffness:*

$M_y = (1260\ in^4/2103\ in^4)163kip\text{-}ft. = 98\ kip\text{-}ft.$

W21 M_x: *From relative stiffness:*

$M_y = (843\ in^4/2103\ in^4)163kip\text{-}ft. = 65\ kip\text{-}ft.$

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Design of 60 ft Runway Girder

Available Moment: L_b = 60 ft., L_r = 63.9 ft., L_p = 13.4 ft.
See table 3-2

$L_p < L_b \leq L_r$ $\quad$ *Therefore use Equation F2 – 2:*

$$M_n = C_b\left[M_p - (M_p - .7F_yS_x)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] \leq M_p$$

$$M_n = 1.0[11500 - (11500 - .7(50)(\frac{2340}{12}))(\frac{60 - 13.4}{63.9 - 13.4})] \leq 11500$$

$M_n = 7186$ *kip-ft.* $\quad \frac{M_n}{\Omega} = \frac{7178}{1.67} = 4303$ *ft-kip*

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Design of 60 ft Runway Girder

Check combined forces on girder compression flange:

$$\frac{M_x}{M_{nx}/\Omega} + \frac{M_y}{M_{ny}/\Omega} \leq 1.0 \qquad \frac{2716}{4303} + \frac{98}{600} = .79 \text{ OK!}$$

where:
$M_x = 2716$ *kip-ft.*
$M_y = 98$ *kip-ft.*

$M_{nx}/\Omega = 4303$ *kip-ft.*
$M_{ny}/\Omega = F_yZ_y/2/\Omega = (50)(481)/2)/1.67/12 = 600$ *kip-ft.*

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Design of 60 ft Runway Girder

Check W21x44 backup beam:

$M_{rx} = 65$ kip-ft
$M_{nx}/\Omega = F_y Z_x/\Omega = (50)(95.4)/12/1.67 = 238$ kip-ft
$M_{nx}/\Omega = 238$ kip-ft > 65.0 kip-ft ok

Use W21x44 backup beam for deflection control & per AIST.

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Design of 60 ft Runway Girder

Evaluate for Seismic Loads: Design Crane Girder to resist loads based on ASCE 7-10 Chapter 13:

$$F_p = \frac{.4 a_p S_{ds} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right)$$

a_p=2.5, R_p=3.5

(Table 13.5-1 "Other flexible components, High deformability element and attachments)

I_p = 1.0 (section 13.1.3)
z =45.9 ft. h= 60.0 ft. S_{ds}=.770

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Design of 60 ft Runway Girder

Evaluate for Seismic Loads: Continued

$F_p = \frac{.4(2.5)(.77)W_p}{\left(\frac{3.5}{1.0}\right)}\left(1 + 2\frac{45.9}{60.0}\right) = .56W_p$

$F_p = .56(122\ kips) = 68.3$ kips $F_p/wheel = 17.1\ kips$

Maximum vertical wheel loads for unloaded crane are 35.8 kips

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Design of 60 ft Runway Girder

Evaluate for Seismic Loads (Continued):

Recall: $M_{DL} = 302$ *kip-ft.*

$M_{LL} = 1931\ kip - ft.$ *(For Vert. wheel loads of 78 kips)*

$M_y = 163\ kip - ft.$ *(For Lat. wheel loads of 6.6 kips)*

For load Case 5a: $(1.11)(D + C_d) + 0.7\rho Q_E$

$M_x = 1.11(302 + (35.8/78)(1931)) = 1319$ *kip-ft.*

$M_y = \frac{.7(17.1)}{(6.6)} 163 = 296\ kip\text{–}ft.$ *(total)*

$M_y = (1260/2103)296\ kip\text{–}ft. = 177$ *kip-ft. (on W40)*

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Design of 60 ft Runway Girder

For Load Case 5a W40 Crane Girder

$$\frac{M_x}{M_{nx}/\Omega} + \frac{M_y}{M_{ny}/\Omega} \leq 1.0 \qquad \frac{1319}{4303} + \frac{177}{600} = .60 \text{ OK}$$

W21: M_x From relative stiffness:

$M_{rx} = (843/2103)296 = 119$ kip-ft

$M_{cx} = F_y Z_x/\Omega = (50)(95.4)/12/1.67 = 238$ kip-ft

$M_{cx} = 238$ kip-ft > 119.0 kip-ft ok

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Design of 60 ft Runway Girder

Recall from Lesson 5, Check Limit states for:

- **Shear**
- **Web Local Yielding J10.2**
- **Web Local Crippling J10.3**
- **Web Sidesway Buckling J10.4**

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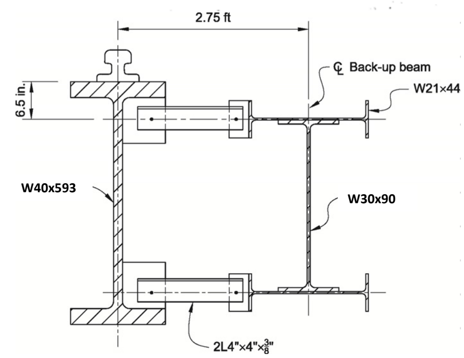
Design of 60 ft Runway Girder

Evaluate for stress riser created by the back up beam connection:



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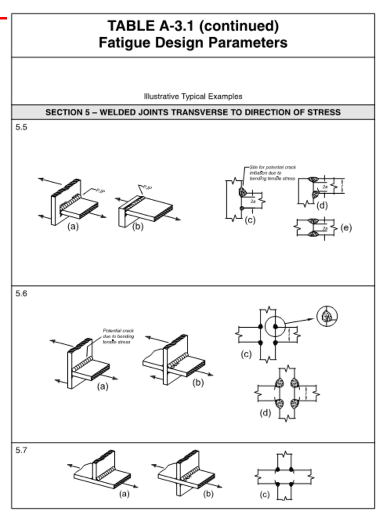
Design of 60 ft Runway Girder

Check the fatigue limit state due to the welded plate to the girder web and tension flange. Refer to AISC Appendix 3.

Table A-3.1, Section 5.7, "Base metal of tension loaded plate elements and on girders and rolled beam webs or flanges at toe of transverse fillet welds adjacent to welded transverse stiffeners."



