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Steel Construction | From the Mill to Topping Out



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Session Description

18.6 Erection Engineering – Stability During Construction November 26, 2018

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. Topics include:

- 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



Learning Objectives

- List why erection engineering is needed on a steel project.
- Identify where in the AISC Code of Standard Practice addresses support of a structure during construction.
- List factors that must be considered and known in order to perform an accurate erection stability analysis.
- Describe how a connection design can affect steel framing stability during erection.

Night School 18: Steel Construction

From the Mill to Topping Out

Session 6: Erection Engineering – Stability During Construction November 26, 2018



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



Night School 18

- 18.1 Introduction to the Steel Construction Process Oct. 15
- 18.2 The Manufacturing of Structural Steel Shapes Oct. 22
- 18.3 A Virtual, Detailed Tour of the Steel Fabrication Process Oct. 29
- 18.4 Connection Design as the Fabricator's Representative Nov. 5
- 18.5 It Doesn't Get Built Without the Erector Nov. 19
- **18.6 Erection Engineering – Stability During Construction Nov. 26**
- 18.7 Field Fixes and Solutions Dec. 3
- 18.8 Quality Control and Quality Assurance Dec. 10



Presentation Outline

1. Introduction
2. Industry Codes and Standards
3. Stability Analysis
4. Effects of Staged Construction
5. Connection Design's affect on stability
6. Miscellaneous EP Topics
7. Questions?



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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.

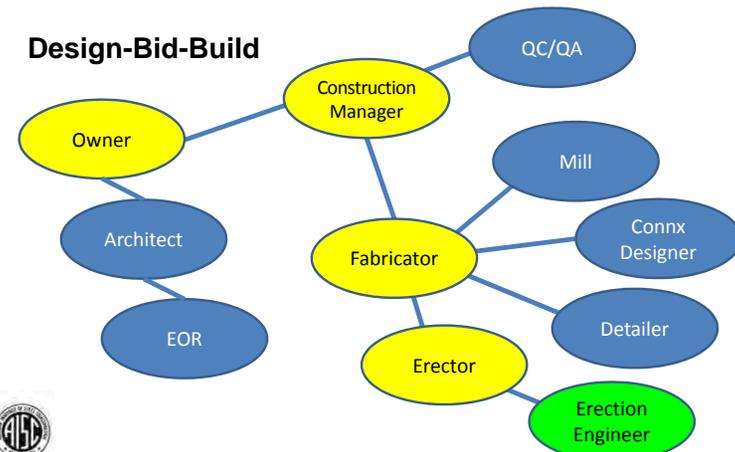
Most directly, the Erector needs the services of an Engineer.

Sometimes, GC procures the Erection Engineer services – for consistency of bids.

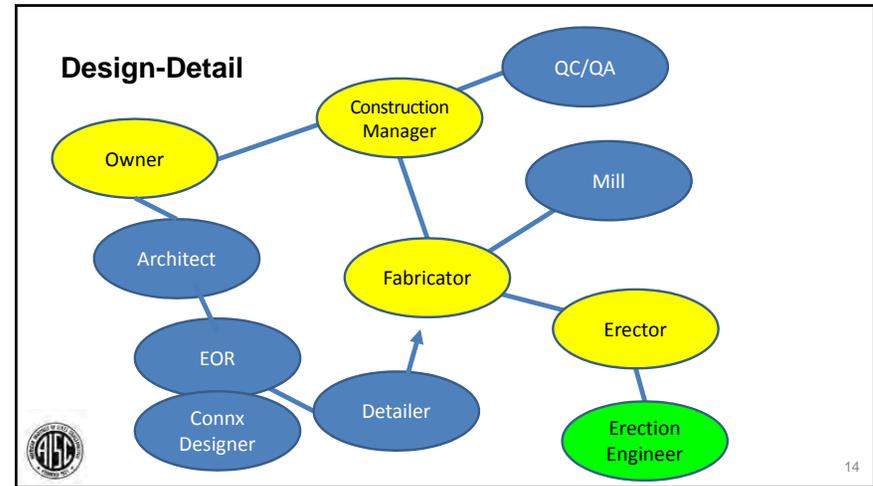
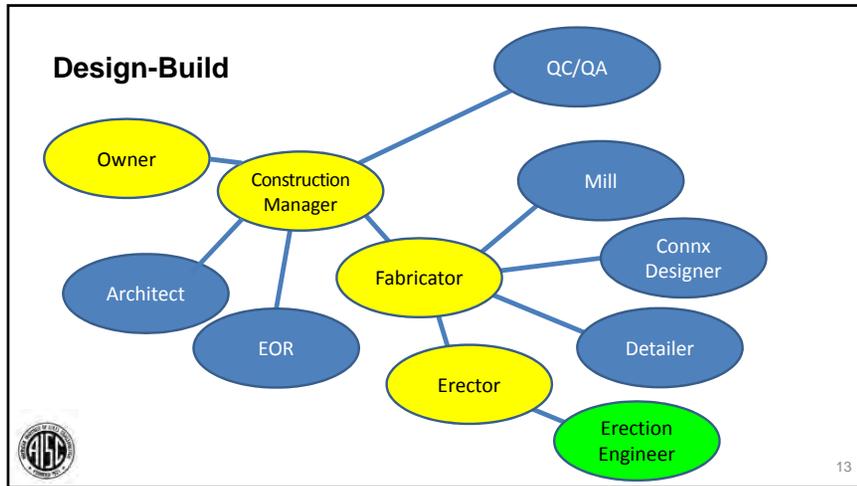


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Design-Bid-Build



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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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Presentation Outline

1. Introduction
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7. Questions?

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Industry Codes and Standards

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Code of Standard Practice

7.10 Temporary Support of Structural Steel Frames

7.10.1. The owner's designated representative for design shall identify the following in the contract documents:

- The lateral force-resisting system and connecting diaphragm elements that provide for the lateral strength and stability in the completed structure.
- Any special erection conditions or other considerations that are required by the design concept, such as the use of shores, jacks or loads that must be adjusted as erection progresses to set or maintain camber, position within specified tolerances or prestress.

