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

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Session 4 – Crane Supporting Steel Structures
July 14, 2020

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Course Description

Crane Supporting Steel Structures
July 14, 2020

This session will address design of crane supporting structures. Topics include: codes and standards, unique considerations, loads and load combinations, repeated loads, and duty cycle analysis. The session will review challenges to the designer such as stepped columns and monosymmetric sections, crane support, monorail and underhung cranes. The session will then discuss crane girders, fatigue-preferred details, and examples of poor practice.

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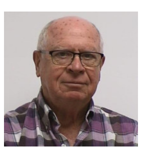
Learning Objectives

- Define what a crane-supporting steel structure is and what makes it unique or different than other industrial buildings.
- Define the governing Codes and Standards for crane-supporting steel structures.
- Discuss unique features of a crane-supporting steel structure.
- Discuss poor details and improved alternatives.

Night School 23: Industrial Structures

Session 4: Crane Supporting Steel Structures
July 14, 2020



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NIGHT SCHOOL SESSIONS

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

8

SESSION 4: Crane-Supporting Steel Structures

LEARNING OBJECTIVES:
- Define what a crane-supporting steel structure is and what makes it unique or different than other industrial buildings
- Define the governing Codes and Standards
- Discuss unique features
- It will not be possible to go into great detail but references will be provided

9

10 Quick Chapters!

1. Introduction
2. Codes, Standards, Limit States
3. Loads, Load Combinations
4. Fatigue
5. Class of Service, Duty Cycles

10

10 Chapters, Cont'd

6 Segmented Columns
7 Beam and Frame Design
8 Bad Practice
9 Good Practice
10 Design Criteria Documents

11

Chapter 1:Introduction

Purpose of this presentation
- **These structures differ from other industrial buildings in several important ways that the Designer must be aware of**
- **This presentation will focus on the unique features of these structures and how to address these topics**

12

Scope and Exclusions

- This presentation is limited to overhead traveling cranes with flanged wheels

13

Excluded

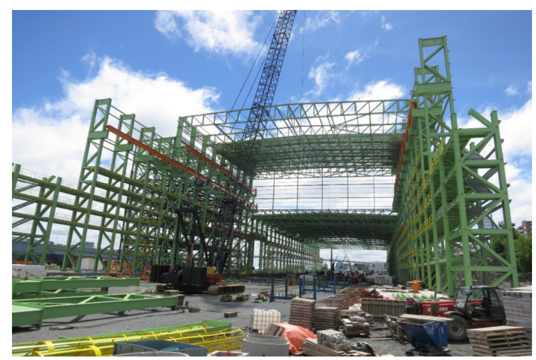
- Cranes with guide rollers
- Underslung cranes
- Monorails
- Gantry cranes
- Semi gantry cranes
- Jib cranes

14

A typical structure

15

A complex multi-tier structure



16

What's so special about these structures?

- For many years loads and realistic load combinations had not been well covered in the Building Codes, particularly the improbability of some loads (some of short duration) acting simultaneously. (All live loads L together)
- Design for repeated loads, not all acting in the same direction.
- Classes of service.
- Crane load eccentricities.
- Segmented (including stepped) columns.
- Application of LRFD provisions to these structures.
- Special construction tolerances.
- Design Criteria Documents

17

North American Practice

- The USA and Canada are very much aligned in design practices based on the same research
- The USA current methods are WSD (allowable stress design) and LRFD also called Strength Design(multiply service loads by load factors) methodology
- Canadian methods are limit states, SI metric
- We will concentrate on strength design
- Crane runway beams are usually called crane beams or crane girders (although they are not part of the crane)

18

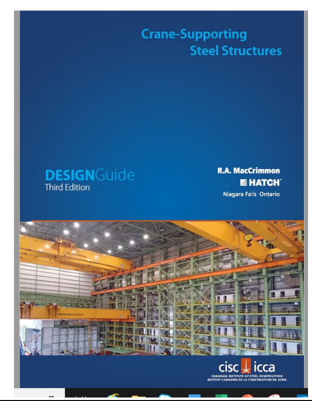
Key References

- AISC Design Guide 7
- AIST Technical Report 13

19

The CISC Guide Reference

- The Canadian Institute of Steel Construction (CISC) has made available a design guide based on North American Practice
- Contains among other topics, a check list with commentaries



20

CISC Guide Table of Contents

1. Introduction
2. Loads, Load Combinations
3. Design for Repeated Loads
4. Checklist for Design and Construction (47)
5. Other Topics (30)
6. Rehabilitation and Upgrading
7. Beam Design Procedures
8. References
9. Figures
10. Design Examples (monosymmetric beam and heavy plate girder)

21

Key Issues

- Fatigue due to directly applied repeated loads
- Distortion induced fatigue-see later slide
- Fabrication and erection tolerances
- Unaccounted for restraints
- Deflections, drift
- Appropriate load combinations
- Class of service, appropriate design criteria accordingly

22

Key Issues Cont'd

- Inadequate clearances
- Historical inaccuracies in crane weights
- Application of notional load concepts to segmented columns
- Design procedures for mono-symmetric runway beams
- Seismic design considerations
- Rehabilitation

23

End of Chapter 1, Introduction

24

Chapter 2-Codes and Standards

- Local Building Code such as IBC
- ASCE/SEI 7-16 for loads
- AISC 360-16 for Material Design Standard
- Occupational Safety and Health Act (OSHA)
- AISC Design Guide 7
- AIST Report 13
- CMAA

25

Influences

- Owner's preferences
- Insurer

26

End of Chapter 2, Codes and Standards

27

Chapter 3 – Loads, Load Combinations

Crane loads are separate from other live loads.

Fatigue is often a critical consideration.

Crane loads have unique characteristics

- Impact
- Applied loads often/always at design magnitude
- Improbability of loads, some of short duration, acting together
- Load combinations are limited to those with a reasonable probability of occurrence
- Lateral loads such as side thrust (what is side thrust?), longitudinal loads
- Loads on end stops
- Specialized classes of cranes such as those with rigid masts require special consideration

28

Loads

Determine vertical impact, lateral, and longitudinal loads based on the local building code which will point to ASCE 7.

For vertical impact in ASCE 7:

- Monorails (powered) 25%
- Cab or remotely operated bridge cranes 25%
- Pendant operated bridge cranes (powered) 10%
- Bridge or monorail cranes with hand geared bridge, trolley and hoist 0%

29

Loads Cont'd

ASCE 7:

Lateral Loads:

- 20% of the sum of the rated capacity and weight of the hoist and trolley

Longitudinal Loads:

- 10% of the maximum wheel loads

30

But there is more!

- The above criteria serve well for many applications but not for the more severe classes of service as in steel mills
- ASCE 7 , C4.9 points to other references which include AIST Technical Report 13 for the more severe classes of service
- Lateral loads are higher in TR13 for a number of reasons such as the nature of the operation, speed, non vertical picks, trolley impact with the end stop

31

AIST Report 13 Recommendations

CRANE	IMPACT %	LATERAL LOAD %	TRACTIVE FORCE %
MILL & LADLE	25	40	20
CLAMSHELL & MAGNET, SOAKING PIT,STRIPPING	25	100	20
MOTOR ROOM	20	30	20
STACKER	25	200	20

SEE DOCUMENT FOR ADDITIONAL REQUIREMENTS

32

Crane Loads-% of Respective Loads-Summary

Crane Type	Vertical incl impact	Total side thrust, greatest of			Tractive force
	Max wheel load	Lifted load	Lifted load + trolley	Lifted load +crane	Max load, Drive wheels
Cab or radio controlled	125	40	20	10	20
Clamshell, bucket, magnet	125	100	20	10	20
Guided arm, stackers	125	200	40	15	20
Maintenance	120	30	20	10	20
Pendant controlled	110		20	10	20
Chain operated	105		10		10
Monorails	115		10		10