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Design of 60 ft Runway Girder

Assume 500,000 cycles: $n_{SR} = 500{,}000,$

Section 5.7 Applies (stress cat. C) $C_f = 44x10^8$, $F_{TH} = 10$ ksi

$F_{SR} = (\frac{C_f}{n_{SR}})^{0.333} \geq F_{TH}$ $F_{SR} = (44x10^8/5x10^5)^{0.333} = 20.6$ ksi

$f_b = M/S_x = (1931 \text{ kip-ft.})(12)/\ 2340 \text{ in.}^3 = 9.9 \text{ ksi} \leq 20.6 \text{ ksi ok}$

For Comparison without the welded attachment
Section 1.1 Applies (stress cat. A) $C_f = 250x10^8$, $F_{TH} = 24$ ksi
$F_{SR} = (250x10^8/5x10^5)^{0.333} = 36.7$ ksi

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Design of an Industrial Crane Building

Lesson 7

- Sixty Foot Runway Girders
  - Perimeter Girder
  - **Interior Girder**
- Roof Longitudinal Bracing
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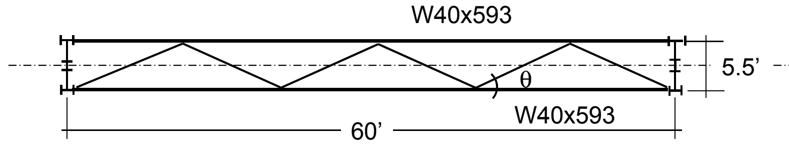
Design of 60 ft Runway Girder

Center Condition:



Try bolting angles to the flanges of the girders. Check angle strength and bending stresses in the angles due to deflection of the runway beams.

Design the bracing angles for the crane lateral loads, or seismic loads, or 2.5% of the axial load in the flange (AIST #13). AIST provision is for the tension flange. Apply criteria to both flanges.

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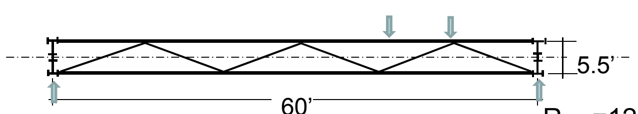
Design of 60 ft Runway Girder

Determine brace force: seismic (.7e=12.0 kips/wheel) controls over lateral crane load (6.6 kips/wheel):



R_{end}=12.0(50+39)/60=17.8 kips

The maximum force in a diagonal member occurs when the crane end truck is located at the end panel point.

Max. Angle Force= 17.8 (137/66)=36.9 kips

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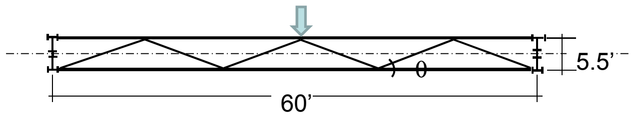
Design of 60 ft Runway Girder

Determine brace force: 2.5% of W40 flange force



Average f_b in bottom flange= 12.87 ksi

Brace force = $.025f_bA$ =.025(12.87)(3.23 in.)(16.7) = 17.4 kips

Applied at mid span

Max Angle Force = (17.4/2)(137/66) = 18.1 kips < 36.9 kips

Seismic Load Controls

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Design of 60 ft Runway Girder

Angle Strength: L=11.4 ft.

Try 2L4x4x5/16 From AISC Manual Table 4-8:

$P_n/\Omega = 54.5\ kips \quad > \ 36.9\ kips \quad OK$

Table 4-8 (continued)
Available Strength in Axial Compression, kips
F_y = 36 ksi
Double Angles—Equal Legs
2L4

Shape		2L4×4×														No. of connectors[a]
		3/4		5/8		1/2		7/16		3/8		5/16		1/4[c]		
lb/ft		37.0		31.4		25.6		22.6		19.6		16.4		13.2		
Design		P_n/Ω_c ASD	ϕ_cP_n LRFD	P_n/Ω_c ASD	ϕ_cP_n LRFD	P_n/Ω_c ASD	ϕ_cP_n LRFD	P_n/Ω_c ASD	ϕ_cP_n LRFD	P_n/Ω_c ASD	ϕ_cP_n LRFD	P_n/Ω_c ASD	ϕ_cP_n LRFD	P_n/Ω_c ASD	ϕ_cP_n LRFD	
X-X Axis	0	235	353	199	299	162	243	142	214	123	185	103	155	75.9	114	
	2	230	346	195	293	158	238	139	210	121	182	101	152	74.6	112	
	4	215	324	183	275	149	224	131	197	114	171	95.4	143	70.7	106	
	6	193	290	164	247	134	202	118	178	103	155	86.4	130	64.7	97.3	
	8	166	249	142	213	116	174	103	154	89.5	134	75.3	113	57.2	85.9	
	10	136	205	117	176	96.3	145	85.5	128	74.7	112	63.1	[illegible]	[illegible]	73.3	b
	12	107	161	93.1	140	76.7	115	68.3	103	59.9	90.1	50.8	[illegible]	40.1	60.3	
	14	80.8	121	70.7	106	58.5	87.9	52.3	78.6	46.1	69.3	39.3	59.1	31.9	47.9	
	16	61.9	93.0	54.1	81.4	44.8	67.3	40.1	60.2	35.3	53.0	30.1	45.2	24.6	37.0	
	18	48.9	73.5	42.8	64.3	35.4	53.2	31.6	47.6	27.9	41.9	23.8	35.7	19.4	29.2	
	20			34.6	52.1	28.7	43.1	25.6	38.5	22.6	33.9	19.3	28.9	15.7	23.7	

...t to indicated axis

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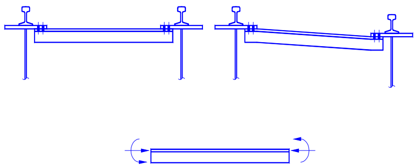
Design of 60 ft Runway Girder

Check fatigue stress in angles from girder deflection, assume ends of braces fixed condition: $M = 6EI\Delta/L^2$ $\Delta = 0.79$ in.



$M = (6)(29000)(2*3.67in.^2)(0.79\ in.)/(137)^2 = 53.8$ kip-in.

$f_b = 2M/S_{xt} = 2*53.8/2.54 = 42.3$ ksi   *NG!*

Avoid connection that resists vertical movement.