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Code of Standard Practice

AISC-303: 7.10.1(a) - Example

All lateral load resistance and stability of the building in the completed structure is provided by moment frames with welded beam to column connections framed in each orthogonal direction (see plan sheets for locations). The composite metal deck and concrete floors serve as horizontal diaphragms that distribute the lateral wind and seismic forces horizontally to the vertical moment frames; the girders inline with the moment frames act as drag struts and deliver the diaphragm shear to the moment frames. The vertical moment frames carry the applied lateral loads to the building foundation; column anchorages have been designed as pinned/fixe.

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Code of Standard Practice

AISC-303: 3.1.2

When option (2) or (3) above is specified, the ODRD shall provide the following information in the structural design drawings and specifications:

- Data concerning loads, including shears, moments, axial forces and transfer forces, that are to be resisted by the individual members and their connections...

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AISC-303: 3.1.2 - Example

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Code of Standard Practice

AISC-303: 7.10.1(a) – Example 2
All lateral load resistance and stability of the building in the completed structure is provided exclusively by precast concrete shear walls at the building perimeter (see plan sheets for locations).

Stability of structural steel is provided by non-structural steel.

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Code of Standard Practice

AISC-303: 7.10.2
 The owner's designated representative for construction shall indicate to the erector prior to bidding, the installation schedule for non-structural steel elements of the lateral-load-resisting system and connecting diaphragm elements identified by the owner's designated representative for design in the contract documents.

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Code of Standard Practice

AISC-303: 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....

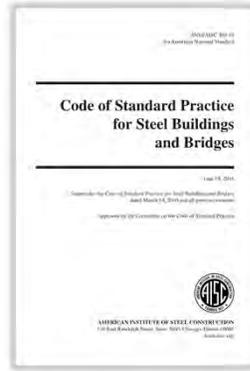
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AISC 303: 2.2

Non-Structural Steel Elements

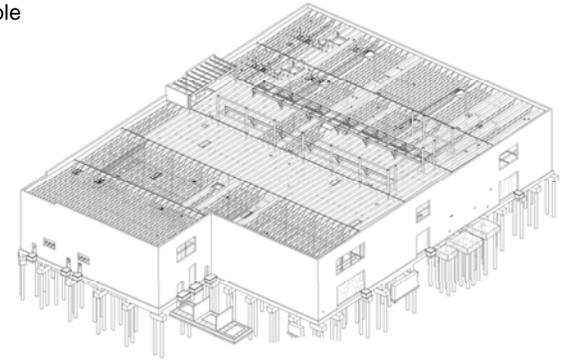
- Masonry Shear Walls
- Concrete Shear Walls
 - Standard Reinforced Construction
 - Precast Construction
- Steel Open-Web Joists
- Steel Joist Girders
- Steel Deck
- Concrete Floor Diaphragms
- Cold-formed steel



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AISC-303: 7.10.1 - Example

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



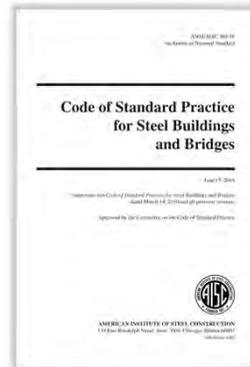
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Code of Standard Practice

AISC-303: 7.10.1

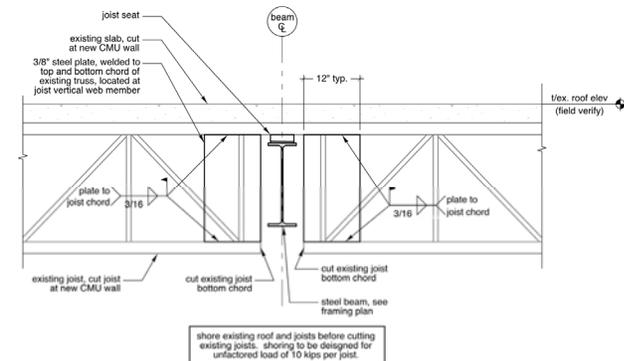
The owner's designated representative for design shall identify the following in the contract documents:

- a) The lateral force-resisting system and connecting diaphragm elements that provide for the lateral strength and stability in the completed structure.
- b) Any special erection conditions or other considerations that are required by the design concept, such as the use of shores, jacks or loads that must be adjusted as erection progresses to set or maintain camber, position within specified tolerances or prestress.



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AISC-303: 7.10.1(b) - Example



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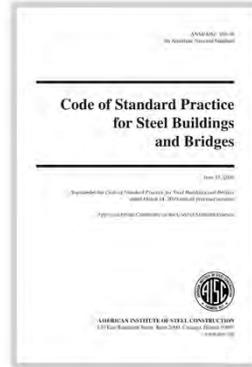


Code of Standard Practice

AISC-303: 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 loads that are likely to be encountered during erection, including those due to **wind** and those that result from erection operations.

