AISC Night School

Today's audio will be broadcast through the internet.

Alternatively, to hear the audio through the phone, dial 888 224 7958.

There's always a solution in steel!

AISC Night School

Today's live webinar will begin shortly.
Please standby.
As a reminder, all lines have been muted. Please type any questions or comments through the Chat feature on the left portion of your screen.

Today's audio will be broadcast through the internet. Alternatively, to hear the audio through the phone, dial 888 224 7958.

There's always a solution in steel!

AISC Night School

AISC is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES). Credit(s) earned on completion of this program will be reported to AIA/CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

There's always a solution in steel!

AISC Night School

Copyright Materials

There's always a solution in steel!

AISC Night School

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.

There's always a solution in steel!

AISC Night School

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

There's always a solution in steel!

AISC Night School

There's always a solution in steel.

Design of Industrial Buildings

Session 5: Crane Girder Design and Frame Analysis

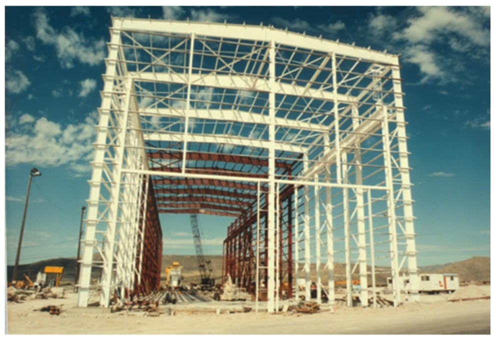
March 6, 2017

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

There's always a solution in steel!

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

There's always a solution in steel!

10

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

$$\text{Lateral load} = .20(100\text{ kips} + 31.2\text{ kips})/4 = 6.6\text{ kips/wheel}$$

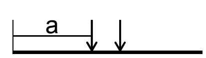
There's always a solution in steel! 11

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

There's always a solution in steel! 12

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

There's always a solution in steel!

13

Design of 30 ft Runway Girder

Calculate Moments:

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

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

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

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

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

There's always a solution in steel!

14

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:

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

Use W36x231

There's always a solution in steel!

15

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.

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

Nominal shear strength, $V_n = 0.6F_yA_wC_v$

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

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

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

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

$V_a = 164$ kips < 554 ok

There's always a solution in steel!

16

Design of 30 ft Runway Girder

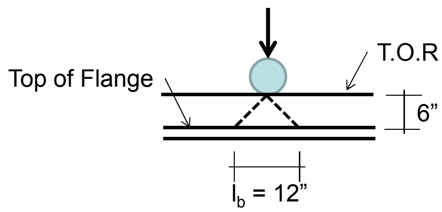
Check Web Local Yielding- AISC J10.2

$\Omega = 1.5$

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

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

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



There's always a solution in steel!

17

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

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

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

There's always a solution in steel!

18

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.

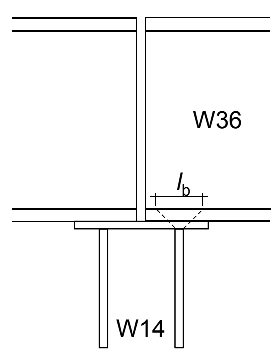
$(h/t_w)/(L_b/b_f) = 42.2/(360/16.5) = 1.93 > 1.7$

Sidesway web buckling limit state does not apply

There's always a solution in steel!

19

Design of 30 ft Runway Girder



There's always a solution in steel!

20

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

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

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

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

There's always a solution in steel!

21

Design of 30 ft Runway Girder

Check Local Web Crippling AISC J10-5a

$l_b/d = 2.36$ in.$/36.5$ in. $= 0.07 < 0.2$

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

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

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

There's always a solution in steel!