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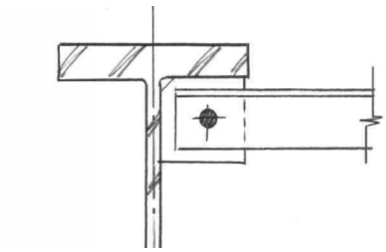
Design of 60 ft Runway Girder

Check Connection for applicable limit states:

- Bolt shear (J3.1)
- Bolt bearing (J3.10)
- Weld and base metal shear rupture (J2.4, J4.2)
- Block shear on angle and gusset (J4.3)
- Tensile rupture on net angle section (D2)



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Polling Question

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Design of an Industrial Crane Building

Lesson 7
- Sixty Foot Runway Girders
  - Perimeter Girder
  - Interior Girder
- **Roof Longitudinal Bracing**
- Longitudinal Building Bracing
- Longitudinal Crane Bracing
- End Wall Bracing

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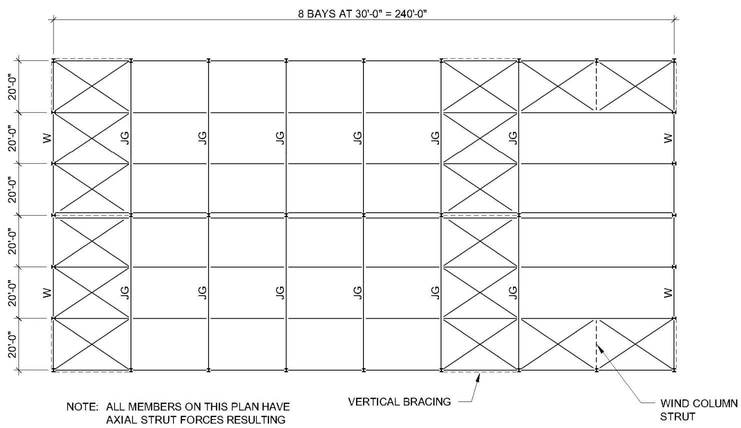
Roof Bracing Plan



NOTE: ALL MEMBERS ON THIS PLAN HAVE AXIAL STRUT FORCES RESULTING FROM WIND AND SEISMIC LATERAL FORCES. THESE AXIAL FORCES SHALL BE PROVIDED TO THE JOIST MANUFACTURER.

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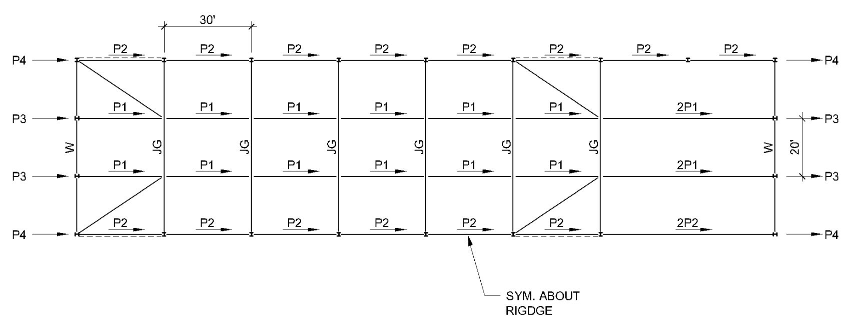
47

Tension Only Brace Forces



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48

Load Calculations - Seismic

Recall from lesson 5:

- The seismic coefficient C_s in the OMF direction was calculated as:

$$\frac{S_{D1}}{T(R/I_e)} = \frac{.427}{1.04(2.5/1.0)} = 0.16 \qquad C_s = .16 \text{ OMF direction}$$

In the OCBF direction the framing is stiffer. The period is shorter.

$$\frac{S_{DS}}{R/I_e} = \frac{0.77}{2.5/1.0} = 0.31 \qquad C_s = .31 \text{ OCBF direction}$$

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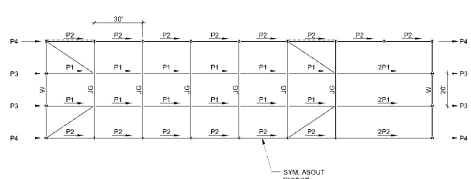
Roof Lateral Loads

- Roof Seismic Loads

$0.7E = 0.7\rho C_s W$
$= (0.7)(1.0)(0.31)(19\text{psf} - 6\text{psf})$
$= 2.8$ psf

$P1 = (2.8\text{psf})(30\text{ft.})(20\text{ft.})/1000$
$= 1.7$ kips

$P2 = 0.5 * P1$
$= 0.8$ kips



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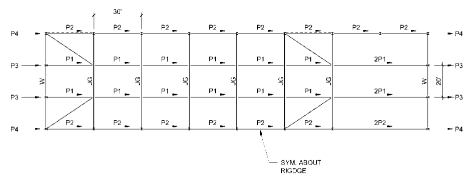
Roof Lateral Loads Cont.

- Endwall Loads (Seismic continued)

  0.7E = $0.7\rho C_s W$
  = (0.7)(1.0)(0.31)(3psf)
  = 0.65 psf

  P3 = (0.65psf)(30ft.)(20ft.)/1000
  = 0.4 kips <u>Use 0.5 kips</u>

  P4 = 0.5*P3
  = 0.25 kips



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Roof Lateral Loads Cont.

- Endwall Loads Cont.
  - Wind vs. Seismic Comparison

  P_w = .6(22.2psf +13.9psf)(30ft.)(60ft.)/1000
  = 39.0 kips

  P_e = (2.8psf)(60ft.)(240ft.)/1000+4(0.8k)
  = 43.5 kips

  $P_e > P_w$, therefore seismic will control roof bracing design

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Analysis:

Perform a second order analysis of the bracing system including:

- The vertical SFRS
- The diaphragm bracing
- Frames and columns
- All loads including leaner column loads

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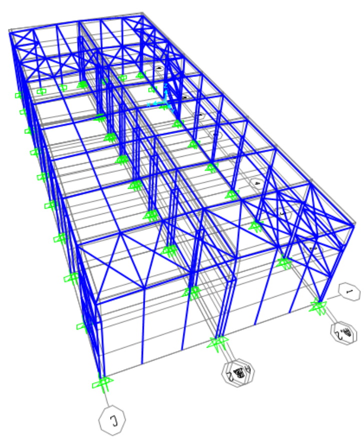
Analysis Cont.



