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Steel Erection: Engineering and Execution

Session 3: Erection Engineering of High-Rise Buildings
September 10, 2020



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Course Description

Erection Engineering of Low-Rise Buildings
September 10, 2020

Modern steel high-rise structures continue to push boundaries related to height, aspect ratio, and complexity of gravity and lateral systems. This, coupled with the desire to build higher and faster, creates increasingly common challenges for erection engineers. Pushing erection ahead of OSHA limits, generating and resisting wind and seismic demands on unclad steel skeletons, and tying tower cranes to slender and partially-completed systems require unique engineering solutions. In this webinar we will explore these challenges and describe approaches that can facilitate constructing today's high-rise steel structures.



AISC Live Webinars

Learning Objectives

- Describe how to treat seismic loads during construction.
- List several sources of temporary support for high-rise building stories where complete lateral systems and diaphragms have yet to be installed.
- Explain how high-rise building deformation can vary over the course of construction and identify strategies for erecting buildings within acceptable tolerances.
- Identify several approaches for bracing tower cranes against all-steel high-rise buildings.



Steel Erection: Engineering and Execution

Session 3: Erection Engineering of High-Rise Buildings

September 10, 2020



Timothy Nelson, S.E.
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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**



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Acknowledgements

Degenkolb Colleagues

- Alan Roberts, S.E.
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- Rainbow Lin

Partners



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Trends in Erection of Steel High-Rise Structures

- No concrete core
- Delayed lateral systems
- Going higher/faster
- Large tower crane demands
- Increased complexity
- Slender and tolerance-sensitive
- Responsibility shift from SEOR to Erector



181 Fremont, San Francisco



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Presentation Topics

1. Demands During Construction
2. Structural Complexity and Tolerances
3. Pushing Height Limits During Construction
4. Erection Aids and Lifting Lugs
5. Tower Cranes



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Topic # 1

Demands During Construction



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AISC Code of Standard Practice

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.

Temporary supports that are required during or after the erection of the structural steel frame for the support of loads caused by non-structural steel elements, including cladding, interior partitions and other such elements that will induce or transmit loads to the structural steel frame during or after erection, shall be the responsibility of others.

From: AISC Code of Standard Practice (COSP) for Steel Buildings and Bridges, June 15, 2016



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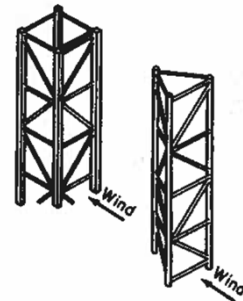
Wind Demands During Construction



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Trussed Tower Analogy (Unclad Structure)

- Loads applied to exposed surfaces (beams, columns, braces)
- Reduced wind velocity per ASCE 37
- Shielding reductions
- Possibility of significant loads
 - Bi-directional effects



Shapiro & Shapiro (2011)



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Trussed Tower Analogy

Determination of Wind Velocity
'q_z' Equation 29.3-1, ASCE 7-10

Reduction in 'V'
Section 6.2.1, ASCE 37-14

Application of Load
Equation 29.5-1, ASCE 7-10

Shielding Reduction
Section 6.2.2, ASCE 37-14

$$q_z = 0.00256 K_z K_{zt} K_d V^2 \text{ (lb/ft}^2\text{)}$$

[In SI: $q_z = 0.613 K_z K_{zt} K_d V^2 \text{ (N/m}^2\text{); } V \text{ in m/s}$]

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

$$F = q_z G C_f A_f \text{ (lb) (N)}$$



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Shielding References

ASCE

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Wind Case Study

All-Steel High Rise

- Approx. 60 stories
- 13'-15' story heights
- Unclad condition (Trussed Tower)

Standards Referenced:

- ASCE 37-14
- AISC DG 10
- ASCE Wind Loads for Petrochemical and Other Industrial Facilities
- AS/NZS 1170.2
- Shapiro & Shapiro 2011

ASCE

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Wind Case Study

ASCE 37-14

- Simple to apply
- Limited benefit of shielding
- Depending on rows of beams, could result in a larger wind area than clad structure.

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.

