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Course Description

Effective Bracing of Flexural Members and Systems in Steel Buildings and Bridges

March 7, 2018

This lecture is focuses on the stability of flexural systems in steel buildings and bridges with a particular emphasis on bracing requirements. The lecture highlights the results from large-scale experiments and parametric finite element analysis on flexural members. The many factors that impact the effectiveness of torsional bracing systems are covered. An overview of the system buckling mode for I-shaped girder systems, which is a relatively new failure mode the profession has become aware of over the past 15 years, is also discussed. Improved details such as the use of split pipe stiffeners and lean-on bracing are also covered.

Learning Objectives

- Describe the factors that impact the effectiveness of torsional bracing systems.
- Describe the system buckling mode for I-shaped girder systems.
- Describe the recent improvements to bracing details split pipe stiffeners and lean-on bracing.
- Describe the results on large-scale bracing experiments and how the results impact bracing requirements.

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Effective Bracing of Flexural Members and Systems in Steel Buildings and Bridges

Presented by
Todd Helwig, PhD
University of Texas at Austin

Effective Bracing of Steel Bridge Girders

Todd Helwig
University of Texas at Austin

March 7, 2018
AISC Webinar

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Outline

- Stability Bracing of I-shaped Girders and Systems (Torsional Bracing)

- System Buckling Mode of Narrow Girder Systems

- Ongoing Steel Girder Research

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The presentation material is focused on bridge systems; however the principles and lessons are applicable to both buildings and bridge applications

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General Stability Bracing Requirements

Effective Stability Bracing must satisfy two primary requirements:

- Adequate Strength – Brace Forces are directly related to the magnitude of the initial out-of-straightness
- Adequate Stiffness – The stiffness is a function of several components

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Bracing of Beams

Stability bracing of beams can be accomplished by either providing:

- Lateral Bracing that restrains the movement of the compression flange
- Torsional Bracing that restrains twist of the section

We will primarily be focusing on torsional bracing (Cross Frames)

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Torsional Bracing of Beams
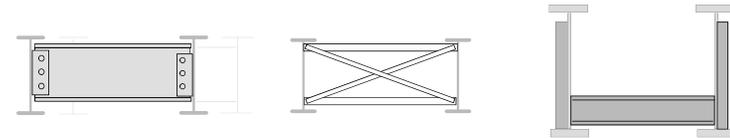
Diaphragms   Cross-Frames   Through-Girders

The fundamental concept with torsional bracing is:
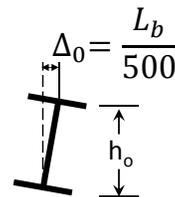
The beam or girder is fully braced at a location if <u>twist is prevented</u>.

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Brace Stiffness and Strength Requirements

AISC Specification Appendix 6 Bracing Provisions:

Stiffness:
$$\beta_T = \frac{2.4LM_r^2}{nEI_yC_b^2}$$

Strength (Commentary):

$$M_{br} = \beta_T\theta_o = \frac{2.4LM_r^2}{nEI_yC_b^2}\frac{L_b}{500h_o}$$

$$\Delta_0 = \frac{L_b}{500}$$

h_o

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System Stiffness of Torsional Bracing
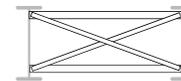
From a stiffness perspective, there are a number of factors that impact the effectiveness of beam torsional bracing.

- Brace Stiffness, β_{Tb}: the stiffness of the brace itself is a function of the layout of the cross-frame
- Cross-Sectional Distortion, β_{sec}: distortion of the cross-section can render a system totally ineffective
- In-Plane Stiffness of the Girder System β_g: cross-frames restrain the girders by linking adjacent girders and the in-plane stiffness can be important in some geometries.

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Demand on the Cross Frame Bracing

The torsional deformation of the girders (either from buckling or torsional moments) result in the following deformation:

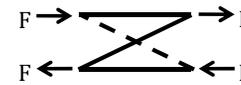M_{br} $+F_T$ $-F_c$ h_b M_{br}
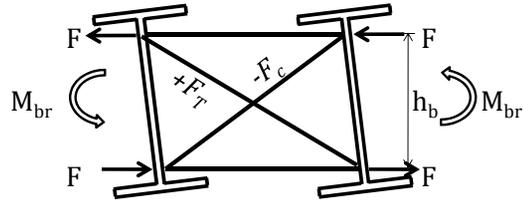
One diagonal is in tension and one is in compression. Depending on our design assumptions, we can idealize the cross frame in a few different ways from a stiffness/strength perspective.

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Brace Stiffness Analytical Formulas

Modeling the Cross Frame as a Truss:

- Tension-only System

$$\beta_{Tb} = \frac{M}{\theta} = \frac{ES^2 h_b^2}{\frac{2L_c^3}{A_c} + \frac{S^3}{A_h}}$$

Z-Frames

- Tension-Compression System

$$\beta_{Tb} = \frac{A_c ES^2 h_b^2}{L_c^3}$$

X-Frames
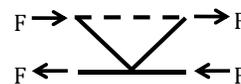
- K-Frame System

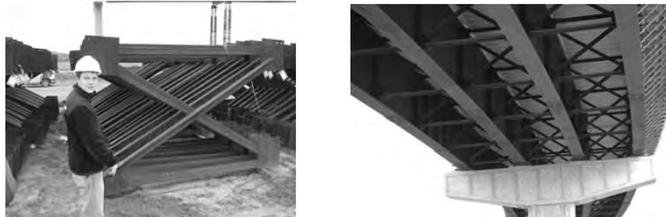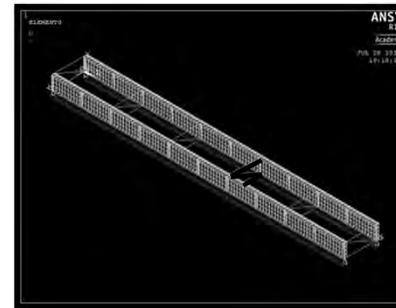$$\beta_{Tb} = \frac{2ES^2 h_b^2}{\frac{8L_c^3}{A_c} + \frac{S^3}{A_h}}$$
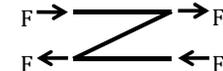
K-Frames

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Improved Cross Frame Systems

- Cross frames often represent one of the most expensive components per unit weight to fabricate.
- The high cost of cross frames is due to the significant welding/bolting and handling requirements.

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Common FEA Representation of X-Frame

Often Modeled as "Z-Frame"

Diagonal must have adequate buckling strength

A research investigation was undertaken to investigate some new geometries and detailing practices for cross frames.

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Improved Cross Frame Systems

- The study was focused on both existing and alternative geometries.
- Included laboratory studies and parametric finite element analyses
- The lab tests consisted of static stiffness and strength tests as well as fatigue tests.
- The experiments are some of the first tests focused on measurements of the stiffness and strength of cross frame systems.

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Improved Cross Frame Systems

- In research, it is not uncommon to "accidently" gain insight and sometimes make major unintended discoveries.
- Some of the more interesting findings from the study were not related to the initial goals of the investigation.
- We are going to focus on the unintended discoveries.

Graduate Research Assistants: Anthony Battistini and Wei Wang
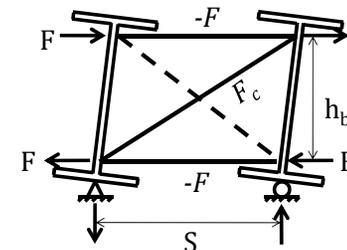Co-PIs: Karl Frank and Mike Engelhardt

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Static Test Setup
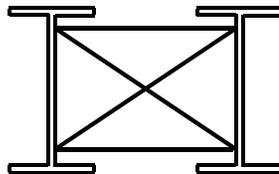
The static test setup was developed to simulate the demand that braces experience due to either buckling or girder torsion place on the brace.
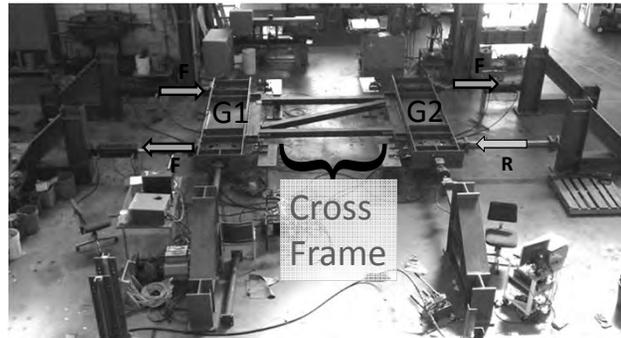
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Static Test Setup

The static test setup was developed to simulate the demand that braces experience due to either buckling or girder torsion place on the brace.
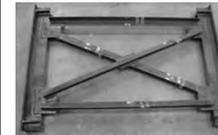
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Large Scale Stiffness/Strength Setup

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Lab Tests: Cross Frame Specimens

