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Erection Engineering: The Science Behind the Art

Presented by

Will Jacobs, V, P.E., S.E.

Clint O. Rex, Ph.D. P.E.

Stanley D. Lindsey & Associates

Atlanta

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Introduction

Erection Engineering:
The Science Behind The Art

William P. Jacobs, V, P.E., S.E.
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Stanley D. Lindsey & Associates
Atlanta, Georgia, USA

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What is Erection Engineering?

- **Typical General Structural Note:**

"The structure is stable only in its completed form. Temporary supports required for stability during all intermediate stages of construction shall be designed, furnished and installed by the contractor. Contractor is responsible for construction analysis and erection procedures, including design and erection of falsework, temporary bracing, etc."

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What is Erection Engineering?

- **The Lingo:**
  - Basket
  - Choker
  - Shackle
  - Clevis
  - Cable Dog
  - Spreader
  - Bridle Sling
  - Turnbuckle
  - Chain Fall
  - Col-Yoom
  - Foot-urr

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Outline

- **Outline**
  - What are the rules to play by?
  - Is there any technical guidance?
  - What loads needs considered?
  - Stability Issues
    - Simple
    - Complex
    - Really Complex
  - Conveying the plan
  - Questions

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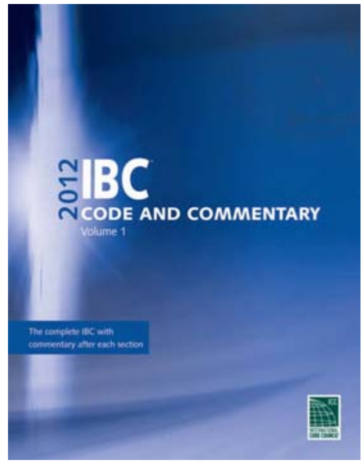
The Rules

- **IBC 2012**

SECTION 2205
STRUCTURAL STEEL

2205.1 General. The design, fabrication and erection of structural steel for buildings and structures shall be in accordance with AISC 360. Where required, the seismic design of structural steel structures shall be in accordance with the additional provisions of Section 2205.2.



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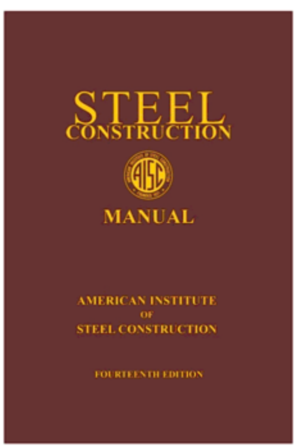
The Rules

- **AISC 14th Ed. Manual**



- 2010 AISC Specification Section M4.2
- Code of Standard Practice Section 7.10.3

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The Rules

- **AISC**
  - 2010 AISC Specification Section M4.2

2. Stability and Connections

The frame of *structural steel* buildings shall be carried up true and plumb within the limits defined in Chapter 7 of the *Code of Standard Practice*. 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.

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The Rules

- **AISC**
  - 2010 AISC Code of Standard Practice Section 7.10.3

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.

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The Rules

- **OSHA**
  - 1926.755(a) – 4 bolts required for column erection
  - 1926.451(c)(1) – Max height to width ratio of unbraced scaffolding 4:1
  - 1926.754(c)(1) – Shear connectors in field only
  - 1926.756(c)(1) – Double connections sharing common bolts
  - 1926.756(d) – Minimum load of 300lb at 18” from face for column splice design
  - 1926.756(e) – Perimeter columns require 48” extension for safety cables

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Outline

- **Outline**
  - What are the rules to play by?
  - **Is there any technical guidance?**
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  - Conveying the plan
  - Questions

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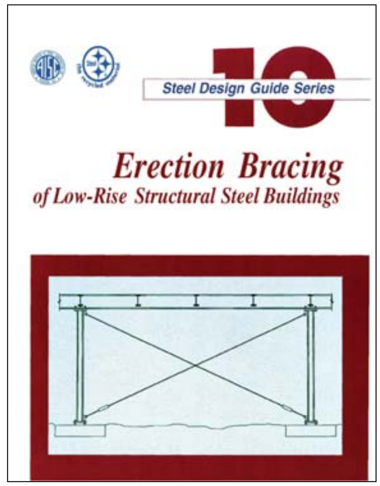
Guidance

- **Guidance – Is there Any?**
  - AISC Design Guide 10



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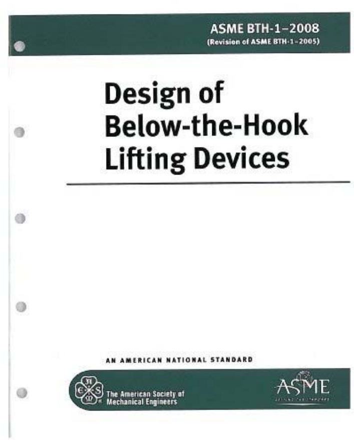
Guidance

- **Guidance – Is there Any?**
  - AISC Design Guide 10
  - BTH-1-2011 Design of Below-the-Hook Lifting Devices



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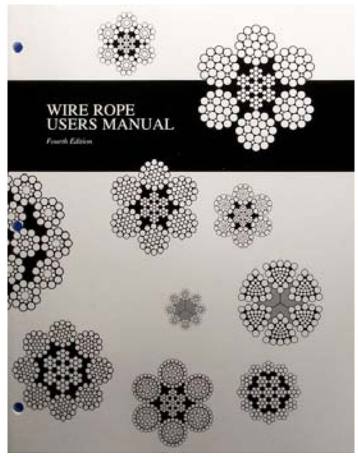
Guidance

- **Guidance – Is there Any?**
  - AISC Design Guide 10
  - BTH-1-2011 Design of Below-the-Hook Lifting Devices
  - WIRE Rope User Manual 4th Edition



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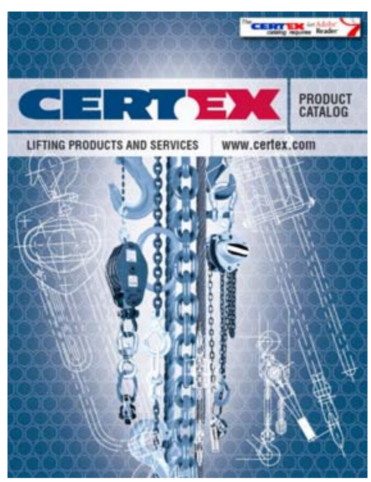
Guidance

- **Guidance – Is there Any?**
  - AISC Design Guide 10
  - BTH-1-2011 Design of Below-the-Hook Lifting Devices
  - WIRE Rope User Manual 4th Edition
  - Manufacturer's Catalogs (Certex / Crosby, etc).



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Outline

- **Outline**
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Loading

- **Dead and Live Loads**
  - Loads are REAL

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Loading

- **Dead and Live Loads**
  - Loads are REAL

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Loading

- **Dead and Live Loads**
  - Deflection Limits…

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Loading

- **Dead and Live Loads**
  - Deflection Limits…

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Loading

- **Dead and Live Loads**
  - Deflection Limits…

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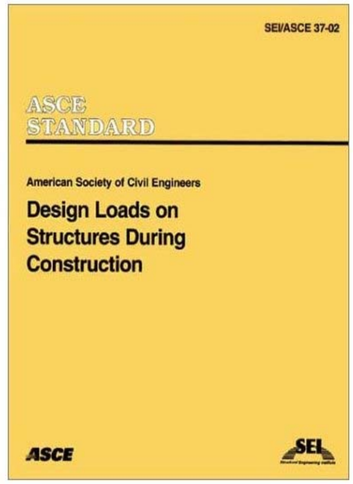
Loading

- **ASCE 37-02**
  - The "ASCE 7" of Construction Loading
  - Contains information on construction dead, live, wind, and seismic loading



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Loading

- **Dead and Live Loads**
  - ASCE 37 Live Load Classes

Table 2 Classes of Working Surfaces for Combined Uniformly Distributed Loads

Operational Class	Uniform Load[a] *psf (kN/m²)*
Very light duty: sparsely populated with personnel; hand tools; *very small amounts of construction materials*	20 (0.96)
Light duty: sparsely populated with personnel; hand operated equipment; staging of materials for lightweight *construction*	25 (1.20)
Medium duty: concentrations of personnel; staging of materials *for average construction*	50 (2.40)
Heavy duty: material placement by motorized buggies; staging of materials for heavy construction	75 (3.59)

[a] Loads do not include dead load, D; construction dead load, C_D; or fixed material loads, C_{FML}.