22

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

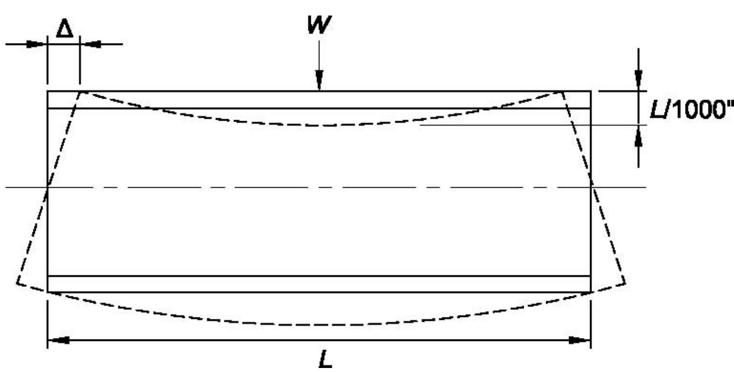
- **Lesson 5**
  - **30 ft. Runway Beam Design**
  - **Runway Details**
  - Wind load Calculations
  - Snow Load Calculations
  - Seismic Forces
  - Load Combinations
  - Frame Design using the Direct Analysis Method

Tie Back Failure

There's always a solution in steel!

25

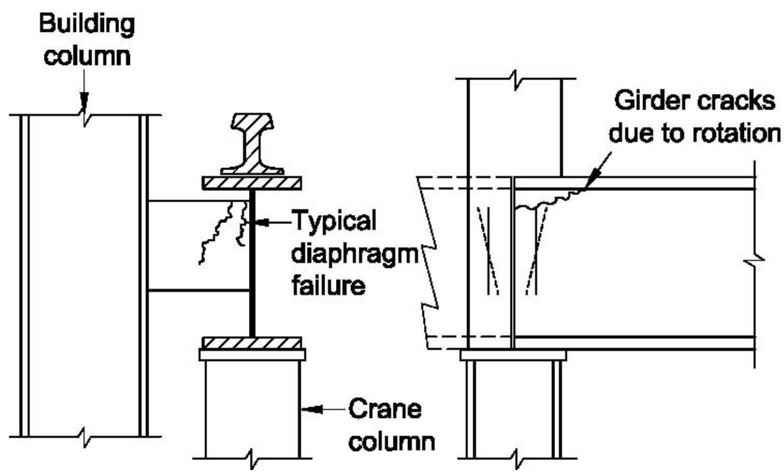
Tie Backs



There's always a solution in steel!

26

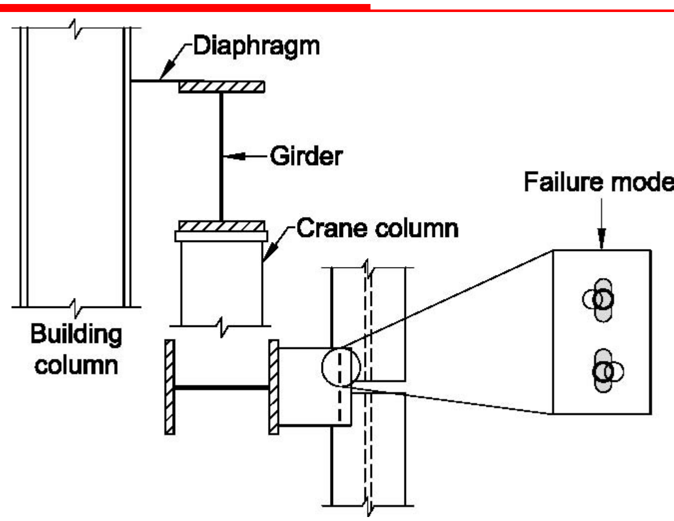
Tie Backs



There's always a solution in steel!

27

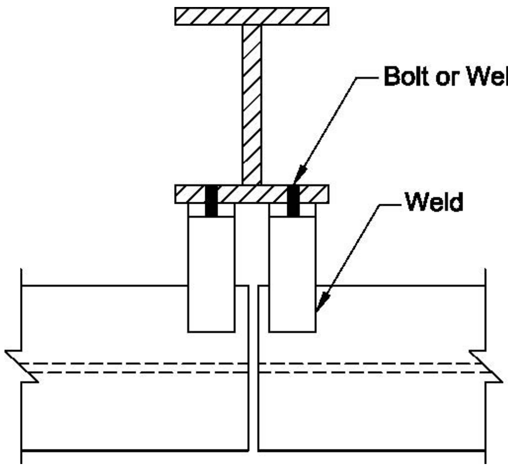
Tie Backs



There's always a solution in steel!