33

Crane Lateral Inertial and Dynamic Forces

- Tractive forces from trolley
- Braking forces from trolley
- Bumper forces due to trolley impacting stop at end of bridge
- Skewing forces, also called oblique travel
- Lateral forces due to dynamic asymmetry
- Lateral forces due to non-vertical lift

34

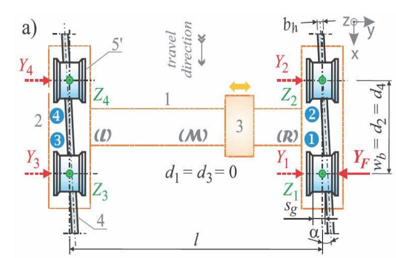
Lateral Forces

- More details on lateral forces follow
- Important to understand local and global effects
- Important to recognize when standard procedures do not apply
- Many wear and tear issues on cranes and runways are associated with alignment and tolerance issues
- Larger lateral forces are generally associated with skewing effects

35

Forces Associated with Crane Bridge Skewing

- Sequence of events
  - Crane assumes skewed position, travelling obliquely
  - Eventually a flange of one of the leading end truck wheels comes in contact with the side of the crane rail.
  - Horizontal frictional forces develop at the wheels to counteract the skewing force



1 - rigid main girder, 2 - rigid end truck, 3 - trolley, 4 - rail, 5' - flanged wheel, 5" - flangeless wheel, 6 - guide roller, (L), (M), (R) - trolley position: (left), (middle), (right)
● wheel vertical force Z (j = 1, ..., 4).

36

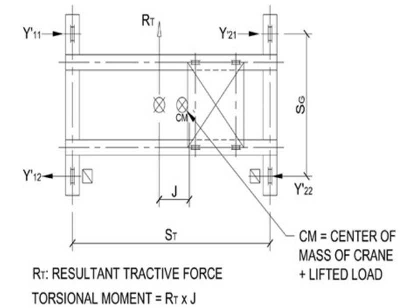
Skewing Forces

- Note that sum of Steering Forces and Frictional Forces sum to zero
- The system is subject to local forces but no net lateral load
- Our current design procedures do not specifically acknowledge skewing behavior (all lateral loads in the same direction)

37

Lateral Forces Due to Dynamic Asymmetry

- These forces occur as the crane is accelerating or decelerating
- Generated if the center of mass of the crane including lifted load does not align with the centroid or resultant of the tractive forces from end truck wheels
- Results in torsional force on bridge, somewhat similar to skewing forces previously discussed



38

North American Practice

- There are several components which contribute to forces perpendicular to the crane runway beams.
- North American practice is that these can be lumped together (simplified) and called “side thrust”, providing satisfactory results for cranes with flanged wheels.
- The side thrust should be assigned in proportion to the lateral stiffness of the beams (example:25 ft spans on side of the runway, 50 ft spans the other side

39

For More Detail on Lateral Forces

- The European, South African and Australian Standards tend to separate these effects into;
  - acceleration of the crane along the runway
  - acceleration of the trolley
  - Skewing
- A suitable reference is DIN EN 1501
- The calculations can be complex!

40

Crane Longitudinal Forces

- Sources
  - Tractive forces from crane end trucks
  - Braking forces from crane end trucks
  - Bumper forces from crane collision with end stops on runway Lateral forces

41

Crane Bumper Forces

- Bumper forces are a dynamic force that varies with bridge speed at impact, mass of crane + trolley (typically not including lifted load) and the load-deformation characteristics of the bumper system
- AIST Technical Report 13 provides more information and example calculations
- CMAA and TR13 use 40 and 100% of rated sped resulting in very large differences in bumper strength requirements

42

Seismic Forces

- Forces unlikely to be provided by the crane supplier
- Dead Load of crane(s) to be positioned for maximum effect on the member being considered
- Restraining devices have been used to prevent cranes jumping the rails
- Refer to ASCE 7 and AISC 341-16 for forces and design procedures for these types of structures
- See definition of industrial building in ASCE 7 , Chapter 11 which provides option to use chapter 15 “non-building structures like buildings”
- For seismic forces on runway beams refer to chapter 13 of ASCE 7

43

Cranes With Guide Rollers

44

Major Differences to Flanged Wheels

- Guidance for guide roller option shown on previous slide is totally on one side of the runway. This system is commonly used by European crane suppliers
- There are other options which involve both rails
- Special shaped crane rails required for proper guide roller performance
- Effect on design of crane rail, rail attachments, crane girder and supporting building structure may be significant

45

Load Combinations

- Refer to ASCE 7, AISC Design Guide 7 and AIST Report 13

46

Load Combinations, ASCE 7

1. $1.4D$
2. $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4. $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5. $0.9D + 1.0W$

C4.9 CRANE LOADS

All support components of moving bridge cranes and monorail cranes, including runway beams, brackets, bracing, and connections, shall be designed to support the maximum wheel load of the crane and the vertical impact, lateral, and longitudinal forces induced by the moving crane. Also, the runway beams shall be designed for crane stop forces. The methods for determining these loads vary depending on the type of crane system and support. MHI (2009, 2010a,b) and MBMA (2012) describe types of bridge cranes and monorail cranes. Cranes described in these references include top running bridge cranes with top running trolley, underhung bridge cranes, and underhung monorail cranes. AIST (2003) gives more stringent requirements for crane runway designs that are more appropriate for higher capacity or higher speed crane systems.

47

LRFD Load Combinations, AIST TR 13

3.10.2.1 LRFD Load Combinations

1. $1.4D$
1a. $1.4D+1.4C_{dm}$
2. $1.2D+1.6L+0.5(L_r \text{ or } S \text{ or } R)$

2a. $1.2(D+C_{dm})+1.6L+1.0(C_{vm}+C_{ss}+C_{ls}) +0.5(L_r \text{ or } S \text{ or } R)$
2b. $1.2(D+C_{dm})+1.6(C_{vm}+C_{ss}+C_{ls})+L+0.5(L_r \text{ or } S \text{ or } R)$
2c. $1.2(D+C_{ds})+1.6(C_{vs}+C_i+C_{ls})+L+0.5(L_r \text{ or } S \text{ or } R)$
3. $1.2D+1.6(L_r \text{ or } S \text{ or } R)+(L \text{ or } 0.5W)$
3a. $1.2(D+C_{dm})+1.6 (L_r \text{ or } S \text{ or } R)+1.0(C_{vm}+C_{ss}+C_{ls})+(L \text{ or } 0.5W)$
4. $1.2D+1.0W+L+0.5(L_r \text{ or } S \text{ or } R)$
4a. $1.2D+1.2C_{dm}+1.0W+L+C_{vm}+0.5(L_r \text{ or } S \text{ or } R)$
5. $1.2D+1.0E+L+0.2S$
5a. $1.2D+1.2C_{dm}+1.0E+C_{vs}+L+0.2S$
6. $0.9D+1.0W$
7. $0.9D+1.0E$
7a. $0.9D+C_{dm} \text{ (or } C_{ds})+1.0E$
8. $1.2D+1.2C_{ds} +1.0C_{vs} +1.0C_{bs}$
9. $0.9(D+C_{ds})+1.6C_{vs(min)}+1.6C_{ss}$
10. $0.9(D+C_{ds})+(1.6C_{ls} \text{ or } 1.0C_{bs})$

- Note that the crane loads are not necessarily all "live" loads
- We can take the weight of the crane components as dead load as long as the result of crane dead and live (lifted) load is not less than 1.4 x (dead + live load)