Calculations shall be performed for each primary axis of the structure. For each calculation, 50% of the wind load calculated for the perpendicular direction shall be assumed to act simultaneously.

ASCE

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Wind Case Study

AISC Design Guide 10

- More detailed evaluation of shielding
- Based on solidity and spacing of frames
- Larger shielding benefit than ASCE 37-14

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 f used in these figures are in consistent units. The total factored area, A , is determined using Equation 2-1:

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

where

- A_1 = projected area of one element, in²
- n = total number of parallel elements
- η = stacking factor taken from Figure 2-2

The stacking factor, η , is a function of the element spacing to the element depth and a solidity ratio, ϕ .

Fig. 2-1 Parameters for Use with Eq. 2-1

ASCE

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Wind Case Study

ASCE Wind Loads for Petrochemical and Other Industrial Facilities

- Slightly simplified shielding based on frame solidity and bay spacing
- Allows for reduction due to solid flooring affecting wind flow
- Cautions there may be cases where wind load on building in erection may control over clad structure

5.2.2 Frame Load

For open frame structures, design wind forces for the main wind force resisting system should be determined by the equation:

$$F = q_s G C_f A \quad (\text{Eq. 5.2.1})$$

$$C_f = C_{f0} / \epsilon \quad (\text{Eq. 5.2.2})$$

C_{f0} is the force coefficient for the set of frames given in Figure 5.2.3, and ϵ is the solidity ratio calculated in accordance with 5.2.4.

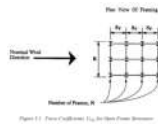
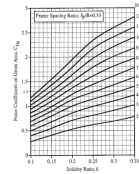


Figure 5.2.3 View of Frames, L_1 for Open Frame Structures



5.2.4.3 The presence of flooring or decking does not cause an increase of the solid area of 5.2.4.1 beyond the inclusion of the thickness of the deck. Load-reducing effects of solid flooring (not grating) may be considered by adjusting the wind load by up to the shielding factor η_{max} .

$$\eta_{max} = 1 - 0.2 (A_{bf} / A_s) \quad (5.4)$$

where A_{bf} / A_s is the ratio of the projected area contributed by horizontal beams (in the vertical windward plane) supporting solid floors to the total projected solid area. This factor should be applied to the frame force coefficient.



Wind Case Study

AS/NZS 1170.2 (Australian / New Zealand Code)

- Similar to ASCE Petrochemical, based on solidity of frames and spacing of frames
- Tabulated values in equations rather than relying on figures

E2.3 Multiple open frames

For structures comprising a series of similar open frames in parallel, the aerodynamic shape factors for the second and subsequent frames shall be taken as the aerodynamic shape factors on the windward frame calculated as in Paragraph E2.2, multiplied by the shielding factor (K_{s2}) obtained from Table E2. The aerodynamic shape factor (C_{f2}) for the structure shall be as follows:

$$C_{f2} = C_{f2,1} + \sum K_{s2} C_{f2,1} \quad \dots E2(5)$$

$C_{f2,1}$ = aerodynamic shape factor for the first frame in the upwind direction, as given in Paragraph E2.2
 K_{s2} = shielding factor for shielded frames in multiple open-frame structures, as given in Table E2
 λ = spacing ratio for parallel open frames, equal to the frame spacing (centre-to-centre) on the projected frame width normal to the wind direction

TABLE E2
SHIELDING FACTORS (K_{s2}) FOR MULTIPLE FRAMES

Angle of wind to frames (θ), degrees	Frame spacing ratio (λ)	Shielding factors (K_{s2})							
		0	0.1	0.2	0.3	0.4	0.5	0.7	1.0
0 (wind normal to frames)	0.5	1.0	0.8	0.7	0.6	0.5	0.2	0.2	0.2
	0.2	1.0	1.0	0.8	0.6	0.4	0.2	0.2	0.2
	1.0	1.0	1.0	0.8	0.5	0.3	0.2	0.2	0.2
	2.0	1.0	1.0	0.9	0.7	0.6	0.4	0.2	0.2
	4.0	1.0	1.0	1.0	0.8	0.7	0.6	0.4	0.2
45	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	0.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	4.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0



Wind Case Study

Cranes & Derricks (Shapiro & Shapiro)