28

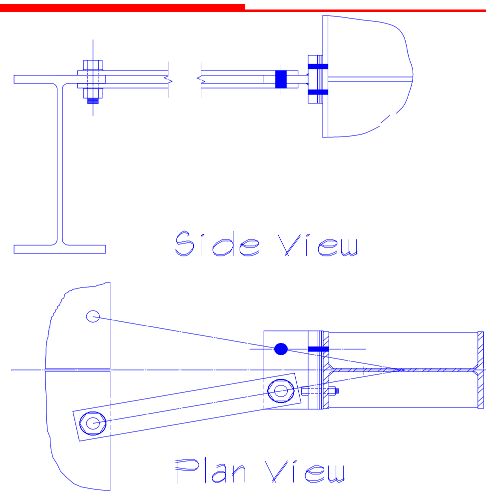
Tie Back Design



There's always a solution in steel!

29

Tie Back Design

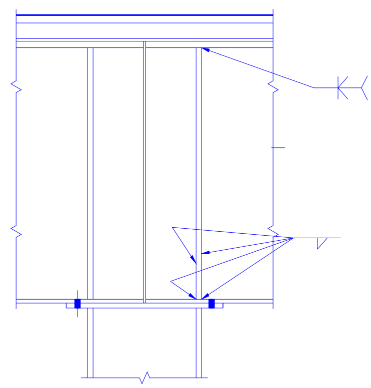


There's always a solution in steel!

30

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.

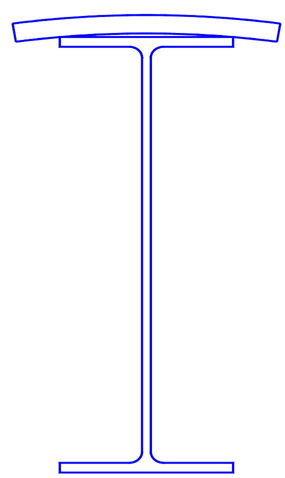


There's always a solution in steel!

31

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)

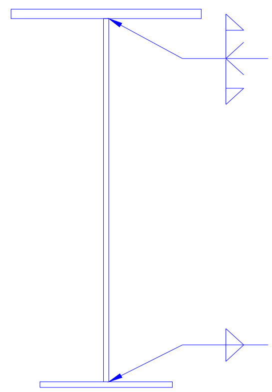


There's always a solution in steel!

32

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



There's always a solution in steel!

33

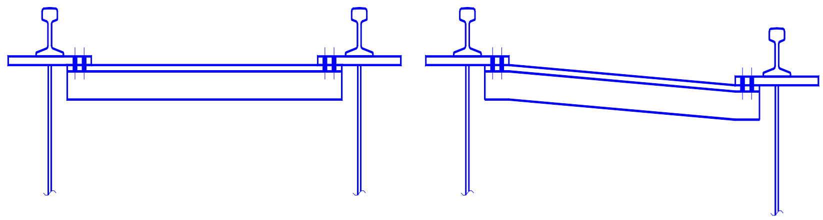
Laced Crane Girders

- 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.

There's always a solution in steel!

34

Crane Girder Lacing

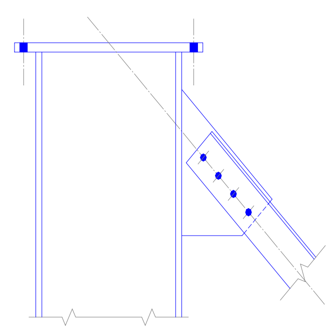


There's always a solution in steel!

35

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.



There's always a solution in steel!

36

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

There's always a solution in steel!

37

Methods of rail Attachment

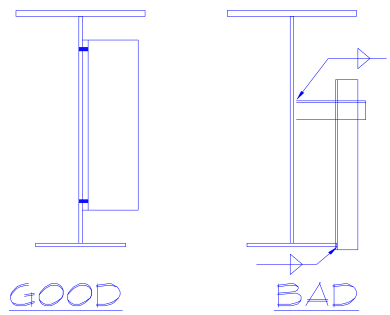
- The commonly accepted methods of rail attachment are:
  - hook bolts
  - rail clips
  - rail clamps
  - patented rail clips

There's always a solution in steel!