Current Details   "New" Details Considered

Single Angle X-Frame

Square Tube Z-Frame

Single Angle K-Frame

Double Angle Z-Frame
(Single Angle Struts)
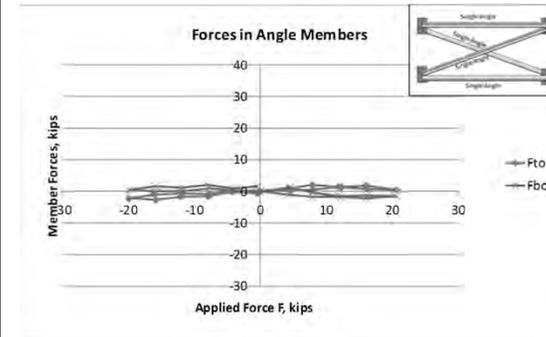
Double Angle Z-Frame
(Double Angle Struts)

Lab Tests: Large Scale Stiffness
Unequal Leg Angle X Frame Stiffness

- Tension diagonal braces compression diagonal so that unbraced length for diagonal is half the length.
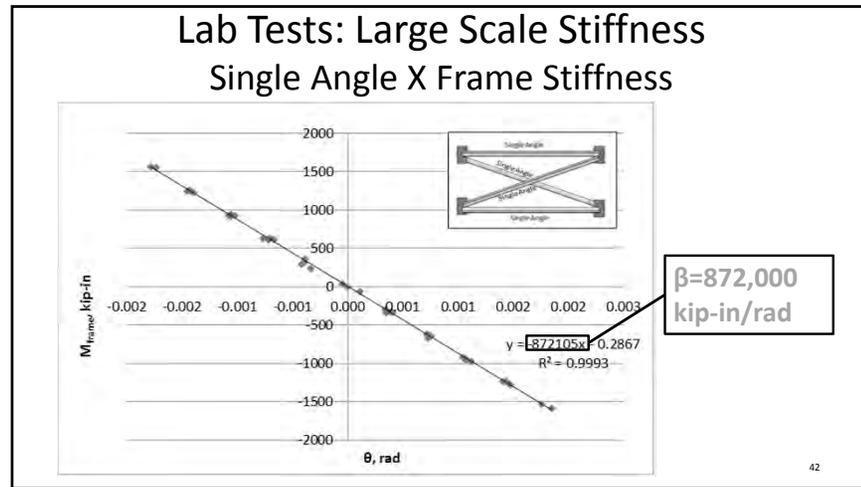
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Lab Tests: Large Scale Stiffness
Single Angle X Frame Forces

- Top and bottom struts are close to zero force member
- Prior to buckling, the compression diagonal generally contributes as much as the tension diagonal

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Lab Tests: Large Scale Stiffness
Single Angle X Frame Stiffness

$\beta=872,000$ kip-in/rad

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Recall: Brace Stiffness Analytical Formulas

- Tension-only Diagonal System

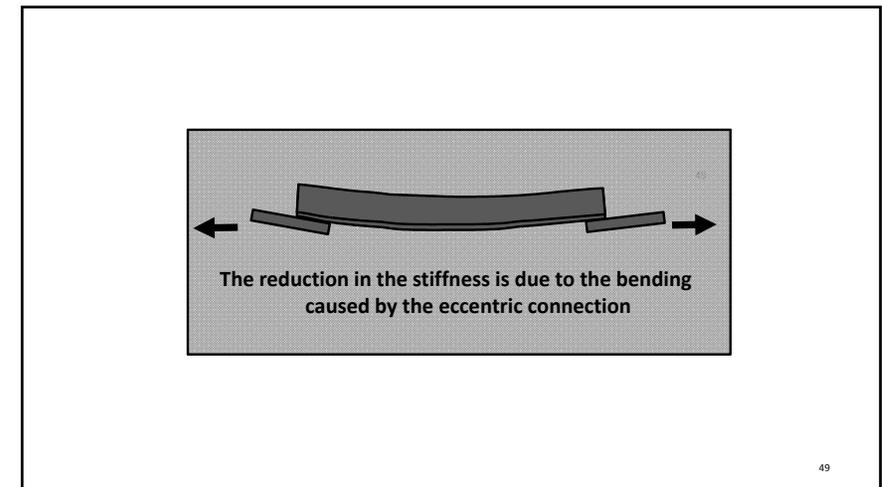
$$\beta_{Tb} = \frac{ES^2 h_b^2}{\frac{2L_c^3}{A_c} + \frac{S^3}{A_h}}$$

Z-Frames

- Tension-Compression System

$$\beta_{Tb} = \frac{A_c ES^2 h_b^2}{L_c^3}$$

X-Frames

- K-Frame System

$$\beta_{Tb} = \frac{2ES^2 h_b^2}{\frac{8L_c^3}{A_c} + \frac{S^3}{A_h}}$$

K-Frames

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Stiffness: Lab vs. Analytical vs. FEA

Type of Cross Frames		Test Results	Analytic Solution	Error %	Line Element Solution	Error %	Shell Element Solution	Error %
Eccentric Connections	Single Angle X Frame	872,000	1,579,000	82%	1,572,000	81%	867,000	-1%
	Single Angle K Frame	760,000	1,189,000	56%	1,180,000	55%	781,000	3%
	Unequal Leg Angle X Frame	1,054,000	1,609,000	53%	1,614,000	53%	1,065,000	1%
	Double Angle Z (Single Struts)	597,000	907,000	52%	905,000	52%	616,000	3%
	Double Angle Z (Double Struts)	1,182,000	1,152,000	-2.5%	1,152,000	-2.5%	1,164,000	-1.5%
	Square Tube Z-frame	658,000	649,000	-1%	647,000	-2%	657,000	0%

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The reduction in the stiffness is due to the bending caused by the eccentric connection

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Large Scale Stiffness Observations

- Truss formulations and line element FEA models overestimate the stiffness of cross frames with single angle members
  - Error largely due to eccentric connection of single angle
- Results from FEA shell element model have good agreement with all test results
  - Use validated model to perform parametric studies

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Commercial Software

- **All** commercial software generally makes use of line elements for the cross frames.
- Even three dimensional models that are used for "complex" systems or research generally use line elements to represent the cross frames.
- The line element model is an efficient representation of the cross frame system. Our goal was to develop a correction factor to be applied to the line element model or the analytical (hand) solution.

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Computational Modeling
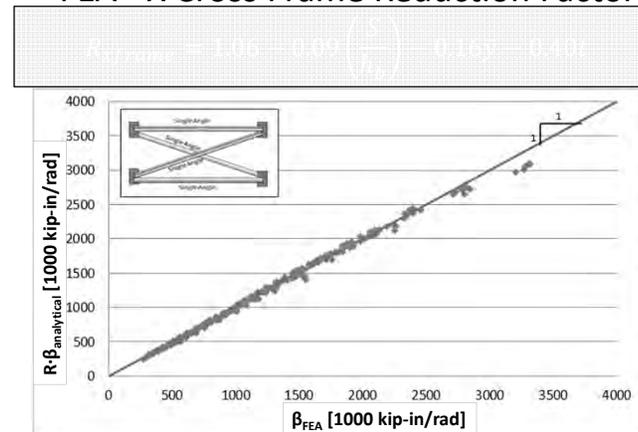### Cross Frame Stiffness Reduction

- Parametric studies were performed to find the correction factor for single angle X and K frames:

$$R = \beta_{FEA} / \beta_{analytical}$$

  - R was found to be dependent upon S/h_b, $\bar{y}$, and t
  - R can be applied to modify the member area in a computer software model when cross frames are modeled using line elements
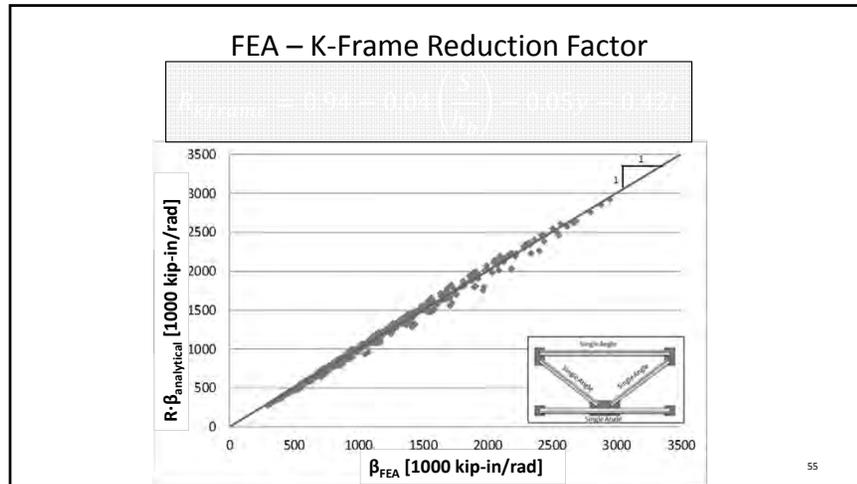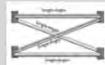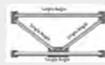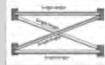
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FEA - X Cross Frame Reduction Factor

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FEA – K-Frame Reduction Factor

Design Recommendations
Reduction Factor Verification

Type of Cross Frames	Test Results	Analytic Solution	Error %	R*Analytic Solution	Error %
Single Angle X Frame	872,000	1,579,000	82%	860,000	-1.4%
Single Angle K Frame	760,000	1,189,000	56%	762,000	0.3%
Unequal Leg Angle X Frame	1,054,000	1,609,000	53%	1,018,000	-3.4%

