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Steel Erection: Engineering and Execution

Session 2: Erection Engineering of Low-Rise Buildings
September 3, 2020



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Course Description

Erection Engineering of Low-Rise Buildings
September 3, 2020

This session provides an overview of the steps taken by the Erector's Engineer to ensure stability of each stage of construction during structural steel erection of low-rise buildings. Topics include:

- AISC Code of Standard Practice requirements for the EOR and Erector
- Design standards / design guides
- The importance of load path
- Global stability
- Element stability (i.e., stability of long-span trusses)
- Temporary bracing / shoring design
- Staged construction considerations
- Design examples



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Learning Objectives

- Explain how the effect of shielding is addressed when calculating wind loads acting on unenclosed buildings during construction.
- Identify a design choice that may ensure truss chord stability during erection without temporary supports.
- Describe why the Occupational Safety and Health Administration (OSHA) requires four anchor bolts for a column, and how the demand on those anchor bolt during erection can greatly exceed OSHA requirements.
- Identify how the choice of moment connection detail can impact the erection of a steel frame.



Steel Erection: Engineering and Execution

Erection Engineering of Low-Rise Buildings

September 3, 2020



Benjamin Miller, PE, SE
Project Engineer
Ruby+Associates, Inc. Structural Engineers
Bingham Farms, MI



Three-Part Webinar Series

- The Erector's Perspective Aug. 27
- **Erection Engineering of Low-Rise Buildings** **Sept. 3**
- Erection Engineering of High-Rise Buildings Sept. 10

Presentation Outline

1. Introduction
2. Industry Codes, Standards, and Guides
3. Stability Analysis – Global and Local
4. Effects of Staged Construction
5. Connection Design's Affect on Stability
6. Summary



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What is a Low-Rise Building?

ASCE 7-10:

Enclosed or partially enclosed buildings that comply with the following conditions:

1. Mean roof height h less than or equal to 60ft.
2. Mean roof height h does not exceed least horizontal dimension



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What is Erection Engineering and Who Needs It?

Design of a system which maintains stability during each stage of construction of the *structural steel* frame.

Most directly, the Structural Steel Erector needs the services of an Erection Engineer.



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Why is Erection Engineering needed?

ODRD designs for stability and structural adequacy in the final, completed condition.

Erector is responsible for stability during each phase/sequence of construction.

Incomplete structures may not be stable without temporary measures during construction.



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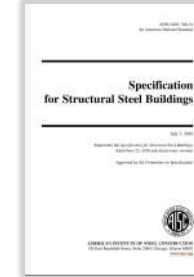
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Industry Codes, Standards, and Guides



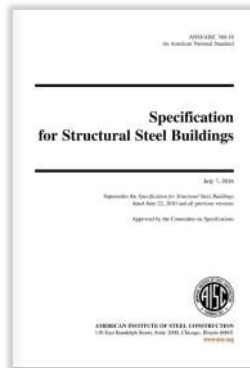
Section M4.2.
The frame of structural steel buildings shall be carried up true and plumb within the limits defined in Code of Standard Practice Chapter 7. As erection progresses, the structure shall be secured to support dead, erection and other loads anticipated to occur during the period of erection. Temporary bracing shall be provided, in accordance with the requirements of the Code of Standard Practice, wherever necessary to support the loads to which the structure may be subjected, including equipment and the operation of same. Such bracing shall be left in place as long as required for safety.

2205.1 General. The design, fabrication and erection of structural steel elements in buildings, structures and portions thereof shall be in accordance with AISC 360.



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Industry Codes, Standards, and Guides



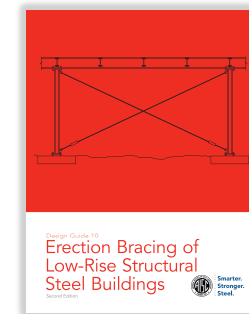
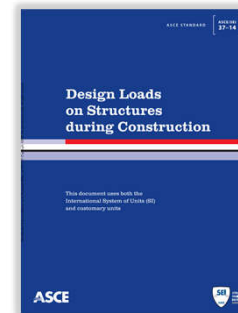
Section 7.10.3.
Based upon the information provided in accordance with Sections 7.10.1 and 7.10.2, the erector shall determine, furnish and install all temporary supports, such as temporary guys, beams, falsework, cribbing or other elements required for the erection operation. These temporary supports shall be sufficient to secure the bare structural steel framing or any portion thereof against load that are likely to be encountered during erection, including those due to wind and those that result from erection operations...

Section 7.10.4.
... Temporary supports provided by the erector shall remain in place until the portion of the structural steel frame that they brace is complete and the lateral force-resisting system and connecting diaphragm elements identified by the owner's designated representative for design in accordance with Section 7.10.1 are installed...



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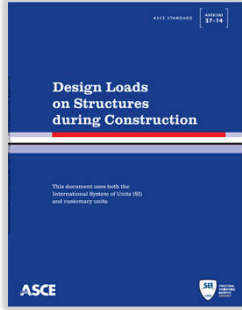
Industry Codes, Standards, and Guides



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ASCE 37 – Chapter 6



6.2 WIND

Except as modified herein, wind loads shall be calculated in accordance with procedures in ASCE/SEI 7-10.

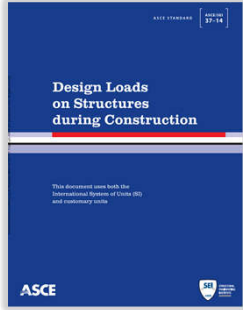
Design wind pressures shall be based on design wind speeds calculated in accordance with Section 6.2.1. The minimum wind pressure of 16 psf (0.77kN/m²) specified by ASCE/SEI 7-10 need not be applied.

6.2.1 Design Wind Speed The design wind speed shall be taken as the following factor times the basic wind speed in ASCE/SEI 7-10, except as required in Section 6.2.1.1.1.

Construction Period	Factor
Less than six weeks	0.75
From six weeks to one year	0.8
From one to two years	0.85
From two to five years	0.9

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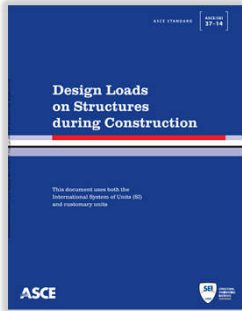
ASCE 37 – Chapter 6 Example



- Risk Category II structure in Detroit, MI
- ASCE 7-10 wind map → 115mph design wind speed
- Structure erected in 6weeks to 1 year time period → 0.8 factor
- Erection Period Design Wind = 0.8*115mph = 92mph
- 92mph is input in the velocity pressure equation given in ASCE 7.
- $q_z = 0.00256(K_z)(K_{zt})(K_d)(V^2)$
- If $K_{zt}=1.0$, $K_d=0.85$, Exposure B with $K_z = 0.85$
- $q_z = 15.7$ PSF
- How is this pressure applied to the structure?