38

Miscellaneous Attachments

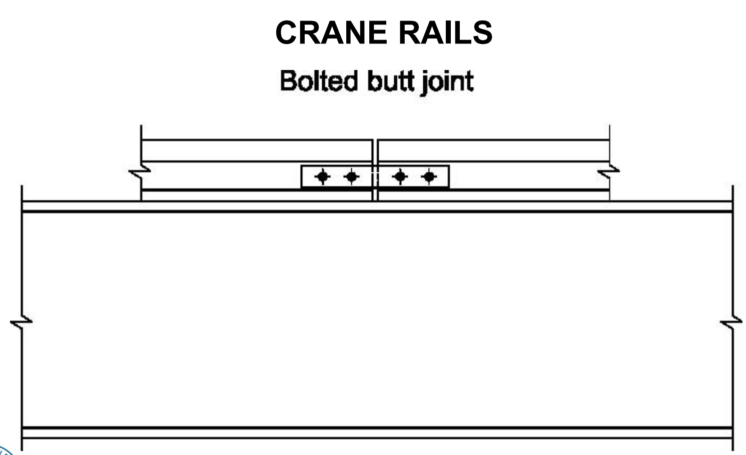
- Coordinate attachments to the crane girder with other trades
- AIST prohibits welding attachments to the bottom flange



There's always a solution in steel!

39

Bolted Rail Joints



There's always a solution in steel!

40

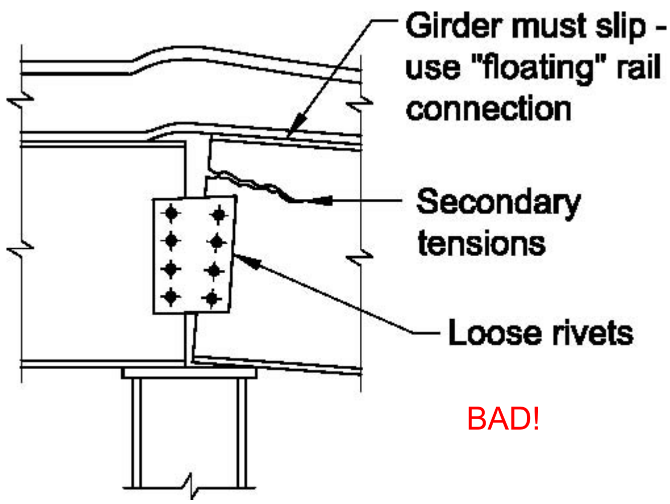
Welded Butt Joints

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

There's always a solution in steel!

41

Diaphragm Plate Failure



BAD!

There's always a solution in steel!

42

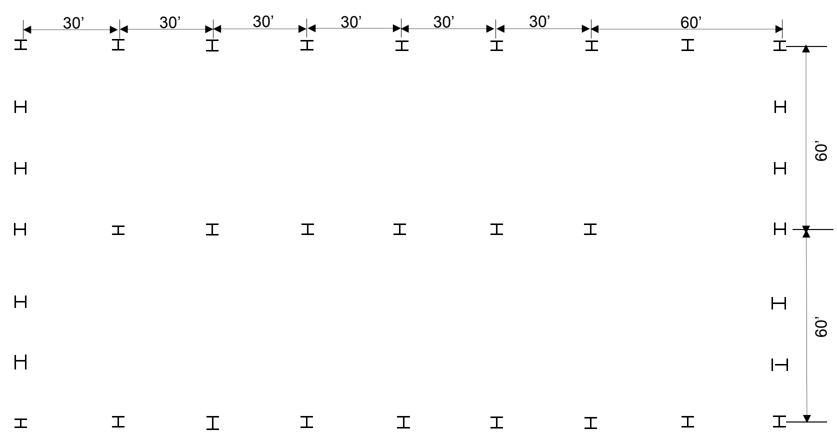
Buildings with Overhead Cranes

- **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

There's always a solution in steel!

43

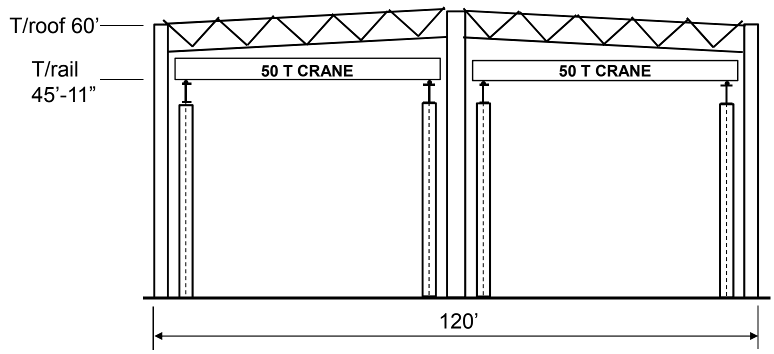
Building Footprint



There's always a solution in steel!