- Provides methods for evaluating shielding of members or frames.
- Examples of how to apply each method
- Applicable for towers of varying sizes

The force the wind exerts on an object can now be expressed as:

$$F = qAC \quad (3.27)$$

where F = force on surface which acts in direction of wind
 q = static pressure at height h of object
 A = face area of object on which wind acts
 C = coefficient

- C_f for wind acting normal to object
- C_{fs} for non-circular cylindrical objects
- C_{fs}^2 for wind at angle to object
- C_{fs} = force coefficient as given in Table 3.2
- η_s = cumulative effect of shielding on an identical cylindrical object
- $\eta_s = \eta_1^2 + \eta_2^2 + \dots + \eta_n^2$ where $\eta_n = (1 - \eta_{n-1})^2$
- η = shielding coefficient as given in Fig. 3.8
- θ = acute angle between wind and surface

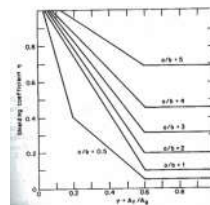


TABLE 3.2 Wind Pressure Coefficients, C_p

Surface	Profile	Value
Windward wall	Flat	0.8
	Roof	0.8
	Vertical	0.8
	Horizontal	0.8
Leeward wall	Flat	-0.5
	Roof	-0.5
	Vertical	-0.5
	Horizontal	-0.5
Roof	Flat	-0.5
	Roof	-0.5
	Vertical	-0.5
	Horizontal	-0.5
Windward roof	Flat	0.8
	Roof	0.8
	Vertical	0.8
	Horizontal	0.8
Leeward roof	Flat	-0.5
	Roof	-0.5
	Vertical	-0.5
	Horizontal	-0.5



Wind Case Study

Trussed Tower Wind Demands Compared to ASCE 37 Non-Shielded Baseline

Method	N/S %	E/W %
ASCE 37	91%	100%*
AISC DG10	52%	51%
ASCE Petrochemical	82%	105%
AS_NZS_1170.2	79%	63%
Cranes & Derricks	40%	85%
Average	69%	81%

*Building geometry did not meet reduction criteria



Seismic Demands During Construction



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Seismic Demands

ASCE 37-14 (Section 6.5)

- Up to 80% reduction on S_s & S_1 (i.e. $0.2 * S_s$, $0.2 * S_1$)
 - One-year construction duration
- F_a/F_v based on unreduced accelerations
- $R = 2.5$
- Equivalent Lateral Force Procedure (ELF) or Response Spectrum Analysis
- While not mandated by Code of Standard Practice, very much a consideration in certain seismic zones & situations.
- Judgement and discretion is necessary.



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RESPONSE COEFFICIENT - DEGENKOLB HEADQUARTERS, DOWNTOWN SAN FRANCISCO

ASCE 7-10, Risk Category II, Site Class D

PARAMETER	0.2 Sec PERIOD	1.0 Sec PERIOD	REFERENCE
MAPPED S	$S_s = 1.50$	$S_1 = 0.60$	ASCE 7-10 FIG 22-1 & 22-2
ASCE 7-14 Req	$S_s = 0.2 \times 1.50 = 0.30$	$S_1 = 0.2 \times 0.60 = 0.12$	ASCE 7-14 SECTION 6.5.2
SITE MODIFICATION	$F_a = 1.00$	$F_v = 1.50$	ASCE 7-10 TABLE 11.4-1 & 11.4-2
SITE-REDUCED S	$S_{MS} = F_a \times S_s$ $= 1.00 \times 0.30$ $= 0.30$	$S_{M1} = F_v \times S_1$ $= 1.50 \times 0.12$ $= 0.18$	ASCE 7-10 EQUATIONS 11.4-1 & 11.4-2
DESIGN S	$S_{DS} = \frac{2}{3} S_{MS}$ $= \frac{2}{3} \times 0.30$ $= 0.20$	$S_{D1} = \frac{2}{3} S_{M1}$ $= \frac{2}{3} \times 0.18$ $= 0.12$	ASCE 7-10 EQUATIONS 11.4-3 & 11.4-4
RESPONSE COEF. C	$C_s = \frac{S_{DS}}{(R/I_e)}$ $= \frac{0.20}{(2.5/1.0)}$ $C_s = 0.08$	$C_s = \frac{S_{D1}}{[T \times (R/I_e)]}$ $= \frac{0.12}{T \times (2.5/1)}$ $C_s = 0.05/T$	ASCE 7-10 EQUATIONS 12.8-2 & 12.8-3 ASCE 7-14 SECTION 6.5.2 by the 'R' FACTOR