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ASCE 37 – Chapter 6



6.2.2 Frameworks without Cladding Structures shall resist the effect of wind acting upon successive unenclosed components.

Treatment of staging, shoring, and falsework with a regular rectangular plan as trussed towers in accordance with ASCE/SEI 7-10 shall be permissible. Unless detailed analyses are performed to show that lower loads may be used, no allowance shall be given for shielding of successive rows or towers.

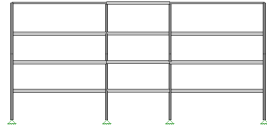
For unenclosed frames and structural elements, wind loads shall be calculated for each element. Unless detailed analyses are performed, load reductions due to shielding of elements in such structures, with repetitive patterns of elements shall be as follows:

1. The loads on the first three rows of elements along the direction parallel to the wind shall not be reduced for shielding.
2. The loads on the fourth and subsequent rows shall be permitted to be reduced by 15%.
3. Wind load allowances shall be calculated for all exposed interior partitions, walls, temporary enclosures, signs, construction materials, and equipment on or supported by the structure. These loads shall be added to the loads on structural elements.

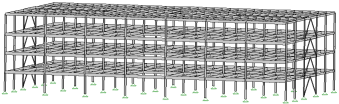
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ASCE 7 – Wind Loads on Other Structures

- 29.4: Design Wind Loads - ...Solid Signs?

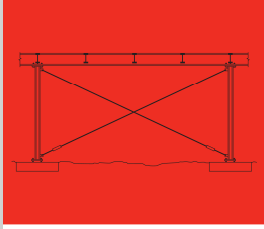


- 29.5: Design Wind Loads - ...Lattice Framework?




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AISC Design Guide 10 – Section 2.2.1



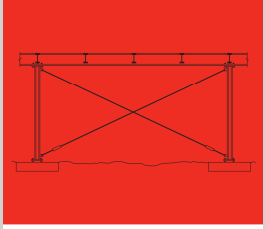
ASCE/SEI 7-10 does not specifically address main wind force-resisting system (MWFRS) wind loading on bare frame open structures. It does however address certain other structures in Chapter 29, such as solid freestanding walls and solid signs, other structures, rooftop structures and equipment, parapets, and roof overhangs. It is the judgment of the authors that the provisions for signs are the best analogous geometries to the surfaces of bare frame open structures. Thus, the appropriate equation for design wind force, F , on bare frame structures is ASCE/SEI 7-10, Equation 29.4-1:

$$F = q_h GC_p A_s \quad \text{(ASCE/SEI 7-10 Eq. 29.4-1)}$$




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AISC Design Guide 10 – Element Shielding



Shielding of multiple parallel elements can also be evaluated using the following equation taken from DIN 1055 *Actions on Structures—Part 4: Wind Loads* (DIN, 2005). See Figures 2-1 and 2-2. Note that the variables a , d , and l used in these figures are in consistent units. The total factored area, A , is determined using Equation 2-1:

$$A = [1 + \eta + (n-2)\eta^2] A_1 \quad (2-1)$$



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AISC Design Guide 10 – Element Shielding

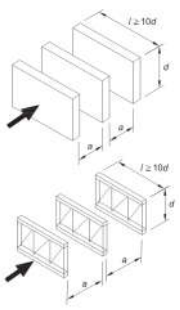


Fig. 2-1. Parameters for use with Fig. 2-2 (DIN, 2005).

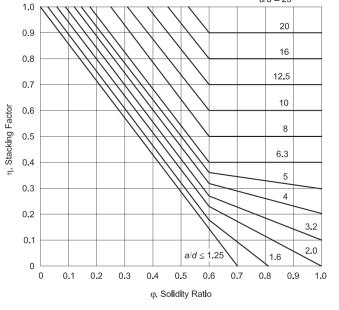

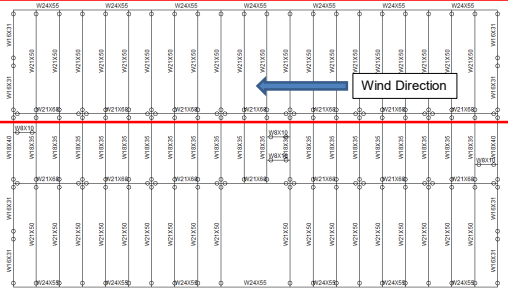


Fig. 2-2. Stacking factor versus solidity ratio (DIN, 2005).



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AISC Design Guide 10 – Element Shielding



ROOF - PLAN VIEW

- Apply DIN 1055 to infill members within the red box.
- Beam – W21x50
- Span – 45ft
- Spacing – 10ft
- Solidity Ratio, $\phi = 1.0$
- a/d ratio – $120''/20.8'' = 5.77$
- Number of elements, $n = 20$
- $A_1 = 45(20.8''(1'/12')) = 78\text{ft}^2$

- $\eta = 0.36 \rightarrow 0.4$ to be conservative
- $A = [1 + 0.4 + (20 - 2)(0.4)^2](78\text{ft}^2)$
 $= 333.8$
 $= 334\text{ft}^2$



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AISC Design Guide 10 – Element Shielding

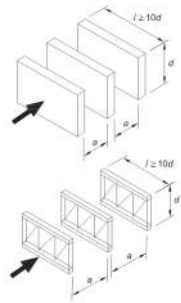


Fig. 2-1. Parameters for use with Fig. 2-2 (DIN, 2005).

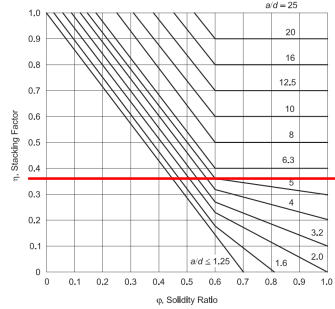


Fig. 2-2. Stacking factor versus solidity ratio (DIN, 2005).