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Loading

- **Wind Loads During Construction**
  - Velocity Reductions

6.2.1 Design Wind Speed
The design wind speed shall be taken as the following factor times the basic wind speed in ASCE 7[1] except as required in 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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Loading

- **Wind Loads During Construction**
  - Force Reductions

Construction Period	Force Reduction Factor
less than six weeks	0.56
from six weeks to one year	0.64
from one to two years	0.72
from two to five years	0.81

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Loading

- **Wind Loads During Construction**
  - Increase for Drag Factors

Construction Period	Force Reduction Factor	Add Drag[1]
less than six weeks	0.56	1.12
from six weeks to one year	0.64	1.28
from one to two years	0.72	1.44
from two to five years	0.81	1.62

1. ASCE 7-10 Figure 29.5-2 Open Signs and Lattice Frameworks – Solidity <0.1.

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Loading

- **Wind Loads During Construction**
  - Reduce for Shielding Effects

Construction Period	Force Reduction Factor	Add Drag[1]	With Shielding[2] Reduction
less than six weeks	0.56	1.12	0.95
from six weeks to one year	0.64	1.28	1.09
from one to two years	0.72	1.44	1.22
from two to five years	0.81	1.62	1.37

1. ASCE 7-10 Figure 29.5-2 Open Signs and Lattice Frameworks – Solidity <0.1.
2. For fourth row of repetitive framing and beyond reduce force by 15%

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Loading

- **Wind Loads During Construction**

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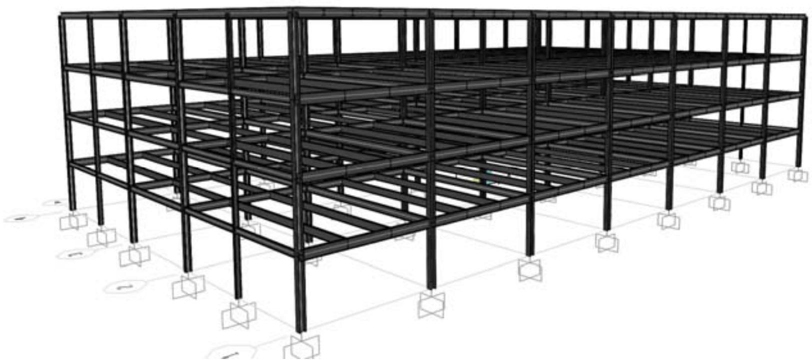
Loading

- **Wind Loads During Construction**
- AISC 14th Ed. Design Examples – Chapter III



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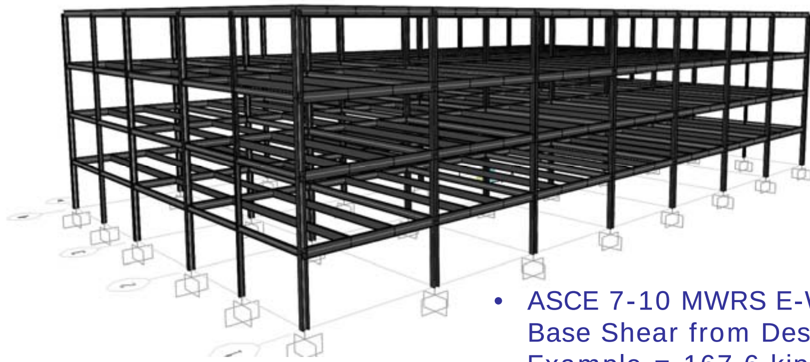
Loading

- **Wind Loads During Construction**
  - AISC 14th Ed. Design Examples – Chapter III



- ASCE 7-10 MWRS E-W Base Shear from Design Example = 167.6 kips

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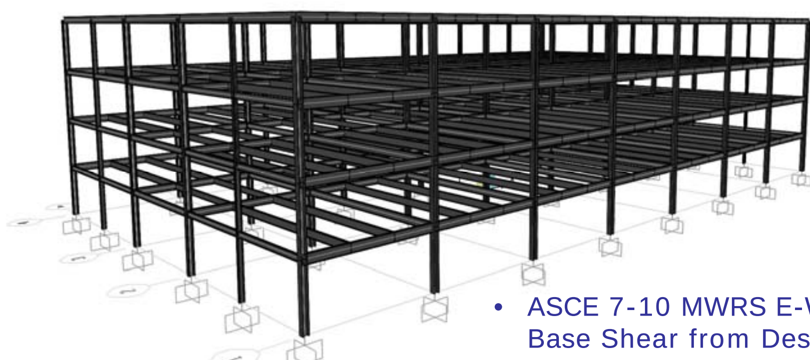
Loading

- **Wind Loads During Construction**
  - AISC 14th Ed. Design Examples – Chapter III



- ASCE 7-10 MWRS E-W Base Shear from Design Example = 167.6 kips
- ASCE 37 = 602 kips??

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Questions

- **Any questions?**

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Outline

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Simple

- **Cribbing Beams**

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Simple

- **Lateral Torsional Buckling**
  - AISC 360-10: Chapter F-Scope

CHAPTER F

DESIGN OF MEMBERS FOR FLEXURE

This chapter applies to members subject to simple bending about one principal axis. For simple bending, the member is loaded in a plane parallel to a principal axis that passes through the shear center or is restrained against twisting at *load* points and supports.

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Simple

- **Lateral Torsional Buckling**
  - AISC 360-10: Chapter F1 – General Provisions

F1. GENERAL PROVISIONS

The *design flexural strength*, $\phi_b M_n$, and the *allowable flexural strength*, M_n/Ω_b, shall be determined as follows:

(1) For all provisions in this chapter

$$\phi_b = 0.90 \text{ (LRFD)} \qquad \Omega_b = 1.67 \text{ (ASD)}$$

and the *nominal flexural strength*, M_n, shall be determined according to Sections F2 through F13.

(2) The provisions in this chapter are based on the assumption that points of support for *beams* and girders are restrained against rotation about their longitudinal axis.

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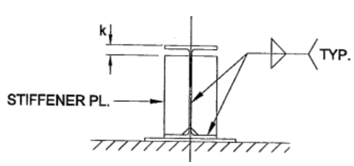
Simple

- **Lateral Torsional Buckling**
  - AISC 360-10: J10.7 / Part 2 of 14th Edition Manual

7. Unframed Ends of Beams and Girders

At *unframed ends* of *beams* and *girders* not otherwise restrained against rotation about their longitudinal axes, a pair of *transverse stiffeners*, extending the full depth of the web, shall be provided.



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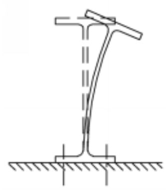
Simple

- **Lateral Torsional Buckling**
  - Connection Design for Steel Structures by Bo Dowswell
  - LTB Capacity is reduced as a result of web distortion



  - Use modified LTB length (British Standard 5950, 1985)

$$l' = l + 2d$$
$$d = \text{beam depth}$$

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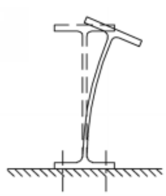
Simple

- **Restraint of Flange**
  - Bolts
  - Welds
  - Clamps
  - But for what force?



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Simple

- **Restraint of Flange**
  - AISC 360-10 Appendix 6

$$M_{rb} = \frac{0.024 M_r L}{n C_b L_b}$$

- For a typical simple span cribbing beam

$L_b = L$

$n = 1$

$M_r =$ Maximum moment along span

$$M_{rb} = \frac{0.024 M_r}{C_b}$$

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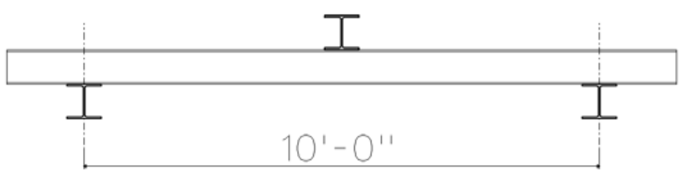
Simple

- **Example**
  - W8x31 Cribbing Beam $P_u = 45\ kips$



$M_u = 45 \times 10/4 = 113\ Kip - ft$

$\phi M_n = 104\ Kip - ft$ ($L_b = 11.4$ ft, $C_b = 1.0$) Actual $C_b = 1.32$

$\phi M_p = 114\ Kip - ft$

$$M_{rb} = \frac{0.024 \times 113}{1.32} = 2.05\ Kip - ft \quad Clamp = \frac{2.05 \times 12}{8} = 3.08\ Kips$$

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Outline

- **Outline**
  - What are the rules to play by?
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Complex

- **Free Standing Trusses**

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Complex

- **What are the issues?**
  - Stability at time of lift not a concern
  - Stability after letting off the hook is concern
  - Self weight stability (i.e. can I connect the ends and let it off the hook)
  - Self weight plus wind stability (i.e. will a good wind cause the truss to fail if it survived being let off the hook)
  - Determining what magnitude of wind will be a problem
  - Sizing of temporary bracing when required
  - Determining temporary splice forces if final truss splices are welded and made in the air

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Complex

- **How do you evaluate these issues?**
  - Hand Methods
  - Direct Analysis Methods

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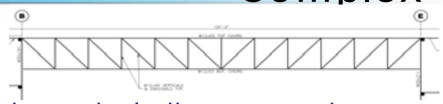
Complex



- **Hand Methods**
  - Get truss weight from fabricator including connections when possible
  - Simple beam and M/d truss analysis to get truss top chord maximum compression
  - Treat top chord like a column with K=1 and L=Length of Truss
  - Consider L/1000 out of straightness on top chord to determine a gravity moment in the top chord
  - Evaluate B_1 factor for moment magnification
  - Determine wind loads
  - Review unity checks
  - Splice forces based on above simple forces
  - Bracing based on Appendix 6