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Topic # 2 Structural Complexity & Tolerances



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Building Behavior During Steel Erection

181 Fremont
Model Courtesy of Arup

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181 Fremont -
<http://www.structuremag.org>

Established Column Line
[75 mm] 3"
2" [50 mm]
38th FL
Slope 1/16" per story
20th FL
Plumb
[50 mm] 2"
1" [25 mm]
Elev. Varies
Slope 1/500
Elev. Varies
Slope 1/500
Building Exterior
Envelope within which all working points must fall
AISC COSP 7.13

C/2 E/W Displacement

Building height (m)

Lateral Displacement (m)

— FINAL E/W POSITION
— CURRENT E/W POSITION
— TOLERANCE
— TOLERANCE

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Building Behavior During Steel Erection

Building Construction - Input the next steel member to be progressed:

Member	Start	End	Level
Column C-1	100	100	Level 21
Column C-2	100	100	Level 21
Column C-3	100	100	Level 21
Column C-4	100	100	Level 21
Column C-5	100	100	Level 21
Column C-6	100	100	Level 21
Column C-7	100	100	Level 21
Column C-8	100	100	Level 21
Column C-9	100	100	Level 21
Column C-10	100	100	Level 21
Column C-11	100	100	Level 21
Column C-12	100	100	Level 21
Column C-13	100	100	Level 21
Column C-14	100	100	Level 21
Column C-15	100	100	Level 21
Column C-16	100	100	Level 21
Column C-17	100	100	Level 21
Column C-18	100	100	Level 21
Column C-19	100	100	Level 21
Column C-20	100	100	Level 21
Column C-21	100	100	Level 21
Column C-22	100	100	Level 21
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Column C-27	100	100	Level 21
Column C-28	100	100	Level 21
Column C-29	100	100	Level 21
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Column C-31	100	100	Level 21
Column C-32	100	100	Level 21
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Column C-92	100	100	Level 21
Column C-93	100	100	Level 21
Column C-94	100	100	Level 21
Column C-95	100	100	Level 21
Column C-96	100	100	Level 21
Column C-97	100	100	Level 21
Column C-98	100	100	Level 21
Column C-99	100	100	Level 21
Column C-100	100	100	Level 21

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Approaches to Shoring

Mega-Truss Falsework – Kicked to Perimeter Shoring

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Topic # 3

Pushing Height Limits During Construction



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OSHA Provisions

[1926.754\(a\)](#)

Structural stability shall be maintained at all times during the erection process.

[1926.754\(b\)\(1\)](#)

The permanent floors shall be installed as the erection of structural members progresses, and there shall be not more than **eight stories** between the erection floor and the upper-most permanent floor, except where the structural integrity is maintained as a result of the design.

[1926.754\(b\)\(2\)](#)

At no time shall there be more than **four floors** or 48 feet (14.6 m), whichever is less, of unfinished bolting or welding above the foundation or uppermost permanently secured floor, except where the structural integrity is maintained as a result of the design.

From: OSHA Safety and Health Regulations for Construction, Section 1926 Subpart R (Steel Erection)

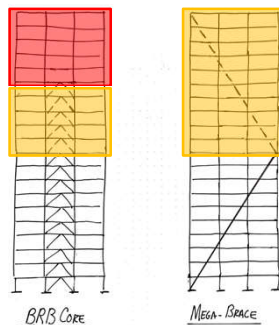


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Delayed Lateral Systems

Leading Edge

Delay Zone



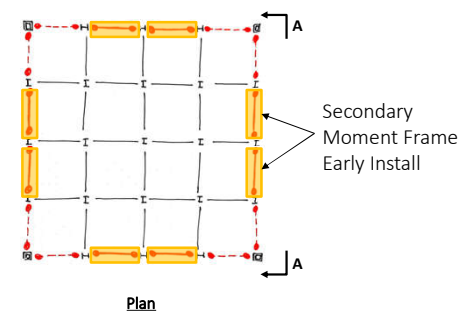
Delay Zone



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Sources of Temporary Lateral Support