48

Partial list of WSD Load Combinations and Fatigue

6a. $D+0.75[L+0.6W+(L_r \text{ or } S \text{ or } R)]$
6a1 $D+C_{dm}+0.75[C_{vm}+L+0.6W+(L_r \text{ or } S \text{ or } R)]$
6a2 $D+C_{dm}+0.75[C_{vm}+C_{ss}+C_{ls}+0.3W+(L_r \text{ or } S \text{ or } R)]$
6b. $D+0.75[L+0.7E+S]$
6b1. $D+C_{dm}+0.75[C_{vs}+L+0.7E+S]$
7. $0.6D+0.6W$
8. $0.6D+C_{dm}$ (or C_{ds})$+0.7E$
9. $D+C_{ds}+C_{vs}+0.67C_{bs}$
10. $0.6(D+C_{ds})+C_{vs(min.)}+C_{ss}$
11. $0.6(D+C_{ds})+C_{vs(min.)}+(C_{ls} \text{ or } 0.67C_{bs})$

3.10.2.3 Fatigue. For purpose of fatigue design, crane loads to be considered are (Cds+Cvs+1/2Css). The number of cycles used as the basis for fatigue design shall be consistent with the building classification covered in Section 1.4. The owner shall designate an increase in the estimated number of load repetitions for any portion of the building structure for which the projected work load or possible changes in building usage warrants.

49

Symbols and Notations, TR 13

C_{ds} – Crane dead load for a single crane with crane bridge and crane trolley positioned to produce the maximum load effect for the element in consideration. Crane dead load includes weight of the crane bridge and trolley.
C_{dm} – Crane dead load for multiple cranes with crane bridges and crane trolleys positioned to produce the maximum load effect for the element in consideration.
C_{vs} – Crane lifted load for a single crane with crane bridge and crane trolley positioned to produce the maximum load effect for the element in consideration.
C_{vm} – Crane lifted load for multiple cranes with the crane bridges and crane trolleys positioned to produce the maximum load effect for the element in consideration.
C_{ss} – Crane side thrust from a single crane in one aisle only.
C_{ls} – Longitudinal crane tractive loads from a single crane in one aisle only.
C_i – Vertical impact due to a single crane in one aisle only.
C_{bs} – Bumper impact due to a single crane in one aisle only at 100% speed.
D – Dead load
E – Earthquake load
F – Loads due to fluids
L – Live loads due to use and occupancy with the exception of snow loads, roof loads and crane runway loads
L_r – Roof live loads

50

End of Chapter 3, Loads

51

Chapter 4 – Design for Repeated Loads

- This is probably the biggest difference between ordinary industrial buildings and those that support cranes
- Session 5 will go into detail
- All classes of crane service may require consideration of fatigue Application of cumulative damage principals
- The AISC reference for fatigue design is AISC 360 Appendix 3

52

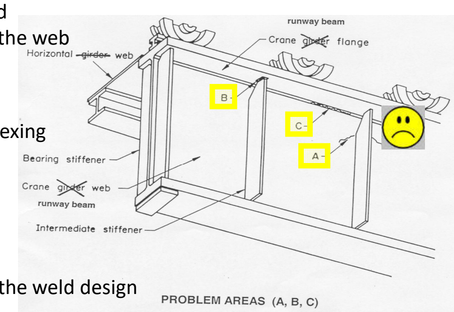
Details Vulnerable to Fatigue Damage

- The following slides illustrate details on crane runway beams which require attention

53

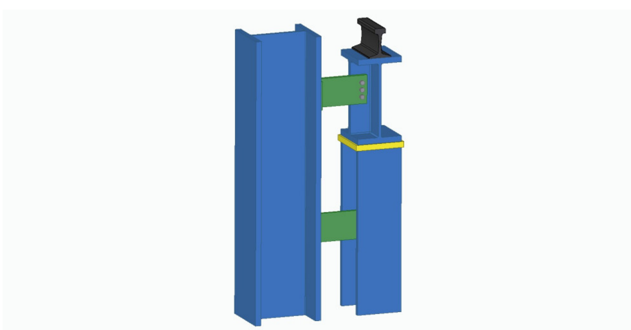
Problems, Runway Beams

- A Distortion induced fatigue caused by repeated out of plane flexing of the web
- B Cracked welds due to repeated flexing of the flange
- C Web to flange connection failure caused by inadequate attention to the weld design



54

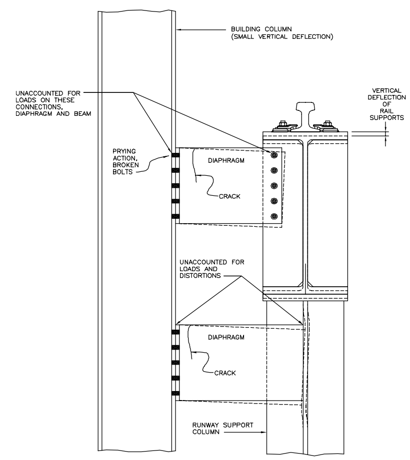
Building Column/Crane Runway Support Column



55

Damage Near Columns

- Note that runway beam deflects vertically (axial shortening) relative to building column as the crane passes
- Forces in diaphragms due to fixity not accounted for
- Distortion induced fatigue at diaphragms



56

Problems at Supports

- Knee braces
- Forces in braces not accounted for
- Prying action on bolts at bearing
- Fillet weld failure at the cap plate
- Fillet weld failure at stiffener
- Forces in splice plates not accounted for
- Gaps under rail due to top of beams elevations

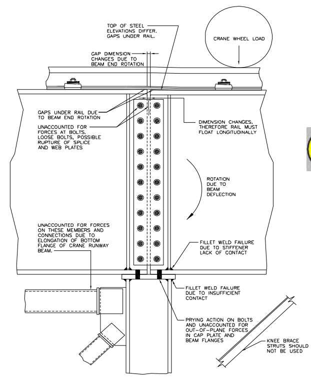
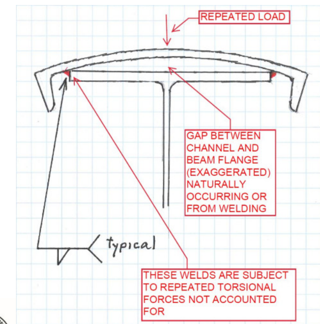


Figure 9. Examples of unaccounted for forces and fatigue damage at beam supports.

57

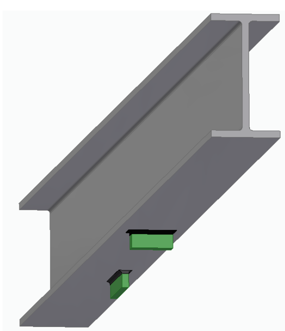
Cap Channel Issues



- A common design
- Naturally occurring gap creates an arching effect
- Welds subject to unaccounted for repeated torsional forces and shear as the arch collapses under repeated vertical loads
- Stitch welds not desirable

58

Unauthorized Attachments



- Details welded to tension flange
- Often unauthorized
- Which detail is worse?

59

Continuous Beam with Tie to Web

- Note damage
- Repeated tensile stresses over the support
- Repeated uplift at discontinuous beam ends

60

Design for Fatigue 101

- Fundamentally, the number of cycles to failure varies inversely (usually to the third power) as the stress range.
- For example, for a given detail it will take 8 (2^3) times the number of cycles at 50% of a given stress range to do the same amount of damage.
- Palmgren-Miner allows us to calculate cumulative damage due to varying stress ranges and can also be expressed as equivalent stress range and equivalent number of cycles.

61

Chapter 4 of the CISC Guide – Design and Construction Measures Check List

- A “check List” has been prepared, with co-relation to class of crane service and numbers of full cycles.
- 46 items are presented, with a commentary.
- This information has not been available in this format.