The erector need not consider loads during erection that result from the performance of work by, or the acts of, others, except as specifically identified by the owner's designated representatives for design and construction, **nor those that are unpredictable, such as loads due to hurricane, tornado, earthquake, explosion or collision.**



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Project Specification

3.02 PREPARATION

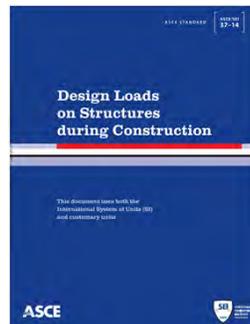
- A. Temporary Shoring and Bracing:
1. The lateral-load resisting or stability-providing system and connecting diaphragms are identified on the drawings. Comply with the provisions of the Code of Standard Practice regarding stability of the structure during the erection process, except where stricter requirements are noted herein.
 2. The Erector shall design and provide all required temporary shoring and bracing to hold structural framing securely in position and **to safely withstand all loads as specified in the Code of Standard Practice and ASCE 37.**



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ASCE 37-14

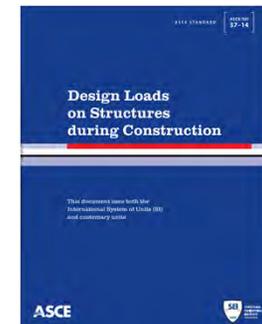
6.2.1.1.1 Construction Period in Hurricane-Prone Areas
For construction between November 1 and June 30 (outside of the hurricane season), the basic wind speed of 115 mph (51 m/s) shall be permitted for structures sited near the Gulf Coast and Eastern Seaboard, where the ASCE/SEI 7-10 specified basic wind speed exceeds 115 mph (51 m/s) (3 second gust) (hurricane-prone areas). The 115 mph (51 m/s) wind speed is permitted to be reduced by the factors in Section 6.2.1 only for a construction period between November 1 and June 30.



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ASCE 37-14

Between July 1 and October 31, basic wind speed of 115 mph (51 m/s) shall be permitted for structures sited near the Gulf Coast and Eastern Seaboard, where the ASCE/SEI 7-10 specified basic wind speed exceeds 115 mph (51 m/s) (3 second gust) provided additional bracing is prepared in advance and applied in time before the onset of an announced hurricane. The 115 mph (51 m/s) wind speed shall not be reduced by the factors in Section 6.2.1 for the construction period. The bracing shall be designed for the full, unmodified wind load determined using the mapped wind speed and procedures found in ASCE/SEI 7-10.



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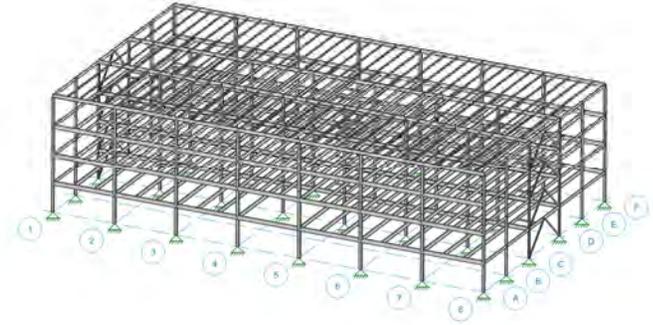
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1. Introduction
2. Industry Codes and Standards
3. **Stability Analysis**
4. Effects of Staged Construction
5. Connection Design's affect on stability
6. Miscellaneous EP Topics
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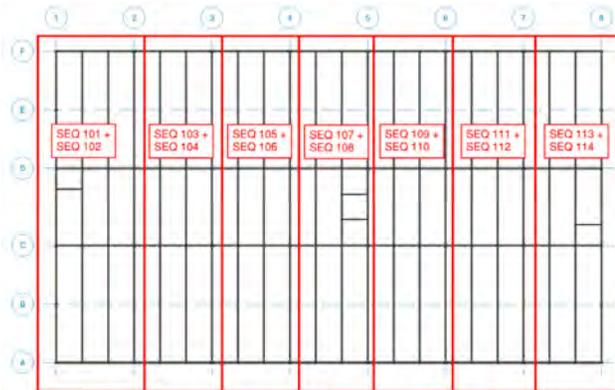
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Stability Analysis



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Sequence Blocking Diagram



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Sequence Blocking Diagram



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Sequenced Analysis

The diagrams illustrate the step-by-step construction of a steel frame. It starts with individual columns, then shows the addition of beams to form a single-story frame, followed by the addition of more stories, and finally the complete multi-story frame structure.

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ASCE 37-14: Wind Loading

6.1 RISK CATEGORY

Unless otherwise required by the authority having jurisdiction, the risk category, as defined in ASCE/SEI 7-10, shall be taken as Risk Category II for all environmental loads during construction, regardless of the risk category assigned for the design of the completed structure.

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 16psf (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 37-14

ASCE 7-10: 27.3.2
 $q_z = (0.00256)(K_z)(K_{zt})(K_d)(V)^2$

$V = 115\text{mph (LRFD)} / 90\text{mph (ASD)}$

$V_{\text{const}} = 0.75 * 115\text{mph} = 86\text{mph} / 0.75 * 90\text{mph} = 68\text{mph}$

Base Wind Pressure during Construction:
 $(0.75)^2 = 0.5625 \rightarrow 56.25\%$ of design pressure

6.2.2 Frameworks without Cladding

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:

- The loads on the first three rows of elements along the direction parallel to the wind shall not be reduced for shielding.
- The loads on the fourth and subsequent rows shall be permitted to be reduced by 15%.