Secondary Lateral Systems



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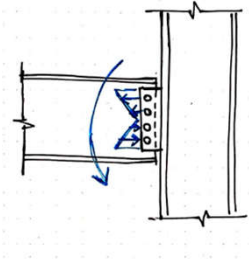

Sources of Temporary Lateral Support

Gravity Connections

- FEMA 355D (2000) Eqn. 5-19

$$k_s = 28000 (d_{bg} - 5.6")$$

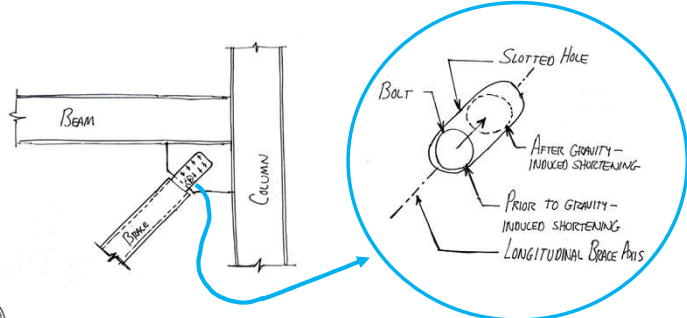

where k_s is in units of kip-in/radian and d_{bg} is in inches.

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Sources of Temporary Lateral Support

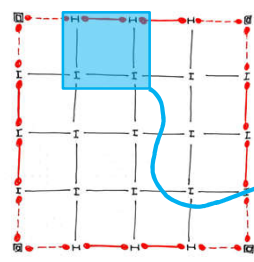
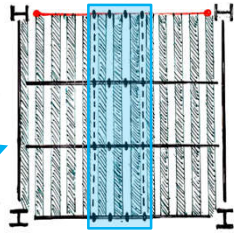
Temporary Bolted Connections


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Sources of Temporary Lateral Support

Metal Deck Diaphragms

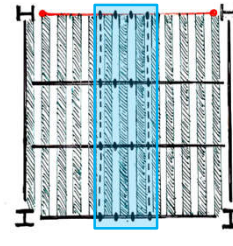
- Support Attachment:
 - Stud
 - Spot weld
 - PAF
 - Screw
- Side-Lap Attachment:
 - Seam Weld
 - Button-Punch
 - Proprietary



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Sources of Temporary Lateral Support

Metal Deck Diaphragms




Negotiating for early or extra strength:

- Expedited install
- Heavier gauge
- Alternate connection method
- Tighter connection spacing

Considerations:

- Who selects the final deck configuration?
- Who is the decker working for?



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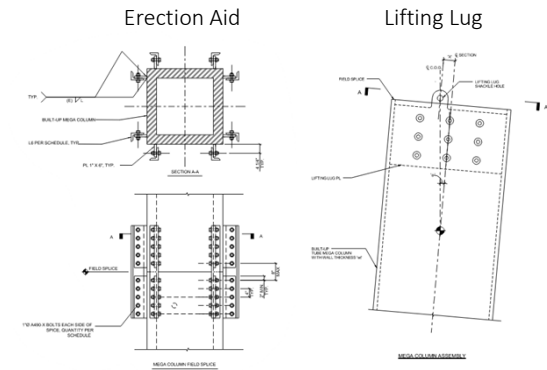
Topic # 4

Erection Aids and Lifting Lugs



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Terminology



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Box Column Erection Aid Design

- OSHA Prescriptive Demand

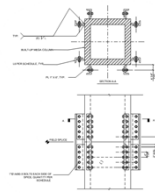
1926.756(d)

Column splices. Each column splice shall be designed to resist a minimum eccentric gravity load of 300 pounds (136.2 kg) located 18 inches (.46 m) from the extreme outer face of the column in each direction at the top of the column shaft.