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Strap Brace Design

Conservatively : Design for analysis results based on load combinations with "overstrength factors" Ω_o level forces.

- Based on analysis: P_r= 18 kips (max)

P_n/Ω = F_yA_g/Ω

= (36ksi)(1/4in.)(4in.)/1.67

= 21.6 kips, Okay

Use 1/4" x 4" A36 Plate

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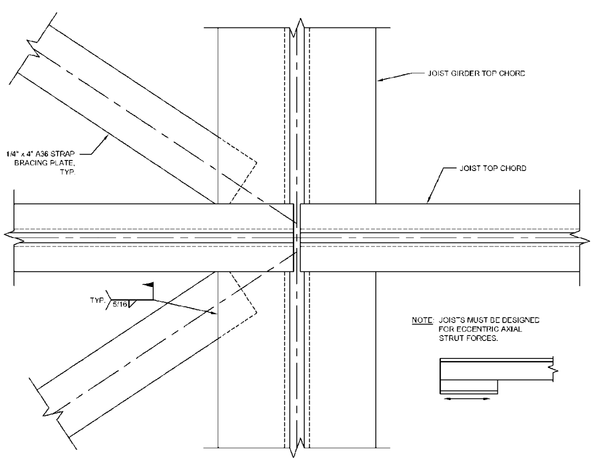
Strap Bracing Connection



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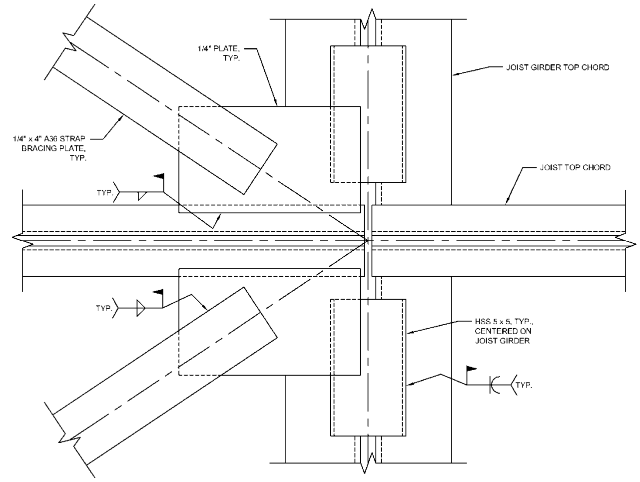
Strap Bracing Alternate Connection



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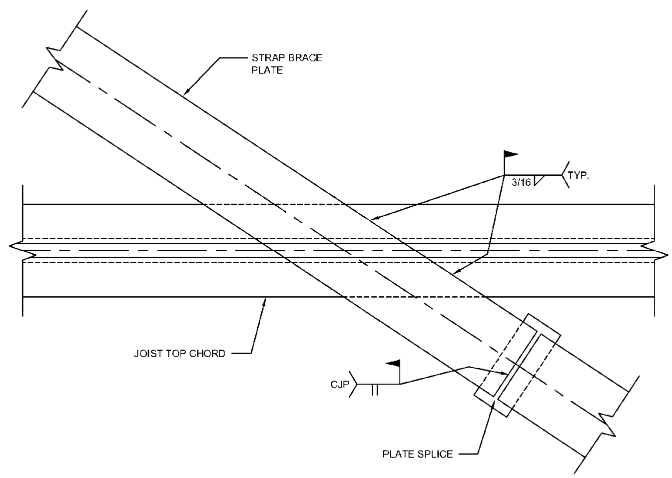
Strap Bracing Connection



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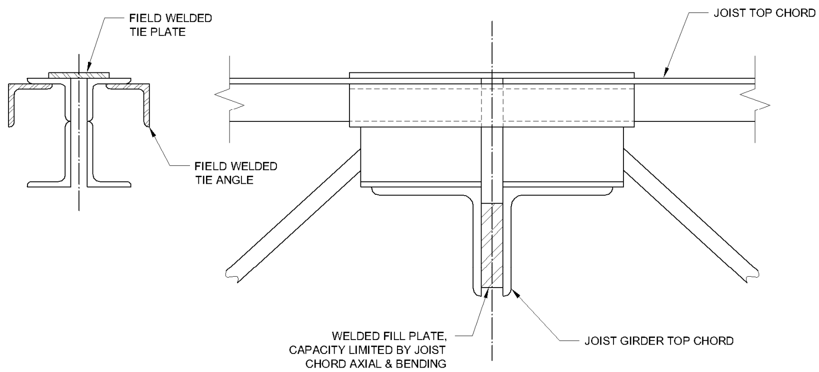
58

Joist Tie Connection Options



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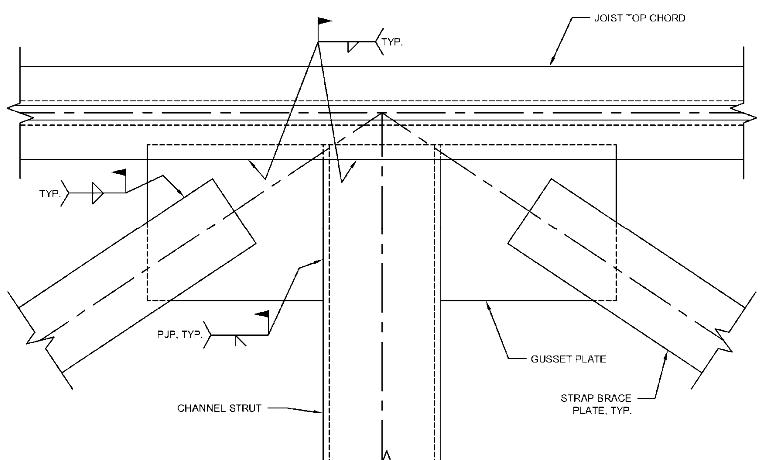
Strap Bracing at Wind Column Strut



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60

Design of an Industrial Crane Building

Lesson 7

- Sixty Foot Runway Girders
  - Perimeter Girder
  - Interior Girder
- Roof Longitudinal Bracing
- **Longitudinal Building Bracing**
- Longitudinal Crane Bracing
- End Wall Bracing

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OCBF AISC 341 Section F1

Members:

- Braces must satisfy the requirements for Section D1.1 for *moderately ductile members.*