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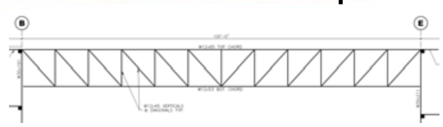
Complex



- **Direct Analysis**
  - Model truss with weight modifications or lump loads to allow for additional weight associated with connections (bare model weight vs. actual fabricator takeoff weight)- reduced stiffness
  - Sweep top and bottom chords
  - Top and bottom chords – continuous members
  - Webs – pins or continuous, depends...
  - Determine wind loads
  - Review unity checks, L = Panel point length
  - Splice forces directly from analysis
  - Bracing (if required) modeled in analysis

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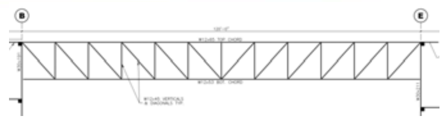
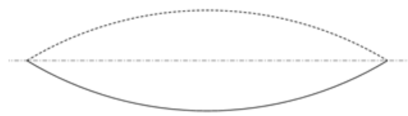
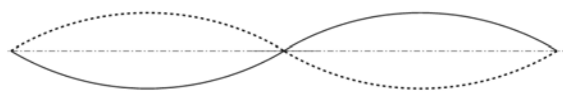
Complex



- **Direct Analysis**
  - Chord Sweep for Simple Truss, L/1000 Out-of-Straight and bottom chord in opposite direction as top chord



  - If need brace, determine required braced based on the above sweep
  - After sizing brace, need to revise sweep to match new potential buckling shape



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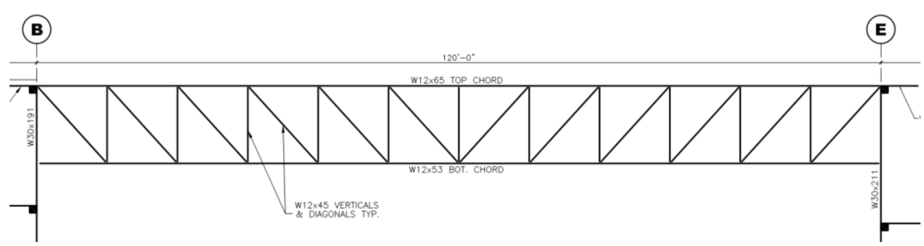
Complex – Case Study 1

- **The Truss**
  - Simple span roof truss
  - 120-ft Long, 11-ft Centerline to Centerline of Chords
  - W12x65 top chord, W12x53 bottom chord, W12x45 webs, webs up (all members)
  - Top & Bottom Chord Splices Near Midspan



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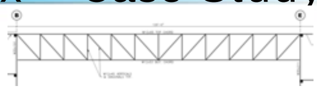
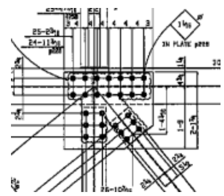
Complex – Case Study 1

- **Hand Analysis**



- Truss weight from fabricator (with connections) = 31,960 lbs.
- Analytical model of bare member truss (members going node to node) = 27,516 lbs.
- Connection Factor = 31,960/27,516=1.16
- Typically on order of 1.1 to 1.25 for bolted
- Top chord force



$$w=\frac{31960}{120}=266\text{ plf}$$

$$M_{truss}=\frac{266\times 120^2}{8}=479{,}400\text{ lb-ft}$$

$$P_d=\frac{479{,}400}{11\times 1000}=43.6\text{ Kips}$$

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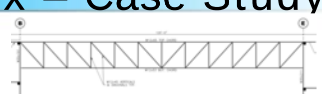
Complex – Case Study 1

- **Hand Analysis**



- Top chord moment from dead load

$$\frac{L}{1000}=\frac{120\times 12}{1000}=1.44\text{ inches}$$

$$M_d=43.6\times 1.44=62.8\text{ Kip-inch}$$

- W12x65 Top Chord, Slenderness, Moment Magnification
  - $A=19.1\text{ in}^2$
  - $I_x = 533\text{ in}^4$
  - $r_x = 5.28\text{ in}$

$$\frac{KL}{r_x}=\frac{1.0\times 120'\times 12}{5.28}=272$$

$$B_1=\frac{C_m}{1-\frac{\alpha P_r}{P_{e1}}}$$

C_m = 1.0 for transverse load (wind, conservative)

$$P_{e1}=\frac{\pi^2 EI^*}{(KL)^2}=\frac{\pi^2(29{,}000)(533)(0.8)}{(1.0\times 120\times 12)^2}=58.9\text{ Kips}$$

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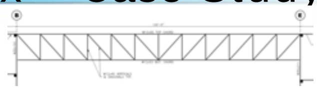
Complex – Case Study 1



- **Hand Analysis**

- B1 @ L.F. of 1.0

$$B_{1.0}=\frac{1.0}{1-\frac{1.0\times 43.6}{58.9}}=3.84$$

- B1 @ L.F. of 1.2

$$B_{1.2}=\frac{1.0}{1-\frac{1.2\times 43.6}{58.9}}=8.95$$

- B1 becomes unstable @ L.F. of 1.35<1.4 so bracing of the top chord would be recommend before letting off the hook

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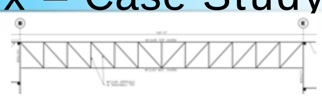
Complex – Case Study 1



- **Hand Analysis**

- Required bracing, Appendix 6, Nodal Brace, w/o Wind

$$P_{rb}=0.01\times P_r=0.01(1.4\times 43.6)=0.61 \text{ Kips}$$

$$\beta_{br}=\frac{1}{\phi}\left(\frac{8P_r}{L_b}\right)=\frac{1}{0.75}\left(\frac{8\times 1.4\times 43.6}{60\times 12}\right)=0.904 \text{ Kips/inch}$$

- Wind loads for 68 MPH wind approximately 13 plf on top chord + 12 plf from web members for total carried by top chord of 25 plf
- Additional brace force from wind

$$P_{rb}=25\times 1.6\times\frac{10}{8\times 1000}\times 60=3.0 \text{ Kips}$$

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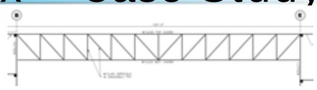
Complex – Case Study 1

• Hand Analysis



- Based on this analysis one would most likely recommend some temporary bracing at mid-span of top chord
- Likely cabling or possibly placement of a roof framing member (roof beam) that could brace it back to a stable portion of the roof
- Bottom chord could be evaluated for wind loads to determine if similar bracing is warranted to help reduce bottom chord wind moments or deflections
- What if the chord had passed the stability check; but, failed the combination of dead plus wind?

$$W_{wind\_68} = 25 \text{ plf}$$
$$W_{wind\_30} = 4 \text{ plf}$$

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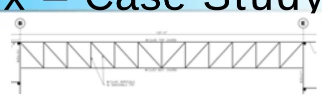
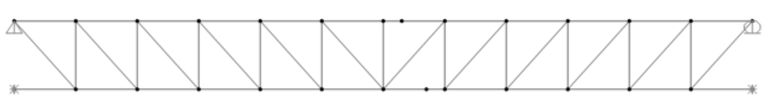
Complex – Case Study 1

• Direct Analysis



- Build model of truss with nominal geometry & reduced stiffness in accordance with direct analysis rules
- Sweep top and bottom chords in a half sine curve in opposite directions to match an L/1000 out of straightness tolerance, 3D analysis, not 2D truss anymore
- Insert nodes at the splice points
- Scale member weights or add distributed point loads in order to match the truss weight from the fabricator
- Boundary conditions should represent what you expect to be in place and connected



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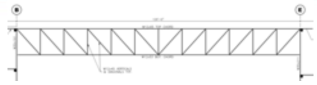
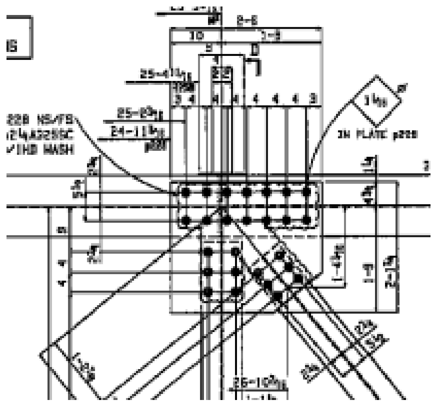
Complex – Case Study 1

- **Direct Analysis**



- Non-linear, P-Δ, P-Δ Large Deformation
- Top and Bottom chord continuous members
- Web members?