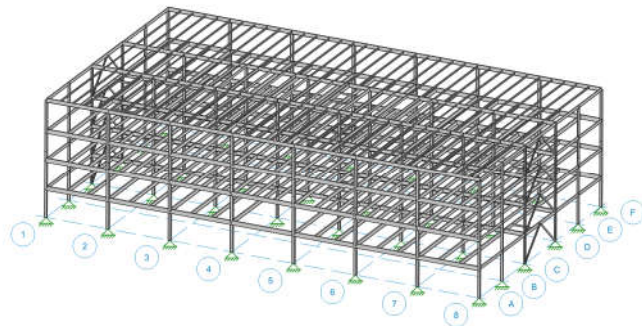


Presentation Outline

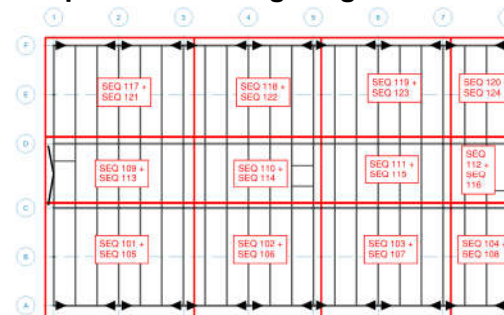
1. Introduction
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Stability Analysis – Global and Local



Sequence Blocking Diagram

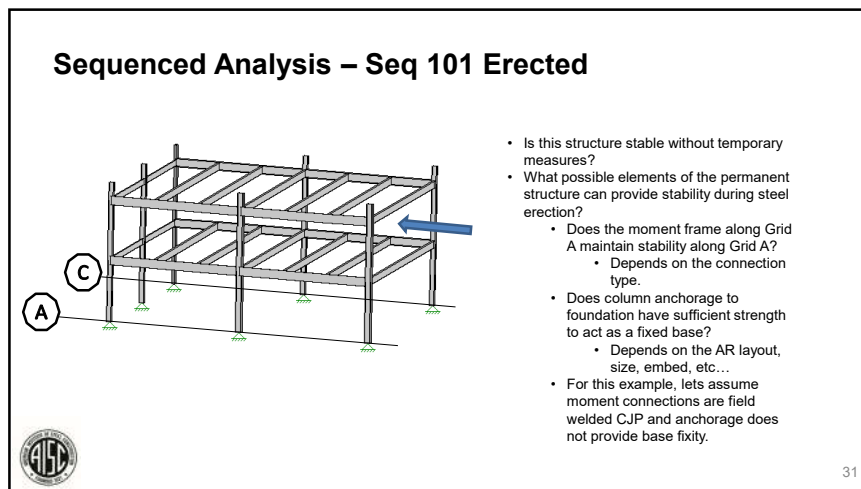
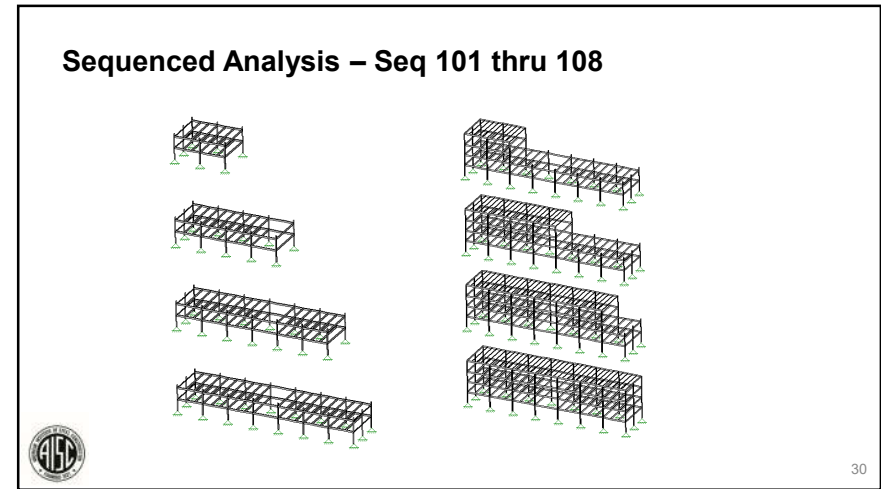
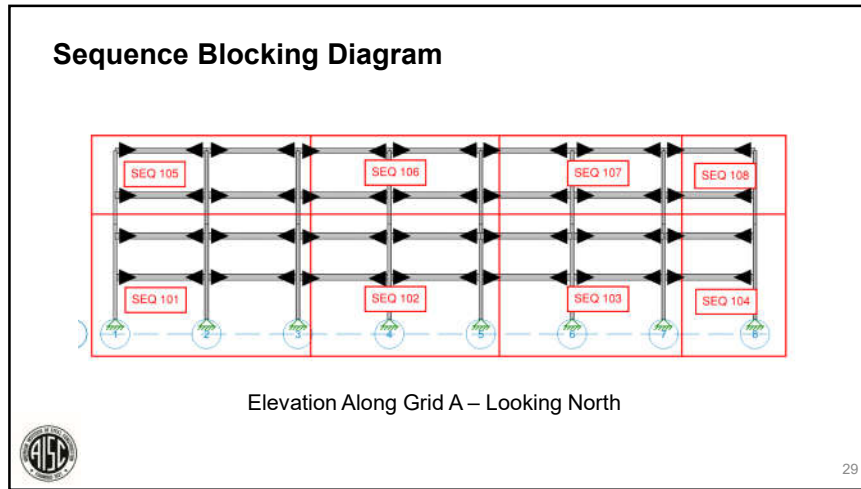


ROOF - PLAN VIEW



- Lateral Load Resisting System consists of concrete slab on metal deck diaphragms at floor levels spanning horizontally to vertical bracing at Grid 1 and Grid 8 and moment frames at Grid A and Grid F.
- At the roof level, the diaphragm consists of metal roof deck only spanning to the vertical bracing and moment frames.





ASCE 37 – Chapter 6 Example

- Risk Category II structure in Detroit, MI
- ASCE 7-10 wind map → 115mph design wind speed
- Structure erected in 6weeks to 1 year time period → 0.8 factor
- Erection Period Design Wind = $0.8 \times 115\text{mph} = 92\text{mph}$
- 92mph is input in the velocity pressure equation given in ASCE 7.
- $q_z = 0.00256(K_z)(K_{zt})(K_d)(V^2)$
- If $K_{zt}=1.0$, $K_d=0.85$, Exposure B with $K_z = 0.85$ (Height = 60ft)
- $q_z = 15.7 \text{ PSF}$

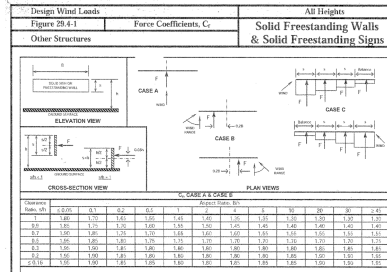
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ASCE 7-10: 29.4 – Solid Signs

- Design Force is given by equation 29.4-1
 $F = q_h(G)(C_f)(A_s)$
- $q_h = 15.7\text{psf}$
- $G = 0.85$
- $C_f = 1.9$
- $A_s = 172\text{ ft}^2$ (accounting for shielding per DG 10 methodology)
- $F = 4361\text{ lbs}$ @ each floor level due to easterly wind

The total design force on the columns ($A_c = 109\text{ ft}^2$) at each Grid line is $F = 2621\text{ lbs}$, due to easterly wind.

