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Course Description

Truss Design and Construction

August 9, 2018

Steel truss design and construction involves more than simply resisting the imposed loads. This webinar will provide insights into the design and construction of floor and roof trusses, covering unique load considerations like rigging, operable partitions and maintenance vehicles that are often required in facilities with long-span framing. Truss deflection and vibration considerations will also be discussed.



Learning Objectives

- List the criteria to consider when establishing deflection limits for trusses.
- Name the resources that can be useful in assessing vibration performance of long-span floor systems.
- Describe the relative advantages and disadvantages of bolted vs. welded truss connections.
- Identify the types of structural shapes commonly used in trusses. Explain how member type selection affects the design.

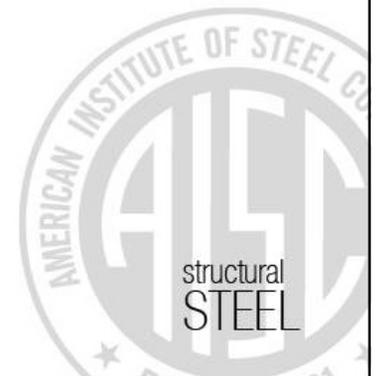


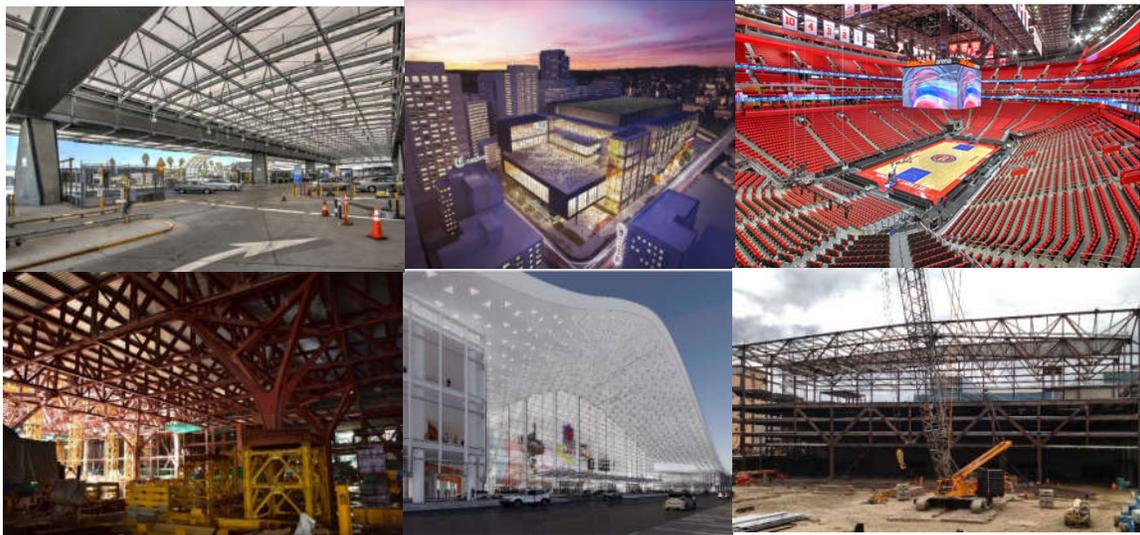
Truss Design and Construction



Presented by
Thomas R. Meyer, P.E., S.E.
Magnusson Klemencic Associates
Seattle, Washington

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Long-Span Steel Floor / Roof Trusses



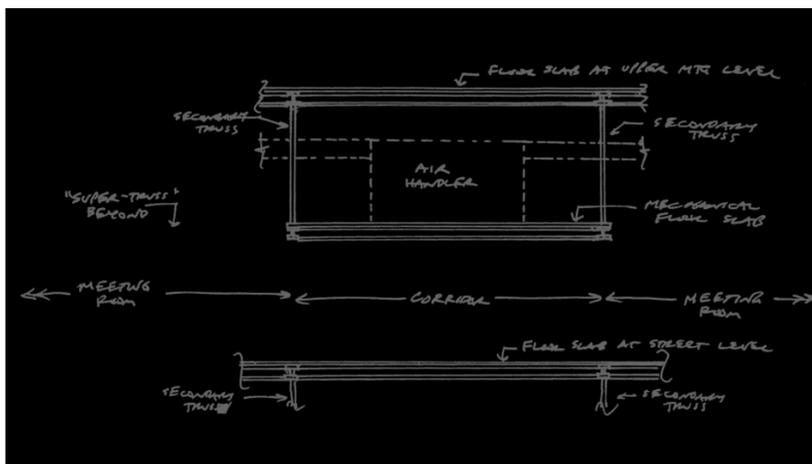
Discussion Topics

- Design Criteria
- Geometry
- Member Shapes
- Analysis
- Member Design
- Connections
- Stability



Design Criteria

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Design Criteria: Loading

Dead Loads and Superimposed Dead Loads

- Steel Self Weight is Significant
- Connection Material Weight

Code-Based Uniform Live Loads

Unique / Facility-Specific Uniform Live Loads

- Exhibit Halls: 350 psf (example)

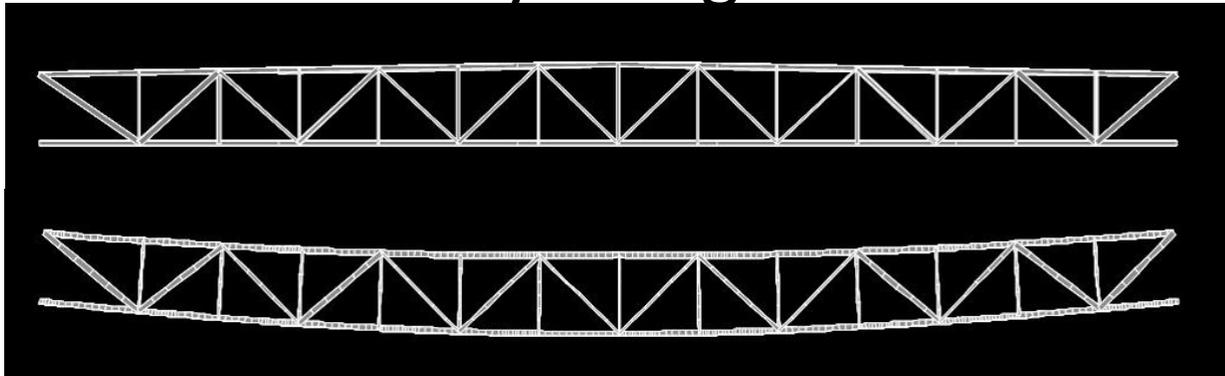
Concentrated Loads

- Vehicles / Operational Equipment
- Operable Partitions
- Rigging



13

Serviceability Design: Deflections



Standard L/240 and L/360 Not Relevant

120' Span: $L/240 = 6''$ and $L/360 = 4''$

Too much deflection!



14



Serviceability Design: Deflections

- Consider Standard Architectural Systems
 - Compensation channels at interior wall heads
 - Joint dimensions in cladding systems
- Consider Specialized Architectural Systems
 - Operable partitions
- Consider Roof Drainage and Ponding



15

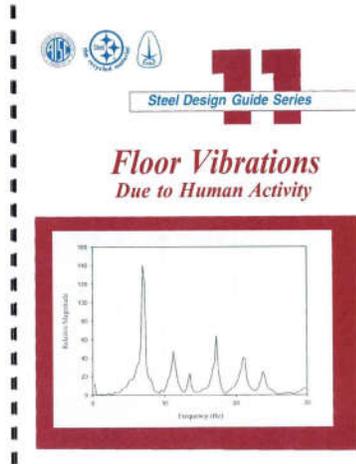
Serviceability Design: Deflections

- Camber
 - AISC Code of Standard Practice
 - Tolerance is $\pm L/800$
 - L = Distance from closest support to point where camber is specified
- Camber Tolerance for 120-ft span = $\pm 0.9''$



16

Serviceability Design: Floor Vibrations



Serviceability Design: Floor Vibrations

- Airport Concourses
- Shopping Malls
 - 1.5% g



Serviceability Design: Floor Vibrations

- Pedestrian Bridges
 - 1.5% g (Indoor)
 - 5.0% g (Outdoor)



19

Serviceability Design: Floor Vibrations

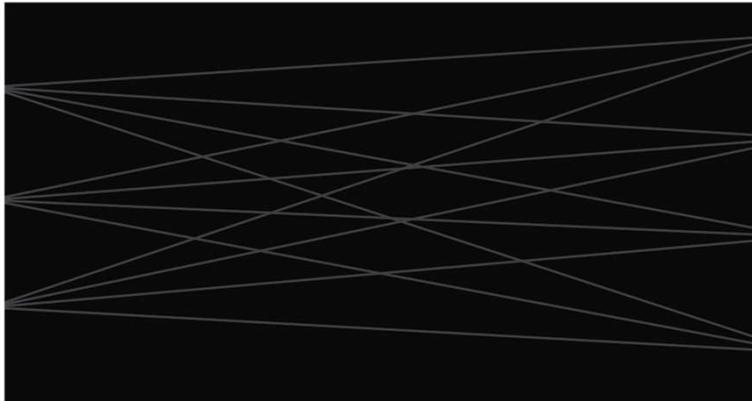
- Dining and Dancing
 - 2.0% g



20

Geometry Considerations

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Geometry Considerations: Depth

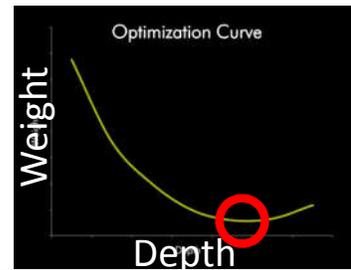
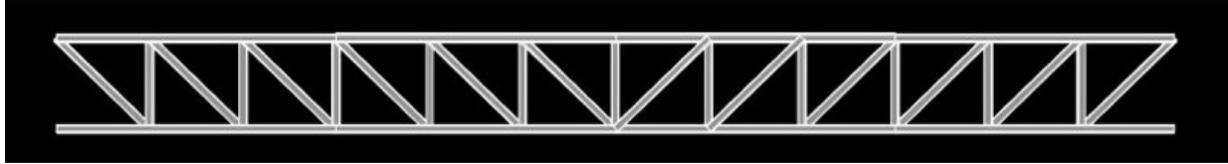
Rule of Thumb Depth: $\text{Depth in Inches} = \text{Span in Ft} / 2$