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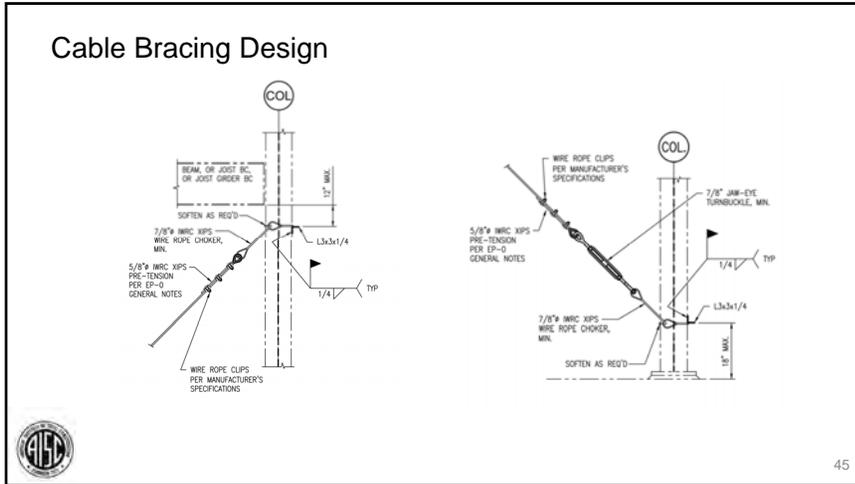
ASCE 7-10

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

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Example Project 2:

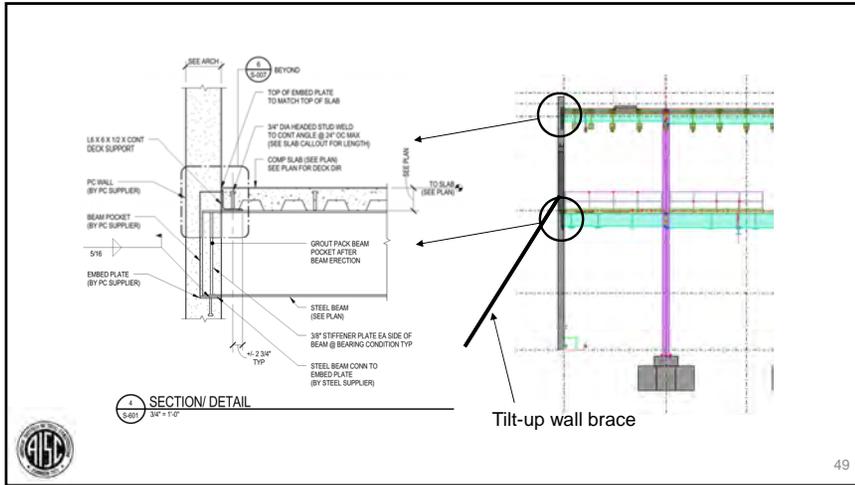
- 2-Story Industrial
- SOMD at Level 2
- Metal Roof Deck
- BF at Grid G
 - Only below Level 2
- Precast Shear Wall

Two Erection Options:

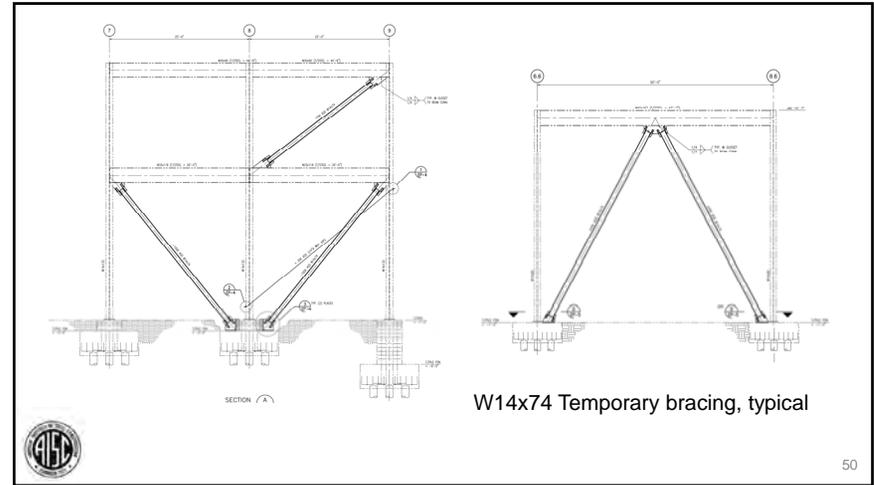
1. Start erection of steel frame first then install precast panels.
2. Start erection of precast panels first then install steel frame.

PCI: Architectural Precast Concrete Third Ed.

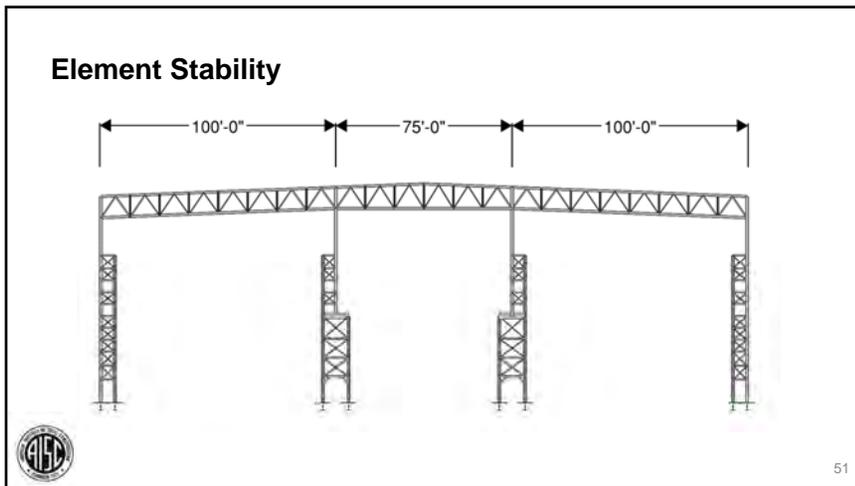
“After erection, each panel must be stable and offer resistance to wind, accidental impact, and loads that may be imposed due to other construction operations.”