62

Equivalent Number of Cycles

- By Palmgren-Miner, the equivalent number of cycles at the highest stress range can easily be calculated. For instance, if there are 104,000 cycles at 219 MPa stress range and 208,000 cycles at 188 MPa stress range, then the equivalent number of cycles at the highest stress range (219 MPa) is:

$104{,}000 + 208{,}000(188/219)^3 = 235{,}584$ cycles.

- An additional term using the fifth power will be necessary if stress ranges are below the constant amplitude threshold stress range.

63

Fatigue Resistant Details

- We should always be conscious of avoiding details that are susceptible to fatigue damage
- In session 5 Jules will be providing lots of good advice

64

End of Chapter 4, Repeated Loads

65

Chapter 5- Class of Service, Duty Cycles

- Establish design criteria for the supporting structure related to the class of crane service
- Introduction to Duty Cycle Analysis

66

Class of Service

- Classes of crane service are well established in North America.
- CMAA (Crane Manufacturer's Association) is a common reference.
- If one takes out several criteria that are not really related to the structure, then the stripped down description of each class for this purpose follows:

67

Class of Crane Service

Life Cycle / CMAA Crane Classifications:

- Class A (Standby or infrequent service) ex. Power plants
- Class B (Light service) 2 to 5 lifts per hour typically well below rated capacity
- Class C (Moderate Service) 5 to 10 lifts per hour averaging below 50% of the rated capacity. A common category, often abused
- Class D (Heavy Service) loads approaching 50% of the rated capacity are handled constantly. Manufacturing facilities

68

Class of service cont'd

Life Cycle / CMAA Crane Classifications:

- Class E (Severe Service) handling loads approaching the rated capacity are handled constantly twenty or more lifts per hour at or near rated capacity. Example scrap yards in steel mills
- Class F (Continuous Severe Service) handling loads approaching rated capacity under severe service conditions, highest reliability throughout its life.

69

Class of Service

- Some sort of link between the class of service of the crane supporting structure and the class of service of the crane(s) would be useful.
- Attempts have been made but history is lacking and there is a wide variation in the recommendations.
- Recommendations have been mostly fatigue related (class of building/number of cycles). See AISC Design Guide #7.

70

Tables 3.2 and 3.3

- The upper table shows CMAA number of full load cycles by class of crane

Table 3.2
CMAA Number of Full Load Cycles by Class of Crane

Class of Crane	Number of Thousands of Full Load Cycles
A	100
B	200
C	500
D	800
E	2 000
F	> 2 000

- The lower table shows range of existing suggestions for design of the supporting structure by class of crane

Table 3.3
Ranges of Existing Suggestions for Cycles for Design of Crane-supporting Structures

Class of Crane	Number of Thousands of Full Load Cycles
A	0 to 100
B	20 to 100
C	20 to 500
D	100 to 2 000
E	500 to 2 000
F	Greater than 2 000

The basis of selecting these numbers is not explained nor is it evident whether these are the total number of cycles or the equivalent number of full cycles (see Section 3.3.3).

71

Class of Crane Service Continued

- The class of crane service can be estimated by calculating, from the load spectrum, the mean effective load factor k.
- For example, if there are 10,000 lifts at full capacity, 70,000 at 30% and 20,000 at 10%, then:

$K = ((1.0^3 x0.1)+(0.3^3 x0.7)+(0.1^3 x0.2))^{1/3} = 0.492$

- From available tables such as in the CISC Guide and CMAA 70, the crane service classification could be A, B, C, or D, depending on the four use categories shown.

72

Relating Class of Crane Service to Class of Structure Service

- After examining the fatigue design criteria (number of full cycles) for each class of crane as shown in the CMAA specifications, one can back calculate the design number of cycles for the structural design of each class of crane.
- After some duty cycle analysis, a reasonable co-relation is found and shown in Table 3.4 of the CISC Guide.
- Adjustments must be made for multiple cranes (duty cycle analysis).

73

Recommended Number of Cycles for Classes of Service for the Supporting Structure (Guide Table 3.4)

Structural Class of Service	Number of Thousands of Full Cycles
SA	20
SB	40
SC	100
SD	400
SE	1000
SF	Greater than 2000

The above table is used to relate to class of crane service in Chapter 4.
This is an approximation. A duty cycle analysis will yield superior results

74

Duty Cycle Analysis

- An examination of the duty cycle of a crane over the length of its runway shows that the loading spectrum for the critical member of the supporting structure is as follows:

% of Max. Wheel Loads	Num. Cycles At That Level	Description
100	62,500	Fully Loaded
80	62,500	Load Intensity and Trolley Positions Vary
60	62,500	Load Intensity and Trolley Positions Vary
40	62,500	Load Intensity and Trolley Positions Vary
30	250,000	Unloaded Crane

75

Duty Cycle Analysis Continued

Calculate the equivalent number of cycles at full wheel load:

$$N = 62{,}500 + 62{,}500(0.8^3 + 0.6^3 + 0.4^3) + 250{,}000 \times 0.3^3 = 118{,}750 \text{ cycles}$$

The supporting structure should be designed for, say, 120,000 cycles of full wheel load

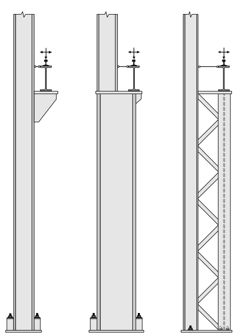
76

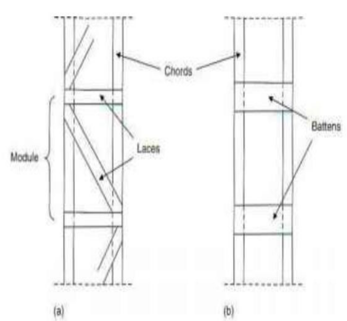
End of Chapter 5, Class of Service, Duty Cycles

Chapter 6-Stepped Columns

- Aspects of these types of crane-supporting columns that the Engineer should be aware of
- Stepped columns are a form of segmented columns
- A segmented column can be defined as a column where there is either a change in section or a change in axial load along its length
- We will use the term stepped and segmented interchangeably herein

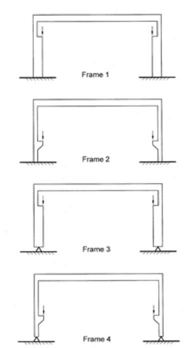
Types Of Stepped Columns





Segmented Columns

- Segmented columns may be stepped or of constant cross section
- Common for crane support but could apply at mezzanines, for instance
- The recommended design approach is AISC Design Guide 7 and AIST Report 13
- The Canadian Standard CSA S16-19 provides a simplified approach
- For Limit States Design see AISC Eng Journal paper by Kennedy and MacCrimmon
- Where notional loads are insignificant(say, less than 5%)compared to applied loads at the same location, the notional loads can be safely ignored

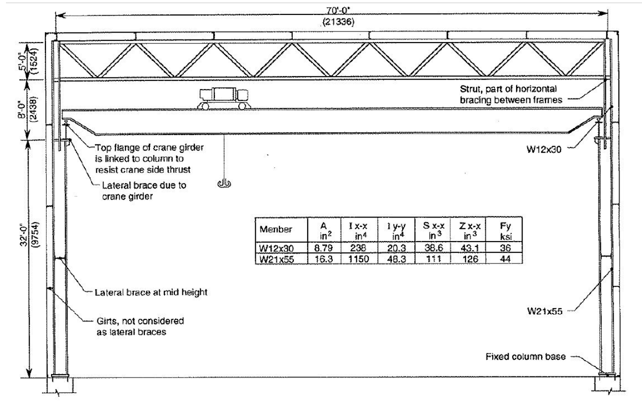


Brackets to Columns

- Generally for lighter applications
- AIST Report 13 recommends not more than 50 kips
- Beyond 50 kips, stepped column is recommended