Connections:

- Load based on the amplified seismic load but need not exceed:
  - Tension: The expected yield strength of the brace $R_yF_yA_g$ (LRFD) or $R_yF_yA_g/1.5$ (ASD)
  - Compression: The lessor of $R_yF_yA_g$ (LRFD) or $R_yF_yA_g/1.5$ (ASD) and $1.14F_{cre}A_g$ (LRFD) or $1.14F_{cre}A_g$ /1.5 (ASD)

    F_{cre} is calculated based on R_yF_y and length from brace end to end

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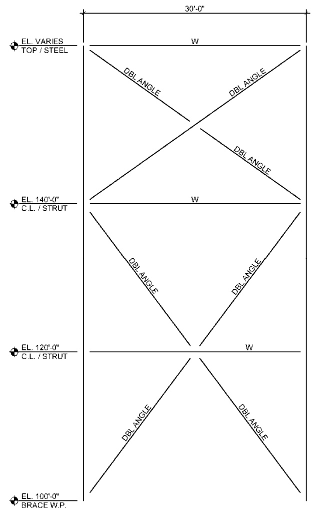
Typical Vertical Brace Elevation



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63

Brace Struts

- Strut Force

  P_r = 39.4 kips

- W12x45 Axial Strength

  P_n/Ω = 57.9 kips (AISC Table 4-1, pg. 4-20)

  <u>Use W12x45 struts</u>

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Lower Brace Forces

- Brace Member Design Force
  P_r = 65.7 kips

- Connection Design Force (Ω load combinations)
  P_r = 101 kips

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Brace Strength

Try 2-L4x4x3/8 Bracing

- Yield Strength (AISC 360 Section D2)
  $P_n/\Omega = F_yA_g/\Omega$
  $= (36\text{ksi})(2)(2.86\text{in.}^2)/1.67$
  = 123.3 kips > 65.7 kips, okay

- Rupture Strength (AISC 360 Section D2)
  $P_n/\Omega = F_uA_e/\Omega$ $\quad A_e = UA_n \quad U=.8$ (Table D3.1)
  $= (58\text{ksi})(2)(0.8)(2.86 - (1.125)(3/8))/2$
  = 113.1 kips > 101 kips, okay

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Vertical Bracing Design

Check 2-L4x4x3/8 Bracing for moderately ductile criteria

b/t=4/.375=10.667

$\lambda_{md}=.38\sqrt{E/F_y}=.38\sqrt{29000/36}=10.78$

$b/t \leq \lambda_{md}$ OK

Use 2-L4x4x3/8

TABLE D1.1
Limiting Width-to-Thickness Ratios for Compression Elements For Moderately Ductile and Highly Ductile Members

	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio: λ_{hd} Highly Ductile Members	Limiting Width-to-Thickness Ratio: λ_{md} Moderately Ductile Members	Example
Unstiffened Elements	Flanges of rolled or built-up I-shaped sections, channels and tees; legs of single angles or double angle members with separators; outstanding legs of pairs of angles in continuous contact	b/t	$0.30\sqrt{E/F_y}$	$0.38\sqrt{E/F_y}$	
Unstiffened Elements	Flanges of H-pile sections per Section D4	b/t	$0.45\sqrt{E/F_y}$	not applicable	
Unstiffened Elements	Stems of tees	d/t	$0.30\sqrt{E/F_y}$ [a]	$0.38\sqrt{E/F_y}$	
Stiffened Elements	Walls of rectangular HSS	b/t	$0.55\sqrt{E/F_y}$ [b]	$0.64\sqrt{E/F_y}$ [c]	
Stiffened Elements	Flanges of boxed I-shaped sections and built-up box sections	b/t			
Stiffened Elements	Side plates of boxed I-shaped sections and walls of built-up box shapes used as diagonal braces	h/t			
Stiffened Elements	Webs of rolled or built-up I-shaped sections used as diagonal braces	h/t_w	$1.49\sqrt{E/F_y}$	$1.49\sqrt{E/F_y}$	

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Vertical Brace Connection Considerations

- Keep connections simple whenever possible.
- Use field bolted connections whenever possible.
- Locate the "Whitmore" section outside of the surrounding members for thick gusset plates.
- Use the Uniform Force Method to determine force distribution in the connection. This method is described in Part 13 of the 14th Edition AISC Manual.
- See AISC Design Guide #29 Vertical Bracing Connections Analysis and Design

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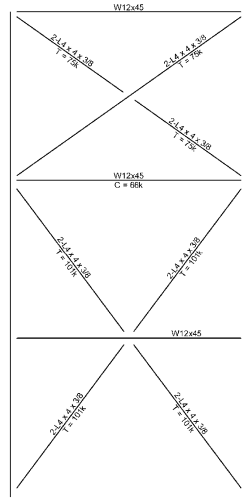
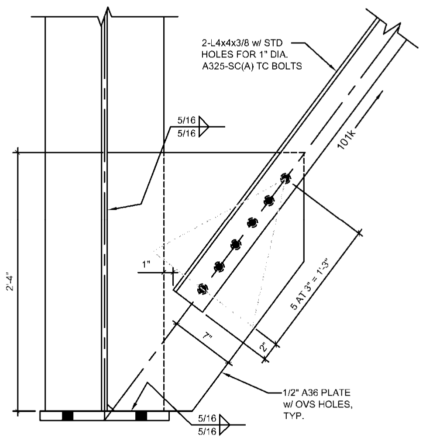
Building Brace Summary



For deep columns verify the bracing system provides torsional stability for the columns per the AISC Appendix 6 requirements.

69

Brace Connection at Column Base



Note SC designation:

Bolted connection must be constructed as if Slip Critical.

If OVS holes are used limit state for bolt slip need not exceed the force based on the load combinations not including the amplified seismic load.