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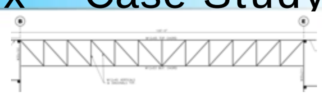
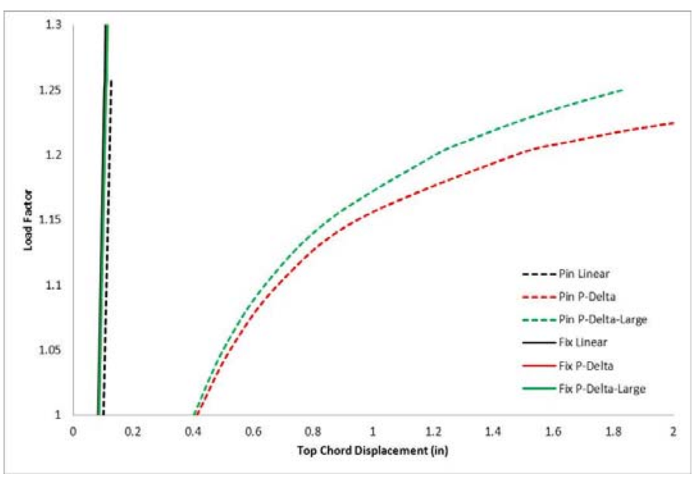
Complex – Case Study 1

- **Direct Analysis**



- Pinned Web Members
- Buckles at a load factor of about 1.25



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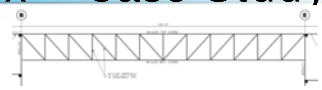
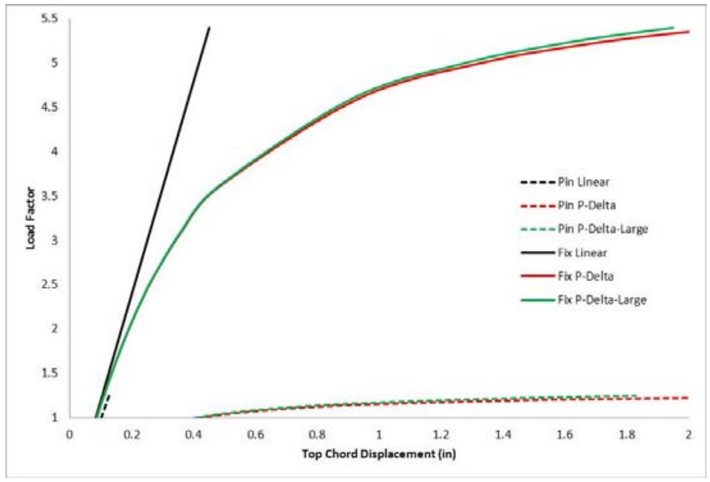
Complex – Case Study 1

- **Direct Analysis**



- Fixed Web Members
- Buckles at a load factor of about 5.5



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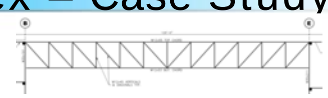
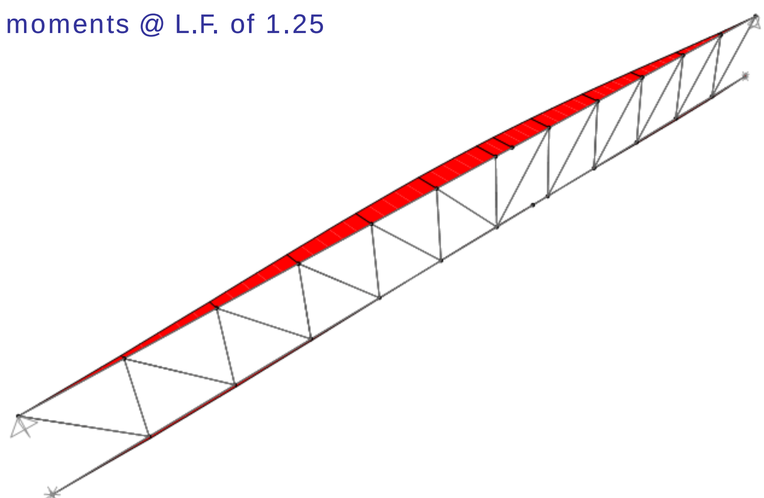
Complex – Case Study 1

- **Direct Analysis**



- Pin Webs
- Truss moments @ L.F. of 1.25



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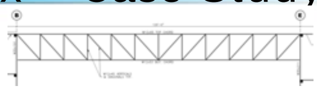
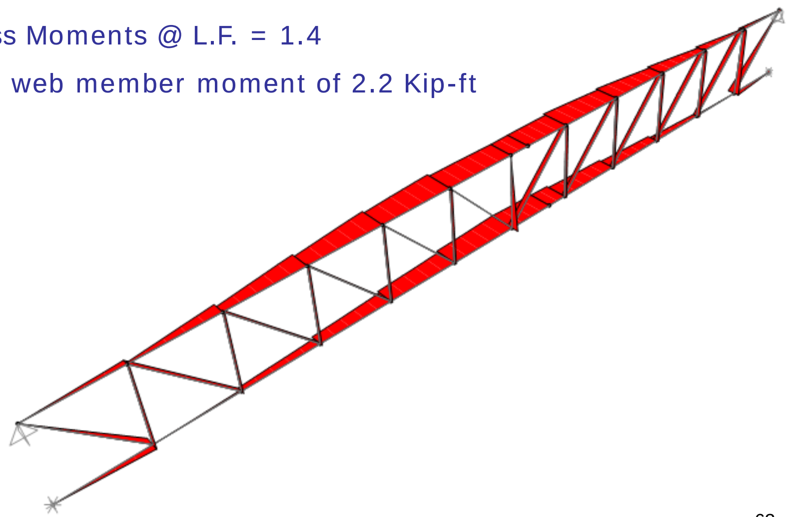
Complex – Case Study 1

- **Direct Analysis**



- Fixed Webs
- Truss Moments @ L.F. = 1.4
- Max web member moment of 2.2 Kip-ft



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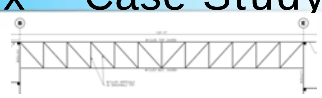
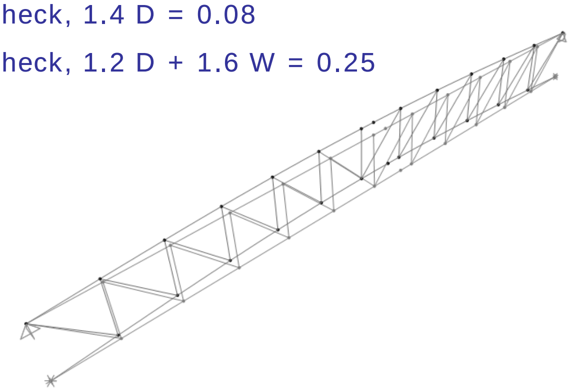
Complex – Case Study 1

- **Direct Analysis**



- Wind V = 68 MPH (0.75 x 90MPH)
- Wind deflection = 9-inches (L/160), strong axis into wind
- Unity Check, 1.4 D = 0.08
- Unity Check, 1.2 D + 1.6 W = 0.25



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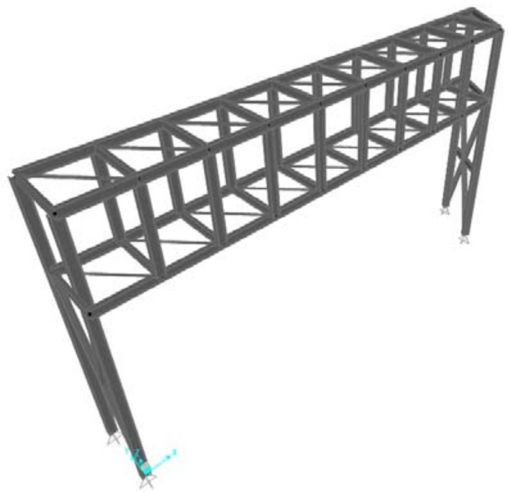
Complex – Case Study 2

- **The Truss**
  - Pedestrian Bridge
  - Box Truss



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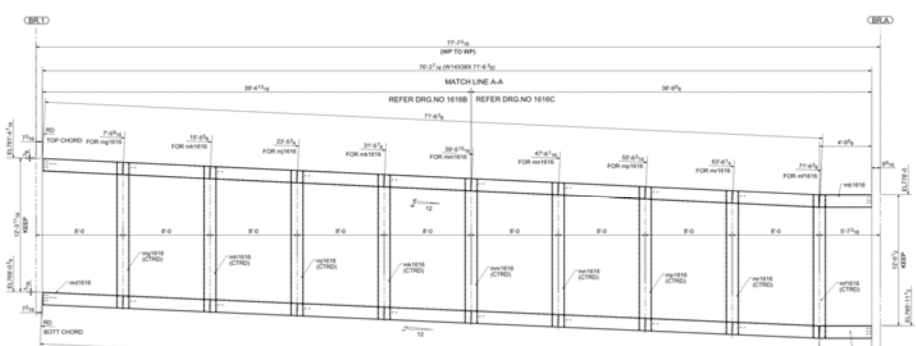
Complex – Case Study 2

- **The Pick**



- 11,000 lbs
- 76.25-feet long connection to connection
- 12-feet tall chord to chord
- W14x38 Top Chord, Strong Axis Vertical