81

Example Frame



Menber	A in²	I x-x in⁴	I y-y in⁴	S x-x in³	Z x-x in³	Fy ksi
W12x30	8.79	238	20.3	38.6	43.1	36
W21x55	16.3	1150	48.3	111	126	44

82

Codes and Standards

- The "go to's" are AISC Design Guide 7 and AIST Technical Report 13
- The path leads to AISC 360 chapter C "stability design methods"
- Other useful references are
- AISC Eng Journal Paper by Schmidt
- Paper by Kennedy and MacCrimmon
- Lecture notes by Ziemian available in the web

83

Canadian CSA S16, Segmented Columns

- Based on Schmidt, and Schmidt using a notional load method for calculating the in-plane slenderness ratio for each segment, the "total length of the member may be used".
- In other words, the in-plane slenderness ratio of each segment is to be calculated using the full length of the column.
- Usually works for strong axis (web to view) as this check seldom governs
- Although convenient, not a rigorous analysis

84

Comments on the Schmidt Paper

- Schmidt (AISC Engineering Journal, Second Quarter, 2001) notes that, in some cases, particularly with pinned column bases, results by this method may be unconservative.
- The author is unaware of an update

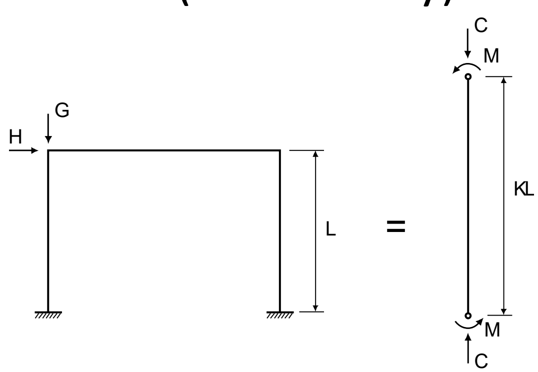
85

Equivalent Lengths

- The concept of equivalent lengths for stepped columns is that for a given loading condition the equivalent prismatic columns have the same buckling load as the stepped column.
- Note that a different load case might well govern for each segment
- It is important that no hinge forms at the step

86

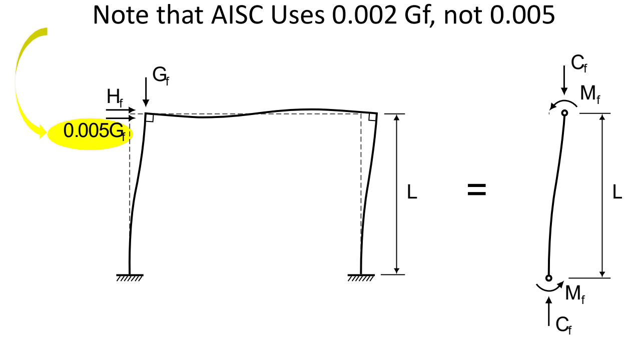
"K" (the old way)



87

Direct analysis ,Notional Loads, P-Δ

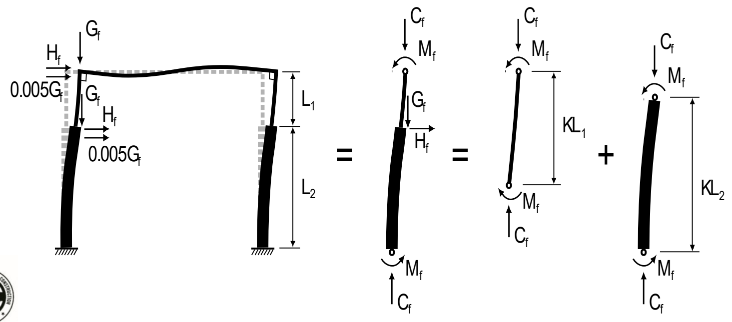
Note that AISC Uses 0.002 Gf, not 0.005



88

Notional Loads, Segmented Columns

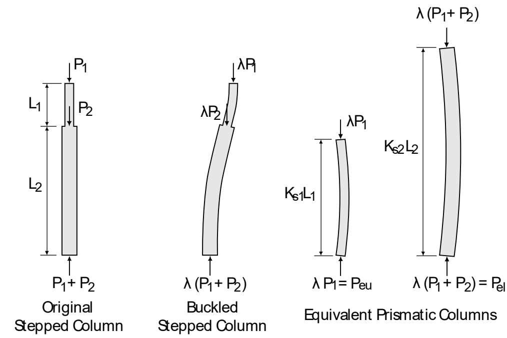
Note that K=1 for the whole column length and no hinge at the step



89

Equivalent length, Each Segment

K=1 for the whole stepped column length



90

End of Chapter 6, Stepped Columns

Chapter 7- Beam and Frame Design

- Unique features of crane runway beam design
- Unique features of Frame design
- Tolerances

92

Unique features of Beam design

- Moving loads
- Simultaneous application of loads of short duration
- Loads applied above the shear center
- Eccentricities of applied loads
- Design for repeated loads
- Serviceability
- Monosymmetric sections

93

Unique Features of Beam Design, Con't

- Bearing Details
- Tie backs to columns
- Bearing Stiffeners
- Details at the web to flange weld on plate girders
- Unfortunately, time does not permit a detailed discussion on each of these features, but AISC Guide 7,AIST Report 13 and the CISC Guide provide plenty of guidance

94

Important Considerations

- Horizontal and Vertical Deflections
- Fatigue sensitive details
- Web crippling
- Bearing details
- Ties to columns

95

You Will Need Crane Data

Get a crane data sheet for the crane or cranes proposed for the project.

- Rated Capacity
- Bridge Weight and Speed
- Trolley Weight
- Wheel Spacing
- Service Classification
- Clearance dimensions
- Bumper Force
- Crane rail size
- Which wheels are driven
- Confirm double flange wheels

96

You will need Design Criteria

- Structure class of service
- Impact, side thrust, longitudinal loads
- Cycles for fatigue design
- Vertical and lateral deflections
- More on Design Criteria later on

97

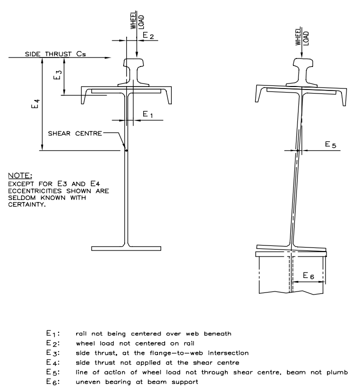
A Few Comments on Deflections

- Excessive vertical and lateral deflections due to crane loads are one of the leading causes of issues with crane operation
- See AISC Design Guide 7 and AIST Technical Report 13
- Vertical deflections due to wheel loads should be as little as span/1000 for the more severe classes of service
- Horizontal deflections should be limited to span/400

98

Typical Eccentricities

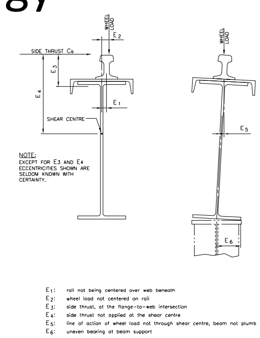
- E1 Rail not centered over web
- E2 Wheel Load not centered on rail
- E3 Side Thrust at web-to-flange
- E4 Side Thrust not applied at shear center
- E5 Line of action of wheel load not through shear center
- E6 Uneven bearing at beam support



99

Flexure Analogy

- There are several eccentricities that create torsional forces on the crane runway beam, most not easy to assess.
- In North America we use the flexure analogy to account for these forces.
- Note that the load eccentricity to the shear center is often very close to the depth of the beam.
- Taking moments about the bottom flange will show that the top flange takes nearly all the load with little residual to the bottom flange.
- The net result is that if we apply all the side thrust to the top flange of the runway beam, we usually won't be far off.