22



Geometry Considerations: Depth



23

Geometry Considerations: Depth

- Span-to-Depth Ratio
- Roof Truss
 - **Relatively flat between 12 and 15**
 - Significant increases above 15
- Floor Truss (Strength-Controlled)
 - **Relatively flat between 8 and 10**
 - Significant increases above 10
- Floor Truss (Vibration-Controlled)
 - **Modest increases between 6 and 8**
 - Significant increases above 8



24



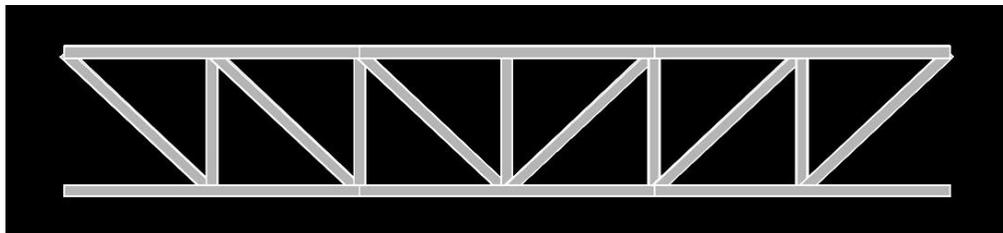
Geometry Considerations: Layout

- Architectural Considerations
 - Tension / Compression Member Efficiency
 - Load Flow
 - M/E/P Routing
-



25

Geometry Considerations: Layout

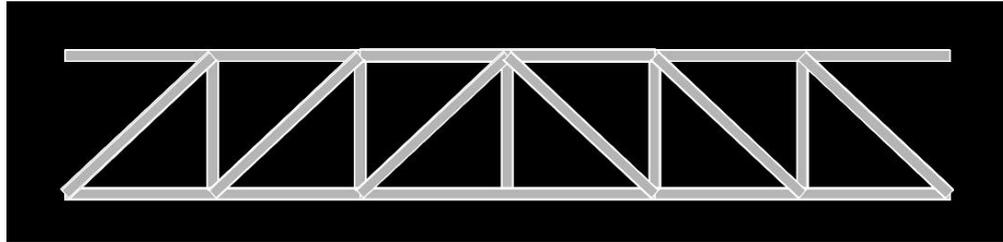


Pratt Truss



26

Geometry Considerations: Layout

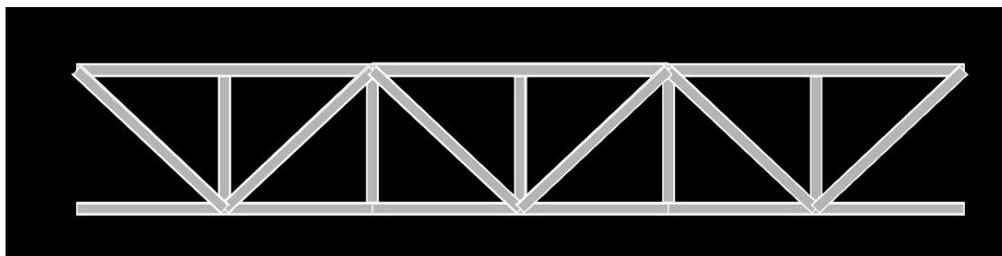


Howe Truss



27

Geometry Considerations: Layout

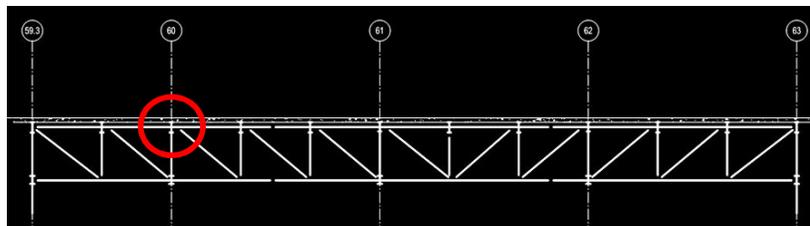


Warren Truss

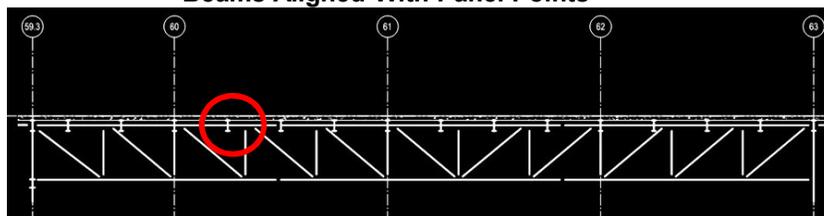


28

Geometry Considerations: Panels



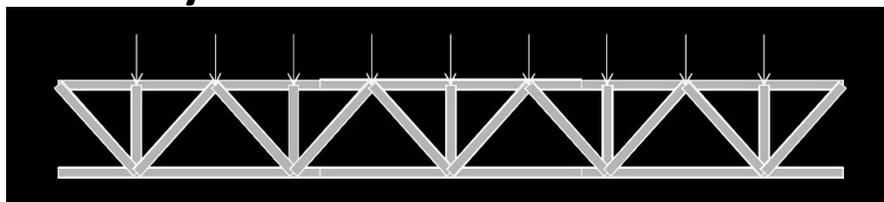
Beams Aligned With Panel Points



Beams Not Aligned With Panel Points

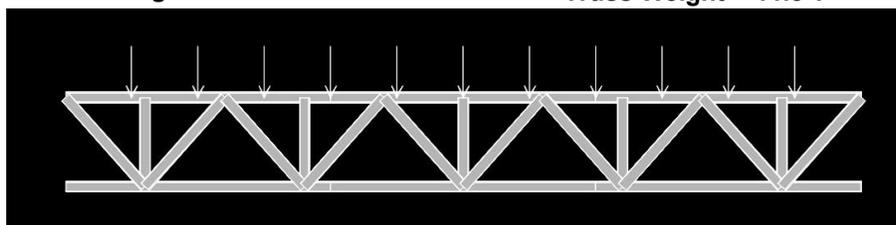


Geometry Considerations: Panels



Beams Aligned With Panel Points

Truss Weight = 11.5 T



Beams Not Aligned With Panel Points

Truss Weight = 11.6 T



Geometry Considerations: Shipping



31

Geometry Considerations: Shipping

- Pre-Fabricated Truss Dimensions:
 - 50'-0" Length x 8'-6" Depth
- Pre-Fabricated Truss Dimensions:
 - 50'-0" Length x 12'-6" Depth

Lay Flat
On Trailer Bed



Lay At Angle
On Trailer Bed



- **Dimensions can be increased with special permits**



32



Geometry Considerations: Shipping



33

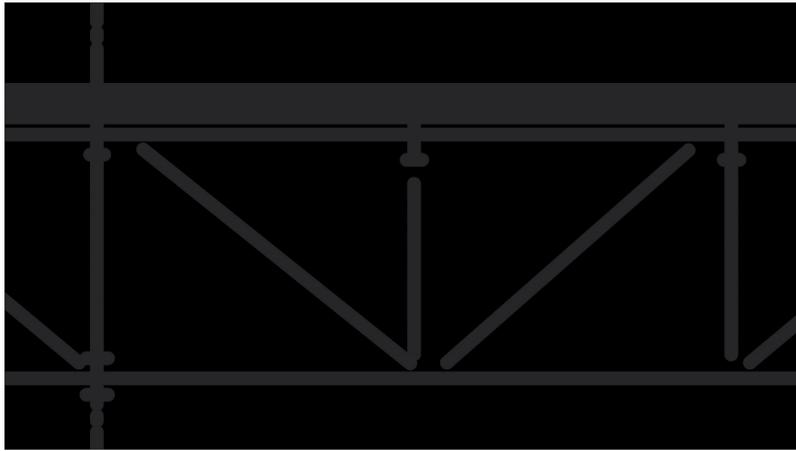
Geometry Considerations: Shipping



34

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Member Shapes



Member Shapes



Member Shapes: Web Members

- Tension Web Members



37

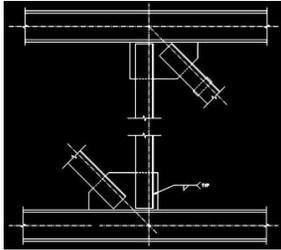
Member Shapes: Web Members

- Compression Web Members

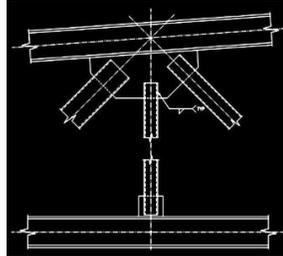


38

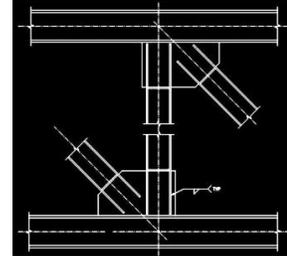
Member Shapes: Web Members



Double Angles



Hollow Structural Sections



Wide Flanges

- Architectural Considerations
- Truss Connection Considerations
- Compression Efficiency Considerations
- Shape Cost Considerations



39

Member Shapes: Chord Members

- Tension Chord



40

Member Shapes: Chord Members

- Compression Chord



41

Member Shapes: Chord Members



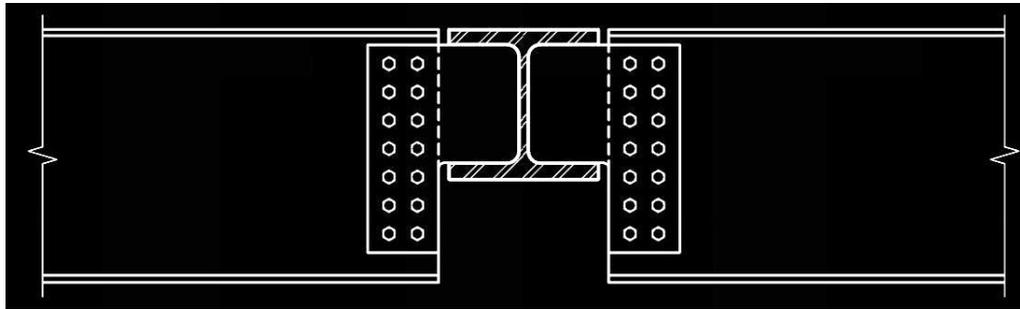
- Architectural Considerations
- Truss Connection Considerations
- Shape Cost Considerations
- Incoming Member Connection Considerations
- Alignment Considerations