44

Cross Section

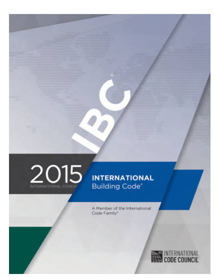


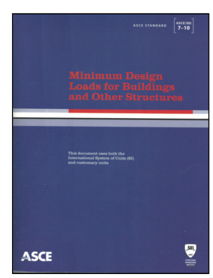
There's always a solution in steel!

45

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





There's always a solution in steel!

46

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)

There's always a solution in steel!

47

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/

There's always a solution in steel!

48

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
α =	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	LW	Total	Side	Roof WL			Internal
			WL	WL	WL	WL	0 to h	h to 2h	> 2h	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

There's always a solution in steel!

49

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

There's always a solution in steel!

50

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

There's always a solution in steel!

51

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.

There's always a solution in steel!

52

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

There's always a solution in steel!

53

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

There's always a solution in steel!

54

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

There's always a solution in steel!

55

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

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

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

There's always a solution in steel!

56

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

There's always a solution in steel!

57

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 …

There's always a solution in steel!

58

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"

There's always a solution in steel!

59

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

There's always a solution in steel!

60

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

There's always a solution in steel!

61

Load Calculations - Seismic

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

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

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

There's always a solution in steel!

62

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

  $$C_s = \frac{S_{DS}}{R/I_e} \le \frac{S_{D1}}{T(R/I_e)} \ge .044 S_{DS} * I_e$$

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

There's always a solution in steel!

65

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

There's always a solution in steel!

66

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.

There's always a solution in steel!

67

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

There's always a solution in steel!

68

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

There's always a solution in steel!

69

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) $(0.6 - 0.14S_{DS})D + 0.7\rho Q_E$

There's always a solution in steel!

70

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.

There's always a solution in steel!

71

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.

There's always a solution in steel!

72

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

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

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

There's always a solution in steel!

73

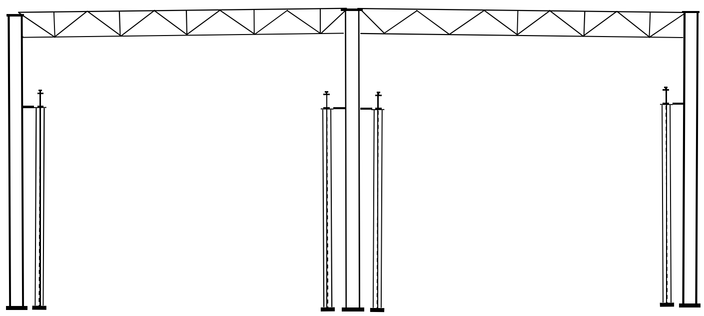
Buildings with Overhead Cranes

- **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**

There's always a solution in steel!

74

Analysis of the Frame



There's always a solution in steel!

75

Analysis of the Frame

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

There's always a solution in steel!

76

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

There's always a solution in steel!

77

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)

There's always a solution in steel!

78

Analysis and Design Methods

- All 3 methods involve a direct or indirect 2nd 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.

There's always a solution in steel!

79

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)

There's always a solution in steel!

80

Direct Analysis Method

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

There's always a solution in steel!

81

Notional Loads

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

$$N_i = 0.002Y_i$$

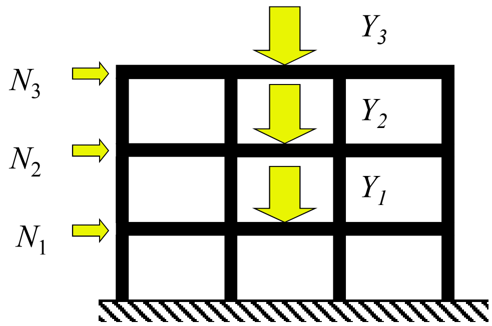
Y_i = the total gravity load on $story_i$

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.