100

Load Applied Above The Shear Center

- Because the beam is usually unsupported laterally and vertical load is applied above the shear center we have to account for a reduction in bending strength. Normally we would adjust Cb as in Bo Doswell's presentation.
- Standard practice is that if we have side thrust as a simultaneous application we can use the flexure analogy to account for load above the shear center. The flexure analogy also compensates for eccentricities E1, E2 and E5
- If we do not have side thrust we must account for this condition in accordance with AISC 360. Some of the AIST TR 13 crane load combinations do not include side thrust.
- It is recommended that the several eccentricities be assessed and included as torsional forces. It may be more convenient to include side thrust and use the flexure analogy.

101

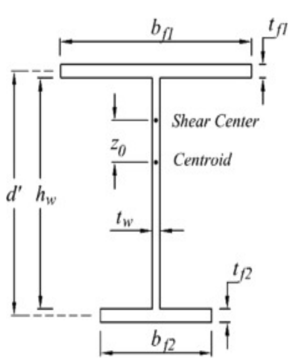
Simultaneous Application of Loads of Short Duration

- Static vertical wheel loads from one crane or more
- Impact
- Side Thrust
- Longitudinal Loads
- Taken care of by proper application of the governing load combinations

102

Monosymmetric Sections

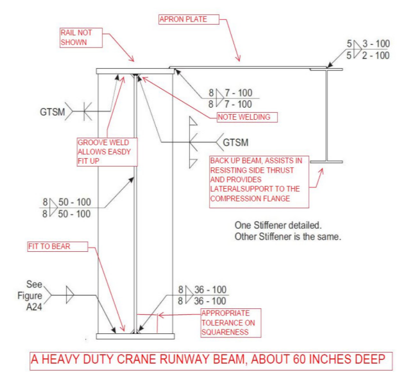
- A section not symmetric about both axes
- A common detail for these structures
- Special considerations for unsupported compression flanges



103

HEAVY DUTY BEAM-Metric Units

- Runway beam with apron plate and back-up beam
- Apron plate design and attachments requires careful attention
- Note web-to-flange weld
- Note welding of bearing stiffeners
- Design of this beam, including for fatigue is in the CISC Guide



104

Beam Design Procedure

7.3 Design Procedure

- Calculate Side Thrust

  Using the side thrust criteria from Table 7.1 and Table 2.1, calculate the side thrust force C_s from each crane to each side of the runway and distribute to the wheels, usually equally. Calculate the side thrust to each wheel as a percentage of the maximum vertical load to each wheel.

- Select a Preliminary Section

  Using the wheel loads, deflection criteria and approximate methods, choose a section that, after further analysis, could provide the required moments of inertia about each axis.

- Moving Load Analysis

  From manual calculations (for assistance, see Beam Diagrams and Formulae in the CISC Handbook), or using a computer, compute the governing deflections, bending moments, shears and reactions for

105

Beam Design Procedure Cont'd

the wheel loads for a single crane and for multiple cranes as may be required. Effects of impact should not be included at this time.

Review the section properties required for deflection and adjust and recalculate if necessary.

- Refine the Trial Section

  Determine class and member properties.

- Calculate Other Forces in the Vertical Plane

  Calculate loads due to Dead Loads, Axial Loads, Tractive Loads, Temperature, Bracing, etc.

- Calculate effects of Torsional Loads
- Re-evaluate Deflections
- Calculate Factored Loads
- Calculate Factored Resistance and Compare to Factored Loads
- Check Local Wheel Support
- Iterate as Necessary
- Design Stiffeners
- Design Bearings and Lateral Restraints
- Design Element Welds and/or Bolts for Factored Loads
- Check for Fatigue Resistance

106

References for Worked Examples

- AISC Design Guide 7
- CISC Design Guide

107

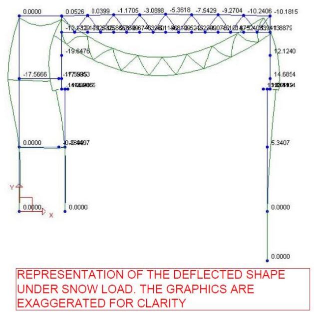
Unique Features of Frame Design

- Stepped columns
- Application of notional loads
- Lateral load sharing between bents
- Tolerances
- Deflection limits

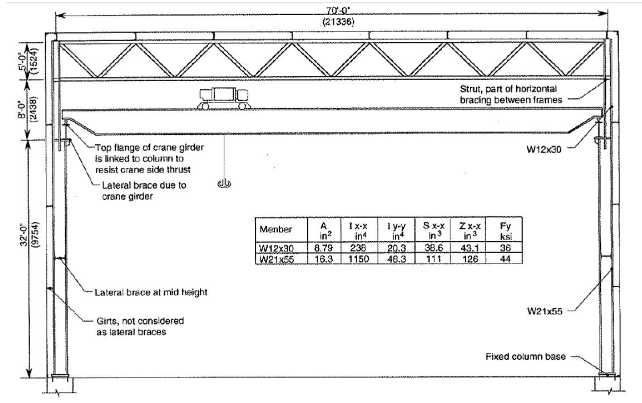
108

Drift Limitations for Frames

- See AISC Design Guide 7 and AIST Technical Report 13
- Rail to Rail dimension must be controlled
- Building sway must be controlled, H/400 or less, depending on the circumstances
- See AISC design Guide 3 (serviceability considerations) for drift criteria for lighter duty cranes



Example Frame



Menber	A in²	I x-x in⁴	I y-y in⁴	S x-x in³	Z x-x in³	Fy ksi
W12x30	8.79	238	20.3	38.6	43.1	36
W21x55	16.3	1150	48.3	111	126	44

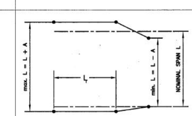
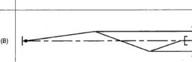
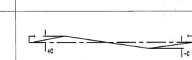
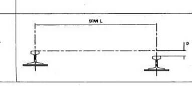
Tolerances

- A crane-supporting structure may well require construction tolerances more stringent than for other industrial structures
- The crane manufacturer requires strict tolerances on rail placement for proper crane operation
- The rail must be properly centered on the beam
- The beam must be properly centered on the column

Rail Alignment Tolerances

- Rail alignment should be to CMAA 70 tolerances unless otherwise specified

TABLE 1.4.2-1

ITEM	FIGURE	OVERALL TOLERANCE	MAXIMUM RATE OF CHANGE
CRANE SPAN (L)		L ≤ 50' A = 3/16" L > 50' ≤ 100' A = 1/4" L > 100' A = 3/8"	1/4" IN 20'-0"
STRAIGHTNESS (B)		B = 3/8"	1/4" IN 20'-0"
ELEVATION (C)		C = 3/8"	1/4" IN 20'-0"
RAIL-TO-RAIL ELEVATION (D)		L ≤ 50' D = ±3/16" L > 50' ≤ 100' D = ±1/4" L > 100' D = ±3/8"	1/4" IN 20'-0"

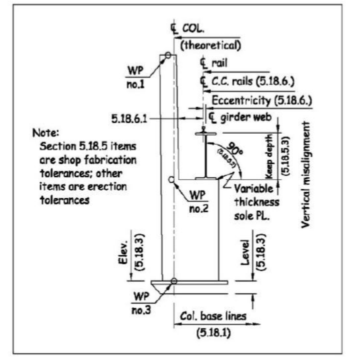
Improper Alignment

- Crane rails not in proper alignment can cause issues with scraping of wheel rims on the rails, broken rail clips, excessive torsion on the beams
- The crane supplier might void the warranty

113

Frame Alignment Tolerances

- Special fabrication and erection measures will be necessary to achieve tight tolerances
- For example, by AIST Report 13, CL of girder web must be within 1/4 in. of specified position