42

Member Shapes: Chord Members

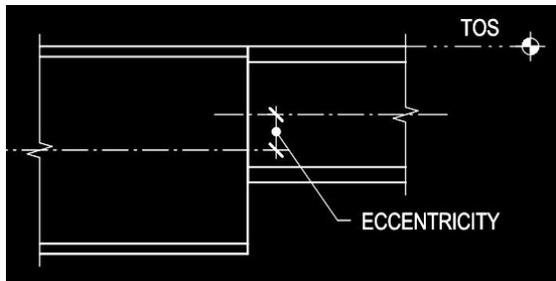
- Incoming Members



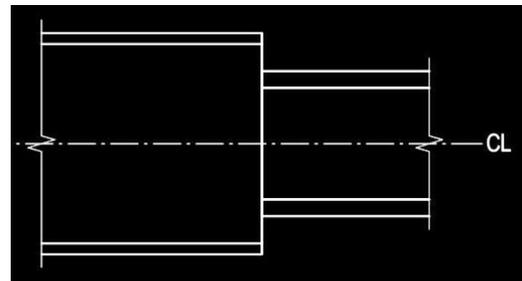
43

Member Shapes: Chord Members

- Alignment



Top of Steel Aligned



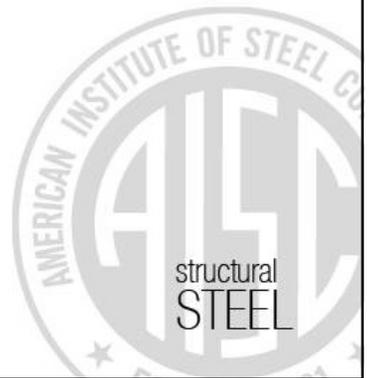
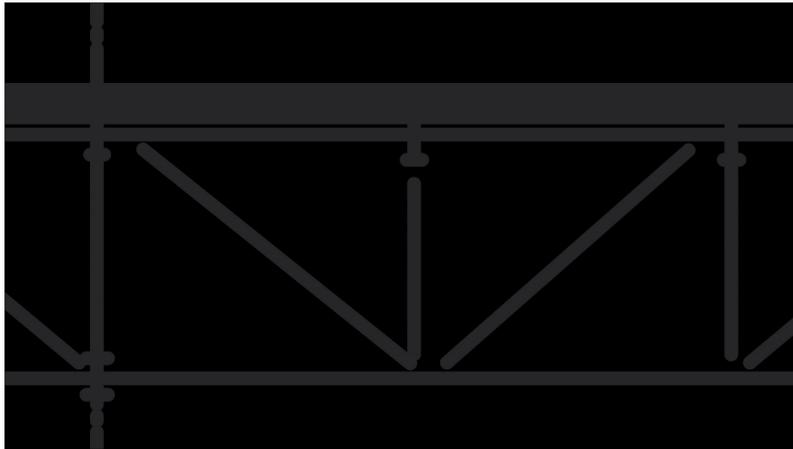
Centerline Aligned



44

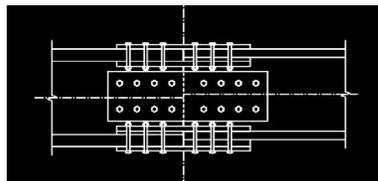
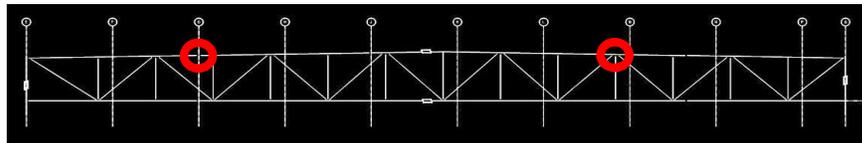
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Truss Analysis

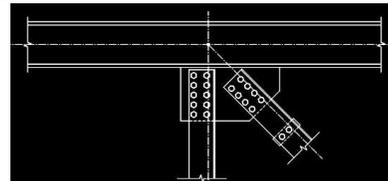


Truss Analysis: Member Fixity

- Pinned Vs. Fixed



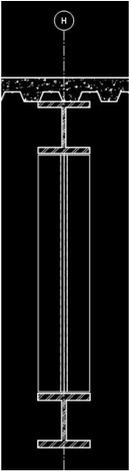
Chord Splices – Pinned or Fixed?



Web Connections – Pinned or Fixed?



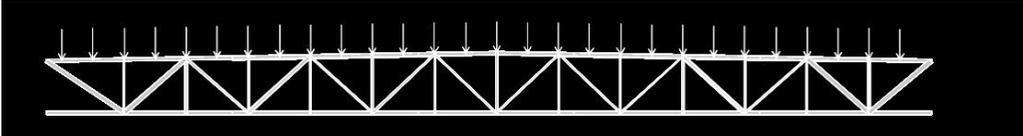
Truss Analysis: Composite Action



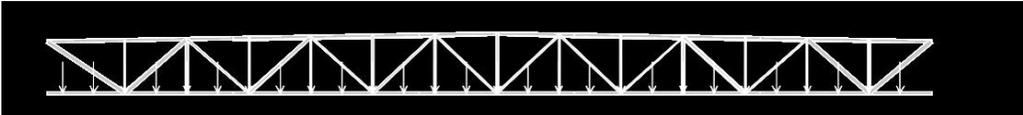
Floor Trusses – Composite or Non-Composite?



Truss Analysis: Applied Loads



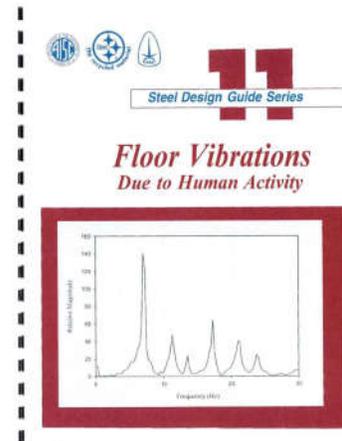
Top Chord Loads



Bottom Chord Loads



Truss Analysis: Floor Vibrations



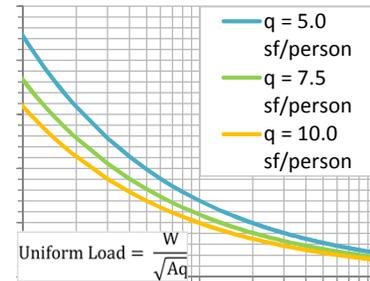
Truss Analysis: Floor Vibrations

- ISO 10137



Truss Analysis: Floor Vibrations

- Uncoordinated Group Walking
 - Uniform Loading



51

Truss Analysis: Floor Vibrations

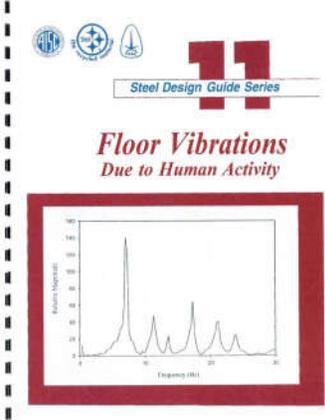
- Rhythmic Excitation



52

Truss Analysis: Floor Vibrations

- Rhythmic Excitation



Basic Hand Calculation



Truss Analysis: Floor Vibrations

- Rhythmic Excitation

Dynamic Amplitude Prediction for Ballroom Floors

ABSTRACT
 To understand the derivation of the modifications proposed herein, a review of the current criteria definitions is presented. The peak dynamic amplitude, in this case acceleration, of a simply supported beam-like floor system subjected to dance-type loads can be conservatively approximated as the steady-state acceleration peak at the mid-span for the dynamic beam under dance as shown in Figure 1, where β is the uniformly distributed constant load specified in Design Guide 11 (Moray et al. 1977). If β is an arbitrary finite load, and β_0 is the steady state acceleration response at mid-span. The dynamic behavior of the beam is governed by the partial differential equation (Moray, 1977)

$$M \frac{\partial^2 C(t)}{\partial t^2} + C(t) = M \beta_0 C(t) + F(t, x) \quad (1)$$

where
 C = homogeneous differential stiffness operator
 C_0 = homogeneous differential damping operator
 M = homogeneous differential mass operator
 $F(t, x)$ = displacement of point x
 $F(t, x)$ = a continuous function along the span of the beam
 $F(t, x)$ = floor loads

Assuming a solution to Equation 1 of the form

$$W(x) = \sum_{n=1}^{\infty} A_n \sin \frac{n\pi x}{L} \cos \omega_n t \quad (2)$$

Fig. 1. Dynamic beam model.

Linda M. Morgan is an assistant professor, architectural engineering department, Pennsylvania State University, University Park, PA.

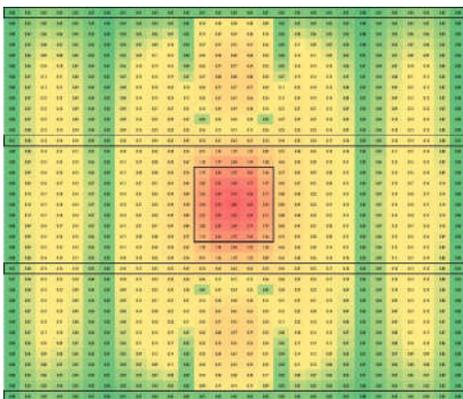
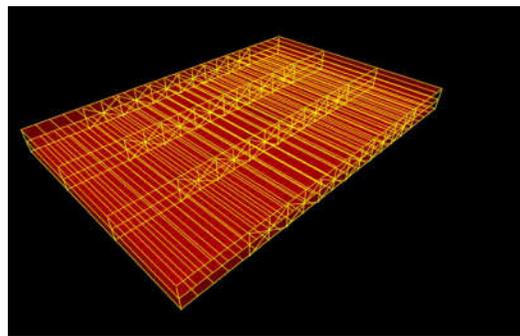
148 / ENGINEERING JOURNAL / THIRD QUARTER / 2002