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Complex – Case Study 2

- **The Numbers**
  - Top Chord Axial Force, $P_d = M_d/12\text{-ft} = 8.72$ kips
  - $KL/r_y = 590$
  - $P_n = 8.07$ kips
  - $P_d/P_n = 1.08$
  - $1.4P_d/0.9P_n = 1.68$
  - No consideration of strong axis moment from vierendeel action
  - No consideration of weak axis moment from wind

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Complex – Case Study 2

- **The Result**

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Questions

- **Any questions?**

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Outline

- **Outline**
- What are the rules to play by?
- Is there any technical guidance?
- What loads needs considered?
- **Stability Issues**
  - Simple
  - Complex
  - **Really Complex**
- Conveying the plan
- Questions

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70

Really Complex

- **"On the Hook" Stability**

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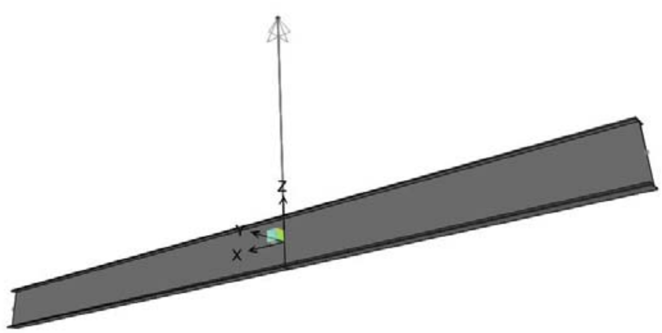
Really Complex

- **"On the Hook" Stability**



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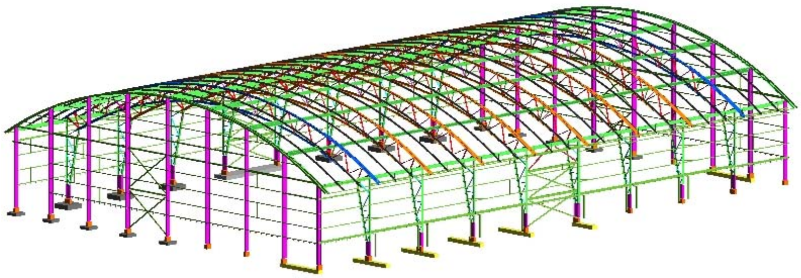
72

Really Complex

- **“On the Hook” Stability**



•226’ long barrel trusses

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Really Complex

- **Occurs all the time with Joists**

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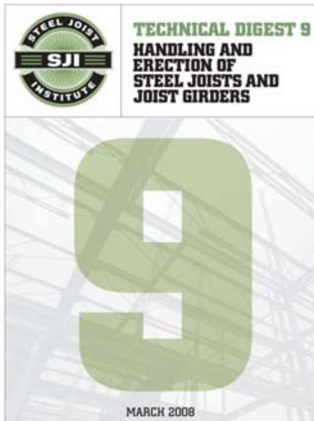
Really Complex

- **SJI Technical Digest 9**



- "Determination of lifting points and rigging techniques by a qualified person is critically important for [long span joists]. The erector must be aware of the possibility that the joist could 'fold-up' under its own weight if not lifted and handled properly."

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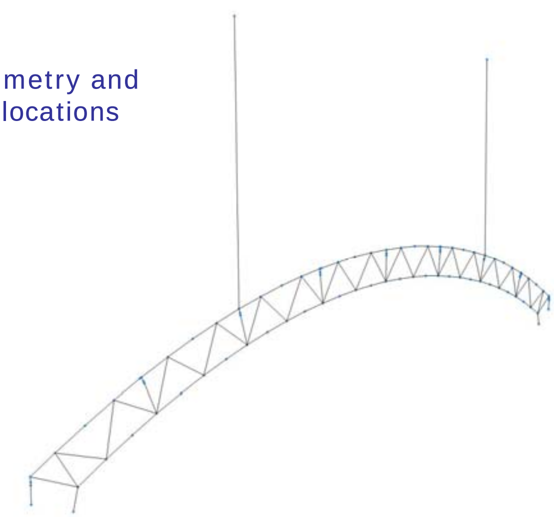
Really Complex

- **Modeling**

- Enter in typical geometry and select trial support locations



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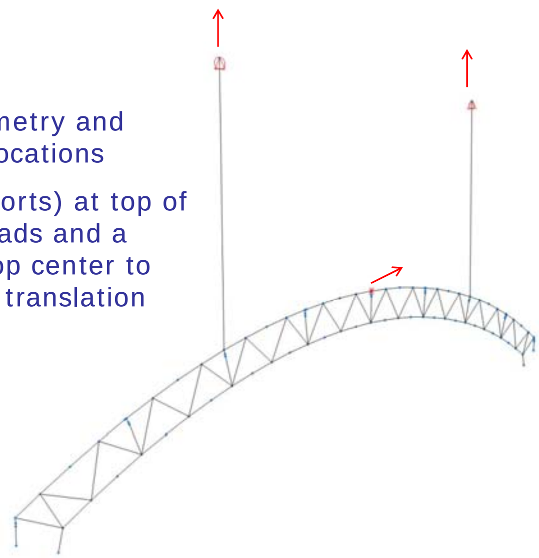
Really Complex

• Modeling

- Enter in typical geometry and select trial support locations
- Add restraints (supports) at top of cables for vertical loads and a lateral restraint at top center to prevent longitudinal translation



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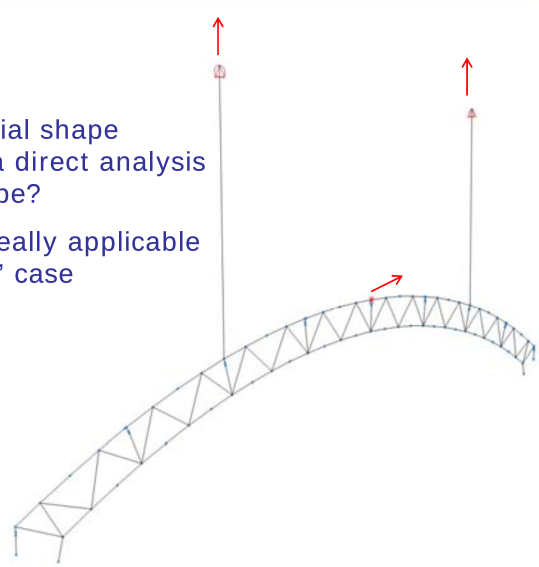
Really Complex

• Modeling

- Now we need an initial shape deformation to run a direct analysis with – but what shape?
- Typical L/1000 not really applicable to this "on the hook" case



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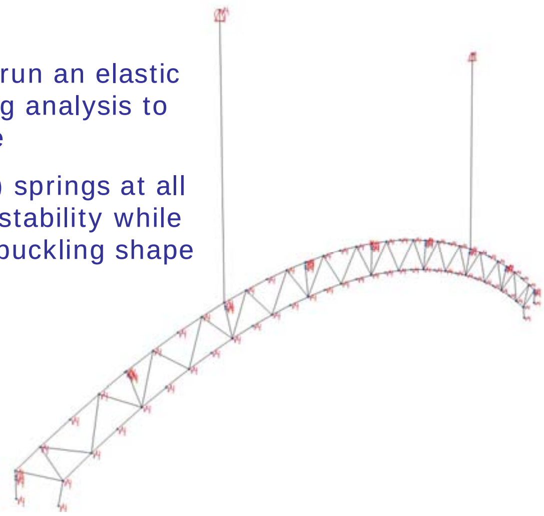
Really Complex

•Modeling

- One possibility is to run an elastic (eigenvalue) buckling analysis to determine the shape
- Add small (0.01k/in) springs at all nodes for analytical stability while not interfering with buckling shape



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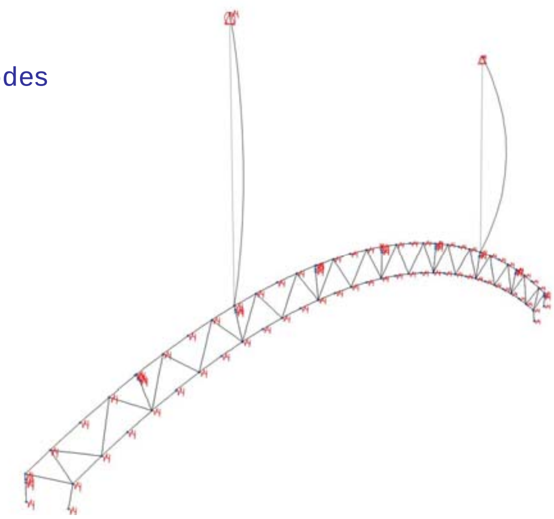
Really Complex