Base Shear on Grid A = 6982 → 7000 lbs



ASCE 7-10 Figure 29.4-1

ASCE 7-10: 29.5 – Lattice Frameworks

- Design Force is given by equation 29.4-1
 $F = q_z(G)(C_f)(A_f)$
- $q_z = 15.7\text{psf}$
- $G = 0.85$
- $C_f = 1.8$
- $A_f = 562\text{ ft}^2$

$F = 13,500\text{ lbs}$ total base shear

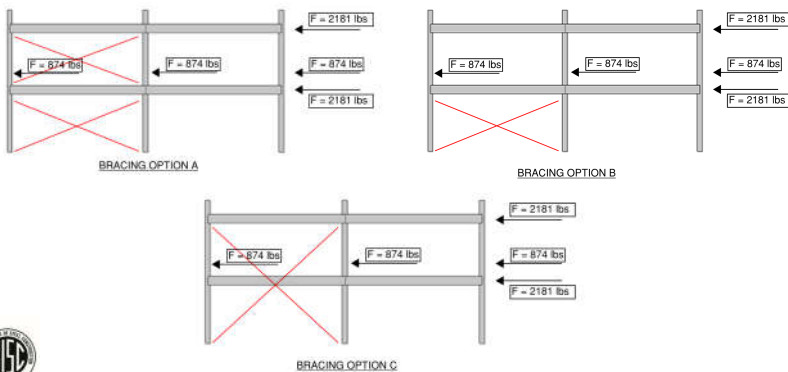
$F_{\text{grid}} = 6750\text{ lbs}$

Comparable design wind load between the two sections of ASCE 7.

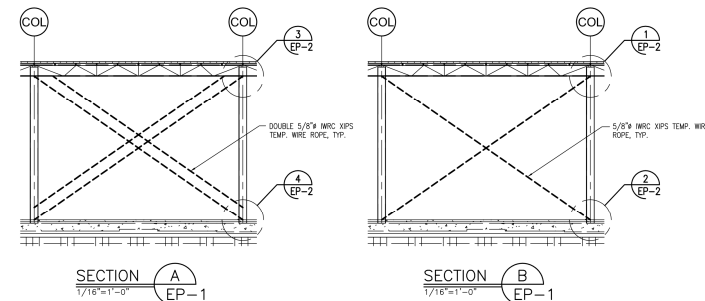
ϵ	Flat-Sided Members	Rounded Members	
		$D\sqrt{q_z} \leq 2.5$ ($D\sqrt{q_z} \leq 5.3$)	$D\sqrt{q_z} > 2.5$ ($D\sqrt{q_z} > 5.3$)
< 0.1	2.0	1.2	0.8
0.1 to 0.29	1.8	1.3	0.9
0.3 to 0.7	1.6	1.5	1.1

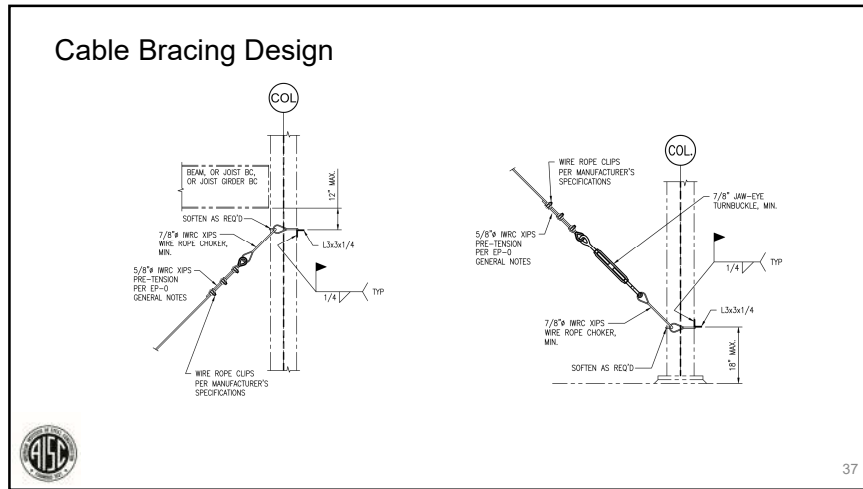
ASCE 7-10 Figure 29.5-2

Sequenced Analysis – Seq 101; Grid A Temp. Bracing



Cable Bracing Design





Example Project 2:

- 2-Story Industrial
- SOMD at Level 2
- Metal Roof Deck
- LLRS - Precast Shear Wall

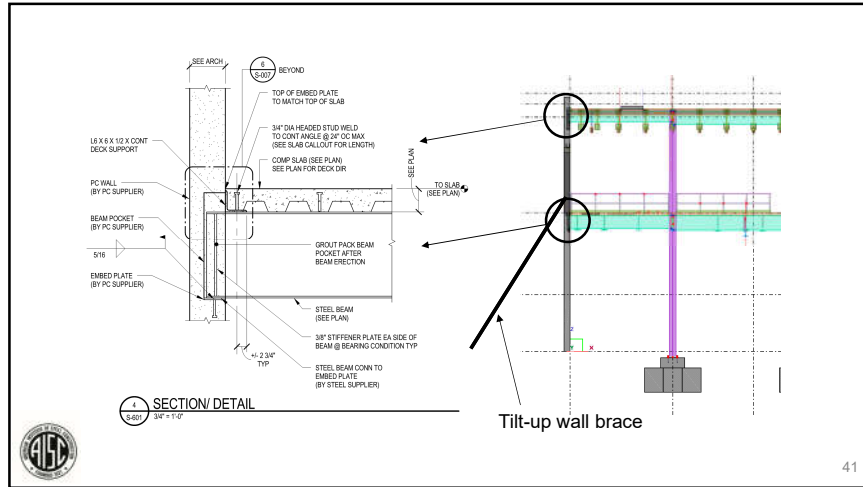
Two Erection Options:

1. Start erection of steel frame first then install precast panels.
2. Start erection of precast panels first then install steel frame.

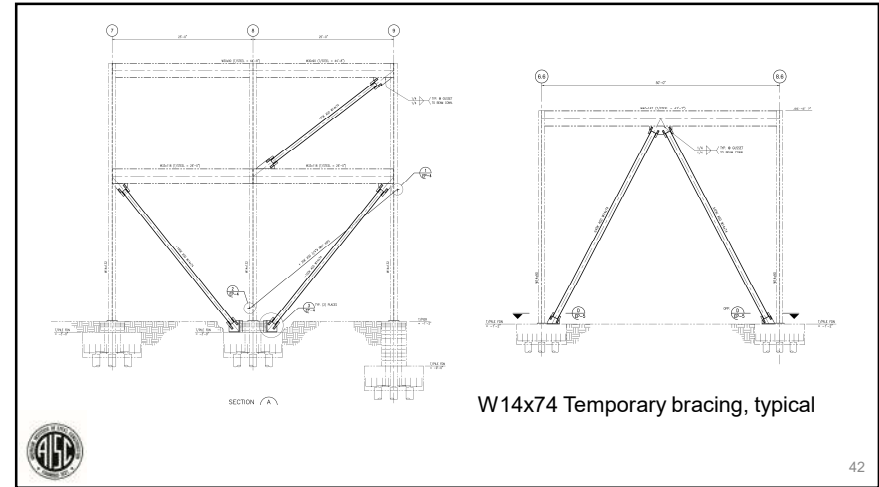
PCI: Architectural Precast Concrete Third Ed.