Modified Hand Calculation



Truss Analysis: Floor Vibrations

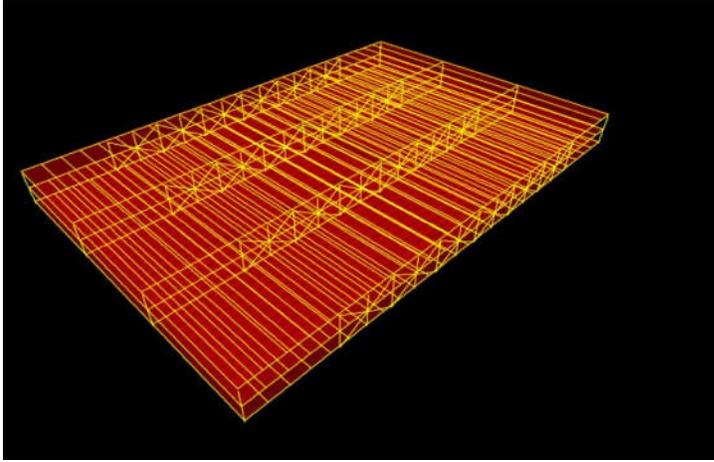
- Rhythmic Excitation



Dynamic Analysis Modeling



Truss Analysis: Floor Vibrations



Truss Analysis: Floor Vibrations

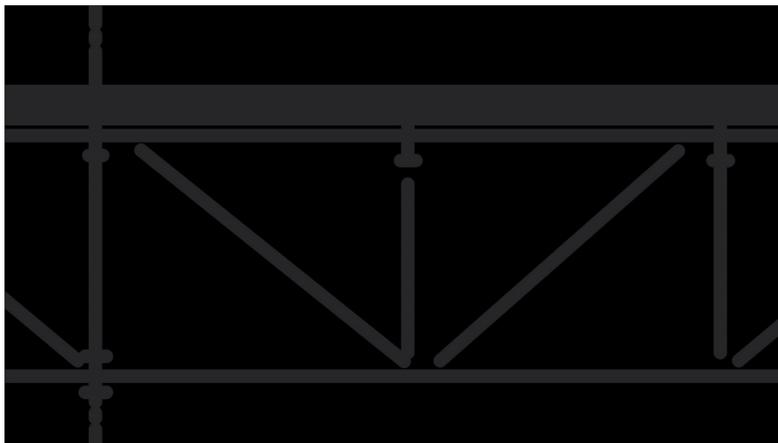
- Basic Hand Calculation:
 - Predicted Floor Acceleration = 10.6% g
- Modified Hand Calculation:
 - Predicted Floor Acceleration = 4.0% g
- Dynamic Analysis Model:
 - Predicted Floor Acceleration = 2.0% g



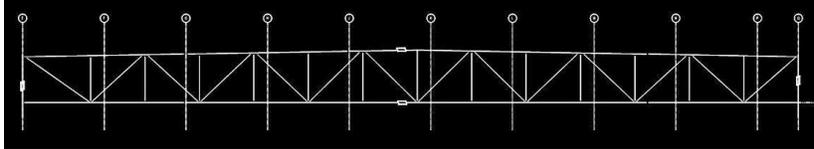
57

Member Design

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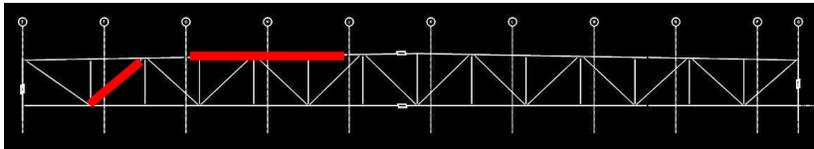
Member Design



59

Member Design

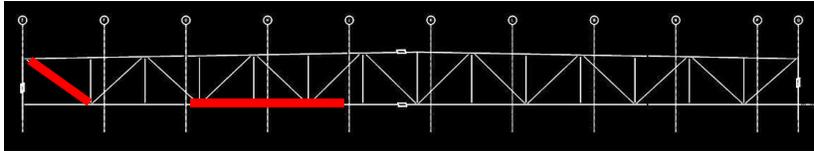
- Compression Members



60

Member Design

- Tension Members



61

Member Design



Compression Members



Tension Members

- Determine member forces and design members per AISC 360 criteria

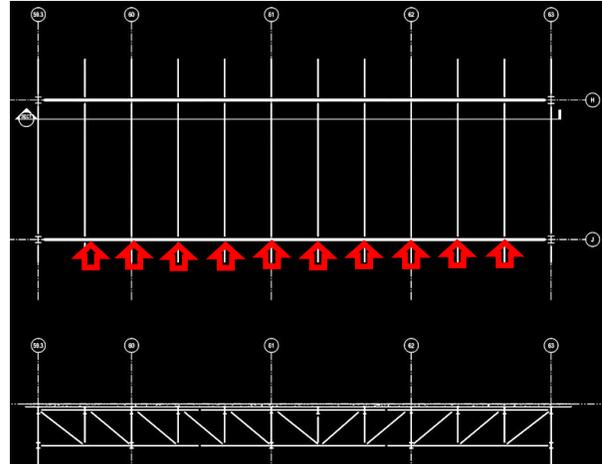


62



Member Design

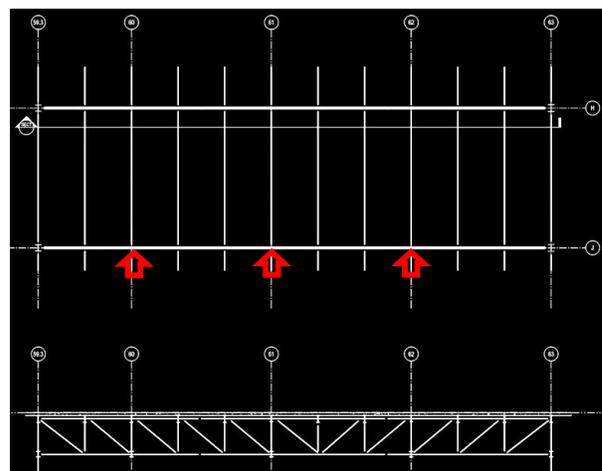
- Brace Points?



63

Member Design

- Brace Points?



64



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Truss Connections



Truss Connections



Bolted Connection



Welded Connection



Truss Connections: Bolted

- Standard Holes vs. Slotted or Oversize Holes?
- F3125 Grade A325 vs. A490 Bolts?
- Bolt Diameter?
- Consistent vs. Variable Bolt Sizes?
- Slip-Critical vs. Bearing Bolts?
- N-Bolts vs. X-Bolts?



67

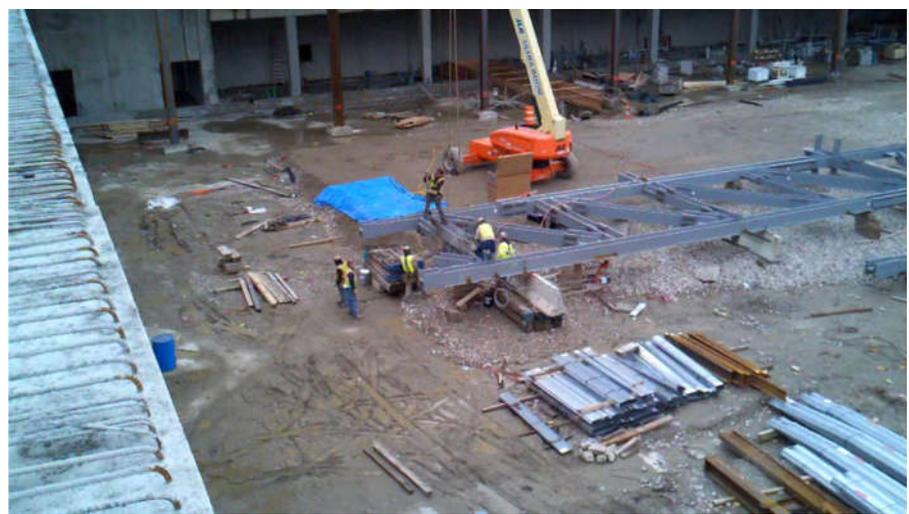
Truss Connections: Bolted

- Consider Net Section and Block Shear
 - Limit DCR During Design?
 - Stagger Bolts?
 - Doubler Plates Required?
- Consider Weld Access if Bolts Don't Fit