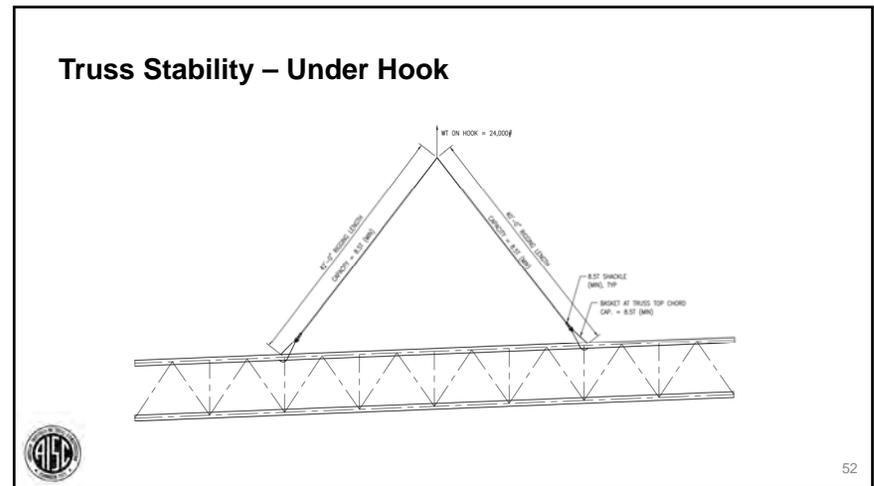
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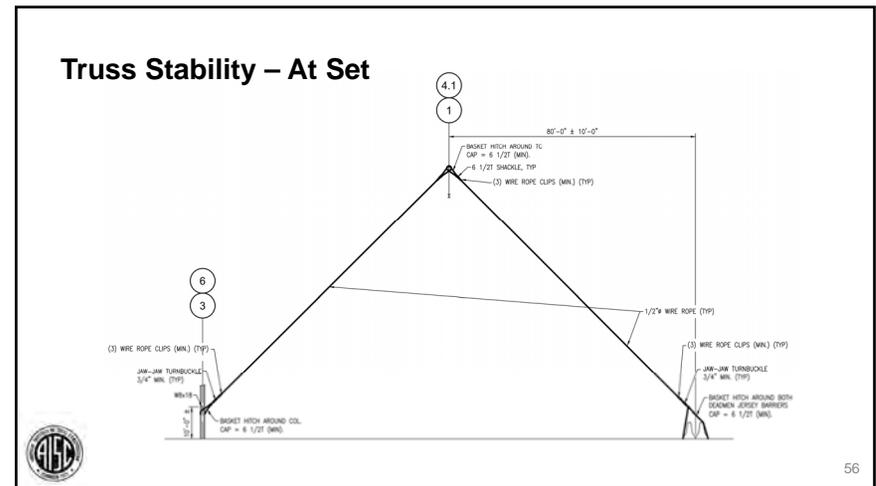
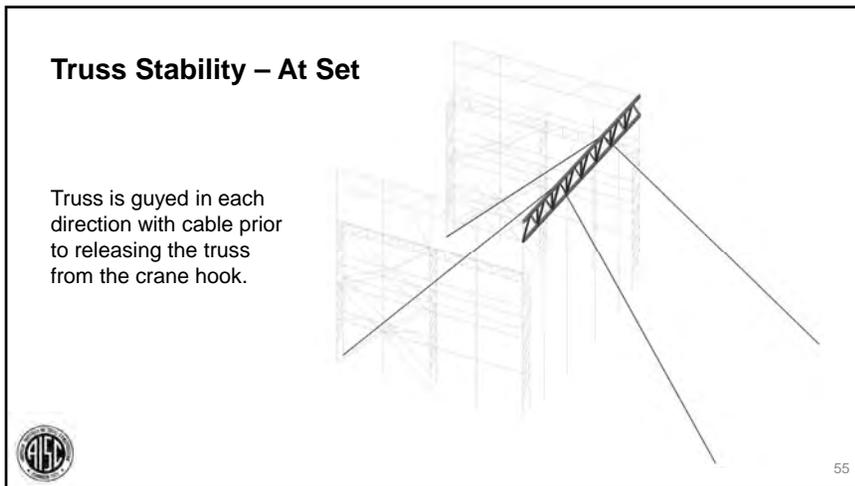
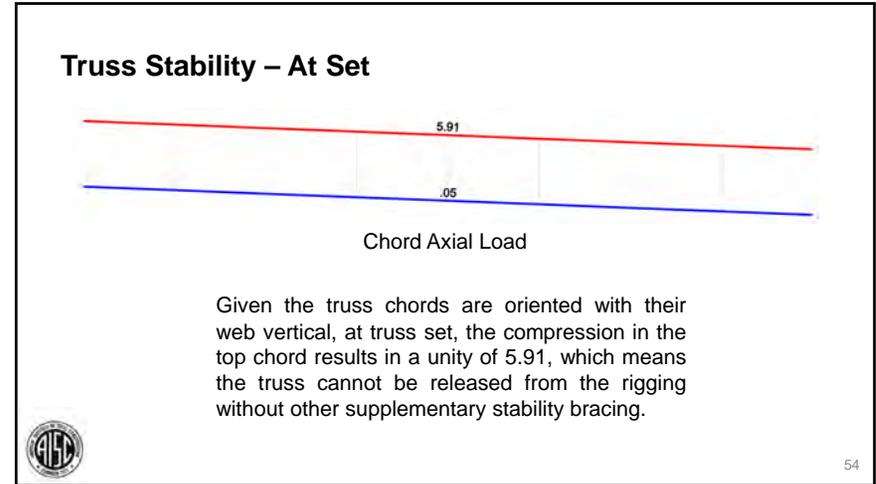
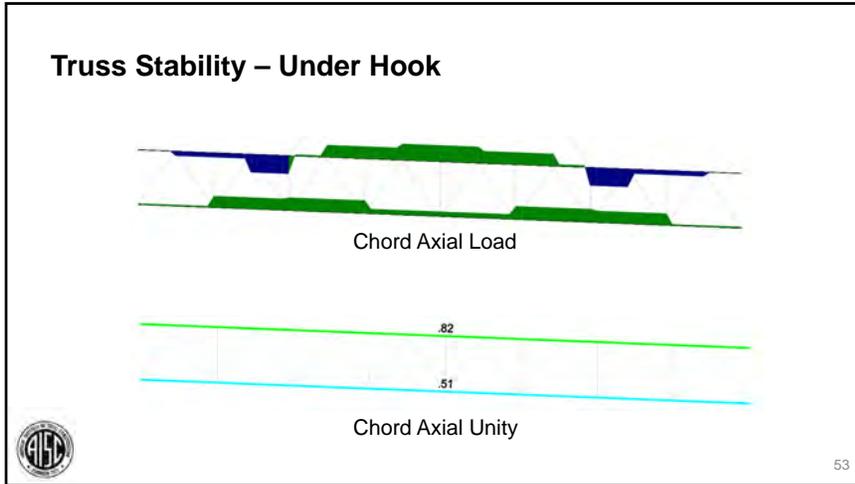