•Setting up Direct Analysis

- Review Buckling Modes



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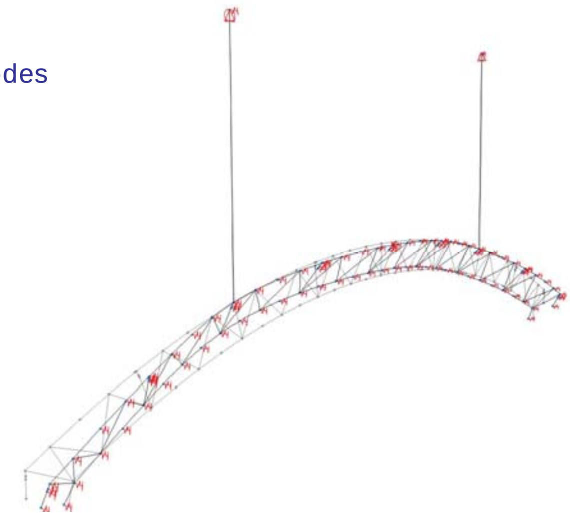
Really Complex

•Setting up Direct Analysis

- Review Buckling Modes



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Really Complex

•Setting up Direct Analysis

- Export Nodal Deflections from Chosen Mode

TABLE: Joint Displacements

Joint	OutputCase	CaseType	StepType	StepNum	U1	U2	U3
Text	Text	Text	Text	Unitless	in	in	in
4	BUCKLE	LinBuckling			0.169826	3.863E-10	-7.752E-10
5	BUCKLE	LinBuckling			0.1698257	2.101E-10	5.312E-10
8	BUCKLE	LinBuckling			-0.340524	1.018E-10	-5.655E-10
9	BUCKLE	LinBuckling			-0.199668	3.157E-11	-1.145E-11
11	BUCKLE	LinBuckling			-0.199668	3.631E-12	2.562E-10
12	BUCKLE	LinBuckling			-0.340524	5.858E-11	4.198E-10
20	BUCKLE	LinBuckling			0	9.694E-10	0
21	BUCKLE	LinBuckling			0	0.000000039	0
311	BUCKLE	LinBuckling			-0.590636	2.696E-10	-8.946E-10
312	BUCKLE	LinBuckling			-0.512215	2.946E-10	-8.946E-10
320	BUCKLE	LinBuckling			-0.541625	2.852E-10	-8.946E-10
321	BUCKLE	LinBuckling			-0.353082	0	1.95E-10
322	BUCKLE	LinBuckling			-0.226107	1.233E-11	1.952E-10
323	BUCKLE	LinBuckling			0.3736833	3.352E-11	1.96E-10
324	BUCKLE	LinBuckling			-0.004095	3.41E-10	-7.644E-10
325	BUCKLE	LinBuckling			-0.234516	1.356E-10	-5.513E-10
326	BUCKLE	LinBuckling			-0.334761	1.014E-10	-5.647E-10
327	BUCKLE	LinBuckling			0.1142929	-1.179E-09	-3.269E-10
328	BUCKLE	LinBuckling			-0.072017	-1.723E-10	3.903E-11
329	BUCKLE	LinBuckling			0.0141603	-6.342E-11	8.978E-13
330	BUCKLE	LinBuckling			-0.195567	2.246E-11	6.419E-11

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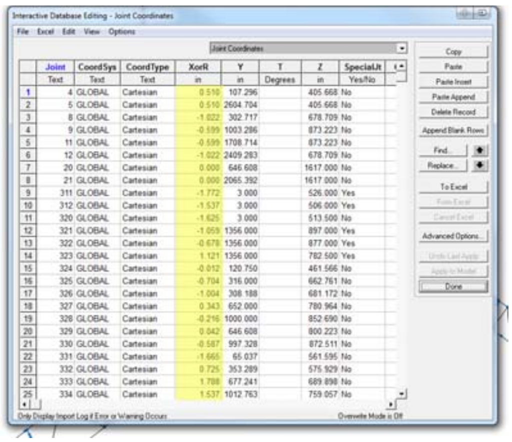
Really Complex

•Setting up Direct Analysis

- Modify Model Geometry to Match Deflections



Interactive Database Editing - Joint Coordinates

File Excel Edit View Options

Joint Coordinates

	Joint	CoordSys	CoordType	XorR	Y	T	Z	SpecialJt
	Text	Text	Text	in	in	Degrees	in	Yes/No
1	4	GLOBAL	Cartesian	0.510	107.296		405.668	No
2	5	GLOBAL	Cartesian	0.510	2604.704		405.668	No
3	8	GLOBAL	Cartesian	-1.022	302.717		678.709	No
4	9	GLOBAL	Cartesian	-0.599	1003.286		873.223	No
5	11	GLOBAL	Cartesian	-0.599	1708.714		873.223	No
6	12	GLOBAL	Cartesian	-1.022	2409.283		678.709	No
7	20	GLOBAL	Cartesian	0.000	646.608		1617.000	No
8	21	GLOBAL	Cartesian	0.000	2065.392		1617.000	No
9	311	GLOBAL	Cartesian	-1.772	3.000		526.000	Yes
10	312	GLOBAL	Cartesian	-1.537	3.000		506.000	Yes
11	320	GLOBAL	Cartesian	-1.625	3.000		513.500	No
12	321	GLOBAL	Cartesian	-1.059	1356.000		897.000	Yes
13	322	GLOBAL	Cartesian	-0.678	1356.000		877.000	Yes
14	323	GLOBAL	Cartesian	1.121	1356.000		782.500	Yes
15	324	GLOBAL	Cartesian	-0.012	120.750		461.566	No
16	325	GLOBAL	Cartesian	-0.704	316.000		662.761	No
17	326	GLOBAL	Cartesian	-1.004	308.188		681.172	No
18	327	GLOBAL	Cartesian	0.343	652.000		780.964	No
19	328	GLOBAL	Cartesian	-0.216	1000.000		852.690	No
20	329	GLOBAL	Cartesian	0.042	646.608		800.223	No
21	330	GLOBAL	Cartesian	-0.587	997.328		872.511	No
22	331	GLOBAL	Cartesian	-1.665	65.037		561.595	No
23	332	GLOBAL	Cartesian	0.725	353.289		575.929	No
24	333	GLOBAL	Cartesian	1.788	677.241		689.898	No
25	334	GLOBAL	Cartesian	1.537	1012.763		759.057	No

Copy
Paste
Paste Insert
Paste Append
Delete Record
Append Blank Rows
Find...
Replace...
To Excel
Advanced Options...
Done

Only Display Import Log if Error or Warning Occurs
Overwrite Mode is Off

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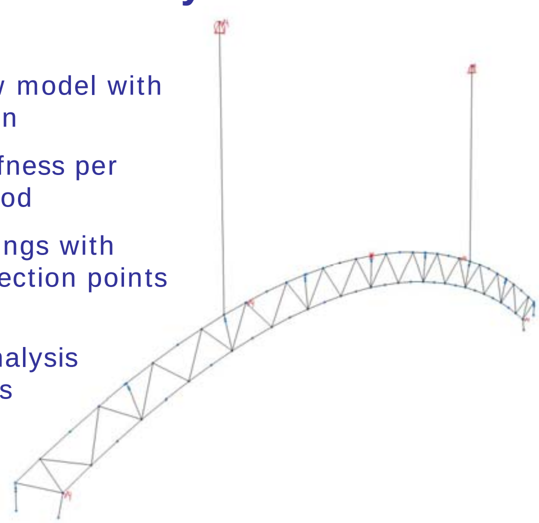
Really Complex

•Setting up Direct Analysis

- Now you have a new model with an initial imperfection
- Reduce member stiffness per Direct Analysis Method
- Replace uniform springs with single springs at inflection points (0.1 k/in)
- Run second order analysis with large deflections



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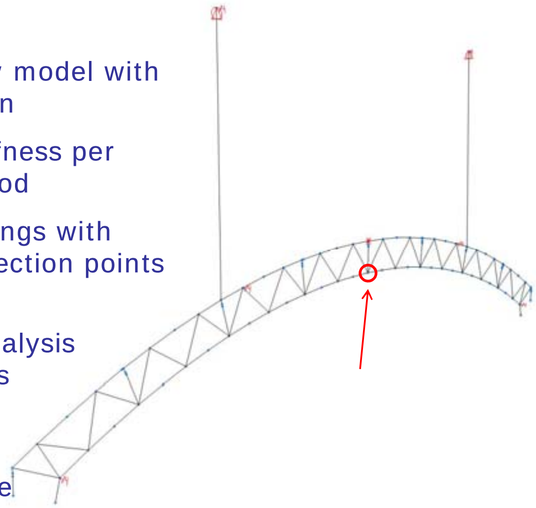
Really Complex

•Setting up Direct Analysis

- Now you have a new model with an initial imperfection
- Reduce member stiffness per Direct Analysis Method
- Replace uniform springs with single springs at inflection points (0.1 k/in)
- Run second order analysis with large deflections
- Track deflections vs. applied loads to see softening of structure