Stiffness Conclusions from Laboratory Tests

- Concentric members show good agreement with analytical models and do not require reduction factor. The Tension-Only model is also conservative and requires no reduction.
- Eccentric connection of single angle reduces stiffness due to bending
- Line element solutions can significantly over-predict stiffness of single angle cross frames
- Applying reduction factor to analytical models can produce relatively accurate estimate of cross frame stiffness

Stiffness Conclusions from Laboratory Tests

- Overestimating the stiffness of the cross frame has a significant effect on design and behavior. The impact of the error has an inverse impact on deformations versus fatigue behavior:

  A) Unconservative in terms of torsional stiffness/stability of the girders

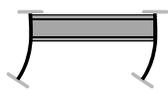 B) Overly – Conservative in terms of the fatigue behavior of the cross frames.
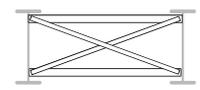
Additional Stiffness Components

β_{sec} – Cross Sectional Distortion
β_g – in-plane Stiffness of Girder

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Understanding Cross Sectional Distortion, β_{sec}
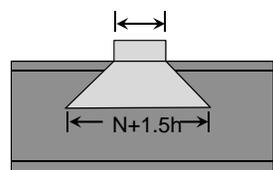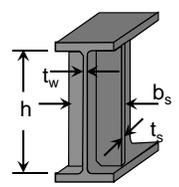

Will distort significantly   Will not distort much

- Cross-Sectional Distortion: depending on the region of the web outside of the depth of the brace, cross-sectional distortion can be significant.
- We can control distortion by providing a web stiffener to increase the bending stiffness of the web.
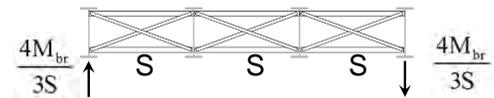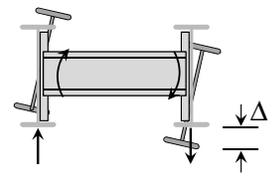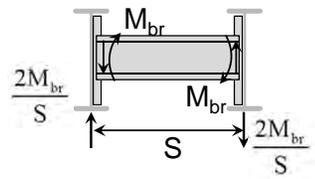
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Cross Sectional Distortion, β_{sec}

Effective Web Width for Distortion

$$\beta_{sec} = \frac{3.3E}{h}\left(\frac{t_w^{3}}{12}(N+1.5h) + \frac{t_s b_s^{3}}{12}\right)$$
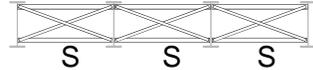
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Girder In-Plane Stiffness
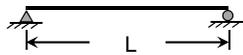

$\dfrac{2M_{br}}{S}$ M_{br} $\dfrac{2M_{br}}{S}$ S

$\dfrac{4M_{br}}{3S}$ S   S   S $\dfrac{4M_{br}}{3S}$

Wider System: Smaller Shear and Stiffer System

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Girder In-Plane Stiffness

The in-plane girder stiffness is a function of the stiffness of the individual girders as well as the number of girders across the width of the bridge:

$$\beta_g = \frac{N_g S^2 E I_x}{L^3}$$

$$N_g = \frac{24(n_g - 1)^2}{n_g}$$

I_x = in-plane moment of inertia of girders

n_g = number of girder across the width of the bridge that are interconnected by the braces.

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Girder In-Plane Stiffness

The in-plane girder stiffness is a function of the stiffness of the individual girders as well as the number of girders across the width of the bridge:
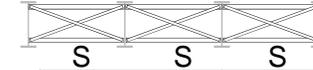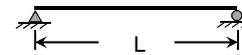

$$\beta_g = \frac{N_g S^2 E I_x}{L^3}$$

$$N_g = \frac{24(n_g - 1)^2}{n_g}$$

n_g	N_g
2	12
3	32
4	54
5	77

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Total Brace Stiffness

As noted earlier, the total brace stiffness is a function of several components. The system torsional brace stiffness is governed by the following expression:

$$\frac{1}{\beta_T} = \frac{1}{\beta_{Tb}} + \frac{1}{\beta_{Sec}} + \frac{1}{\beta_g}$$

β_T = Total System Stiffness

β_{Tb} = Stiffness of cross frame/brace

β_{Sec} = Effect of cross sectional distortion

β_g = In-plane stiffness of effect of girder system

Note: β_T will be less than smallest of β_{Tb}, β_{sec}, or β_g

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In Design, $\beta_{T\ Req'd}$ is App. 6 Stiffness Requirement

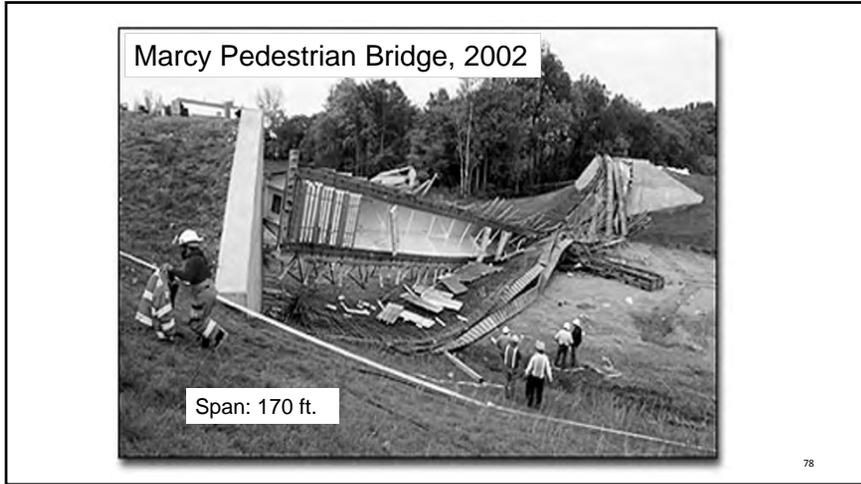$$\frac{1}{\beta_{T\ Req'd}} \geq \frac{1}{\beta_{Tb}} + \frac{1}{\beta_{Sec}} + \frac{1}{\beta_g}$$

$\beta_{T\ Req'd}$ = Total Required System Stiffness (App. 6 Equation)

β_{Tb} = Stiffness of cross frame/brace

β_{Sec} = Effect of cross sectional distortion

β_g = In-plane stiffness of effect of girder system

What Happens if the above expression isn't satisfied? Let's look at the case when $\beta_g < \beta_{T\ Req'd}$?
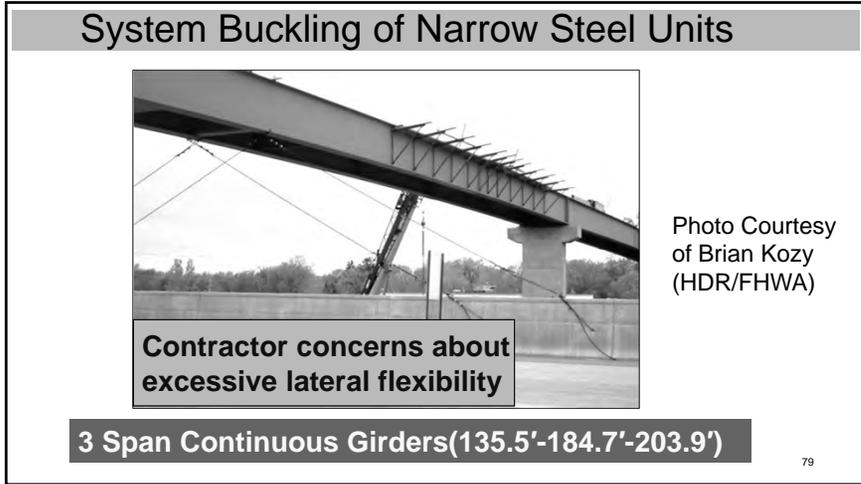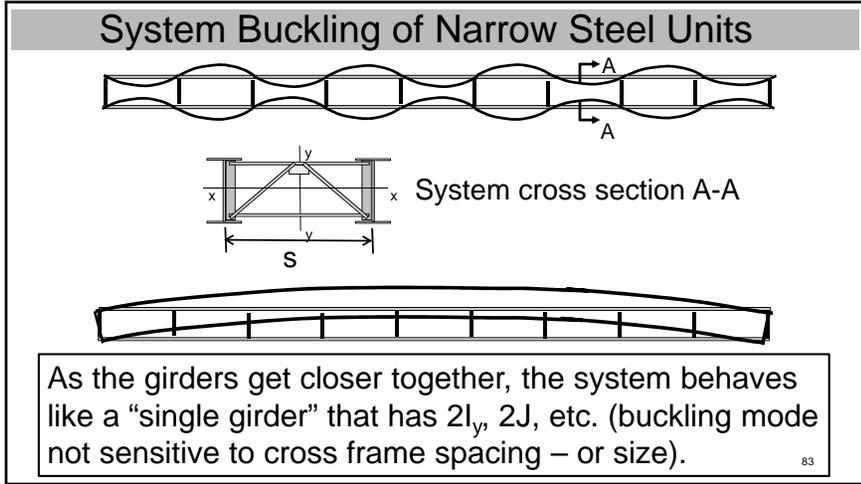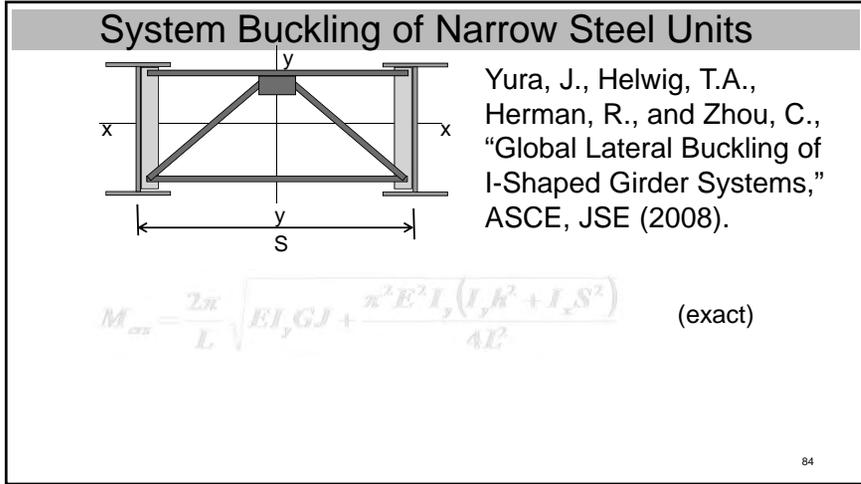
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Inadequate In-Plane Stiffness– Bridge Widening