- Additional Demand Considerations

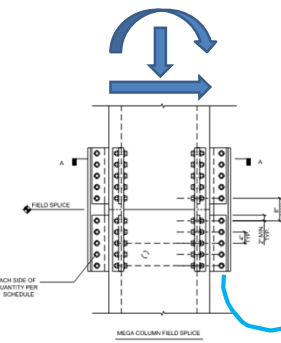
- Wind: ASCE 37-14 demands
- Seismic: ASCE 37-14 demands or $0.2 \cdot W$
- Impact: Lateral point load at top of column, min 1 kip

- Capacity: Per standard ASD or LRFD methods



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Box Column Erection Aid Design



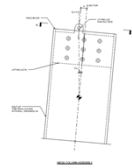
Gravity Resistance – Bearing at splice
Overturning & Shear – Thru erection aid



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Box Column Lifting Lug Design

- Demand: Unfactored gravity weight
- Capacity: Nominal capacity with a factor of safety added



Method	Category	Recommended Factor of Safety
David T. Ricker's <i>Design and Construction of Lifting Beams</i> (Engineering Journal 4 th Quarter 1991)	n/a	5
ASME-BTH-1 <i>Design of Below-the-Hook Lifting Devices</i>	Category A – Predictable magnitude/variation	2
	Category B – Unpredictable magnitude/variation	3
	Category C – Special devices	6

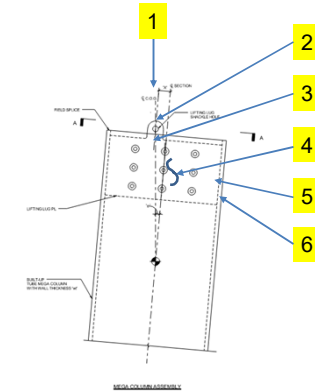


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Box Column Lifting Lug Design

Design Considerations

1. CG Alignment
2. Bearing/tearout
3. Tension at gross and net sections
4. Shear/flexure on lug plate
5. Weld to box wall
6. Localized effects on box wall



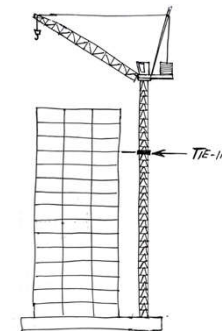
46

Topic # 5 Tower Cranes

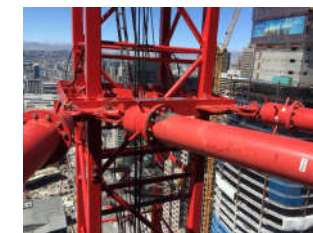


47

Tower Cranes



250 Howard,
San Francisco



181 Fremont,
San Francisco



48

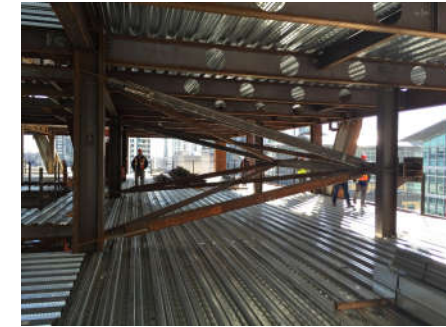
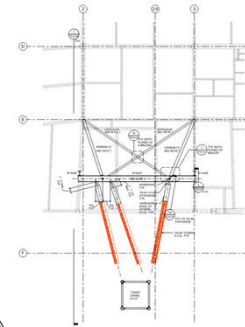
Things to Think About

- Demands – Are they ASD or LRFD Level?
- Stiffness Requirements – Have they been provided?
- Bolted Shoe – Who designs the bolts?
- Cladding limitations?
- Delayed Lateral Systems – Where to send the loads?