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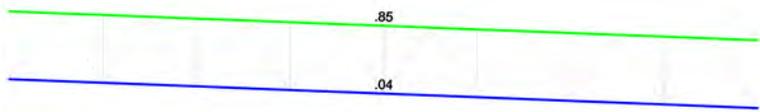


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Truss Stability – At Set



If the truss chords were oriented with their web horizontal, this truss could be released from the crane without supplemental stability bracing.



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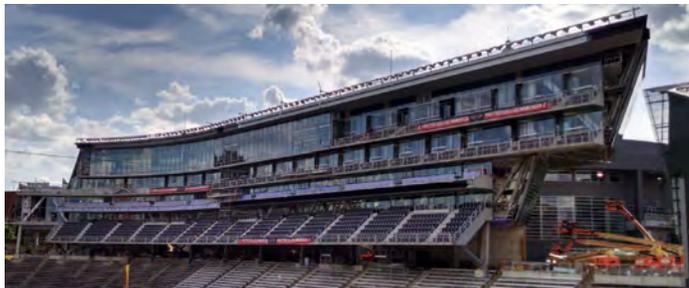
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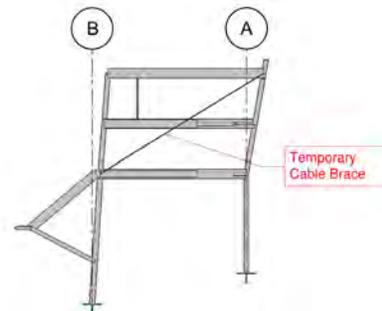
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Nippert Stadium



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Nippert Stadium



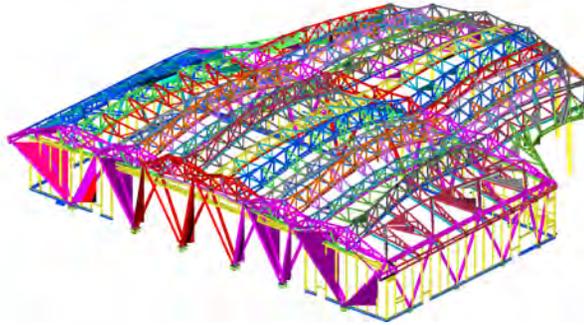
Component	E-FRAC		F-FRAC	
	Moment (k-ft)	Max. (k-ft)	Moment (k-ft)	Max. (k-ft)
AC10	10	2	20.0	7.4
AC11	4	1	8.0	2.9
AC12	-11	-4	-10.7	-3.9
AC13	20	7	20.0	7.4
AC14	14	5	14.0	5.1
AC15	-19	-7	-18.3	-6.5
AC16	18	6	18.0	6.4
AC17	16	5	16.0	5.8
AC18	-11	-4	-10.7	-3.9
AC19	8	3	8.0	2.9
AC20	-8	-3	-7.8	-2.8
AC21	44	16	44.0	16.0
AC22	3	1	3.0	1.1
AC23	11	4	11.0	4.0
AC24	9	3	9.0	3.3
AC25	-11	-4	-10.7	-3.9
AC26	8	3	8.0	2.9

Component	E-FRAC		F-FRAC	
	Moment (k-ft)	Max. (k-ft)	Moment (k-ft)	Max. (k-ft)
BC10	21	8	21.0	7.6
BC11	-4	-1	-4.0	-1.4
BC12	-15	-5	-14.7	-5.3
BC13	36	13	36.0	13.0
BC14	28	10	28.0	10.1
BC15	-15	-5	-14.7	-5.3
BC16	12	4	12.0	4.3
BC17	10	4	10.0	3.6
BC18	-4	-1	-4.0	-1.4
BC19	5	2	5.0	1.8
BC20	-18	-6	-17.8	-6.4
BC21	18	6	18.0	6.4
BC22	24	9	24.0	8.6
BC23	3	1	3.0	1.1
BC24	11	4	11.0	4.0
BC25	9	3	9.0	3.3
BC26	-11	-4	-10.7	-3.9
BC27	8	3	8.0	2.9
BC28	11	4	11.0	4.0