“After erection, each panel must be stable and offer resistance to wind, accidental impact, and loads that may be imposed due to other construction operations.”





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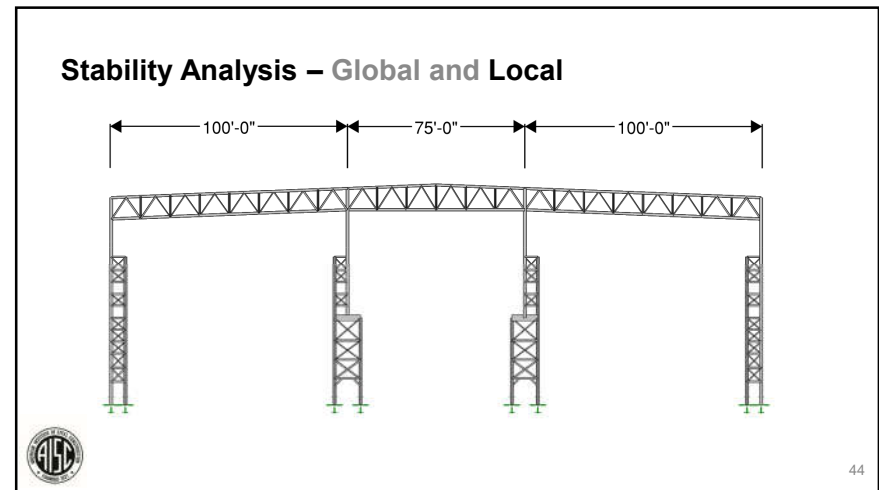


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Presentation Outline

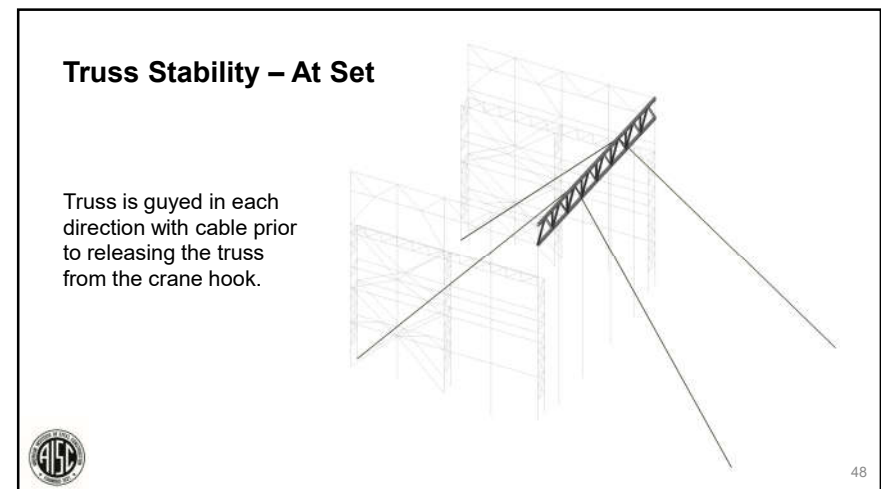
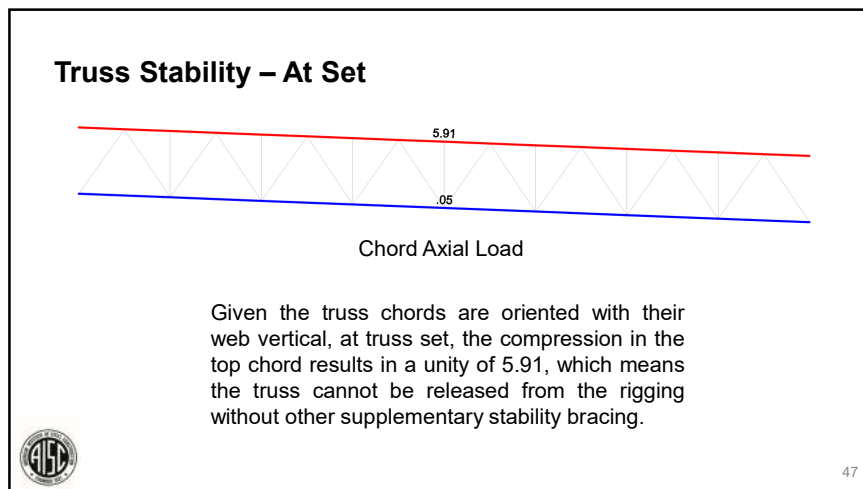
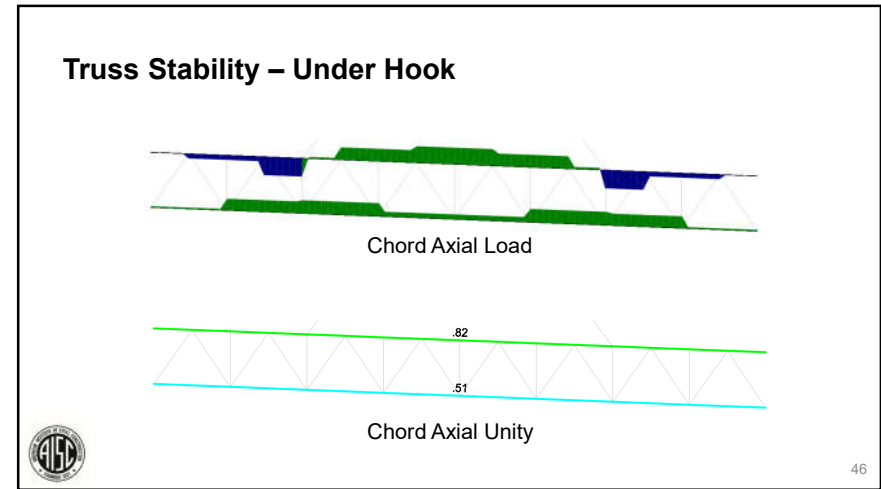
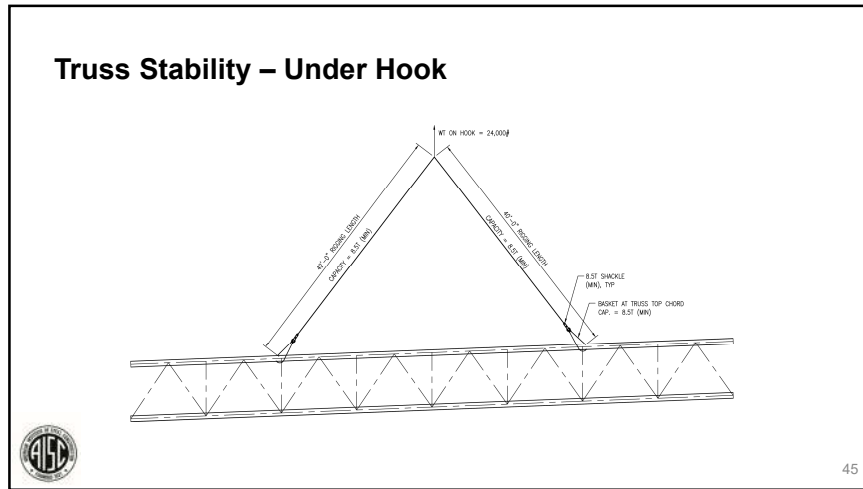
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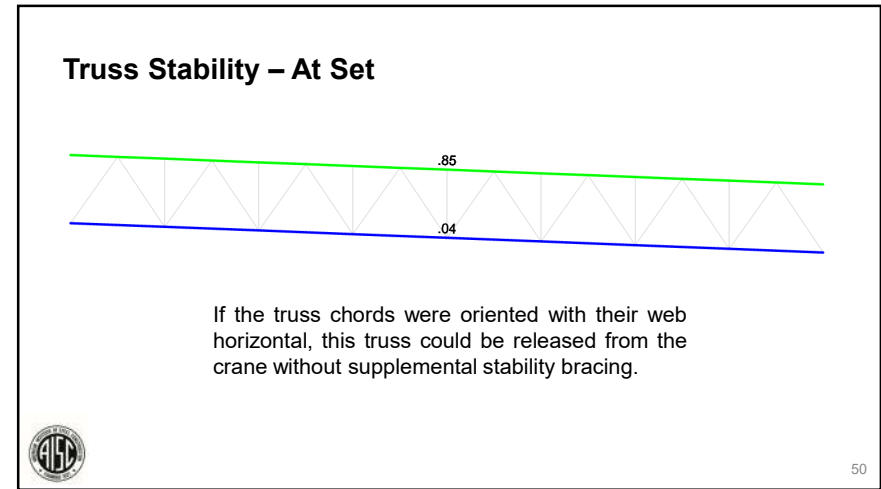
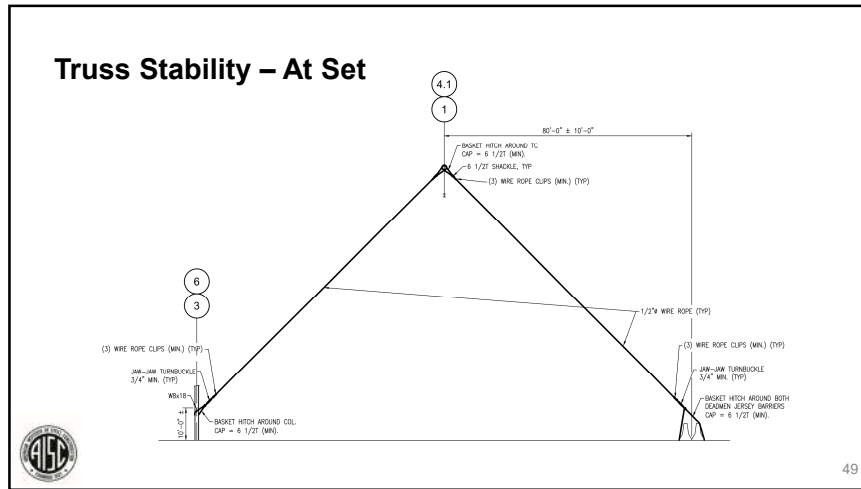
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Truss Stability – Comp. Chord Aspect Ratio