Twin Girder bridge widening

L~170 ft.

S~8 ft.

Assumed "L_b" = 17 ft.

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System Buckling of Narrow Steel Units

Girder Bottom Flange

10"

Plumb Line Dropped from Top Flange: Lateral Deformation = 10 inches

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System Buckling of Narrow I-
Girder Systems
(Related to Inadequate In-Plane
Girder Stiffness)

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History of System Buckling Mode

- Marcy Pedestrian Bridge (2002) – consisted of a single box girder with no top lateral truss.
- Girder had closely spaced internal K-frames (behaved very similar to a twin I-girder system)

Tub behaved similar to twin I-girders

Marcy tub girder failed due to buckling

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Marcy Pedestrian Bridge, 2002

Span: 170 ft.

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System Buckling of Narrow Steel Units

Photo Courtesy of Brian Kozy (HDR/FHWA)

Contractor concerns about excessive lateral flexibility

3 Span Continuous Girders(135.5′-184.7′-203.9′)

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System Buckling of Narrow Steel Units

System cross section A-A

As the girders get closer together, the system behaves like a "single girder" that has $2I_y$, $2J$, etc. (buckling mode not sensitive to cross frame spacing – or size).

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System Buckling of Narrow Steel Units

Yura, J., Helwig, T.A., Herman, R., and Zhou, C., "Global Lateral Buckling of I-Shaped Girder Systems," ASCE, JSE (2008).

$$M_{crx} = \frac{2\pi}{L}\sqrt{EI_y GJ + \frac{\pi^2 E^2 I_y \left(I_y K^2 + I_x S^2\right)}{4L^2}}$$

(exact)

84

14

System Buckling of Narrow Steel Units

Yura, J., Helwig, T.A., Herman, R., and Zhou, C., "Global Lateral Buckling of I-Shaped Girder Systems," ASCE, JSE (2008).

~~$M_{crs} = \frac{2\pi}{L}\sqrt{EI_y GJ + \frac{\pi^2 E^2 I_y \left(? + I_x S^2\right)}{4L^2}}$~~ (exact)

~~$M_{crs} = \frac{\pi^2 SE}{L^2}\sqrt{I_y I_x}$~~ (simple)

85

System Buckling of Narrow Steel Units
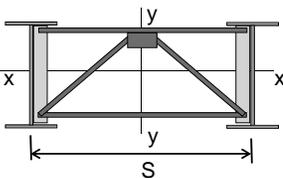
Increasing the girder spacing does increase the buckling capacity (buckling stress)

	Analysis Type	Girder Spacing S (in.)		
		80	110	150
Eigenvalue Buckling Analysis	ANSYS	21.3 ksi	28.6 ksi	38.7 ksi
	Exact	21.4 ksi	28.7 ksi	39.2 ksi
	Simple	20.7 ksi	28.2 ksi	38.8 ksi

86

System Buckling of Narrow Steel Units

AASHTO Equation for System Buckling of Narrow I-Girder Units (2015 interim specification):

$$M_{gs} = \frac{\pi^2 SE}{L^2}\sqrt{I_{y\,eff}I_x}$$

To avoid excessive 2nd order deformations during deck placement, total factored positive girder moment limited to 50% of M_{gs}.

87

System Buckling of Narrow Steel Units

Graduate Research Assistant: Liwei Han

AASHTO Equation for System Buckling of Narrow I-Girder Units (2017 specification): Limit raised from 50% to 70%.

$$M_{gs} = C_{bs}\frac{\pi^2 SE}{L^2}\sqrt{I_{y\,eff}I_x}$$

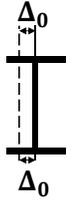C_{bs} is a moment gradient factor for the system buckling mode

Simply supported or partially erected continuous sys.: $C_{bs} = 1.1$
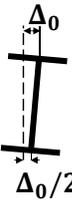
Continuous Systems: $C_{bs} = 2.0$

88

System Buckling of Narrow Steel Units
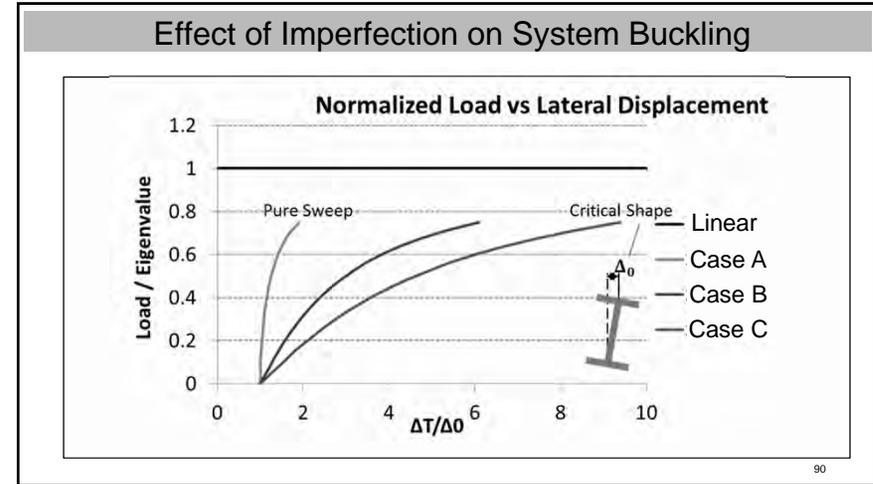
- Effect of initial imperfection shape

| Case A | Case B | Case C |

Previous studies have shown "Section C" is Critical Shape

Effect of Imperfection on System Buckling

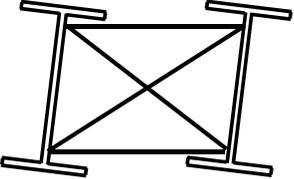Normalized Load vs Lateral Displacement
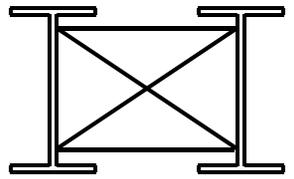
Linear
Case A
Case B
Case C

How Likely is the "Critical Shape" Imperfection

How Likely is the "Critical Shape" Imperfection

"Critical Shape" – Diagonals would be different lengths

"Rectangular" Cross Frame

Cross frames are detailed to control the geometry of the section. Although there may be girder drops in this geometry, the cross frames will generally be relatively "square".

Imperfection Study

Prior to Intermediate Cross Frame Installation

Initial Imperfection

Frame #		1	2	3	4
Girder 1	Δtop (in.)	0	0.80	1.28	1.44
	Δbot (in.)	0	0	0	0
Girder 2	Δtop (in.)	0	0.80	1.28	1.44
	Δbot (in.)	0	0	0	0

Imperfection Study

Prior to Intermediate Cross Frame Installation

The girders often have to be "pulled/pushed" straight to fit cross frames into place.

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Imperfection Study

Prior to Intermediate Cross Frame Installation

The girders often have to be "pulled/pushed" straight to fit cross frames into place.