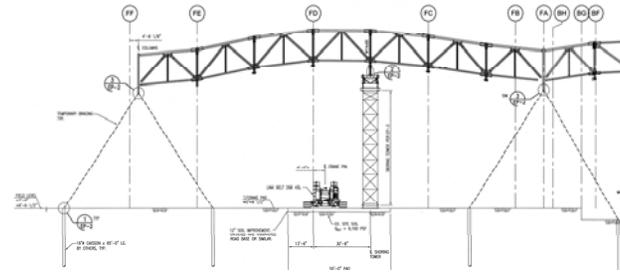
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Flex Field Truss Shoring



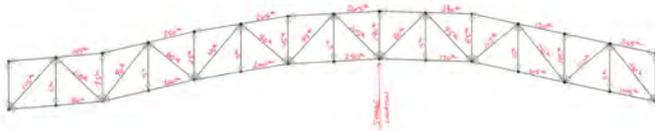
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Flex Field Truss Shoring



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Flex Field Truss Shoring



LONGITUDINAL RIDGE TRUSS STEEL SIZES		
ELEMENT	NORTH	SOUTH
TOP CHORD	W14x68 - W14x99	W14x68 - W14x90
BOTTOM CHORD	W14x68 - 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.

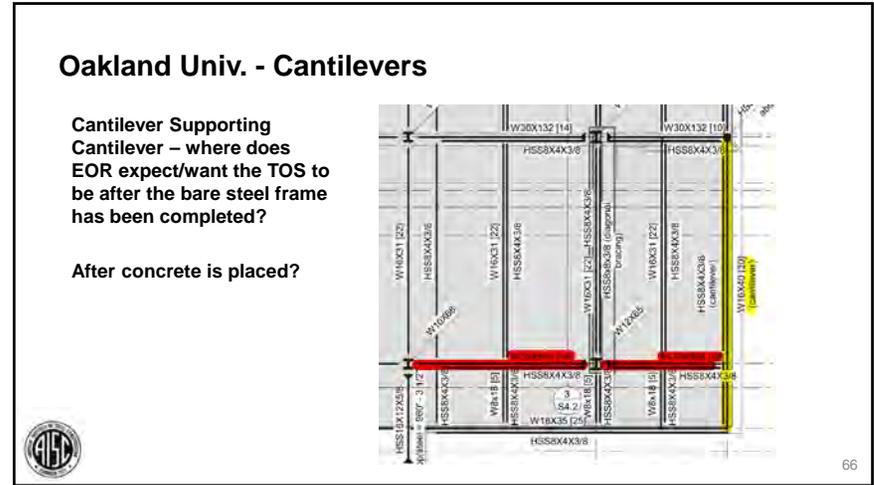
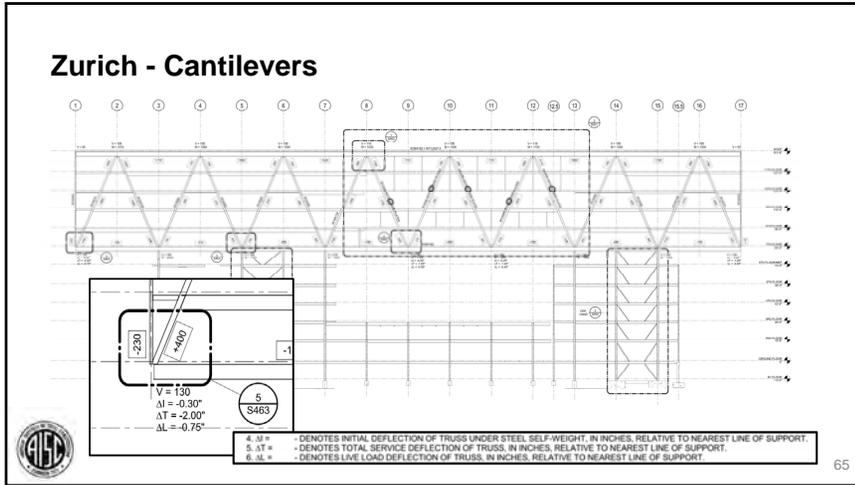


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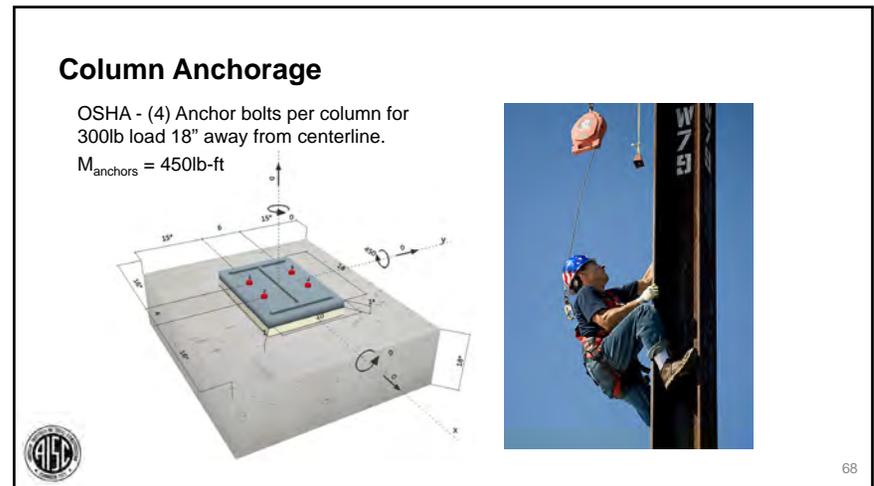
Zurich - Cantilevers



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OSHA

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	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: 58 [psi]
resulting tension force in (x/y)=(0.541/0.000): 769 [lb]
resulting compression force in (x/y)=(0.003/0.000): 769 [lb]

Anchor forces based on a rigid base plate assumption!