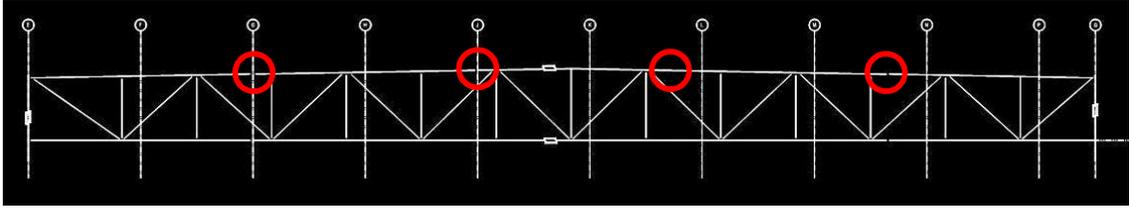


68

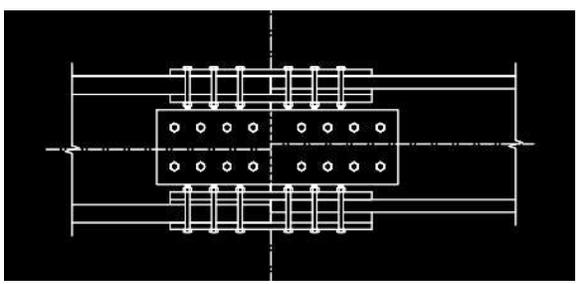
Truss Connections: Bolted



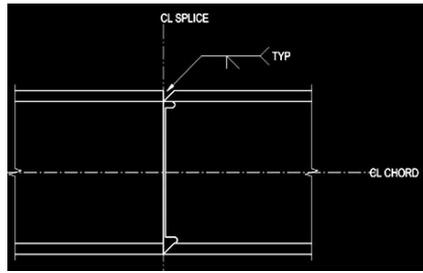
Truss Connections: Chord Splices



Truss Connections: Chord Splices



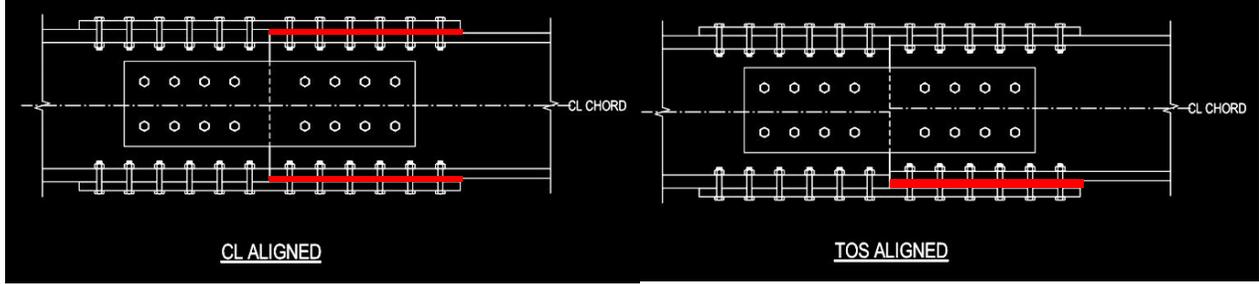
Bolted Splice



Welded Splice



Truss Connections: Chord Splices



CL ALIGNED

TOS ALIGNED

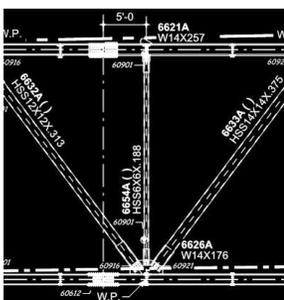
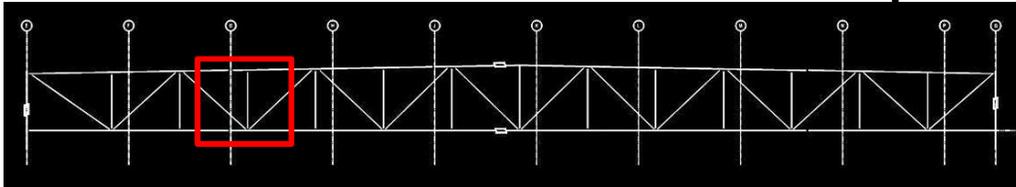


Truss Connections: Chord Splices



73

Truss Connections: Chord Splices



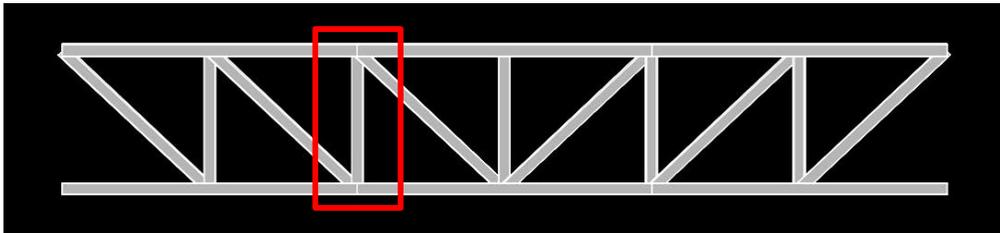
- Considerations
 - Splice Length
 - Conflict with Truss Web Connections
 - Conflict with Incoming Beam Connections
 - Conflict with M/E/P System Routing



74



Truss Connections: Web-to-Chord



75

Truss Connection: Web-to-Chord

*To Gusset Plate or Not To Gusset Plate...
That Is The Question*



76



Truss Connections: Web-to-Chord

- No Gusset Plate
- Pros
 - Often Architecturally Preferred
 - Reduces M/E/P Routing Conflicts
- Cons
 - No Bolted Options
 - Extensive CJP / PJP Welding Typically Required
 - Slower Site Assembly
 - Not Appropriate for All Shapes



77

Truss Connections: Web-to-Chord

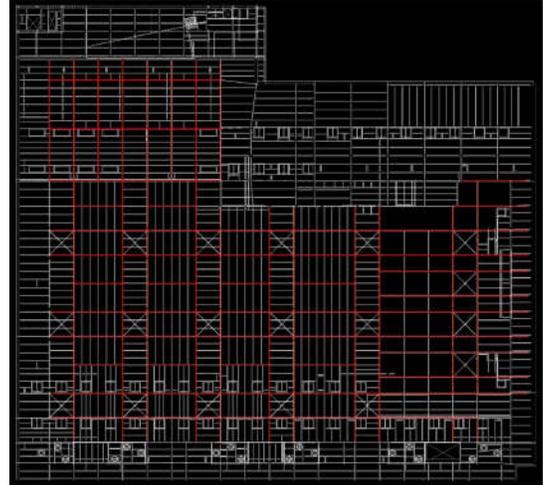
- Gussets
- Pros
 - Bolted or Fillet Welded Connections
 - Faster Site Assembly
- Cons
 - Can Create M/E/P Routing Challenges



78

Truss Connections: Web-to-Chord

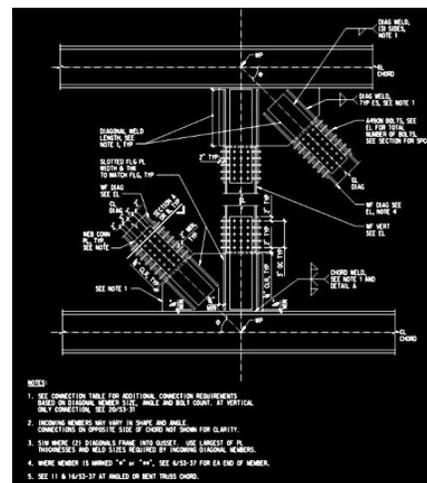
- Gusset Plates Connections



Truss Connections: Web-to-Chord

- Gusset Plate Connections

CONNECTION TABLE								
# NO. 15 IN DIAGONAL MEMBER	ANGLE EXCESS	GUSSET PL. THICKNESS (INCH)	NUMBER OF WEB PLATES	WEB PLATE THICKNESS (INCH)	DIAGONAL WELD LENGTH (INCH)	DIAGONAL WELD SIZE (INCH)	CHORD PP. WELD (INCH)	CHORD PP. WELD (SPACING) (INCH)
14	30 x # 1.50	1/2	1	1/2	8	1/4	1/4	1/4
21	30 x # 1.50	1/2	1	1/2	13	1/4	1/4	1/4
21	30 x # 1.50	1/2	1	1/2	13	1/4	1/4	1/4
22	30 x # 1.50	1/2	1	1/2	11	1/4	1/4	1/4
22	30 x # 1.70	1/2	1	1/2	11	1/4	1/4	1/4
28	30 x # 1.50	1/2	1	1/2	11	1/4	1/4	1/4
28	30 x # 1.50	1/2	1	1/2	11	1/4	1/4	1/4
33	30 x # 1.70	1/2	1	1/2	14	1/4	1/4	1/4
35	30 x # 1.50	1/2	1	1/2	14	1/4	1/4	1/4
44	30 x # 1.40	1/2	1	1/2	16	1/4	1/4	1/4
44	45 x # 1.70	1/2	1	1/2	16	1/4	1/4	1/4
55	30 x # 1.40	1/2	1	1/2	17	1/4	1/4	1/4
55	30 x # 1.70	1/2	1	1/2	17	1/4	1/4	1/4
66	30 x # 1.40	2	1	2	21	1/4	1/4	1/4
66	45 x # 1.70	1/2	1	2	21	1/4	1/4	1/4
77	30 x # 1.40	1/2	2	1/2	24	1/4	1/4	1/4
77	45 x # 1.70	1/2	2	1/2	24	1/4	1/4	1/4
88	30 x # 1.40	1/2	2	1/2	24	1/4	1/4	1/4
88	45 x # 1.50	1/2	2	1/2	24	1/4	1/4	1/4
88	45 x # 1.70	1/2	2	1/2	24	1/4	1/4	1/4
99	30 x # 1.50	1/2	2	1/2	28	1/4	1/4	1/4
99	30 x # 1.70	1/2	2	1/2	28	1/4	1/4	1/4
110	30 x # 1.40	1/2	2	1/2	28	1/4	1/4	1/4
110	30 x # 1.70	1/2	2	1/2	28	1/4	1/4	1/4
121	30 x # 1.40	3	2	1/2	30	1/4	1/4	1/4

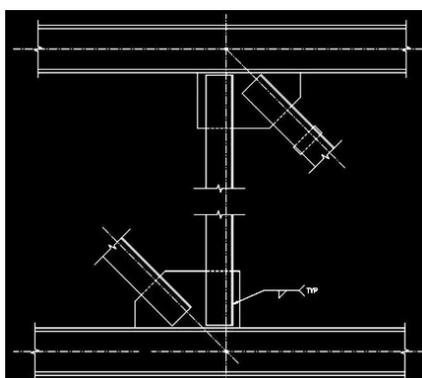
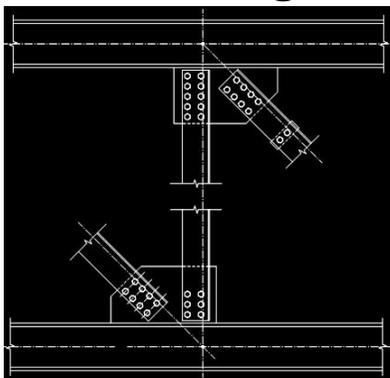


Truss Connections: Web-to-Chord



Truss Connections: Web-to-Chord

- Double Angles



Truss Connections: Web-to-Chord

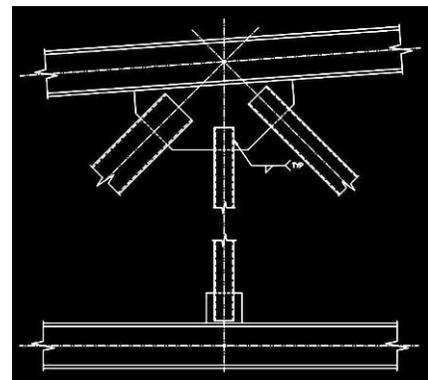
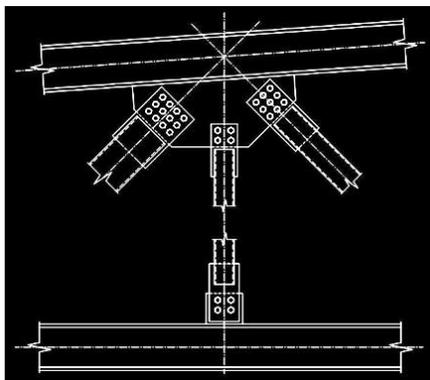
- Minimum Leg Length for Bolted Connections
 - < 6" – 1 Row
 - 6" – 2 Rows (Staggered)
 - 8" – 2 Rows (In Line)
- Bolt Groups Can Be Long
- Easy Field Bolt Installation / Fillet Welding
- Don't Forget about Shear Lag Effects
- Don't Forget about Stitch Plates