There's always a solution in steel!

82

Direct Analysis Method



$$N_i = 0.002Y_i$$

There's always a solution in steel!

83

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.

There's always a solution in steel!

84

Direct Analysis Method

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

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

- Apply notional loads in the direction of sway!

There's always a solution in steel!

85

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

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

There's always a solution in steel!

86

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).

There's always a solution in steel!

87

Direct Analysis Method

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

There's always a solution in steel!

88

Direct Analysis Method

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

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

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

$\alpha = 1.0$ (LRFD) $\qquad \alpha = 1.6$ (ASD)

There's always a solution in steel!

89

Direct Analysis Method

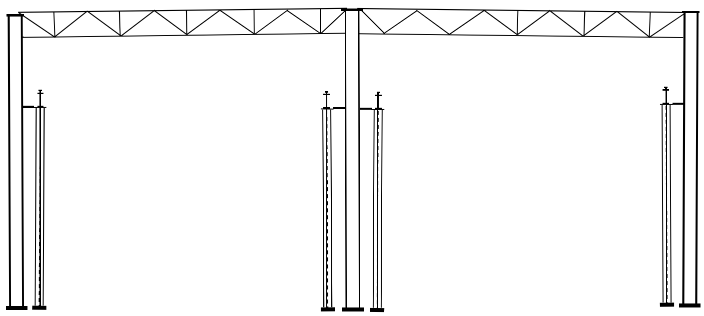
- For LRFD
  - Conduct analysis using LRFD combinations
- For ASD
  - Conduct analysis using 1.6 * ASD combinations
  - Divide final forces and moments by 1.6

(Accounts for nonlinearity of 2nd order analysis)

There's always a solution in steel!

90

Actual Frame



There's always a solution in steel!

91

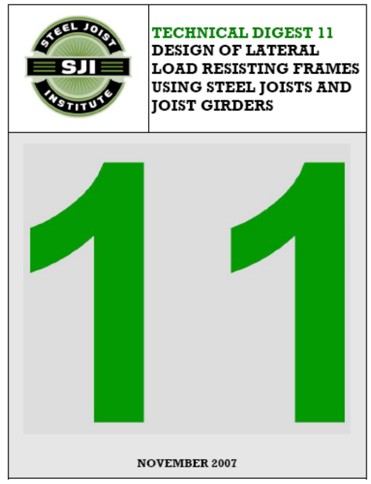
Model Details

- 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 2nd order analysis
  - Leaners increase 2nd order effects

There's always a solution in steel!

92

Reference


STEEL JOIST INSTITUTE SJI

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

11

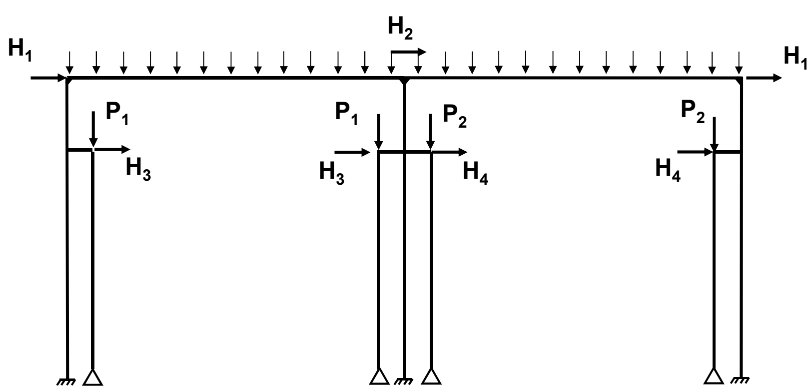
NOVEMBER 2007

There's always a solution in steel!

93

Frame Model

The Model



There's always a solution in steel!

94

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

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

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

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

  $R_M = 0.85$ (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”)

There’s always a solution in steel!

97

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

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

There’s always a solution in steel!

98

Estimate 2nd-Order Effects

- Small Effects

  $$1.0 \le B_2 \le 1.1$$

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

  $$1.1 < B_2 \le 1.5$$

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

  $$B_2 > 1.5$$

  – Must use Direct Analysis, K=1

There's always a solution in steel!