3 Tension load

	Load N_u [lb]	Capacity ϕN_c [lb]	Utilization $\rho_u = N_u / \phi N_c$	Status
Steel Strength*	283	14,529	2	OK
Pullout Strength*	283	15,305	2	OK
Concrete Breakout Strength**	769	37,598	2	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: 3,267 [psi]
resulting tension force in (x/y)=(0.941/0.000): 54,838 [lb]
resulting compression force in (x/y)=(0.083/0.000): 54,838 [lb]

Anchor forces based on a rigid base plate assumption!

3 Tension load

	Load N_u [lb]	Capacity ϕN_c [lb]	Utilization $\rho_u = N_u / \phi N_c$	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)=(0.037/0.000): 25,616 [lb]

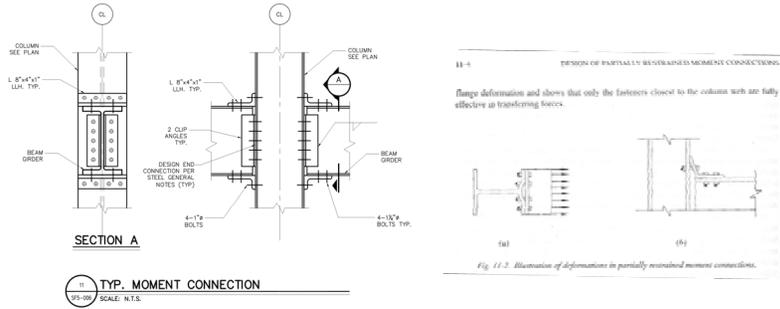
Anchor forces based on a rigid base plate assumption!

3 Tension load

	Load N_u [lb]	Capacity ϕN_c [lb]	Utilization $\rho_u = N_u / \phi N_c$	Status
Steel Strength*	12,808	14,529	88	OK
Pullout Strength*	12,808	15,305	84	OK
Concrete Breakout Strength**	25,616	37,598	68	OK
Concrete Side-Face Blowout, direction **	N/A	N/A	N/A	N/A

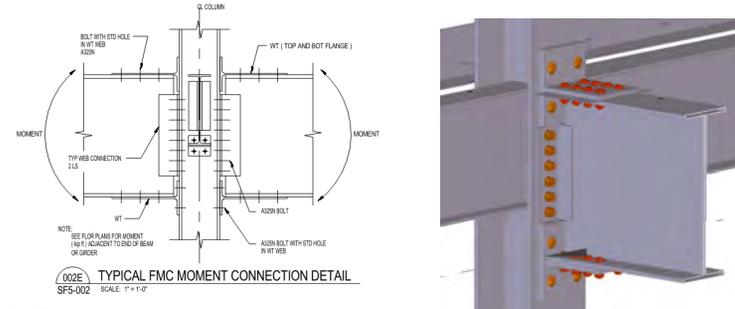
72

5. Connection Design's Affect on Stability



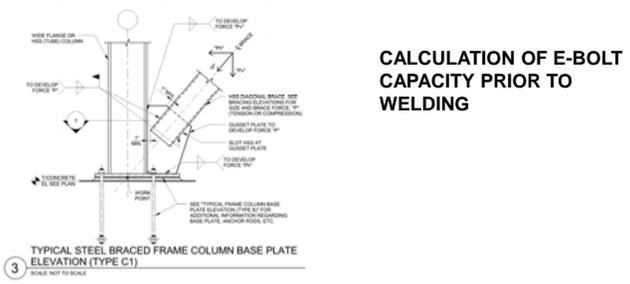
73

5. Connection Design's Affect on Stability



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5. Connection Design's Affect on Stability



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5. Connection Design's Affect on Stability



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Presentation Outline

1. Introduction
2. Industry Codes and Standards
3. Stability Analysis
4. Effects of Staged Construction
5. Connection Design's affect on stability
6. Miscellaneous EP Topics
7. Questions?



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6. Miscellaneous Erection Procedure Topics

- Shoring**
- Crane Logistics**
- Heavy Lift Engineering**



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West Point Science Center

Complete seismic upgrade of the facility which required removal and replacement of the existing floor diaphragms to meet current code.

Multi-span header and EFCO shoring towers were used to support existing trusses.



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6. Miscellaneous Erection Procedure Topics



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6. Miscellaneous Erection Procedure Topics



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6. Miscellaneous Erection Procedure Topics



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Summary:

- EOR has a role in the Erection Procedure
 - Code of Standard Practice: 7.10.1 and 7.10.2
- There are simple design changes the EOR can implement in order to simplify steel erection.
 - Easier steel erection results in less field time and less cost to the owner.
- Erection Engineer is often one of the last consultants involved, earlier involvement is beneficial.
- Erection Engineering services go beyond just reviewing the building's sequenced construction.

AISC | Questions?



Smarter.
Stronger.
Steel.

Individual Webinar Registrants

CEU/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!



Individual Webinar Registrants

CEU/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.



8-Session Registrants

CEU/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 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 - click on Current Course Details.

Reasons for quiz:

- EEU – must take all quizzes and final to receive EEU
- CEUs/PDHS – If you watch a recorded session you must take quiz for CEUs/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 CEUs/PDHS.



8-Session Registrants

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

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



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



Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.

Night School Resources for 8-session package Registrants

Go to www.aisc.org and sign in.

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.



Night School Resources for 8-session package Registrants

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



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