100

Imperfection Study

Initial Imperfection
Step 1

Girders Pulled Straight
Step 2

$\Delta_{top}= ?$ $\Delta_{top}= ?$

Cross Frame Installed
Step 3

System Released
Step 4

$\Delta_{bot}=?$ $\Delta_{bot}=?$

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Midspan Deformations During Cross Frame Installation
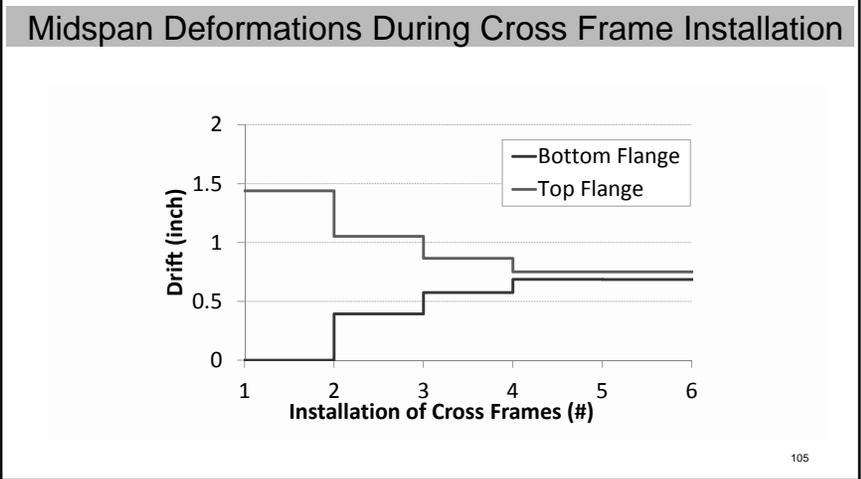
Imperfection Study

Midspan Imperfections and Displacements

"Critical Shape"

		Before	After
Girder 1	Δtop (in.)	1.44	0.75
	Δbot (in.)	0	0.69
Girder 2	Δtop (in.)	1.44	0.75
	Δbot (in.)	0	0.69

Although several different initial shapes were considered, the "final" shape after the near full depth cross frames were installed was close to a pure sweep with D = L_b/1000.

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Imperfection for Appendix 6 Torsional Bracing Provisions

Additional work is necessary to determine the imperfection likely to occur in practice.

Shallow Brace

Likely Imperfection for design is probably "critical shape" with $\theta_o = L_b/(500h)$

Deep Brace

Likely Imperfection for design is probably "pure" sweep of L_b/500

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Bracing Details:
Lean on bracing and split pipe stiffener

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Lean-On Bracing Details
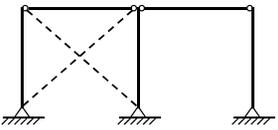
Lean-On Bracing in Frames

Graduate Research Assistants: Liqun Wang, James Deaver, ans Carlos Romero, Michelle Romage-Chambers
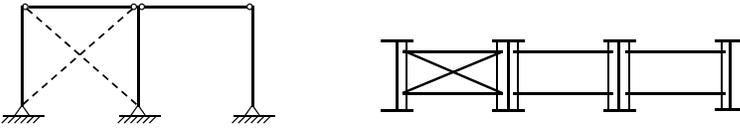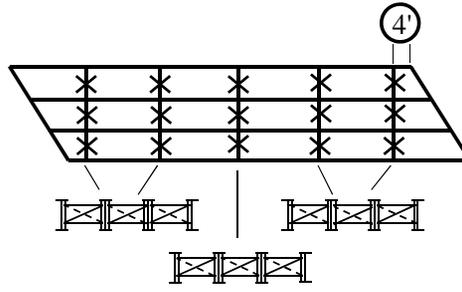
111

Lean-On Bracing Details
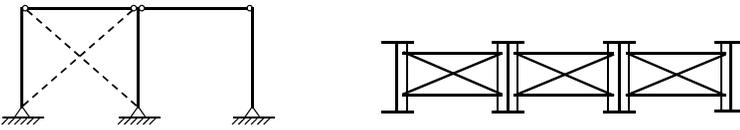
Lean-On Bracing in Frames

Lean-On Bracing in Beams

Graduate Research Assistants: Liqun Wang, James Deaver, ans Carlos Romero, Michelle Romage-Chambers

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Lean-On Bracing Details

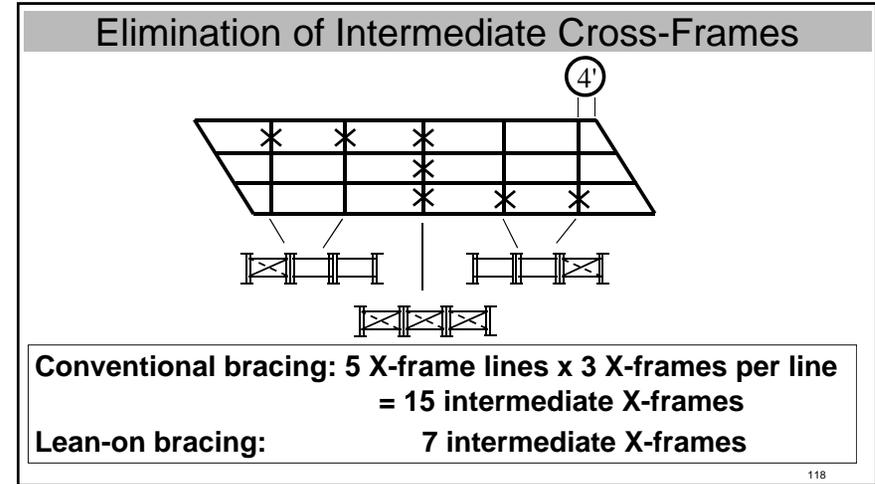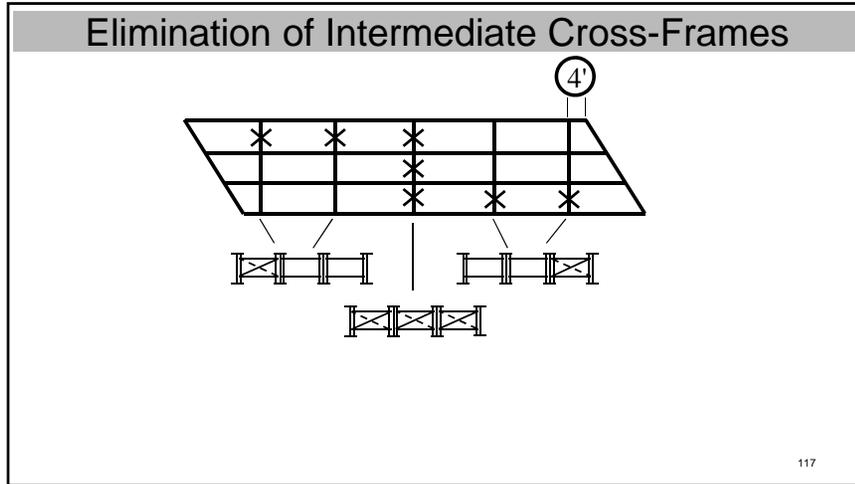*Lean-On Bracing in Frames*

Lean-On Bracing in Beams

Graduate Research Assistants: Liqun Wang, James Deaver, ans Carlos Romero, Michelle Romage-Chambers

113

Elimination of Intermediate Cross-Frames

116

Elimination of Intermediate Cross-Frames

④'

117

Elimination of Intermediate Cross-Frames

④'

Conventional bracing: 5 X-frame lines x 3 X-frames per line
= 15 intermediate X-frames
Lean-on bracing: 7 intermediate X-frames

118

STIFFNESS & STRENGTH FOR LEAN-ON X-FRAMES

Girders per X-frame

$n_{gc} = 4$

Brace Stiffness:

$$\beta_b = \frac{E s^2 h_b^2}{\dfrac{n_{gc} L_d^3}{A_d} + \dfrac{s^3}{A_c}\left(n_{gc} - 1\right)^2}$$

Brace Strength:

$$F_d = \frac{n_{gc}\, F\, L_d}{s}$$

$$F_s = (n_{gc}-1)F$$

$F = M_{br}/h_b$

Define n_{gc} as the number of girders per cross-frame.

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Advantages of Lean-On Bracing

- Easier fit-up of X-frames near supports during erection

- Reduce brace forces due to truck loading in completed bridge

- With fewer braces:
  - Economic benefit both at time of erection and in ongoing maintenance (fewer cross-frames to inspect)

Implementation – 3 bridges in Lubbock, Texas with skew angles in excess of 60 degrees

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20

Bracing Layout for Lubbock Bridge

60 Degree
Support Skew

Conventional Bracing
80 Intermediate
X-frames

Lean-On Bracing
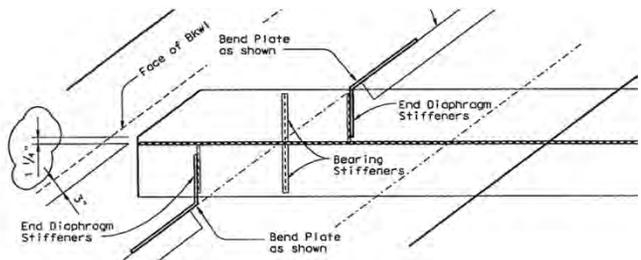28 Intermediate
X-frames

121

Split Pipe Stiffeners

Graduate Research Assistants: Craig Quadrato and
Anthony Battistini
Co-PIs: Karl Frank and Mike Engelhardt