83

Truss Connections: Web-to-Chord

- HSS



84

Truss Connections: Web-to-Chord

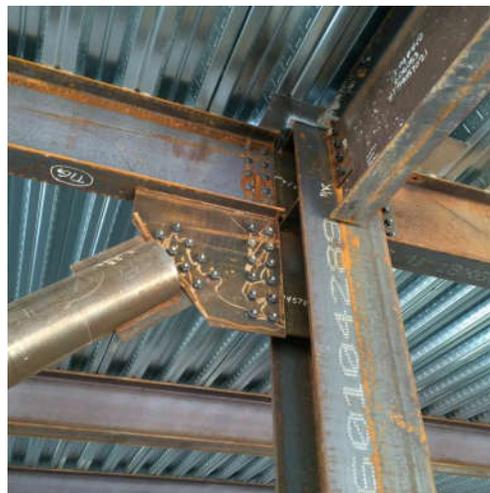
- Weld HSS Directly to Gusset Plate
 - Over-Size Slot for Tolerance?
 - Patch Plates Required?
 - Field Welding



85

Truss Connections: Web-to-Chord

- Connection Plate Bolted to Gusset Plate
 - Shop Welding / Field Bolting
 - Eccentricity Somewhere

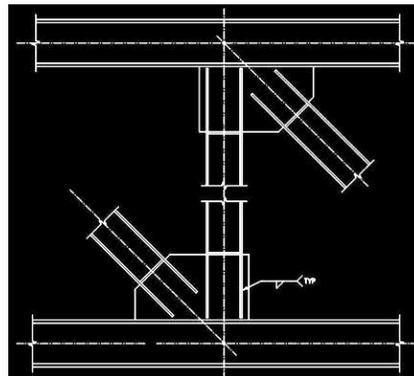
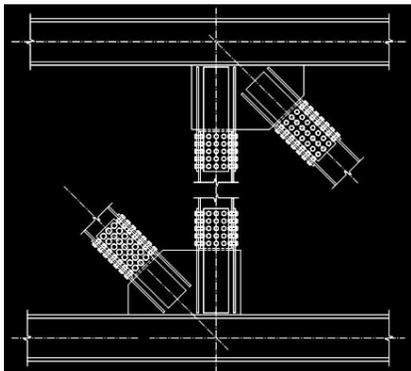


86



Truss Connections: Web-to-Chord

- Wide Flange



87

Truss Connections: Web-to-Chord

- Wide Flange



88



Truss Connections: Web-to-Chord

- Wide Flange
- Large Number of Bolts per Row
 - Compact Connections
 - Net Section Issues
 - Doubler Plates



89

Truss Connections: Web-to-Chord

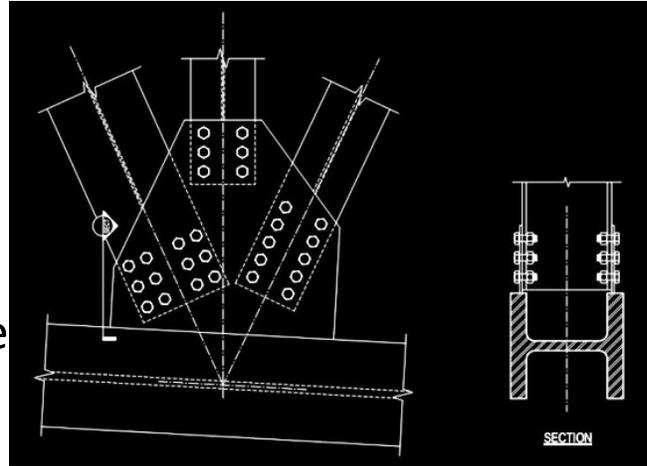
- Webs Horizontal
- **Works Great If All Members Same Size**
- **If Not...**
 - Filler Plates Required for External Gusset Plates



90

Truss Connections: Web-to-Chord

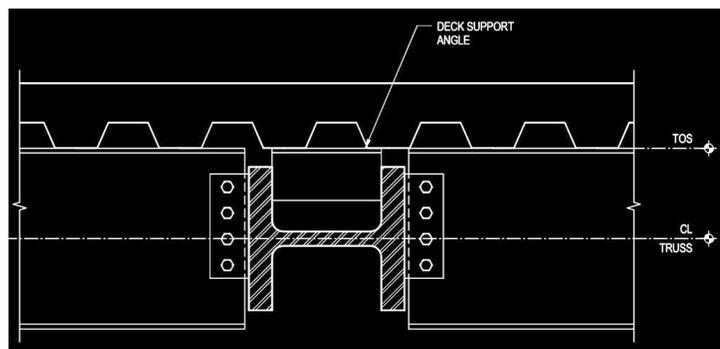
- Webs Horizontal
- **Works Great If All Members Same Size**
- **If Not...**
 - Co-Planar Gusset Plate to Chord Flange Weld Can Be Challenging



91

Truss Connections: Web-to-Chord

- Web Horizontal



Floor or Roof Deck Support



92



Truss Connections: End Connections

- Similar to Vertical Bracing Connections

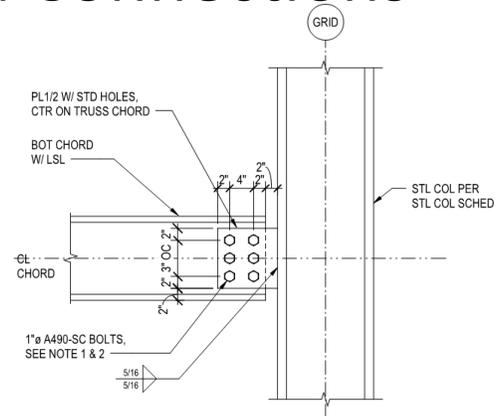


Vertical Bracing Connections—
Analysis and Design



Truss Connections: End Connections

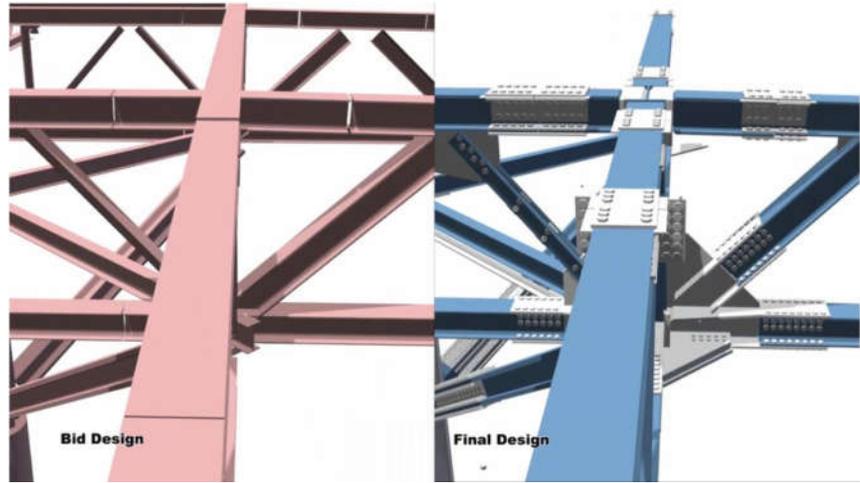
- Bottom Chord – Slotted vs. Locked



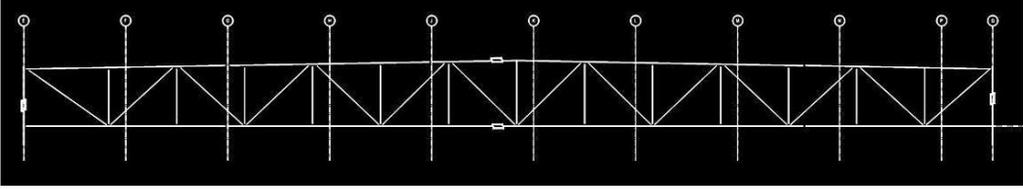
- NOTES:
1. PROVIDE (6) BOLTS FOR W14 CHORDS, (8) BOLTS FOR W21-W27 CHORDS, AND (12) BOLTS FOR W30-W44 CHORDS.
 2. BOLTS SHALL BE FINGER TIGHT UNTIL ALL TRUSSES ARE ERECTED AND STEEL DECK AND CONCRETE IS INSTALLED, THEN BOLTS SHALL BE TIGHTENED TO SLIP-CRITICAL CRITERIA.



Truss Connections: Material Weight



Truss Connections: Material Weight



Well-Proportioned Truss: ~ 15% Connection Factor

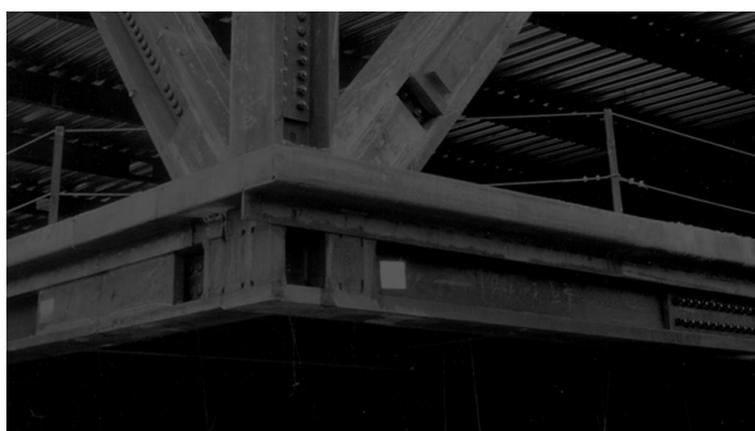


Poorly-Proportioned Truss: Connection Factors Increase Rapidly



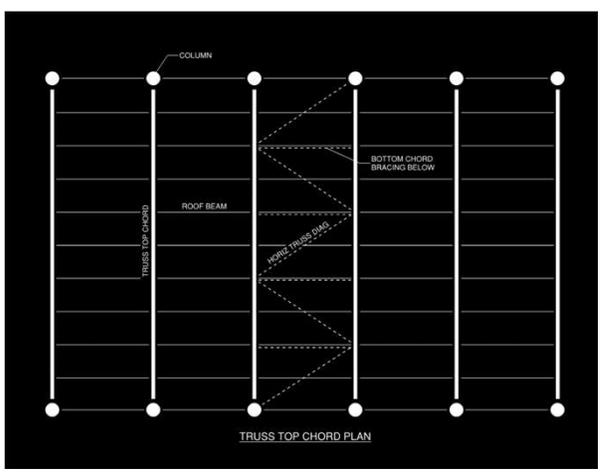
There's always a solution in steel.