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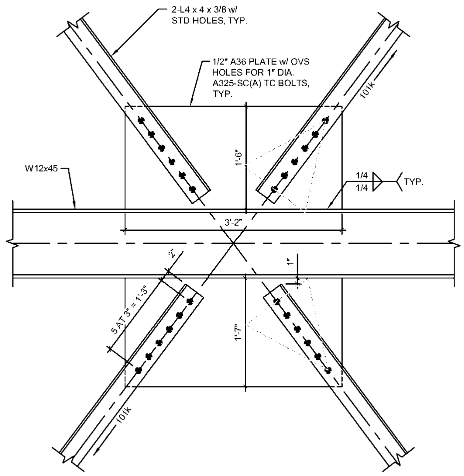
Brace Connection



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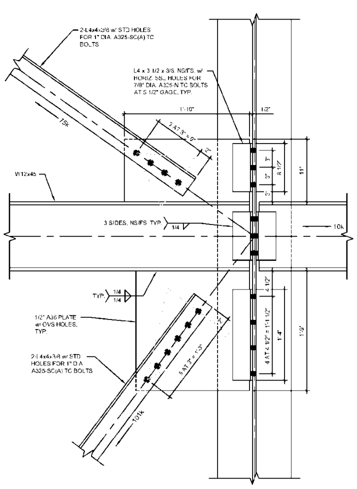
Brace Connection Detail



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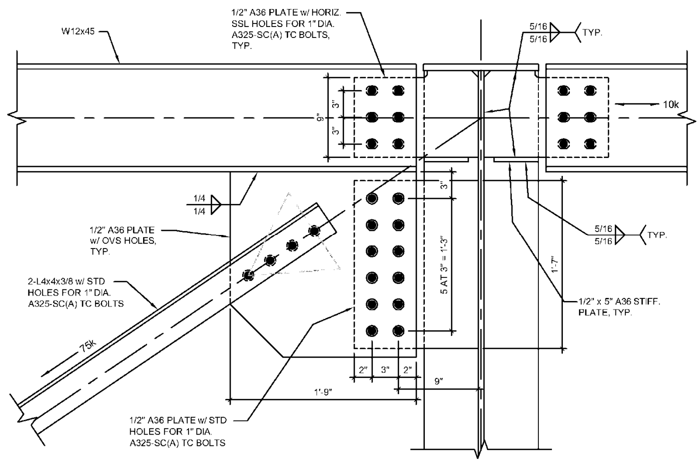
Brace Connection at Roof



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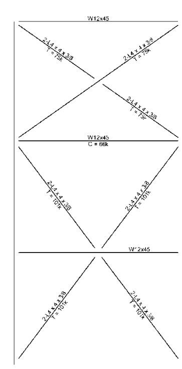
BRACING AT TRUSS BOTT. CHORD

The OMF columns need to be directly or indirectly braced at the hinge locations.

- Use Appendix 6.
- Since the truss is 5' deep, working a 5' deep panel into the longitudinal bracing is not practical. Use knee braces to the edge joist or edge beam.



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Design of an Industrial Crane Building

Lesson 7

- Sixty Foot Runway Girders
  - Perimeter Girder
  - Interior Girder
- Roof Longitudinal Bracing
- Longitudinal Building Bracing
- **Longitudinal Crane Bracing**
- End Wall Bracing

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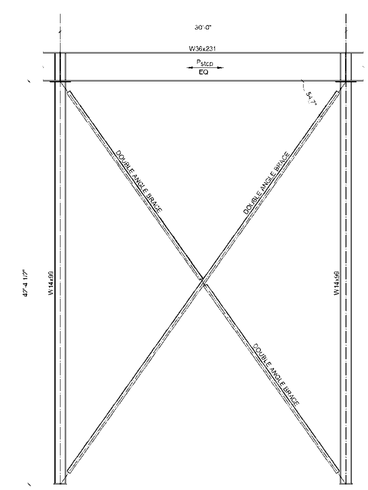
Crane Longitudinal Bracing



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Crane Bumper Force

- Tractive Force, C_{ls}

  $2C_{ls}$ = (2)(0.20)(78k/wheel)

  = 31.2 kips

- Crane Weight, C_d

  $10\%C_d$ = (0.10)(90.8+31.2)

  = 12.2 kips

  Refer to AISC Design Guide 7

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Crane Longitudinal Seismic OCBF Forces

Total seismic weight on one runway:

W= (2*35.8k)+(.309*30x6+.671*60)+(.09*8*45/2)=183.7 kips

0.7E = (0.7)(.31)(183.7 kips)

= 39.7 kips

For member design,

$0.7\rho E$ = (1.3)(39.7)

= 51.8 kips, controls over bumper force

For connection design,

$0.7\Omega_o E$ = (2)(39.7)

= 79.4 kips

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Crane Brace Design

Two Braces provided each side of runway

- Yielding Check,

  P = 51.8k/2/cos(54.7˚) = 44.8 kips

  A = $\Omega P/F_y$

  = (1.67)(44.8k)/36ksi

  = 2.1 in.^{2}

  Try 2-L4x4x3/8 braces A_g=5.72 in^2

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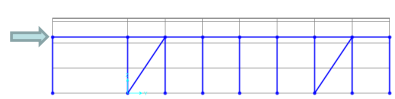
Crane Brace Design

Second Order Analysis is required!

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

- From 1st-order analysis:



$\sum H = 51.8\,\text{kips} \quad \Delta_H = .36\,\text{in.}$

$R_M = 1.00$ (braced frame)

- Elastic buckling load from Eq. C2-6b

$$\sum P_{e2} = R_M \frac{\sum HL}{\Delta_H} = 1.00 \frac{(51.8)(540)}{.36} = 78794\,\text{kips}$$

(lateral load, at crane ht. Δ at crane ht. =540")

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Crane Brace Design

- Summation of Supported Gravity Load

$$\alpha\sum P_{nt} = 1.6(168) = 268 \text{ kips}$$

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

$$B_2 = \frac{1}{1-\dfrac{\alpha\sum P_{nt}}{\sum P_{e2}}} = \frac{1}{1-\dfrac{1.6(183.7)}{78794}} = 1.004$$

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81

Crane Brace Design

Two Braces provided each side of runway

- 2-L4x4x3/8 braces A_g=5.72 in^2

Member:

P_r= 44.8 kip < P_n/Ω= (36)(5.72)/1.67=123.3 kips

Member at Connection (Ω_o Force):