122

Common X-Frame Plate Stiffener Details

Larger Skews: Separate bearing and end diaphragm stiffeners
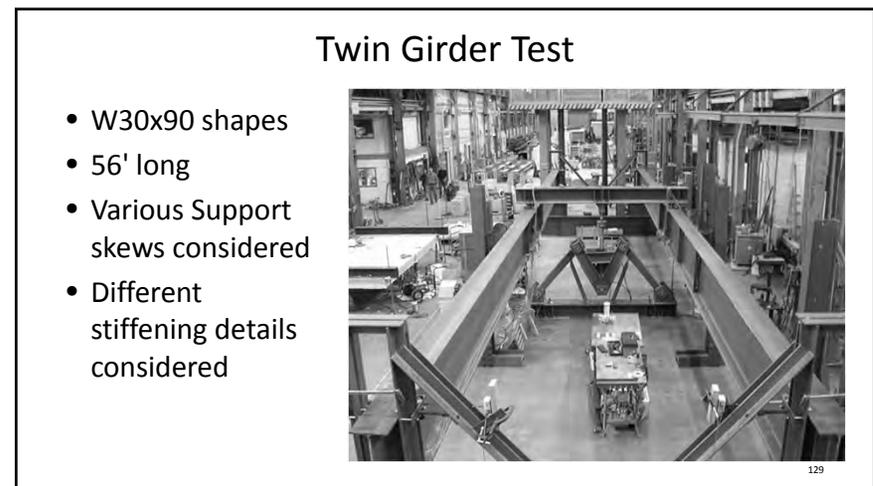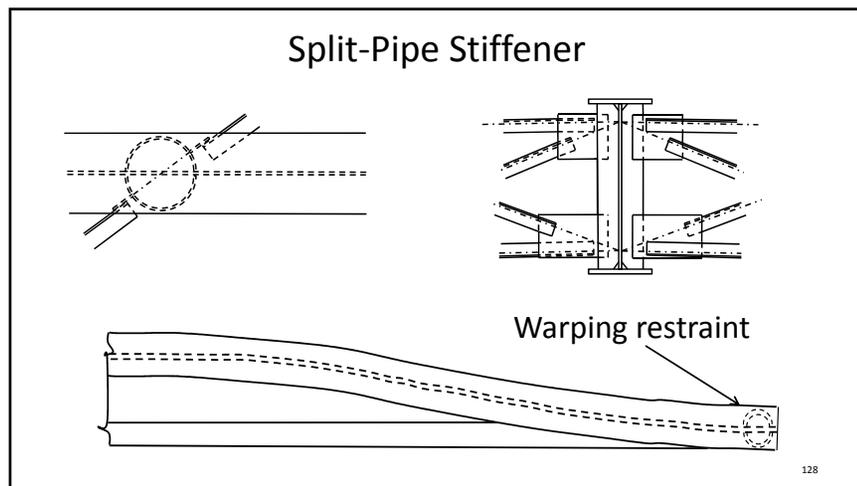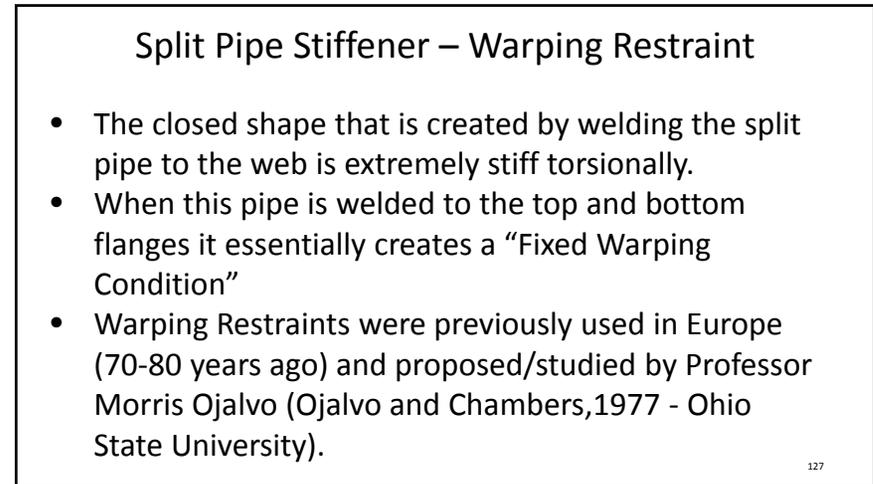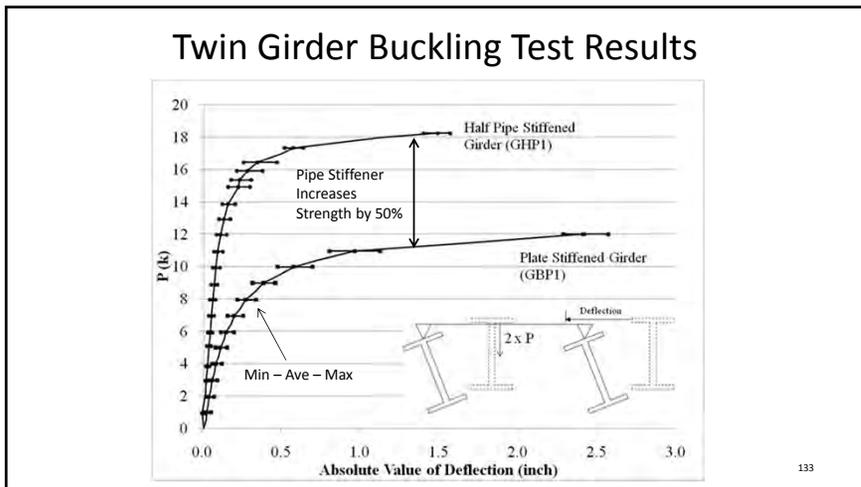

Note: 4 Stiffener Plates Plus Bent Plates Often Used 123
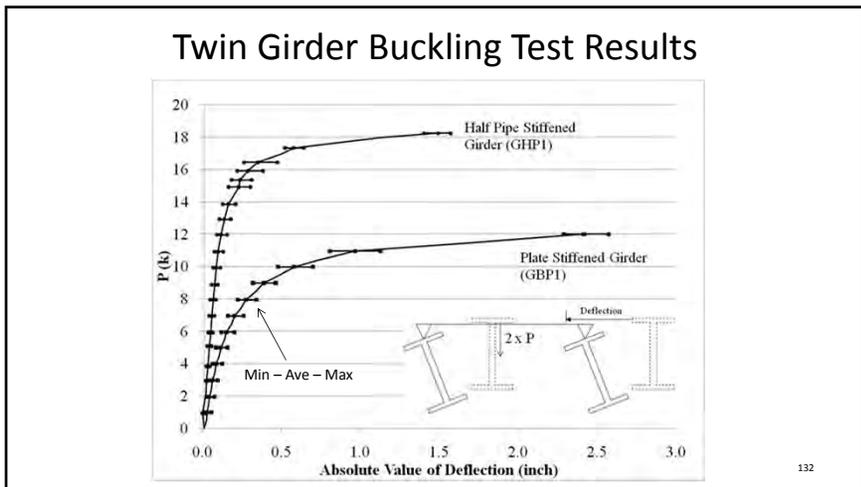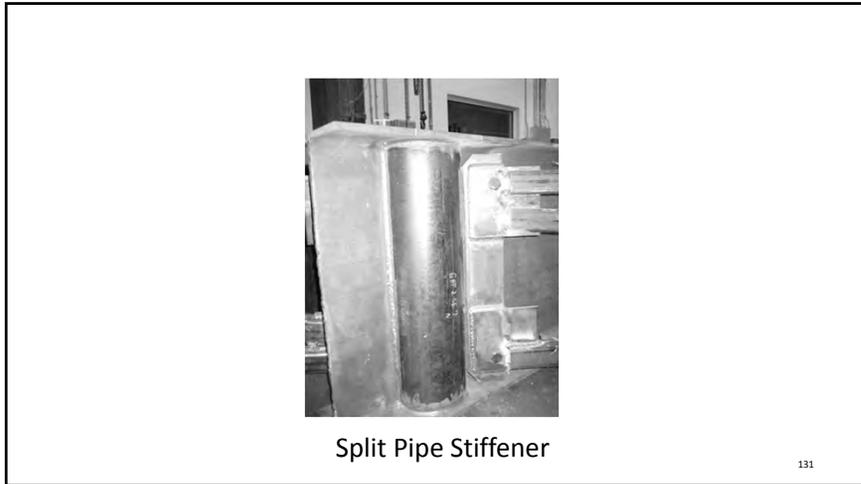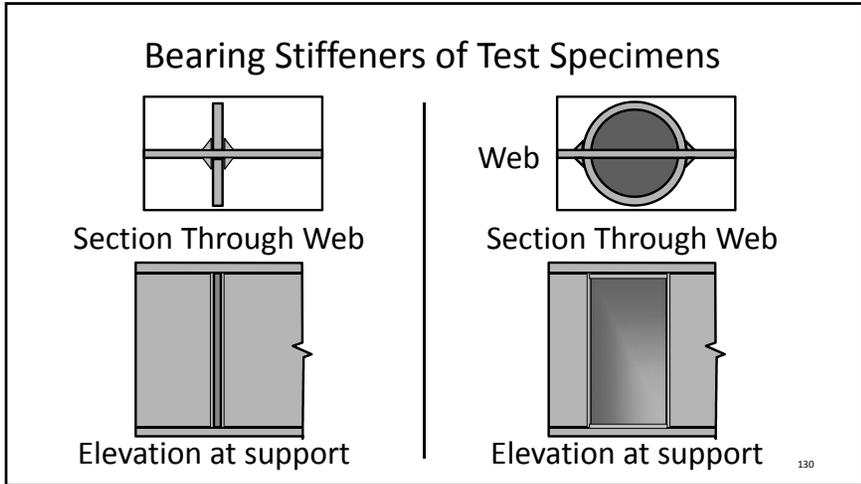
Bent Plate Details

$$\frac{1}{\beta_T} = \frac{1}{\beta_{bskew}} + \frac{1}{\beta_{sec}} + \frac{1}{\beta_g} + \frac{1}{\beta_{conn}}$$

The bent plate adds an additional component and the flexibility of this plate has a significant impact on the system stiffness. 124

Split Pipe Stiffener – Heavy Skew Angles

Replace 4 Stiffener Plates with Two Split Pipe Stiffeners

Web

Section Through Web

Elevation at support

125

Split Pipe Stiffener – Warping Restraint

- The closed shape that is created by welding the split pipe to the web is extremely stiff torsionally.
- When this pipe is welded to the top and bottom flanges it essentially creates a "Fixed Warping Condition"
- Warping Restraints were previously used in Europe (70-80 years ago) and proposed/studied by Professor Morris Ojalvo (Ojalvo and Chambers,1977 - Ohio State University).