Stability Considerations



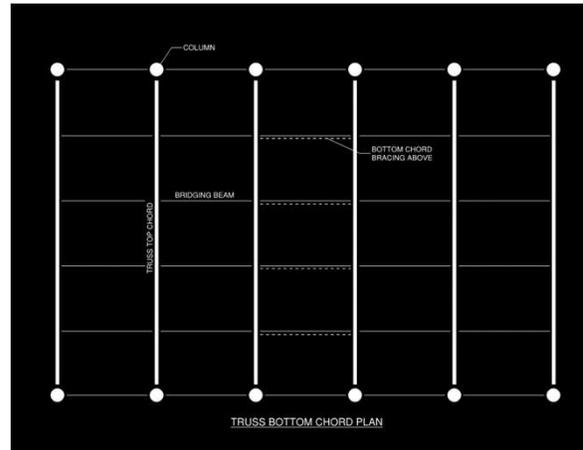
Stability Considerations

- Top Chord Plan



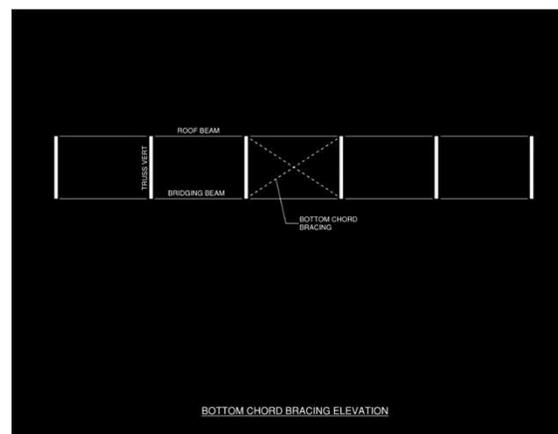
Stability Considerations

- Bottom Chord Plan



Stability Considerations

- Bracing Elevation



Stability Considerations

- AISC Appendix 6.3 (Beams & Trusses)
 - Limit the twist of the truss
 - Provide lateral bracing at compression chord
 - Provide torsional bracing to connect the tension and compression chords
 - Provide tension chord bracing to stabilize compression web members



101

Stability Considerations

- Items to Consider
 - Consider all trusses buckling in the same mode
 - Consider both strength *and* stiffness of stability load path
 - Don't forget bracing at the tips of cantilever trusses
 - Watch for chord axial load reversal
 - Add bracing forces to all dead load cases
 - Consider the type of bracing appropriately
 - Panel Bracing
 - Point Bracing

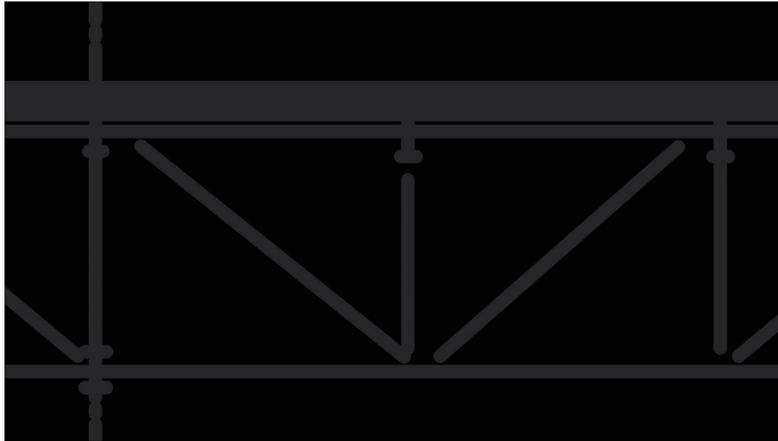


102



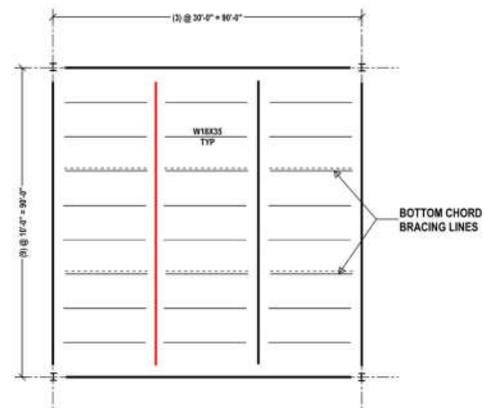
There's always a solution in steel.

Examples



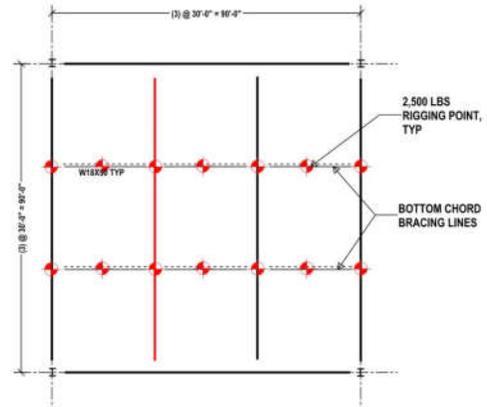
Example 1: Geometry

- Top Chord Framing Plan
 - 90'-0" x 90'-0" bay
 - Trusses at 30'-0" o.c.
 - 4 1/2" slab on 3" steel deck (7 1/2" total)
 - W18x35 beams 10'-0" o.c.



Example 1: Geometry

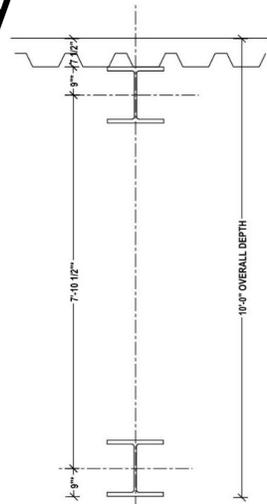
- Bottom Chord Framing Plan
 - 2,500 lbs. Rigging Loads
 - W18x50 Rigging Beams
 - Bottom Chord Bracing @ 30'-0"



105

Example 1: Geometry

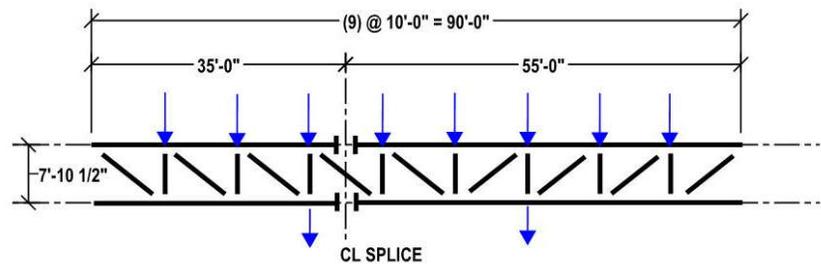
- Truss Section
 - 10'-0" overall structural depth
 - Span-to-depth = 9
 - 7'-10 1/2" effective truss depth



106

Example 1: Geometry

- Truss Elevation
 - (1) splice



107

Example 1: Geometry

- Members
 - W14 chords (A992, $F_y = 50$ ksi)
 - HSS webs (A500, Grade C, $F_y = 50$ ksi)



108

Example 1: Loading Criteria

- Dead Loads
 - Slab on Steel Deck (75 psf)
 - Steel Framing
 - Ceiling/MEP/Miscellaneous SDL (10 psf)
 - Truss Self-weight
- Live Loads
 - 250 psf Uniform Live Load
 - Rigging (per diagram)



109

Example 1: Serviceability Criteria

- Live Load Deflection < 2.0 inches
- Not Sensitive to Floor Vibrations

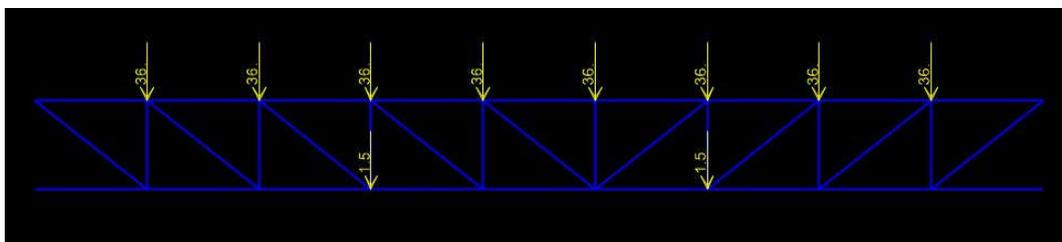


110



Example 1: Analysis

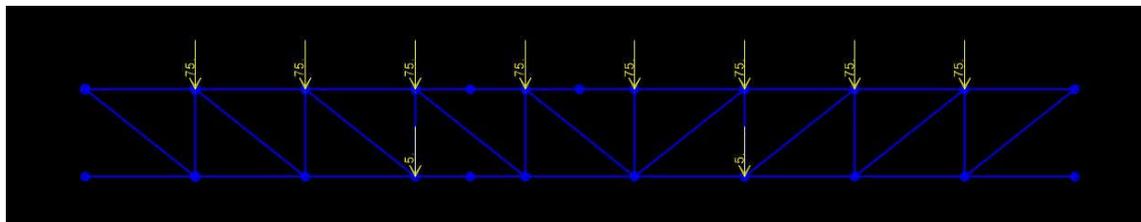
- Applied Loads – Dead Loads



111

Example 1: Analysis

- Applied Loads – Live Loads

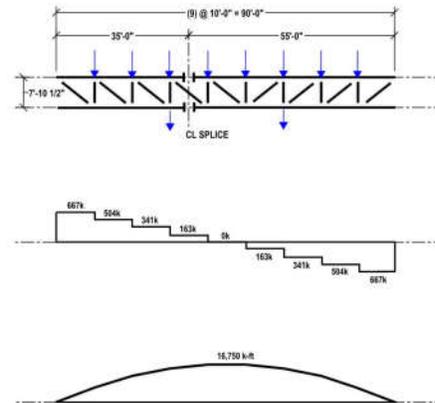


112



Example 1: Analysis

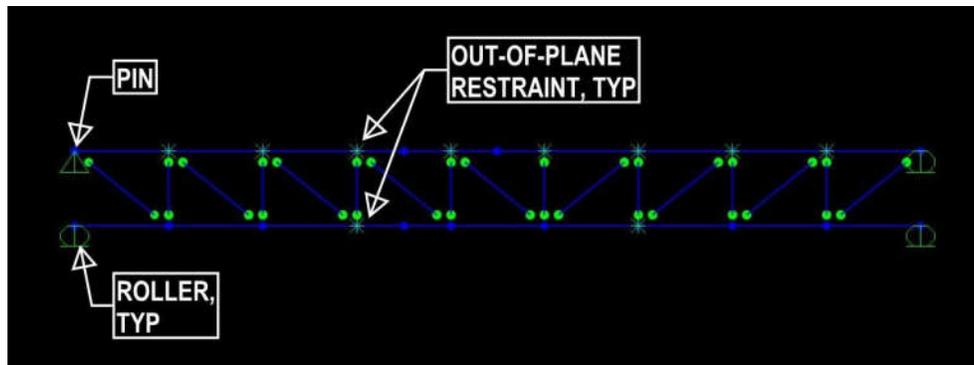
- Preliminary Hand Calculation
 - Shear: 667 k
 - Midspan Moment: 16,750 k-ft
- Estimate Chord Force
 - $16,750 \text{ k-ft} / 7.875 \text{ ft} = 2,127 \text{ k}$
- Load Combination: $1.2D+1.6L$