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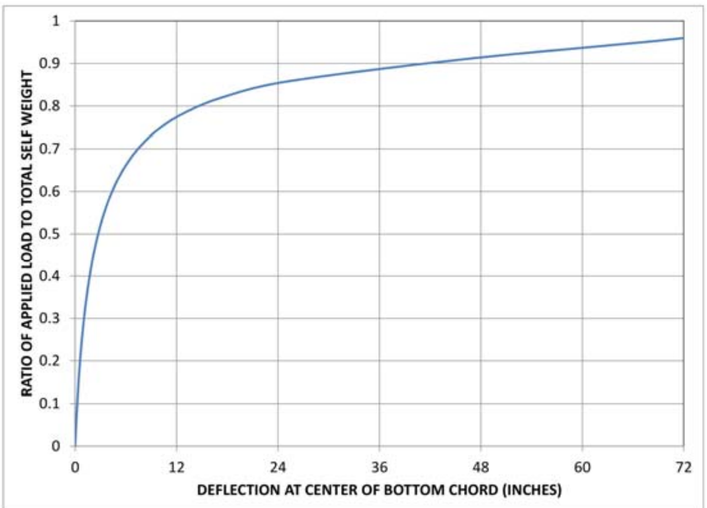
Really Complex

•Analysis Results



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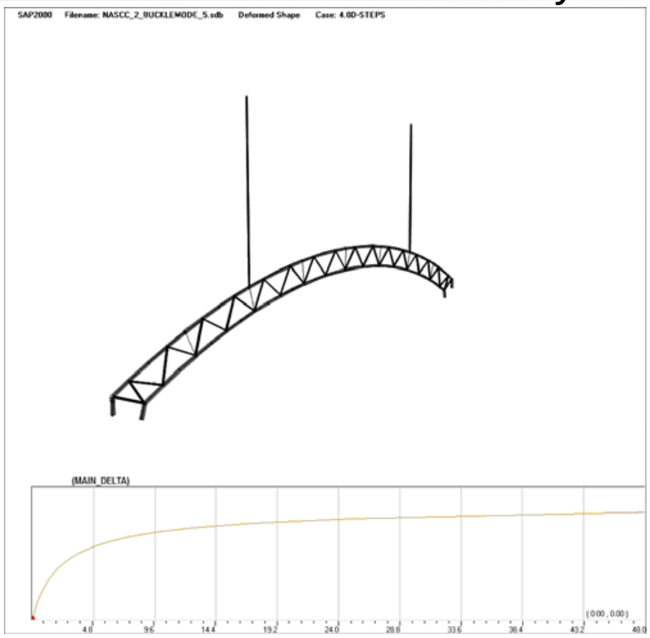
Really Complex



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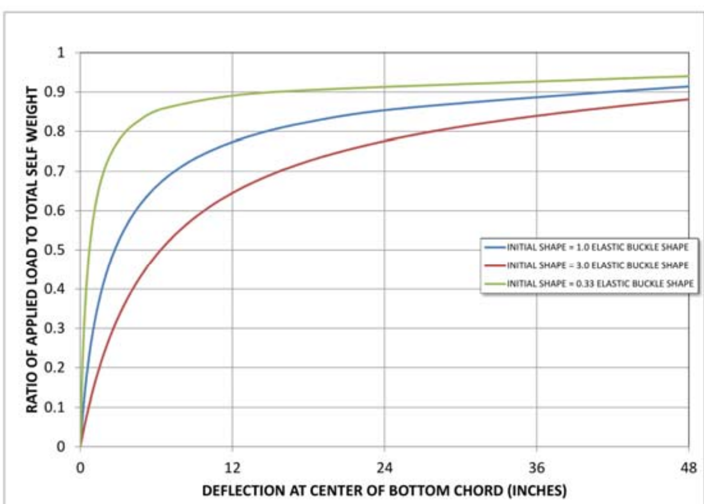
Really Complex

• **Analysis Results**



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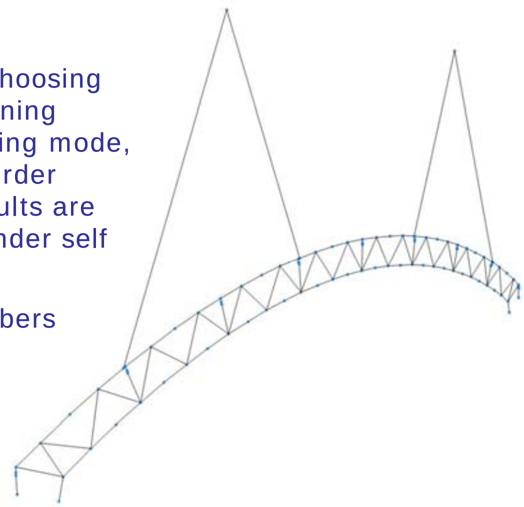
Really Complex

•Re-Analyzing

- Repeat the process of choosing support points, determining initial shape from buckling mode, and running a second-order direct analysis until results are satisfactory (stability under self weight is achieved)
- Check strength of members



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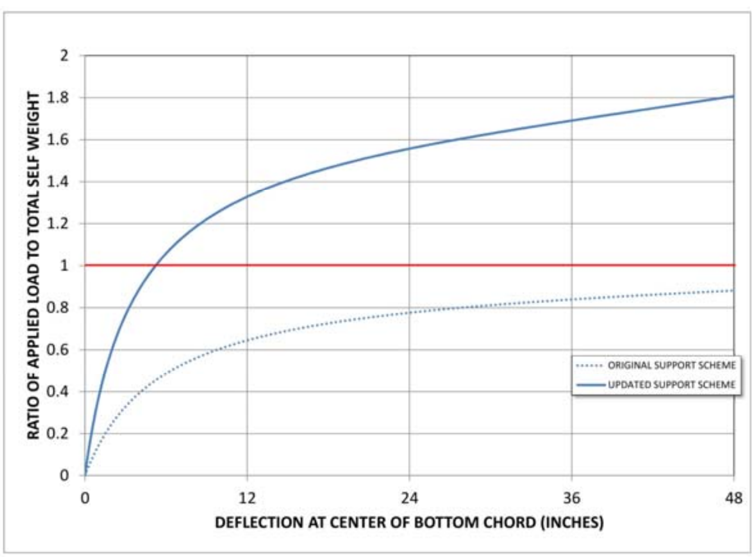
Really Complex

•Re-Analyzing



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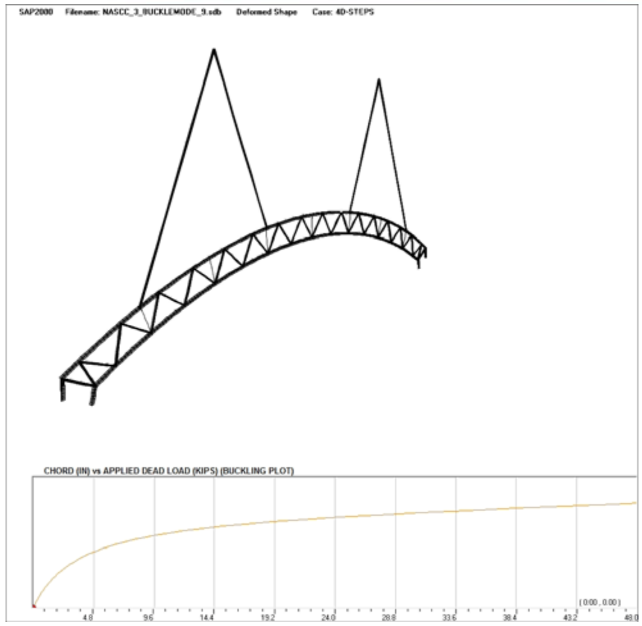
Really Complex



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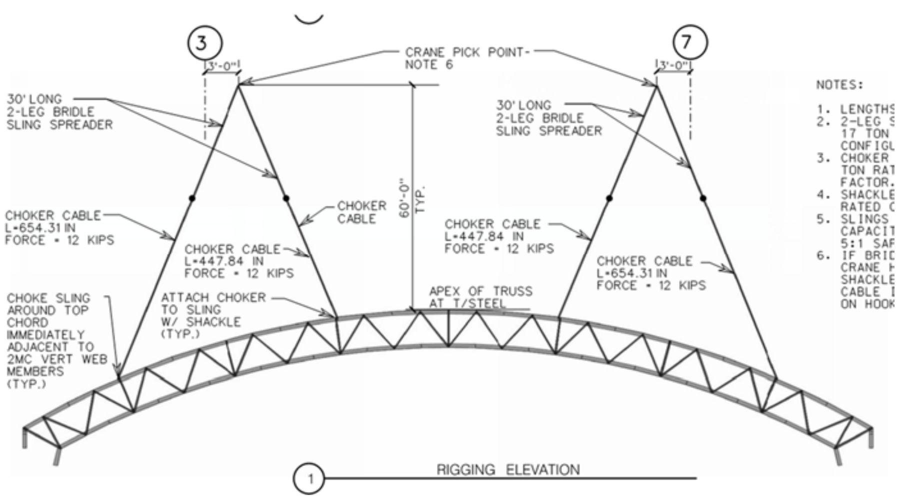
Really Complex

- **The Real World…**



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Really Complex

- **The Real World…**

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Really Complex

- **The Real World…**

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94

Really Complex

- **The Real World…**

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95

Really Complex

- **The Real World…**

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96

Really Complex

- **The Real World…**

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Really Complex

- **The Real World…**

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Really Complex

- **The Real World…**

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Outline

- **Outline**
  - What are the rules to play by?
  - Is there any technical guidance?
  - What loads needs considered?
  - Stability Issues
    - Simple
    - Complex
    - Really Complex
  - **Conveying the plan**
  - Questions

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The Plan

- **Erection Plans**
  - Discuss with the Erector BEFORE starting work what the final deliverable will be.
    - o Steps/Hand Sketches
    - o More Developed Steps with 2-D Details
    - o Full 3D Color-Coded Staged Construction BIM Models
  - The engineered erection sequence is generally in addition to and works in conjunction with the fabricator's E-Sheets.
  - Coordinate connection requirements with the Fabricator

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The Plan

- **Steps / Hand Sketches**

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ERECTION SEQUENCE FOR STEEL AT CORNER INTERSECTION OF I-13.8 GRIDS

SEE ATTACHED SKETCHES A-C FOR ADDITIONAL INFORMATION

X01 COMPLETE FULL PENETRATION WELDS OF W24X335 BACKSPAN TO W24X306 GIRDER AT LEVEL 12.