99

Perform 2nd-Order Analysis!

Structural Instability Detected!

Joint 14 Degree of Freedom MX

There's always a solution in steel!

100

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)

There's always a solution in steel!

101

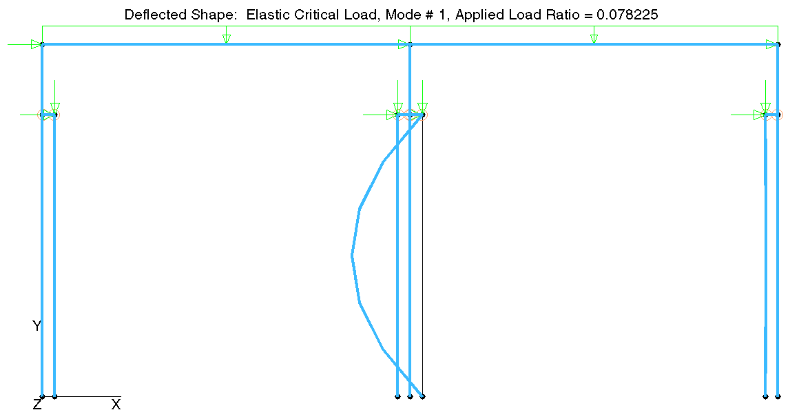
Identifying 2nd Order Errors

- 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

There's always a solution in steel!

102

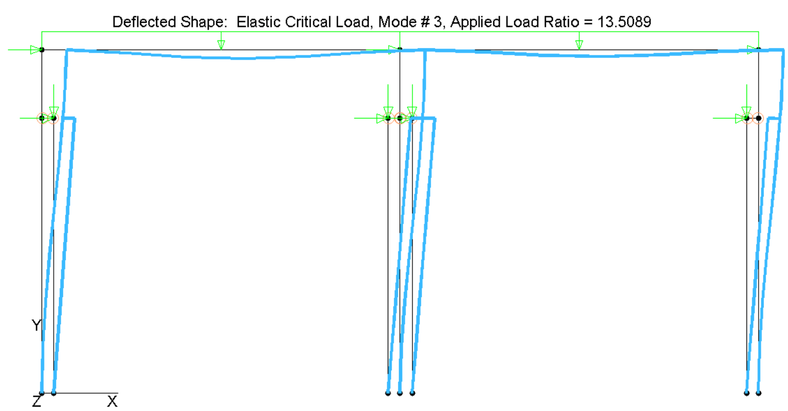
Element Instability



There's always a solution in steel!

103

Sidesway Instability



There's always a solution in steel!

104

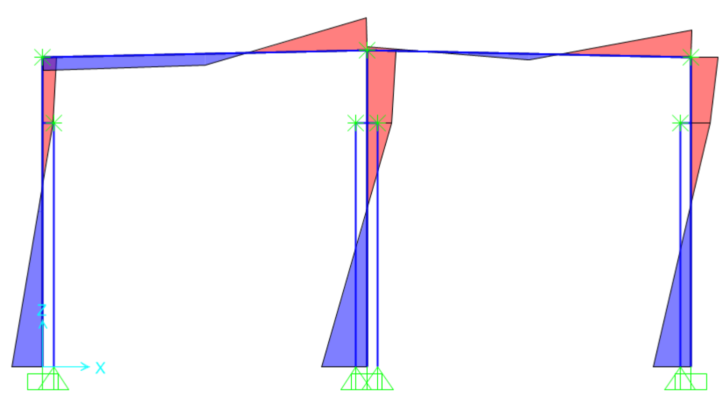
Analysis Input

- 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.

There's always a solution in steel!

105

Analysis Results - ASD



There's always a solution in steel!

106

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

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

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

There's always a solution in steel!

109

End of Lesson 5

There's always a solution in steel!

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!

There's always a solution in steel!

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.

There's always a solution in steel!

8-Session Registrants

PDH Certificates

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

There's always a solution in steel!

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.

There's always a solution in steel!

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.

There's always a solution in steel!