P_r= 68.7 kips

$P_n/\Omega = F_u U A_n/\Omega$

P_n/Ω = (58ksi)(0.8)(5.72-2*1.125*0.375)/2

= 113.1 kips > 68.7 kips, okay

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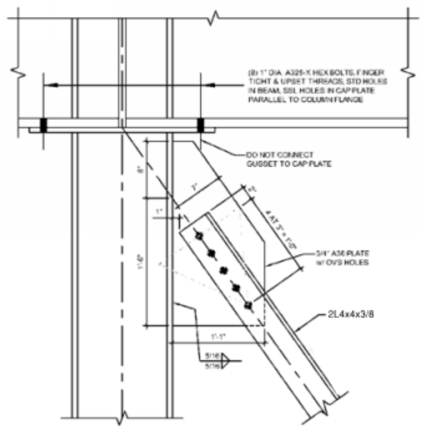
Crane Brace Connection



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Design of an Industrial Crane Building

Lesson 7

- Sixty Foot Runway Girders
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- Longitudinal Building Bracing
- Longitudinal Crane Bracing
- **End Wall Bracing**

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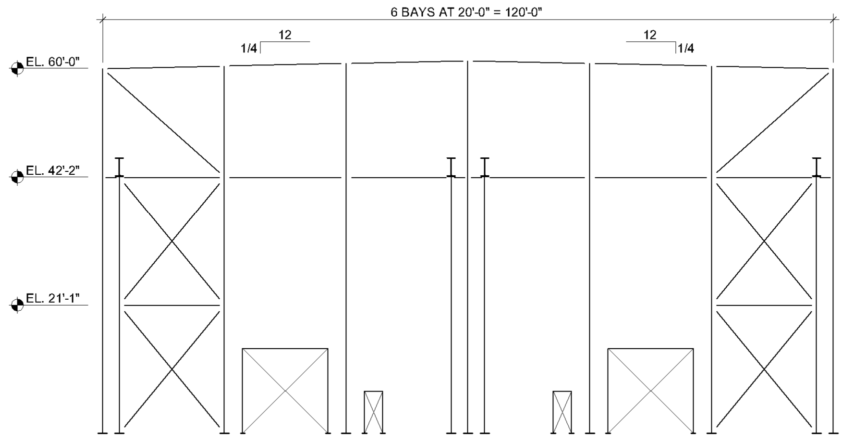
End Wall Vertical Bracing



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Endwall Considerations

- The maximum tributary width is 30 feet, adjacent to 60 foot bay. Therefore, gravity and wind loads will be identical to typical interior bay.
- Crane lateral seismic forces are resisted by the endwall vertical bracing.

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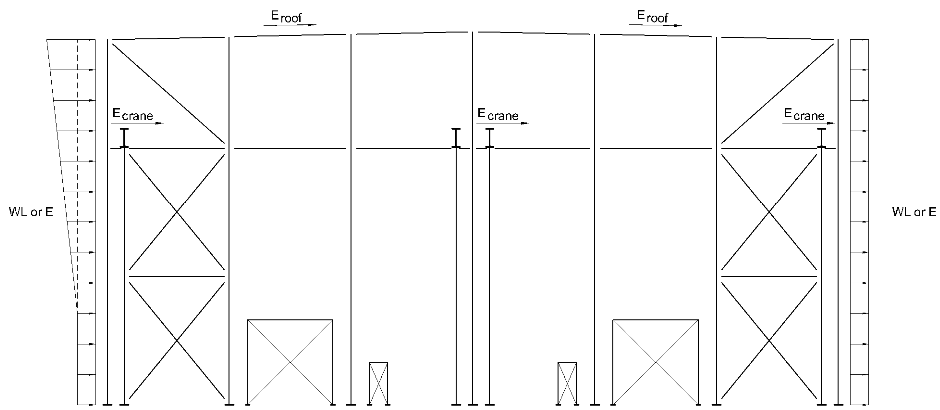
Endwall Lateral Loads



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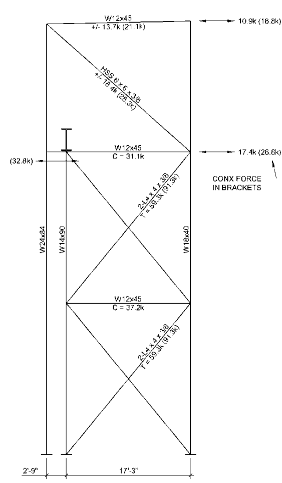
Endwall Forces From 2nd Order Analysis



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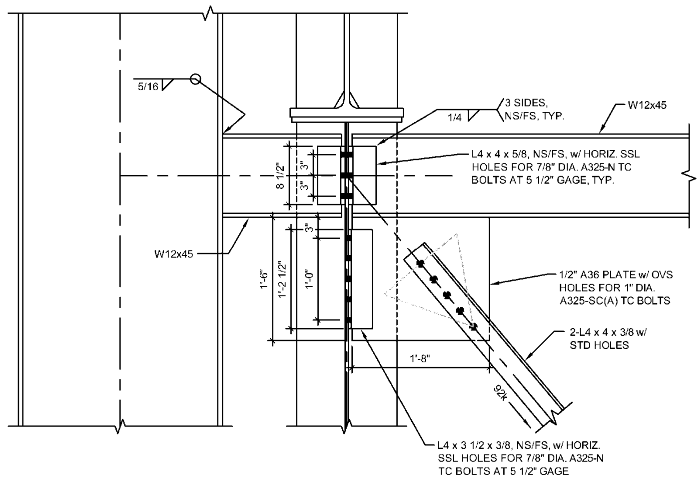
Endwall Brace Connection



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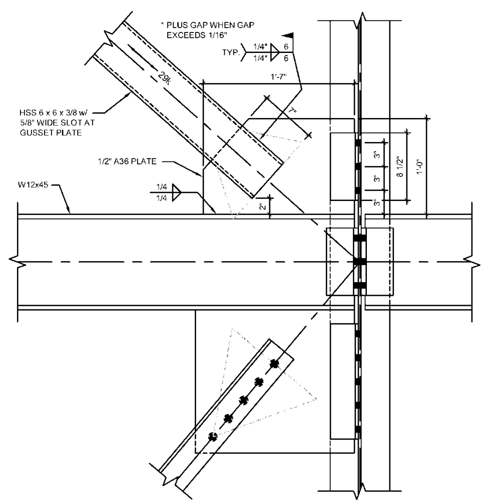
Endwall Brace Connection