113

Example 1: Analysis

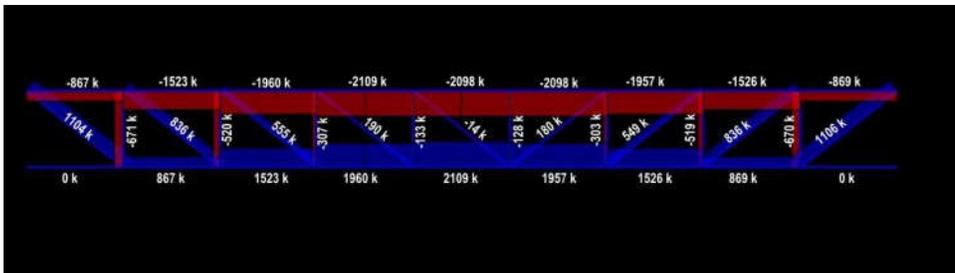
- Boundary Conditions and Releases



114

Example 1: Analysis

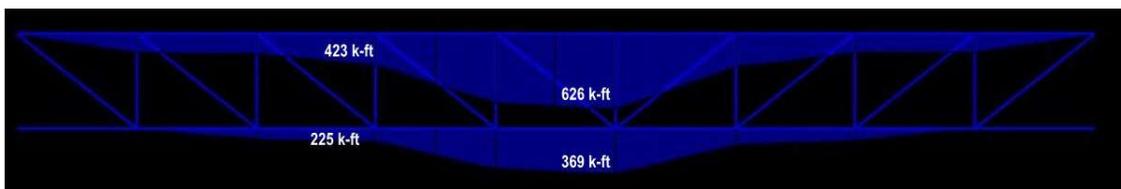
- Member Forces - Axial



115

Example 1: Analysis

- Member Forces - Moments



116



Example 1: Design

- Unbraced Lengths – Top Chord
 - $L_x = 10'-0''$
 - $L_y = 30'-0''$
 - $L_{LTB} = 10'-0''$
- Unbraced Lengths – Bottom Chord
 - $L_x = 10'-0''$
 - $L_y = 30'-0''$
 - $L_{LTB} = 30'-0''$



117

Example 1: Design

- Unbraced Lengths – Verticals
 - $L_x = 7'-10 \frac{1}{2}''$
 - $L_y = 7'-10 \frac{1}{2}''$
- Unbraced Lengths – Diagonals
 - $L_x = 12'-9'' \pm$
 - $L_y = 12'-9'' \pm$

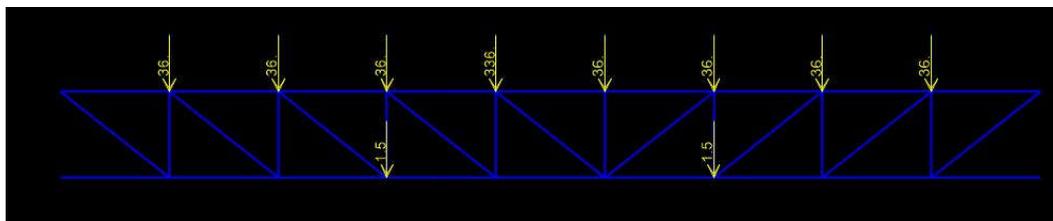


118



Example 2: Analysis

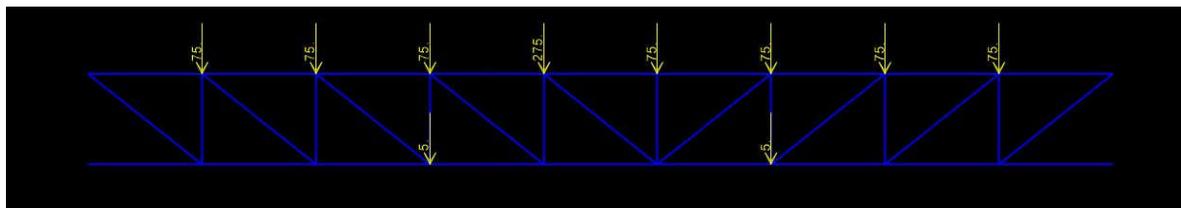
- Applied Loads – Dead Loads



121

Example 2: Analysis

- Applied Loads – Live Loads

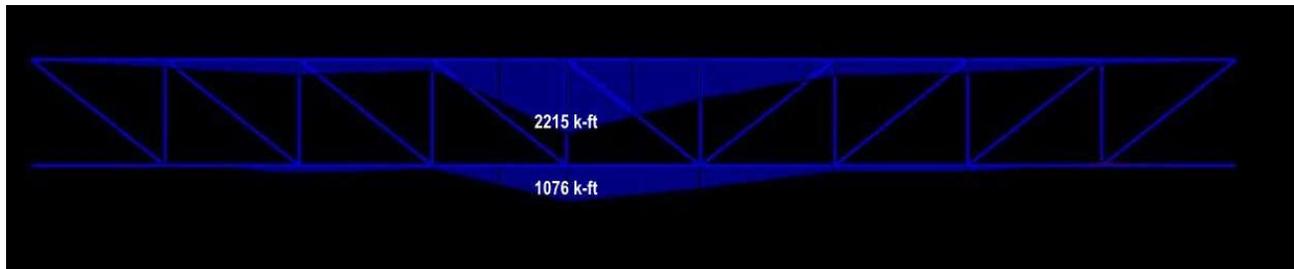


122



Example 2: Analysis

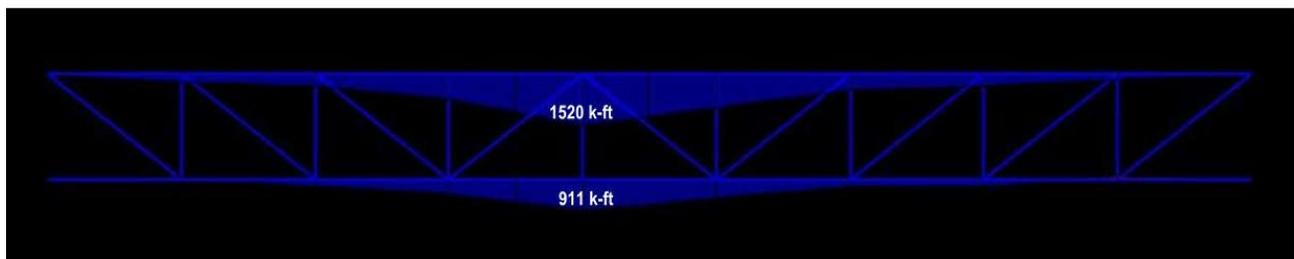
- Member Forces – Moments (1.2D+1.6L)



123

Example 2: Analysis

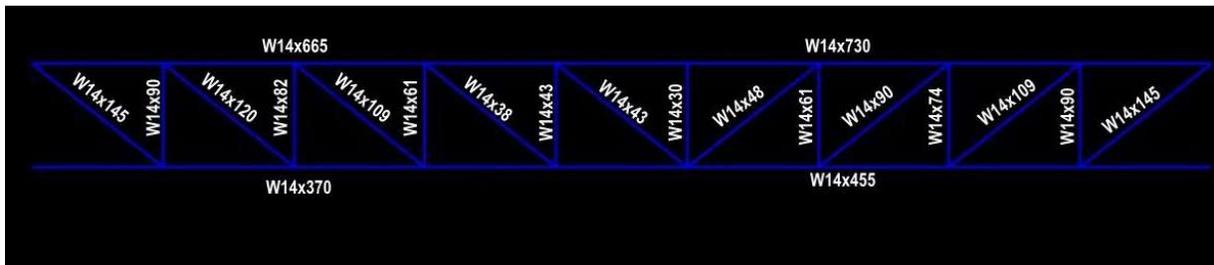
- Member Forces – Moments (1.2D+1.6L)



124

Example 2: Design

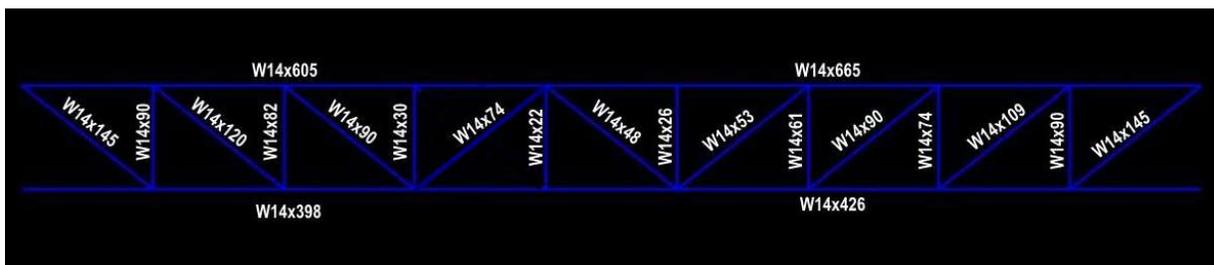
- Design Results
 - Self-weight: 58.1 tons (1,291 plf)



125

Example 2: Design

- Design Results
 - Self-weight: 55.0 tons (1,222 plf)



126



Questions?



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!



PDH Certificates

Within 2 business days...

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



Thank You

Please give us your feedback!
Survey at conclusion of webinar.



There's always a solution in steel.