Rule of Thumb:

- $L/b < 80$: Stability of chord likely ok
- $80 \leq L/b < 100$: Design check of chord is necessary
- $100 \leq L/b$: Secondary bracing likely required

L = maximum dimension (inches) of:

- Distance between lifting points
- Length of cantilever portion of lift
- Distance between braced points
- Distance between points of support

b = width of compression flange (inches)

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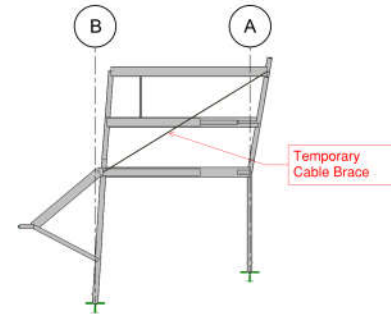


Nippert Stadium



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Nippert Stadium



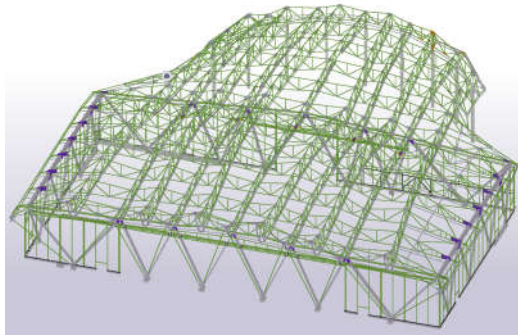
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	M _x (k-ft)	M _y (k-ft)	M _x (k-ft)	M _y (k-ft)
AS21B	3	-0.9	-2.9	-2.0
AS21C	36	0	-0.9	1.4
AS21E	4	-4	3.0	-2.0
AS21F	13	-4	-0.9	1.0
AS21G	32	-2	-22.9	-2.1
AS21H	14	2	10.0	1.4
AS21J	-17	3	-15.1	3.1
AS21K	16	2	-12.9	1.4
AS21L	-18	-2	-12.9	1.4
AS21M	23	3	20.0	2.1
AS21N	-11	5	7.8	3.4
AS21O	6	-2	-2.1	-2.1
AS21P	-6	-2	2.1	-2.1
AS21Q	-22	7	-25.0	5.0
AS21R	44	0	11.4	4.5
AS21S	4	4	2.8	2.8
AS21T	8	6	6.4	3.6
AS21U	-15	10	-13.7	6.1
AS21V	2	0	6.4	6.1

Location	1-2021		1-2021	
	M _x (k-ft)	M _y (k-ft)	M _x (k-ft)	M _y (k-ft)
BS21A	7	-1	-2.9	-2.0
BS21B	27	-8	-19.3	-2.6
BS21C	-4	4	3.0	-2.0
BS21D	13	-4	-0.9	1.0
BS21E	32	3	-22.9	-2.1
BS21F	14	2	10.0	1.4
BS21G	-17	4	-15.1	3.1
BS21H	16	2	-12.9	1.4
BS21I	-18	-2	-12.9	1.4
BS21J	23	3	20.0	2.1
BS21K	-11	5	7.8	3.4
BS21L	6	-2	-2.1	-2.1
BS21M	-6	-2	2.1	-2.1
BS21N	-22	7	-25.0	5.0
BS21O	44	0	11.4	4.5
BS21P	4	4	2.8	2.8
BS21Q	8	6	6.4	3.6
BS21R	-15	10	-13.7	6.1
BS21S	2	0	6.4	6.1