127

Split-Pipe Stiffener

Warping restraint

128

Twin Girder Test

- W30x90 shapes
- 56' long
- Various Support skews considered
- Different stiffening details considered

129

Bearing Stiffeners of Test Specimens

Web

Section Through Web | Section Through Web

Elevation at support | Elevation at support

130

Split Pipe Stiffener

131

Twin Girder Buckling Test Results

Half Pipe Stiffened Girder (GHP1)

Plate Stiffened Girder (GBP1)

Min – Ave – Max

132

Twin Girder Buckling Test Results

Half Pipe Stiffened Girder (GHP1)

Pipe Stiffener Increases Strength by 50%

Plate Stiffened Girder (GBP1)

Min – Ave – Max

133

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Ongoing Steel Girder Studies

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Improved Details in Steel Tub Girders

This project is focused on improving the behavior and economy of Trapezoidal Box Girder systems:
1) Studying modifications in geometrical layout of girders
2) Modifications of the bracing systems

Graduate Research Assistants: Stalin Armijos Moya and Yang Wang
Co-PIs: Mike Engelhardt, Tricia Clayton, and Eric Williamson

135

Improved Details in Steel Tub Girders

- Tub girders are very stiff in the finished condition
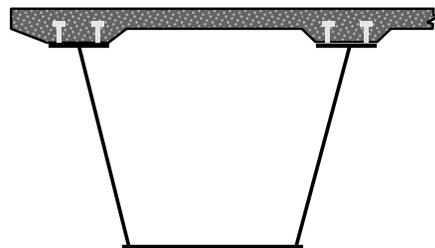
136

Improved Details in Steel Tub Girders

- Tub girders are very stiff in the finished condition
- Open section during construction
- Bracing consists of top lateral truss and internal/external K-frames
- Primary role of the bracing is during construction.

Bracing systems in twin tub girder during construction

138

Improved Details in Steel Tub Girders

1. Web Slope

a) Conventional web slope   b) Lower web slope

Benefit: Potentially reduce number of girder lines

140

Improved Details in Steel Tub Girders

2. Top Flange Offset

a) Centered Top Flanges   b) Offset Top Flanges

Benefits: Eliminate gusset plates and improve bracing efficiency.

142

Improved Details in Steel Tub Girders

3. Top Lateral Truss Layout

a) Continuous top lateral truss

b) Truss diagonals only near ends

(Primarily for straight or mildly curved girder applications)

144

Improved Details in Steel Tub Girders

4. Internal Cross Frame Layout

a) K-frames located at every panel point

b) K-frames located (every 2, 4, 6 panel points)

(Straight and horizontally curved girders)

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Experimental Specimens Fabricated by Hirschfeld
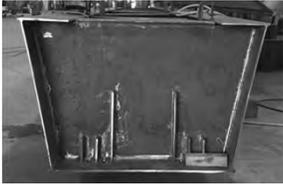
1) Standard Section   2) Offset Flange Section   3) Lower Slope Section

86 ft. Girder lengths (84 ft. clear span)

147

Experimental Test Setup
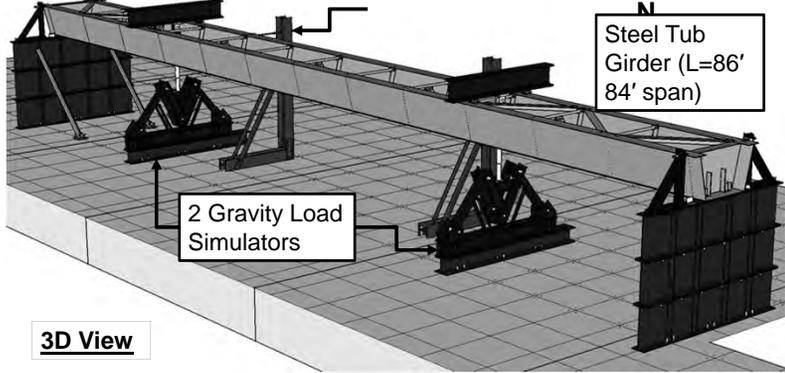
Steel Tub Girder (L=86' 84' span)

2 Gravity Load Simulators

3D View

148

Gravity Load Simulators Setup

αP e $(1-\alpha)P$
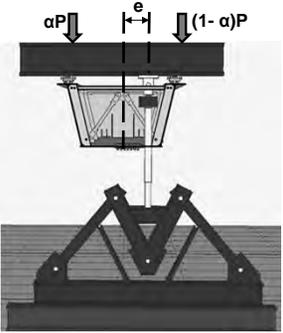
Load Cases
- Bending Only (e=0)
- Bending + Torsion (e>0)

149

Gravity Load Simulators – Loading Conditions

GLS concentric   eccentricity=8" R~1200 ft.   eccentricity=16" R~600 ft.

150

Bracing Layout Optimization

Top Flange Lateral Bracing Layout

No Top Lateral Bracing

Partial Bracing

151

UT Bridge Version 2.2 Released in February 2018

Version 1.0 – Jason Stith, Brian Petruzzi, and Jun Kim (2009)
Version 2.0, 2.1, 2.2 – Paul Biju-Duval (2017-2018)

Co-PIs: Eric Williamson, Mike Engelhardt, Karl Frank, and Tricia Clayton

UT Bridge
Version 2.0
UT Austin, 2016
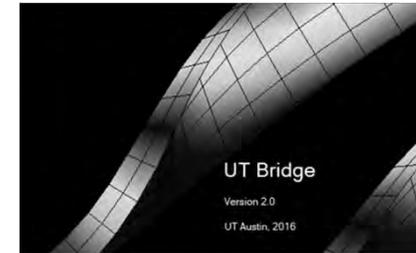
152

Specify "Features" of the Analysis
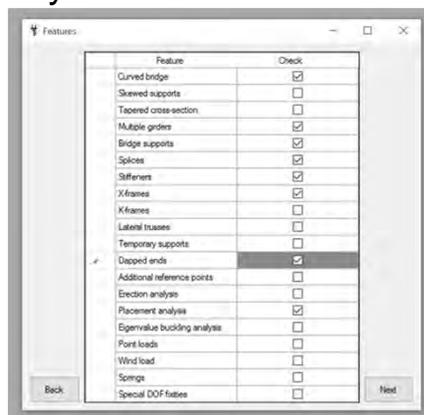
153

Pop-up Panels Prompt User for Basic Model Geometry

154

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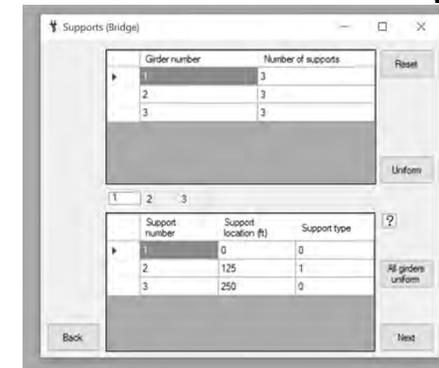
Cross Frame Properties and Spacing

R- Factor

X-Type, K-Type, Lean On

157

Modelling Erection Stages

- Once the model is fully defined, the program can be used as a tool to evaluate various erection stages.

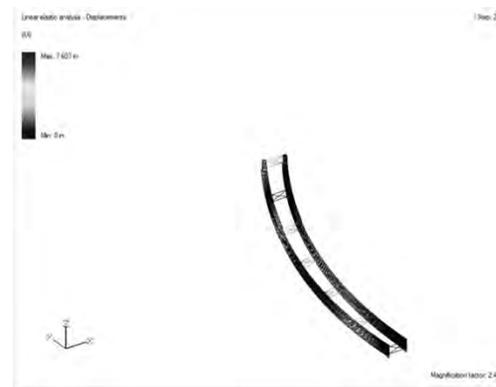- The need for temporary supports such as shore towers or holding cranes can be easily evaluated.