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Load-Spreading Approach

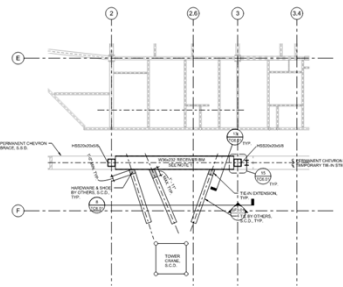


181 Fremont, San Francisco



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Perimeter Approach

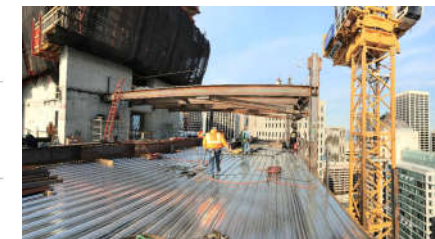
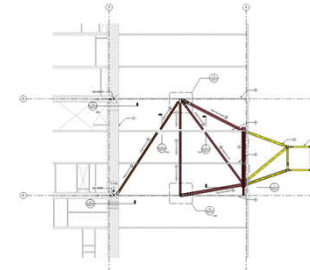


181 Fremont, San Francisco



51

“Minimal Removal” Approach



250 Howard, San Francisco



52



Final Thoughts

- Erection Engineer plays an important role
- Responsibilities shifting
- Creativity and understanding of behavior are paramount
- Role of ASCE 37



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Degenkolb
Tim Nelson
415-354-6413
tnelson@degenkolb.com

AISC | Questions?



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3-Session Registrants

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Course Resources

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3-Session Registrants

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Course Resources

Event	Start Date
Scientific Design in Steel	1/11/2009 12:00:00 AM
4-Session Package-Design of Facade Attachments	5/8/2018 1:00:00 PM
10.18.8-Session Package-Night School 18 - Fundamentals of Connection Design	10/15/2017 7:00:00 PM
10.18.10-Session Package-Night School 18 - Seismic Design in Steel	2/9/2018 7:00:00 PM
10.17-Session Package-Night School 17-Design of Facade Attachments	7/10/2018 7:00:00 PM
10.18.6-Session Package-Night School 18- Steel Construction: Mill To Transport Out	10/15/2018 7:00:00 PM
10.18.8-Session Package-Night School 18- Connection Design	2/4/2019 7:00:00 PM
10.20.20-Session Package-Night School 20- Classical Methods of Structural Analysis	6/18/2019 1:00:00 PM
8-Session Package-Design in Steel - Concepts & Examples	7/16/2018 1:00:00 PM

3-Session Registrants

Course Resources

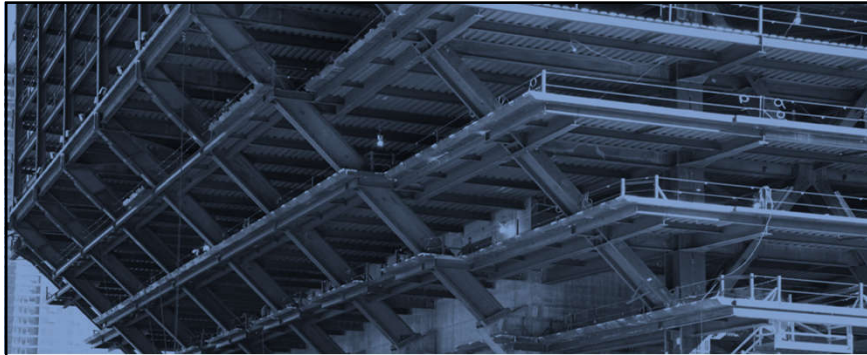
EDUCATION PUBLICATIONS AWARDS AND COMPETITIONS TECHNICAL RESOURCES STEEL SOLUTIONS CENTER

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Design of Facade Attachments

4-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Videos	Quiz	Attendance
EQ: Facade Fundamentals	N/A	Download	View	Pass	N/A
1.0: Facade Attachments Part 1	May 9 2018 1:30PM EDT	Download	Available 05/10/2018 5:00PM EDT	Available 05/11/2018 5:30 PM EDT	Pending
1.2: Facade Attachments Part 2	May 18 2018 1:30PM EDT	Download	Available 05/18/2018 5:00PM EDT	Available 05/21/2018 5:00 PM EDT	Pending
1.3: Facade Attachments - Building Lateral Drifts	May 23 2018 1:30PM EDT	Download	Available 05/23/2018 5:00PM EDT	Available 05/23/2018 5:00 PM EDT	Pending
Final Exam	N/A			Available 5/27/2018 5:00 PM EDT	



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| Thank you

**Smarter.
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Steel.**