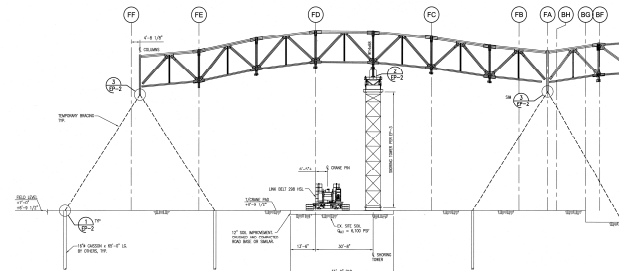
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Flex Field Truss Shoring



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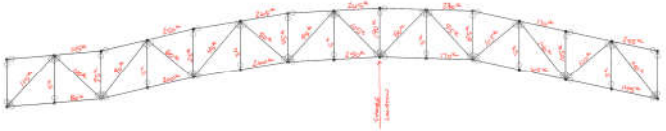
Flex Field Truss Shoring



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Flex Field Truss Shoring



LONGITUDINAL RIDGE TRUSS STEEL SIZES		
ELEMENT	NORTH	SOUTH
TOP CHORD	W14x88 - W14x99	W14x88 - W14x90
BOTTOM CHORD	W14x88 - W14x90	W14x90
DIAGONAL	W12x65 - W12x79	W12x65 - W12x79
VERTICAL	W12x26 - W14x68	W12x26 - W14x68


FOR AN ENVELOPE ONLY. REFER TO THE DIGITAL FABRICATION MODEL FOR EXACT SIZE AND LOCATIONS. ALL MEMBER SIZES ARE SUBJECT TO FURTHER REFINEMENT PRIOR TO ISSUANCE OF CONSTRUCTION DOCUMENTS.



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Presentation Outline

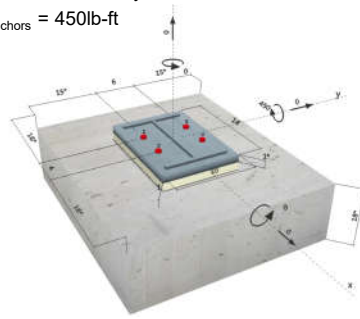


1. Introduction
2. Industry Codes and Standards
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Column Anchorage

OSHA - (4) Anchor rods per column for 300lb load 18" away from centerline.
 $M_{anchors} = 450lb-ft$

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OSHA

2 Load case/Resulting anchor forces

Load case: Design loads

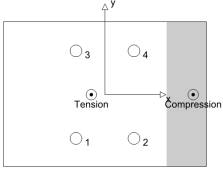

Anchor	Tension force	Shear force	Shear force x	Shear force y
1	283	0	0	0
2	102	0	0	0
3	283	0	0	0
4	102	0	0	0

max. concrete compressive strain: 0.01 [%]
 max. concrete compressive stress: 56 [psi]
 resulting tension force in (x,y)=(0.941/0.000): 769 [lb]
 resulting compression force in (x,y)=(0.063/0.000): 769 [lb]

Anchor forces based on a rigid base plate assumption!

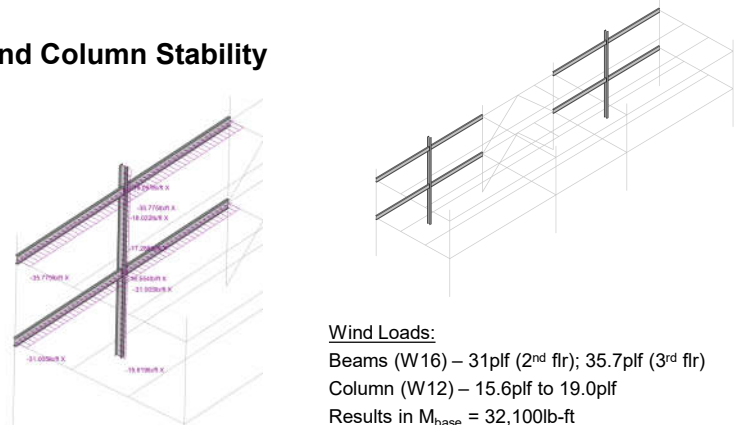
3 Tension load

	Load N_u [lb]	Capacity ϕN_n [lb]	Utilization $\beta_u = N_u / \phi N_n$	Status
Steel Strength*	283	14,529	2	OK
Pullout Strength*	283	15,305	2	OK
Concrete Breakout Strength**	769	37,598	3	OK
Concrete Side-Face Blowout, direction **	N/A	N/A	N/A	N/A

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Wind Column Stability



Wind Loads:
Beams (W16) – 31plf (2nd flr); 35.7plf (3rd flr)
Column (W12) – 15.6plf to 19.0plf
Results in $M_{base} = 32,100\text{lb-ft}$

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Wind Column Stability

2 Load case/Resulting anchor forces
Load case: Design loads

Anchor reactions [lb]
Tension force: (+Tension, -Compression)

Anchor	Tension force	Shear force	Shear force x	Shear force y
1	20,163	0	0	0
2	7,256	0	0	0
3	20,163	0	0	0
4	7,256	0	0	0

max. concrete compressive strain: 0.92 [%]
max. concrete compressive stress: 3,987 [psi]
resulting tension force in (x/y)=(-0.941/0.000): 54,838 [lb]
resulting compression force in (x/y)=(6.083/0.000): 54,838 [lb]

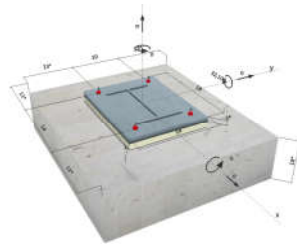
Anchor forces based on a rigid base plate assumption!