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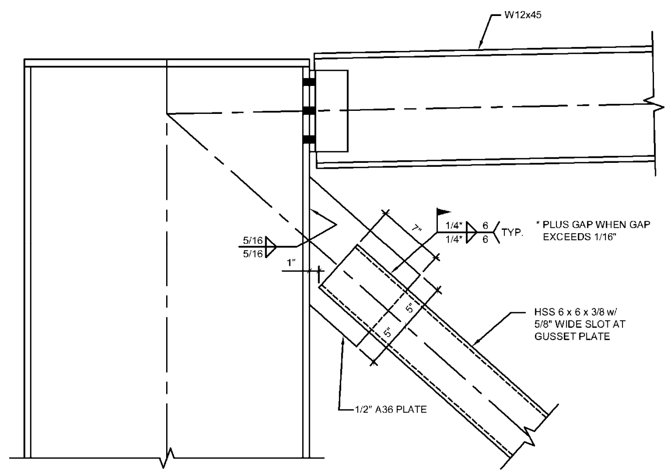
Endwall Brace Connection



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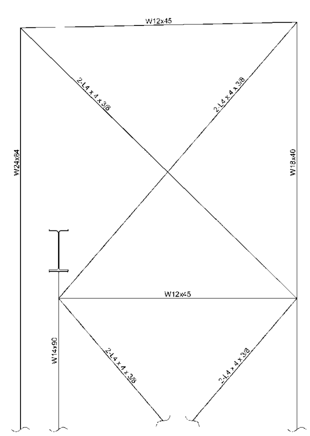
Endwall Brace Alternate



Lower W12 beam below crane beam to allow for vertical brace connection. Now tension only angle bracing can be used instead of HSS single brace. This results in more cost effective connection design and erection.

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End of Session 7

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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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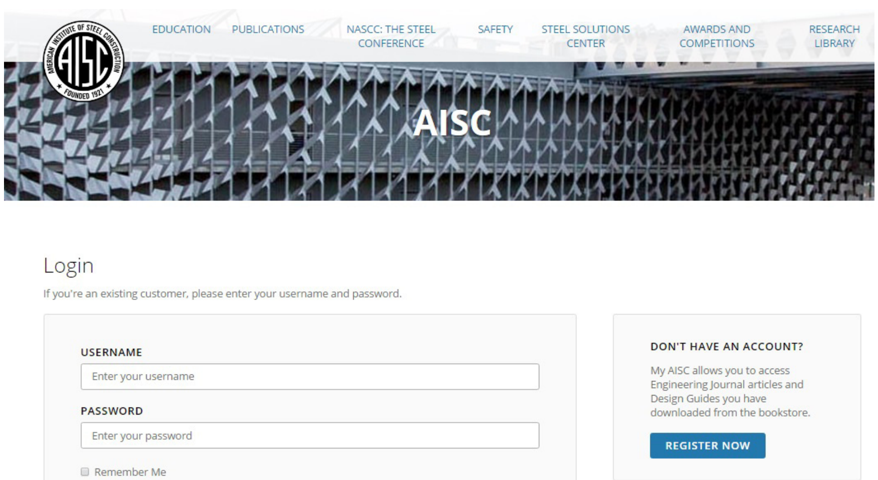
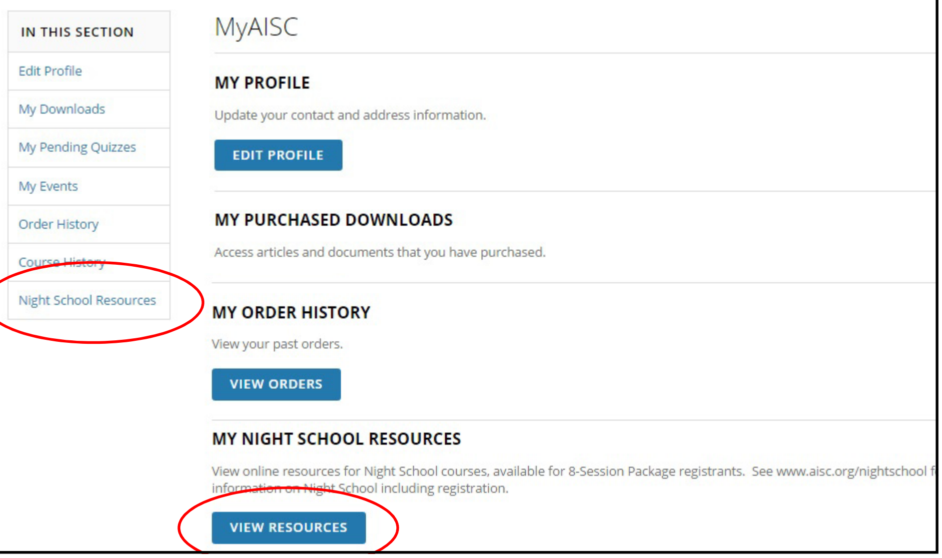
Night School Resources for 8-session package Registrants

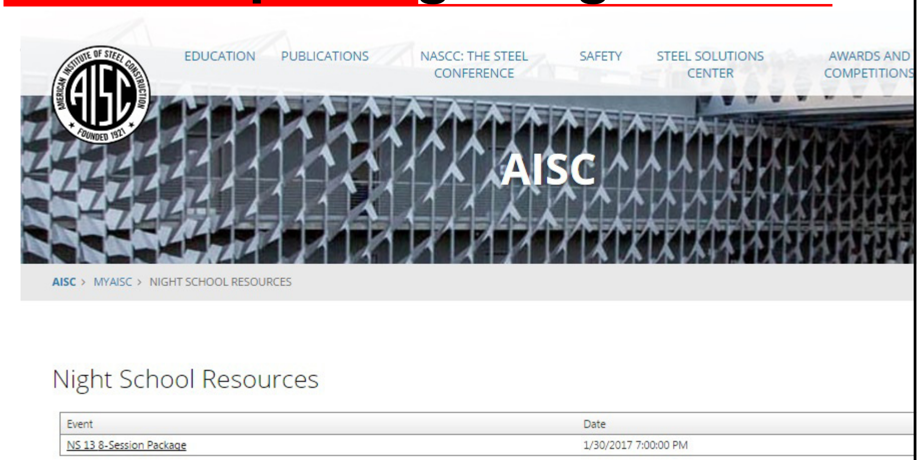
Go to www.aisc.org and sign in.



Night School Resources for 8-session package Registrants



Night School Resources for 8-session package Registrants



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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	

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.

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