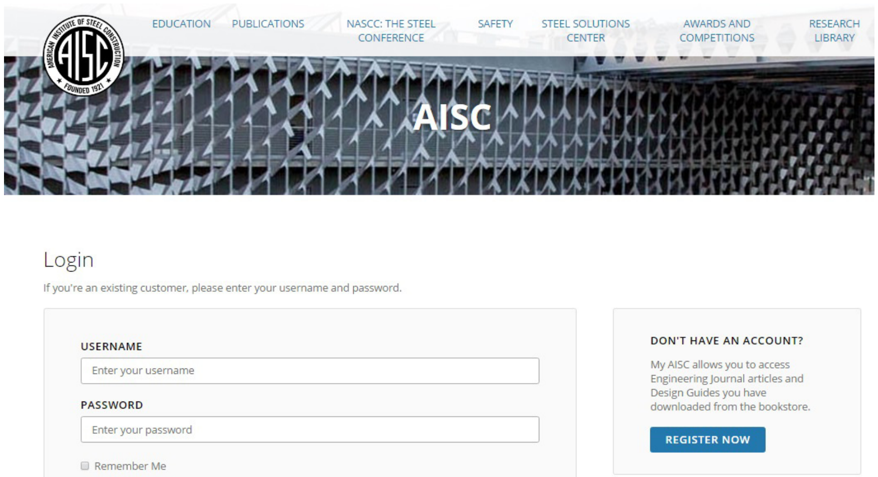
Night School Resources for 8-session package Registrants

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

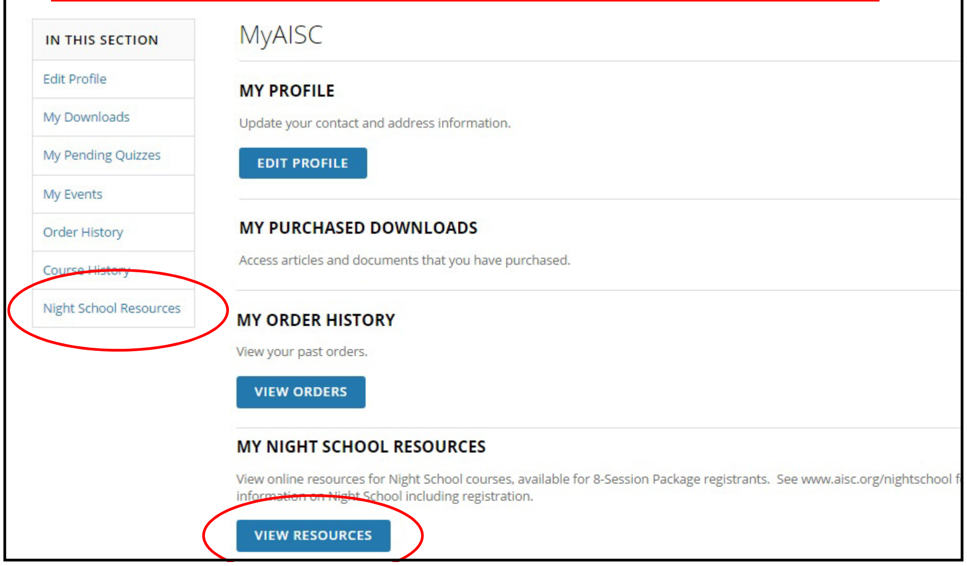
There's always a solution in steel!

Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.



Night School Resources for 8-session package Registrants



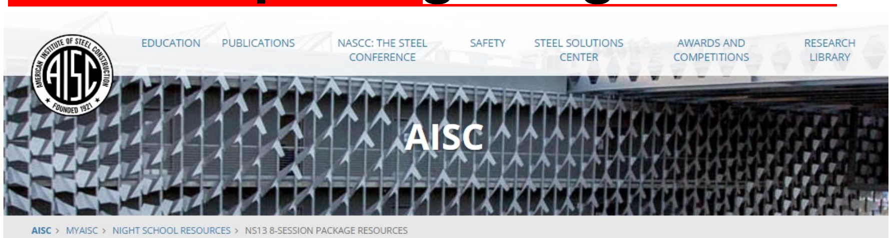
Night School Resources for 8-session package Registrants

Night School Resources

Event	Date
NS 13 8-Session Package	1/30/2017 7:00:00 PM

There's always a solution in steel!

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.

There’s always a solution in steel!

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.

There’s always a solution in steel!

There's always a solution in steel.

Thank You

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

structural
STEEL