114

Construction Tolerances AIST – Columns

- Column Base Lines –parallel with gauge maintained to +/-1/8”.
- Base Plates-+/-1/16” from elevation level within .01” across length or width.
- Columns maximum deviation from true plumb +/-1/8” at the crane bearing and at the top of the column. Girder seat to be located on column within +/-1/32” from column tolerance

115

Fabrication Tolerances AIST - Crane Runway Beams

- HORIZONTAL SWEEP 1/4” IN 50 FEET.
- CAMBER TOLERANCE +/-1/4” IN 50 FEET
- GIRDER ENDS: FLANGES FLAT AND PERPENDICULARITY TO ENDS
  - FLATNESS +/-1/32”
  - PERPINDICULARITY OF THE WEB AND BOTTOM FLANGE +/-1/64” PER FOOT OF FLANGE WIDTH
  - GIRDER DEPTH AT ENDS +/-1/32” (variable thickness sole plate)

116

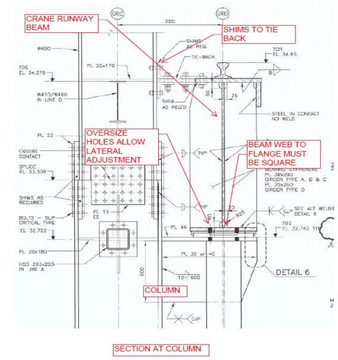
Construction Tolerances AIST - Crane Runway Beams and Rails

- BEAM ALIGNMENT (CENTERLINE OF TOP FLANGE) +/-1/4" OF THEORETICAL BASE LINE
- CENTER TO CENTER OF RAILS +/-1/4" FROM THEORETICAL DIMENSION ON THE DRAWINGS
- RAIL HORIZONTAL MISALIGNMENT +/-1/4" PER 50 FEET WITH A MAXIMUM OF +/-1/2" TOTAL
- CRANE RAILS SHALL BE CENTERED OVER THE WEBS…MAXIMUM RAIL ECCENTRICITY OF ¾ THE GIRDER WEB THICKNESS. (BUT CONSIDER THE CLIPS!)

117

Tolerances Illustration

- Illustration at support
- Beam web to flange must be square
- Beam must bear evenly on the support or the tie-back will be subjected to unacceptable axial forces
- All these tolerances show the need to specify experienced fabricators and erectors using special procedures



118

End of Chapter 7, Beams, Frames, Tolerances

119

Chapter 8-Examples of Bad Practice

- We only have time for a few
- The CISC Guide contains more information

Examples of Poor Framing Practice

- Excessive deflections of the frame
- Forces at connections due to sway, elastic shortening, etc. not accounted for
- Torsion in columns due to longitudinal loads
- Movements relative to masonry not accounted for
- Failure to design for fatigue
- Loose erection tolerances, not compatible with crane mfgr's recommendations

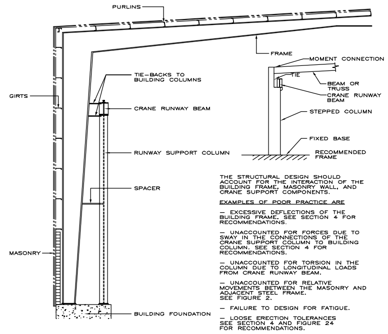
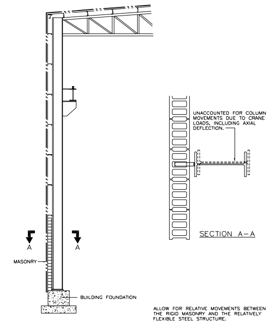


Figure 1. A common example of a crane supporting structure.

121

Dissimilar Materials

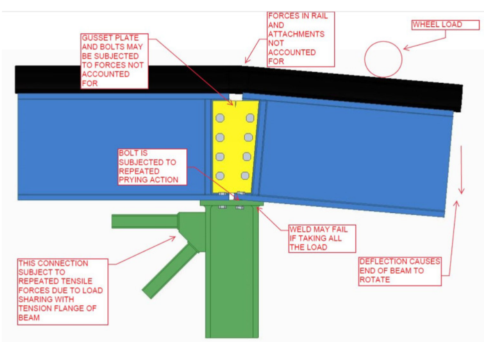


- Avoid embedding components of crane-supporting structures in masonry
- Where possible, use flexible connections

122

Problems at Supports

- View of a Typical Runway Beam Support Illustrating Issues
- Note end rotation of the beam and need for articulated tie back connection detail



123

End of Chapter 8, Bad Practice

124

Chapter 9 Examples of Good Practice

- We'll illustrate some examples of good practice
- Many more examples are available in the references including but not limited to AISC Design Guide 7, AIST Report 13 and the CISC Design Guide

125

Suitable for All Classes of Service

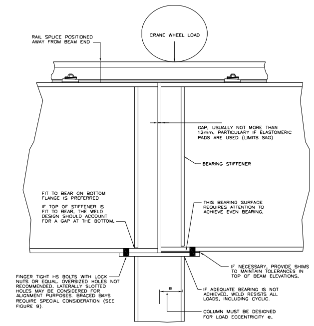
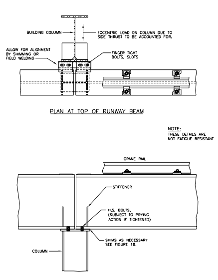


Figure 18. Bearing detail suitable for all classes of service.

- Weld at the column cap
- Bolts outside the column cap
- Eccentricity
- Shims as necessary
- Slotted Holes for alignment
- Stiffeners fit to bear
- Gap between beams
- Rail splice

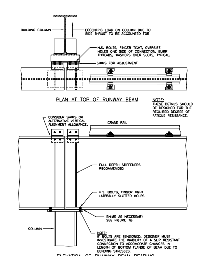
126

Light Duty Details



127

Medium Duty Details



128

Fatigue Resistant Support

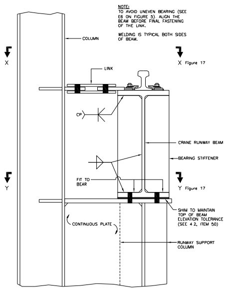


Figure 16. Example of a fatigue resistant beam support.

- Continuous plate
- Shims
- Stiffeners
- Links

129

At top and Bottom Flanges

- Slotted holes for lateral adjustment
- Articulated links to accommodate rotation due to flexure
- Links provide means of adjustment

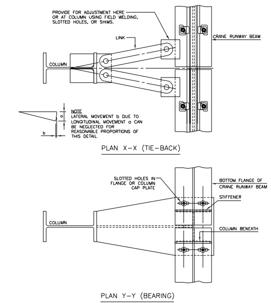
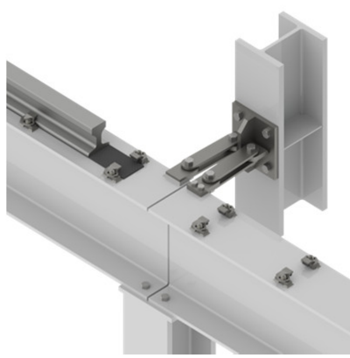


Figure 17. Details from figure 16.

130

Articulated Links

- Adjustable
- The only force is side thrust
- Allows rotation of beam end due to flexure
- Allows a degree of vertical differential movement between beam and column
- But note the sub standard bearing detail!



131

Roof Bracing

- Roof horizontal bracing is recommended, similar to the plan shown
- Aids alignment in steel erection
- Shares side thrust with adjacent frames
- Diaphragm action not recommended

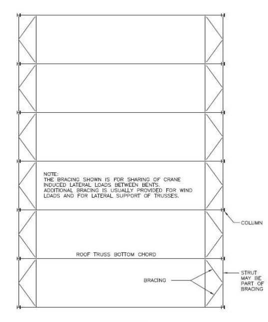


Figure 3
Typical Horizontal Roof Bracing at Lower Chords of Roof Trusses

132

A Typical Structure-is it good?