X02 ERECT W24X335 AT LEVEL 9.

X02.1 SWING W24X335 INTO POSITION AND HOLD WITH CRANE.

X02.2 ATTACH TEMPORARY CABLE SUPPORT DIAGONAL FROM NEAR END OF W24X335 AT LEVEL 9 TO INTERSECTION OF W24X335 AND W24X306 AT LEVEL 12 (SEE ELEV. C).

X02.3 ATTACH TEMPORARY HORIZONTAL CABLES (2) FROM NEAR END OF W24X335 TO COLUMNS AT H-13 AND H-14 AT LEVEL 9.

X02.4 ADJUST TEMPORARY SUPORT CABLE LENGTHS AS NEEDED TO HOLD W24X335 TIP AT DESIRED ELEVATION AND PLAN POSITION ONCE CRANE HAS BEEN RELEASED.

X02.5 RELEASE CRANE

X03 ERECT W36X395 AT LEVEL 9

X03.1 MAKE ANY FINAL TEMPORARY SUPPORT CABLE OR ROD LENGTH ADJUSTMENTS NECESSARY TO ACHIEVE DESIRED CANTILEVER TIP ELEVATION (CAMBER UP 0.75-INCHES).

X03.2 REMOVE TEMPORARY HORIZONTAL CABLES

X04 COMPLETE FULL PENETRATION WELDS OF W24X335 TO W24X306 GIRDER AT LEVEL 9 (BOTH SIDES OF GIRDER).

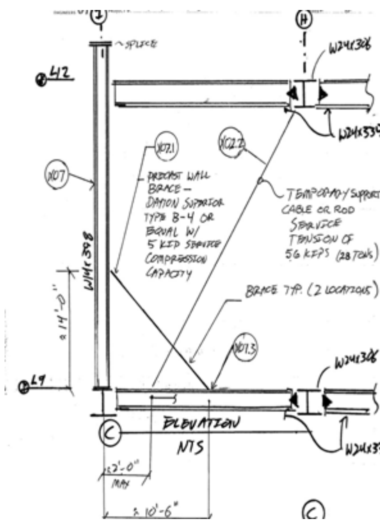
X05 COMPLETE FULL PENETRATION WELDS OF W36X395 TO COLUMN AT INTERSECTION OF GRID I-13 AT LEVEL 9 (BOTH SIDES OF COLUMN).

X06 FILL IN INTERMEDIATE DIAGONAL FRAMING AT LEVEL 9.

X07 ERECT 3-STORY PIECE OF W14X398 CORNER COLUMN AT I-13.8 FROM LEVEL 9 TO 12.

X07.1 ATTACH TEMPORARY PRECAST BRACES TO W14 COLUMN AT FLANGE FACING GRID LINE 13.8 AND WEB FACING GRID LINE I (SEE ELEV. C AND PLAN A).

X07.2 SWING W14 INTO PLACE AND HOLD.



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The Plan

- **"One Sheeters"**
  - Standard primarily 2-D drawings with Steps and Details

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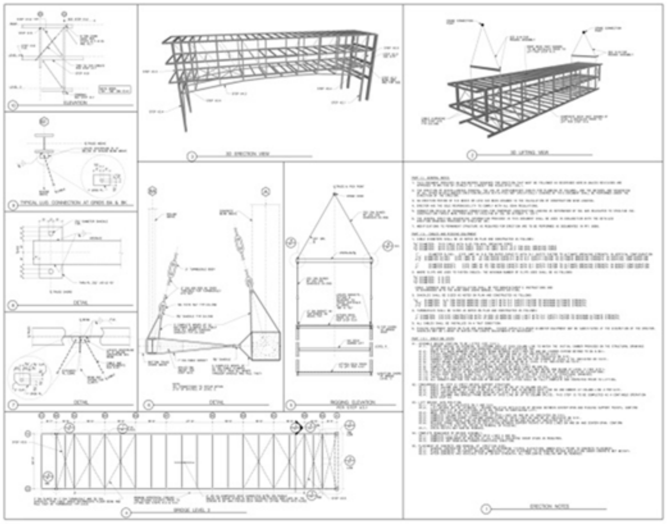
The Plan

- **"One Sheeters"**



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The Plan

- **“One Sheeters”**
  - Reasonable amount of detail
  - Adequate for a majority of jobs
  - Allows for some reasonable amount of flexibility

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The Plan

- **“The Works”**
  - Full 3-D BIM-Based Presentation of Each Step

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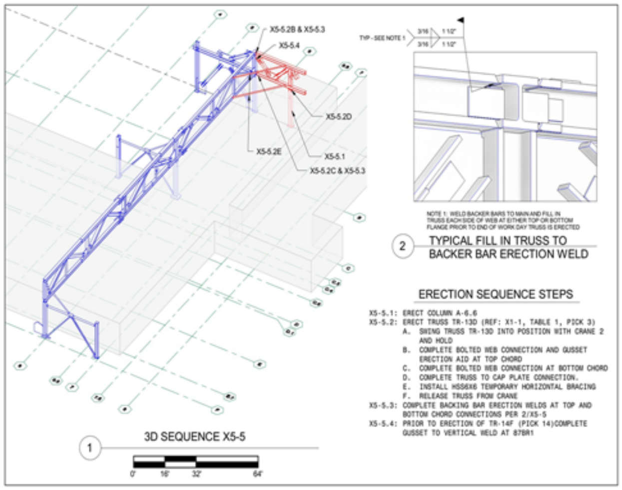
The Plan

- **"The Works"**



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The Plan

- **"The Works"**
  - Provides explicit direction for each sequence – useful for tracking progress (for all parties involved) and visualizing erection procedures
  - Very little flexibility in the field can cause some issues
  - "Owner Friendly"

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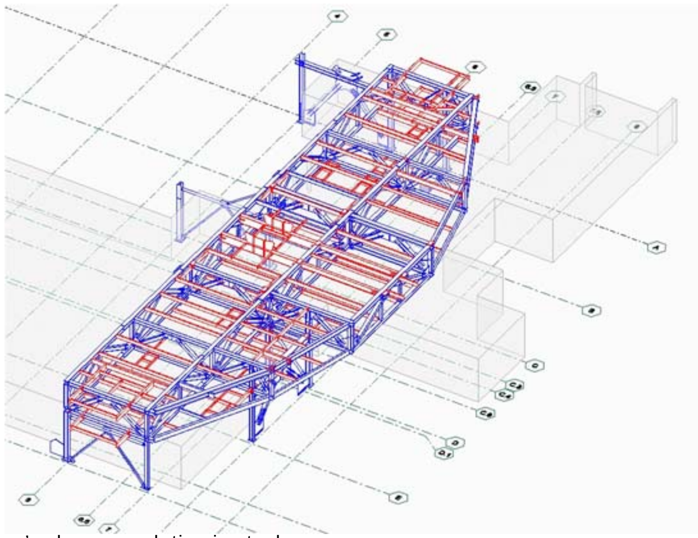
The Plan

- **"The Works"**



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The Plan

- **Erection Plans**
  - Talk through possible erection sequences with the erector – they have done this for a long time!
  - Use their ideas and verify / modify based on analysis.
  - Have the superintendent / field personnel that will be on the job involved as early as possible.
  - Be realistic – things change in the field – an open dialog is necessary

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Outline

- **Outline**
- What are the rules to play by?
- Is there any technical guidance?
- What loads needs considered?
- Stability Issues
  - Simple
  - Complex
  - Really Complex
- Conveying the plan
- **Questions**

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Questions

Thank you!

Any questions?

STRUCTURAL ENGINEERS
SDL 1966

Will Jacobs, V, P.E., S.E.

Clint O. Rex, Ph.D. P.E.

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Please give us your feedback!

Survey at conclusion of webinar.

Thank You!

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