3 Tension load

	Load N_{ax} [lb]	Capacity ϕN_c [lb]	Utilization $\beta_{ax} = N_{ax}/\phi N_c$	Status
Steel Strength*	20,163	14,529	139	not recommended
Pullout Strength*	20,163	15,305	132	not recommended
Concrete Breakout Strength**	54,838	37,598	146	not recommended
Concrete Side-Face Blowout, direction **	N/A	N/A	N/A	N/A

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Preferred Anchorage Detail



2 Load case/Resulting anchor forces
Load case: Design loads

Anchor reactions [lb]
Tension force: (+Tension, -Compression)

Anchor	Tension force	Shear force	Shear force x	Shear force y
1	12,808	0	0	0
2	0	0	0	0
3	12,808	0	0	0
4	0	0	0	0

max. concrete compressive strain: 0.29 [%]
max. concrete compressive stress: 1,267 [psi]
resulting tension force in (x/y)=(7.000/0.000): 25,616 [lb]
resulting compression force in (x/y)=(8.037/0.000): 25,616 [lb]

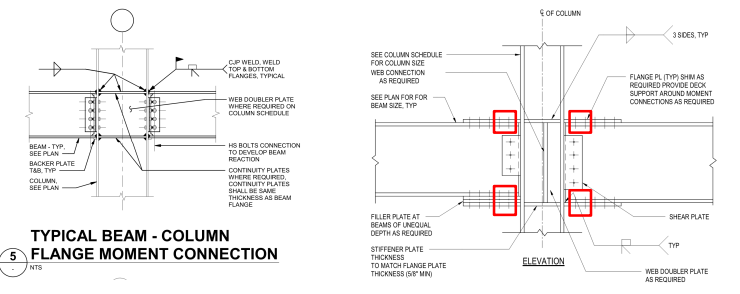
Anchor forces based on a rigid base plate assumption!

3 Tension load

	Load N_{ax} [lb]	Capacity ϕN_c [lb]	Utilization $\beta_{ax} = N_{ax}/\phi N_c$	Status
Steel Strength*	12,808	14,529	89	OK
Pullout Strength*	12,808	15,305	84	OK
Concrete Breakout Strength**	25,616	28,622	90	OK
Concrete Side-Face Blowout, direction **	N/A	N/A	N/A	N/A

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5. Connection Design's Affect on Stability



TYPICAL BEAM - COLUMN FLANGE MOMENT CONNECTION

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5. Connection Design's Affect on Stability

SECTION A
TYP. MOMENT CONNECTION
SCALE: N.T.S.

Figure 11-2 illustrates the column flange deformation and shows that only the fasteners closest to the column web are fully effective in transferring forces.

Fig. 11-2. Illustration of deformations in partially restrained moment connections.

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5. Connection Design's Affect on Stability

TYPICAL FMC MOMENT CONNECTION DETAIL
SCALE: 1"=1'-0"

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5. Connection Design's Affect on Stability

TYPICAL STEEL BRACED FRAME COLUMN BASE ELEVATION (TYPE C1)
SCALE: NOT TO SCALE

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5. Connection Design's Affect on Stability

EXAMPLE:

ALLOWABLE $P_{ALLOW} = 750^k$

$HSS\ 8 \times 8 \times 5/16"$

SHEAR CAPACITY:

$$A_{gave} = \frac{\pi (0.75)^2}{4} = 0.442 \text{ in}^2 \quad \phi = 2$$

$$R_n = A_{gave} (F_u) = 0.442 \text{ in}^2 (58 \text{ ksi}) = 11.5 \text{ k} \quad \frac{R_n}{\phi} = 5.75 \text{ k}/\text{IN}$$

BENDING CAPACITY: $\phi = 1.67$

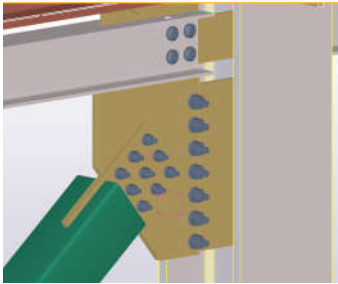
$$M_n = F_y (Z) \leq 1.6 M_y = (36 \text{ ksi}) (0.75^3) \leq 1.6 (36 \text{ ksi}) (\pi) (0.75^3) / 32$$

$$M_n = \frac{P L}{4} \quad 2.53 \text{ k} \cdot \text{in} \leq 2.39 \text{ k} \cdot \text{in}$$

$$M_n \leq \frac{M_y}{\phi} \quad \frac{P (2 \times 3.825^2)}{4} = \frac{2.39 \text{ k} \cdot \text{in}}{1.67} \quad P = 0.75 \text{ k} = 750^k$$

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5. Connection Design's Affect on Stability



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Presentation Outline

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Summary:

- Design codes do not reference standards for stability design during erection.
 - Erection Engineering involves a significant level of judgement in design.
- ASCE 37 and AISC DG 10 provide guidance for stability design during steel erection.
- Stability is not only a global consideration; stability must be reviewed on a local basis as well.
- Connection design plays an important role in stability of partially erected structures.

AISC | Questions?



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



Single-Session Registrants

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3-Session Registrants

CEU / PDH Certificates

One certificate will be issued at the conclusion of the course.



3-Session Registrants

Attendance and PDH Certificates

- You have two options to receive credit for each session.
 - Option 1: Watch the live session.
 - Option 2: Watch the recording and pass the associated quiz.

Videos and Quizzes

- For each session, find access within two business days after the live air date. (An email will be sent from webinars@aisc.org.)
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- Only the registrant will receive a certificate for the course.



3-Session Registrants

Course Resources

Access to video recordings and quizzes can be found on your AISC account.



3-Session Registrants

Course Resources

Go to www.aisc.org and sign in.

3-Session Registrants

Course Resources

Go to www.aisc.org and sign in.

3-Session Registrants

Course Resources

Event	Start Date
Seminar: Design in Steel	1/17/2002 12:00:00 AM
4-Session Package: Design of Facade Attachments	5/6/2019 1:00:00 PM
101.13 4-Session Package: Night School 13 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
101.16 4-Session Package: Night School 16 - Seminar: Design in Steel	2/5/2018 7:00:00 PM
101.17 4-Session Package: Night School 17 - Design of Facade Attachments	7/10/2018 7:00:00 PM
101.18 4-Session Package: Night School 18 - Steel Construction: Mill To Tensioning Out	10/15/2018 7:00:00 PM
101.20 4-Session Package: Night School 20 - Connection Design	2/6/2019 7:00:00 PM
101.20 4-Session Package: Night School 20 - Connection Design: Fundamentals of Structural Analysis	6/20/2019 7:00:00 PM
4-Session Package: Seminar: Design in Steel - Concrete & Examples	7/16/2018 1:00:00 PM

3-Session Registrants

Course Resources

Event	Date	Handouts	Videos	Quiz	Attendance
01: Facade Fundamentals	N/A	Download	Video	Pass Score: 100	N/A
1.1 Facade Attachments Part 1	May 9 2019 1:00PM EDT	Download	Available 05/11/2019 5:00PM EDT	Available 05/11/2019 5:00 PM EDT	Pending
1.2 Facade Attachments Part 2	May 18 2019 1:00PM EDT	Download	Available 05/18/2019 5:00PM EDT	Available 05/18/2019 5:00 PM EDT	Pending
1.3 Facade Attachments - Building Laterals Drafts	May 23 2019 1:00PM EDT	Download	Available 05/25/2019 5:00PM EDT	Available 05/25/2019 5:00 PM EDT	Pending
Final Exam	N/A			Available 5/27/2019 5:00 PM EDT	