133

End of Chapter 9, Good Practice

134

Chapter 10-Design Criteria

- Every project should have a design criteria document, agreed to by all
- For your reference the following slides show a range of topics that could be covered

135

The Design Criteria Document

Design Criteria for Crane-Supporting Steel Structure

Design Criteria	
Codes and Standards	
Importance (see NBCC 2015)	
Life of the Structure	
Materials (Plates, Shapes, Fasteners, etc.)	
Span	
Provision for Future Expansion?	
Simple Span?	
Lateral Support for Top Flange?	
Top of Rail Elevation, or Height from Main Floor	
Required Clearance to U/S Beam	
Side Thrust Equally Distributed Both Sides of Runway?	
Number of Cranes, Each Runway	
Collector Rail Mounting Details	

136

Design Criteria Cont'd

Design for Future Additional Cranes	
Jib Cranes, or Provision for Jib Cranes	
Design for Future Upgrades	
Class of Cranes	
Service (Description)	
Type of Duty (see Table 2.1 and Section 3.4.2)	
Crane Hook Capacity — # hook(s) each; Capacity each hook	
Weight of Crane Bridge	
Weight of Crane Trolley	
Bridge Wheels per Rail — Total Number; Driven	
Bridge Wheel Spacing	
Minimum Distance Between Wheels of Cranes in Tandem	

137

Design Criteria Cont'd

Maximum Wheel Load, Each Crane (not including impact)	
Minimum Wheel Load, Each Crane (not including impact)	
Crane Rail — Description; Self load	
Rail Joints (bolted or welded)	
Resilient Pad Under Rail?	
Bridge Speed	
Type of Bumper	

138

Design Criteria Cont'd

Bumpers Supplied with Crane?	
Bumper Force on Runway End Stop (Ultimate Load)	
Fatigue Criteria: Vertical - Equivalent passes on one crane, maximum wheel loads Horizontal - Equivalent cycles of side thrust at 50% of maximum side thrust	
Deflection Criteria: Vertical Limit (one crane, not including impact) Horizontal Limit	
Impact Criteria: Percentage of maximum wheel loads, one crane only	
Foundation Conditions, Limitations	
Other Considerations (such as extreme temperatures, etc.)	
*Weight Certified?	

139

End of Chapter 10-Design Criteria

- The next slide will provide references

140

Useful References

- AISC TG for Industrial Buildings and Nonbuilding Structures has compiled an extensive list of references for industrial buildings, including crane-supporting structures
- A sample is shown on the right
- The complete "Resources List" is provided on your viewing console.

Crane Buildings	back to top

AIST (2003), Guide for the Design and Construction of Mill Buildings, Technical Report #13, Association of Iron and Steel Technology, Warrendale, PA.

AISE (1991),"Old Mill Buildings vs. Current Design Loads - A Survival Approach," Iron & Steel Engineer, Vol. 68, No. 5, Pittsburgh, PA.

Griggs, P. A. (1976), "Mill Building Structures," Proceedings, Canadian Structural Engineers Conference.

MacCrimmon, R.A. (2005), Guide for the Design of Crane Supporting Steel Structures, Canadian Institute of Steel Construction, Willowdale, Ontario

Cranes and Crane Beams	back to top

ASME (2008), Design of Below-the-Hook Lifting Devices, BTH-1-2008, American Society of Mechanical Engineers.

ASME (2004), Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder), NOG-1-2004, American Society of Mechanical Engineers.

CMAA (2004), Specification for Top Running and Under Running Single Girder Electric Overhead Cranes Utilizing Under Running Trolley Hoist, Specification No. 74 (Revised), Crane Manufacturers Association of America, Charlotte, NC.

CMAA (2004), Specification for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes, Specification No. 70 (Revised), Crane Manufacturers Association of America, Charlotte, NC.

CSA (1996), Safety Standard for Maintenance and Inspection of Overhead Cranes, Gantry Cranes, Monorails, Hoists and Trolleys, Standard B167-96, Canadian Standards Institute, Mississauga, Ontario, Canada.

141

The End

- This is the end of this fast paced presentation
- There are other topics such as forms of longitudinal bracing, base plate fixity, rail fastenings, rail splices, rail selection that time does not permit. See the design guides
- I would like to sincerely thank all those that assisted in preparation and you, the audience, for your attendance

142

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Individual Session Registrants

PDH Certificates

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

Individual Session Registrants

PDH Certificates

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

Individual Session Registrants

PDH Certificates

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

8-Session Registrants

PDH Certificates

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

8-Session Registrants

Access to the quiz

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

Quiz and attendance records

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

Reasons for quiz

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

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

8-Session Registrants

Access to the recording

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

PDHs via recording

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

8-Session Registrants

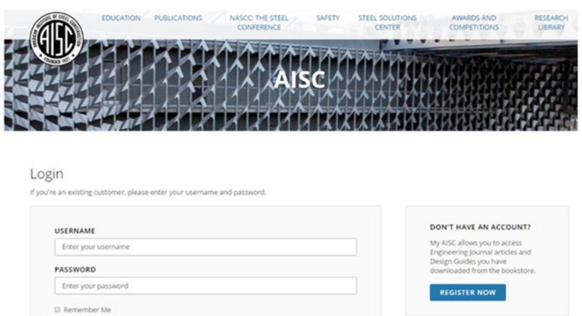
Night School Resources

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

8-Session Registrants

Night School Resources

Go to www.aisc.org and sign in.



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Night School Resources

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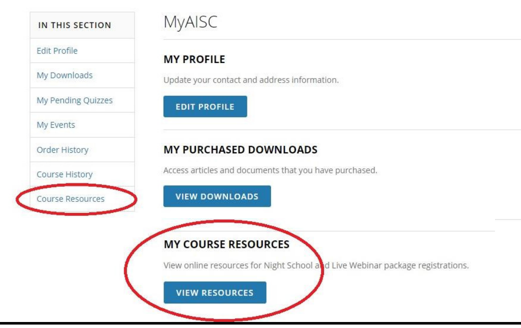
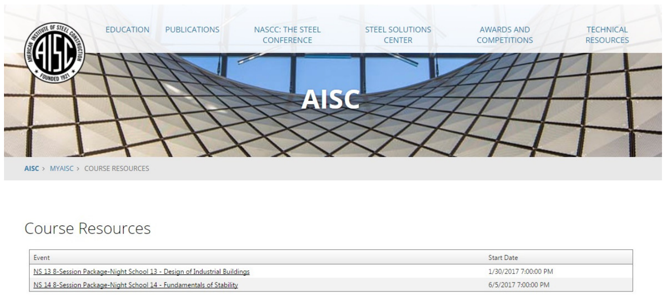


8-Session Registrants

Night School Resources

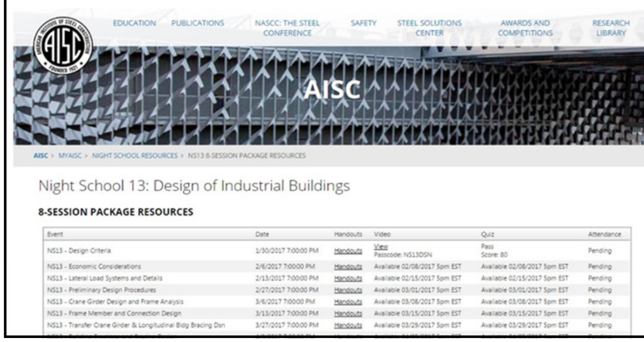


Course Resources

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

8-Session Registrants

Night School Resources



Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

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

8-Session Registrants

Night School Resources

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

8-Session Registrants

Night School Resources

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