158

Modelling Erection Stages
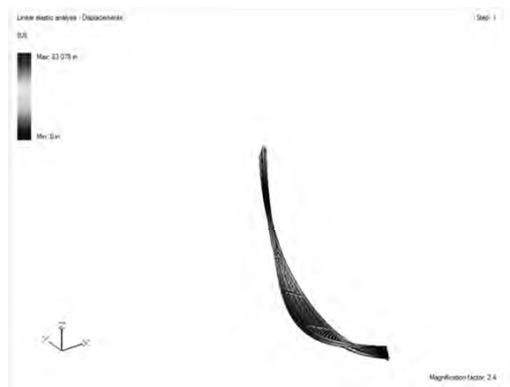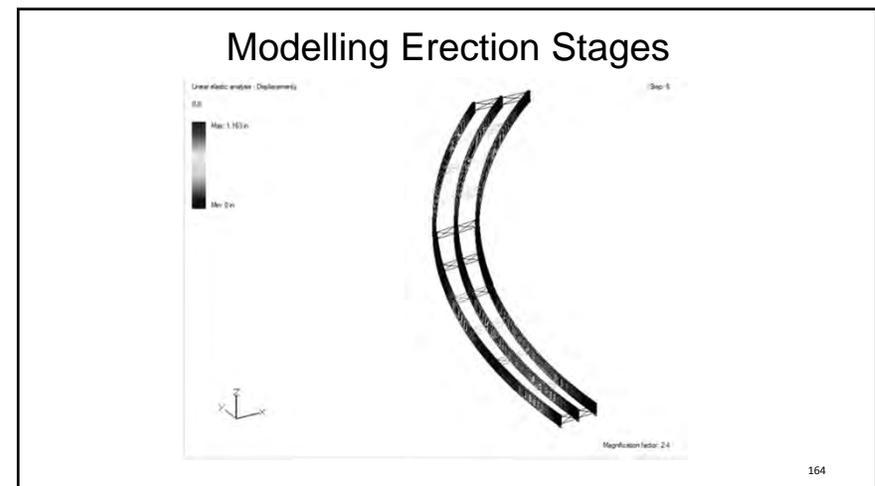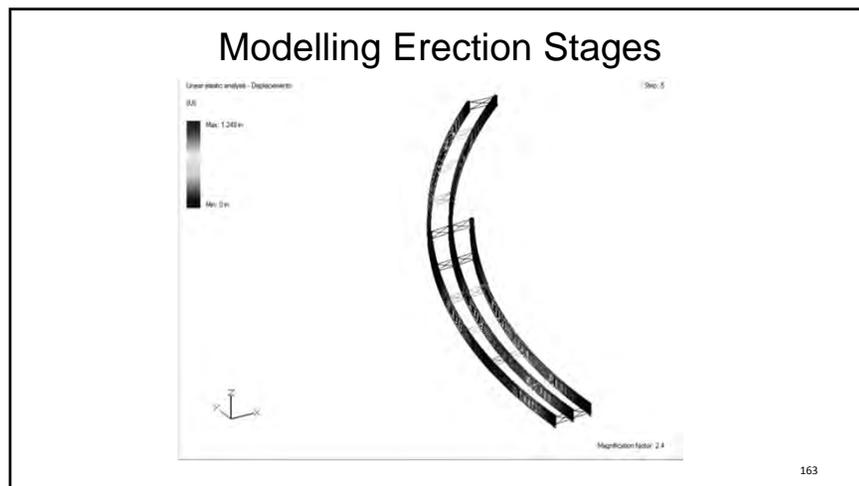

159

Modelling Erection Stages

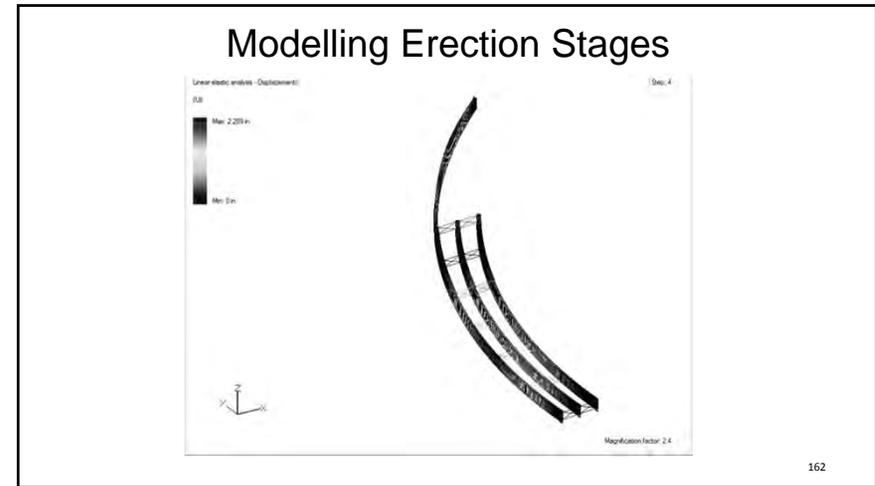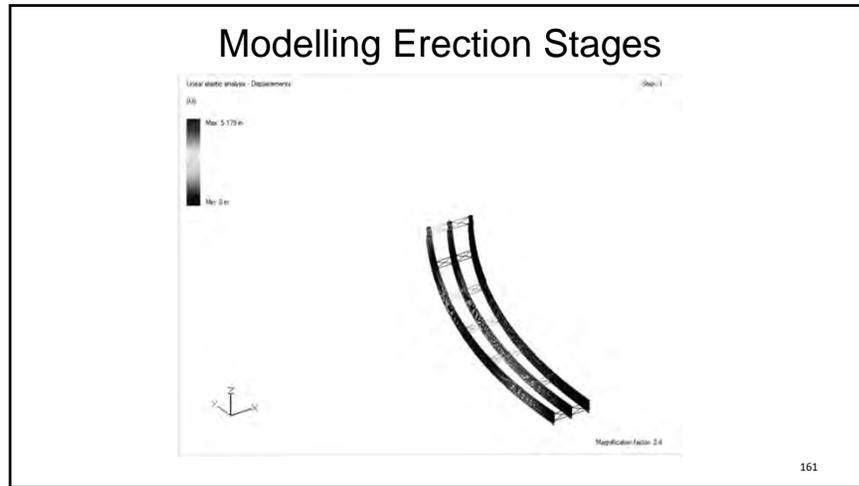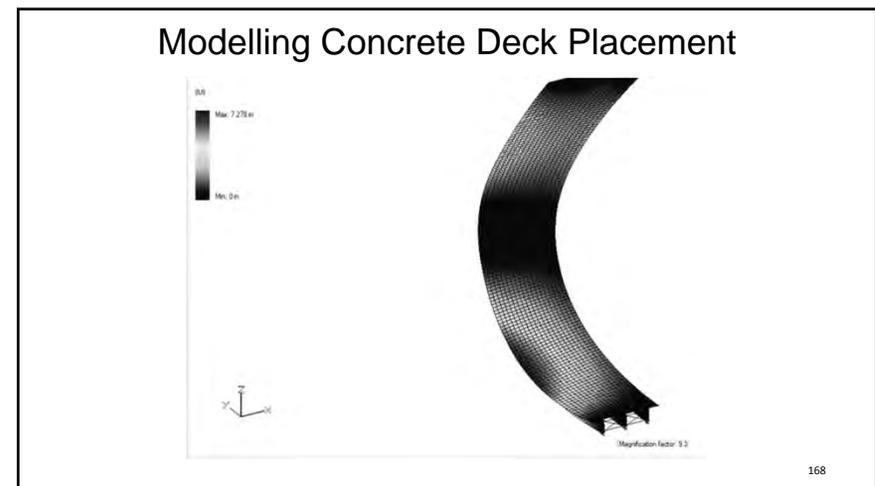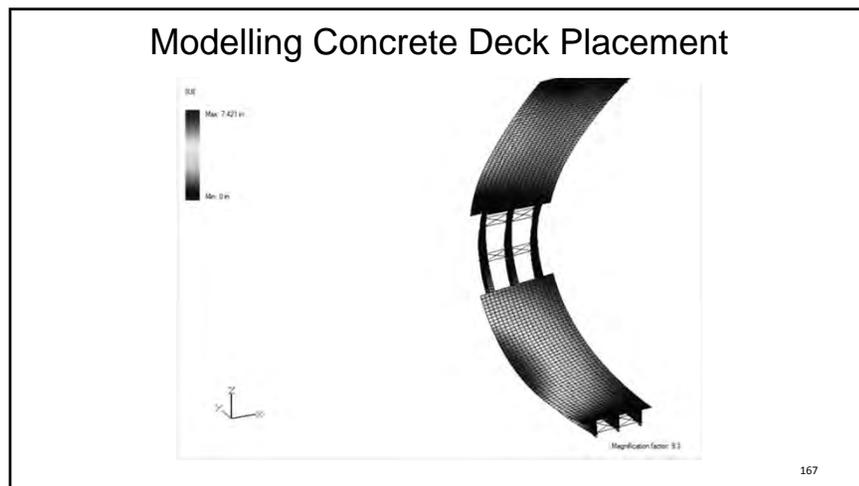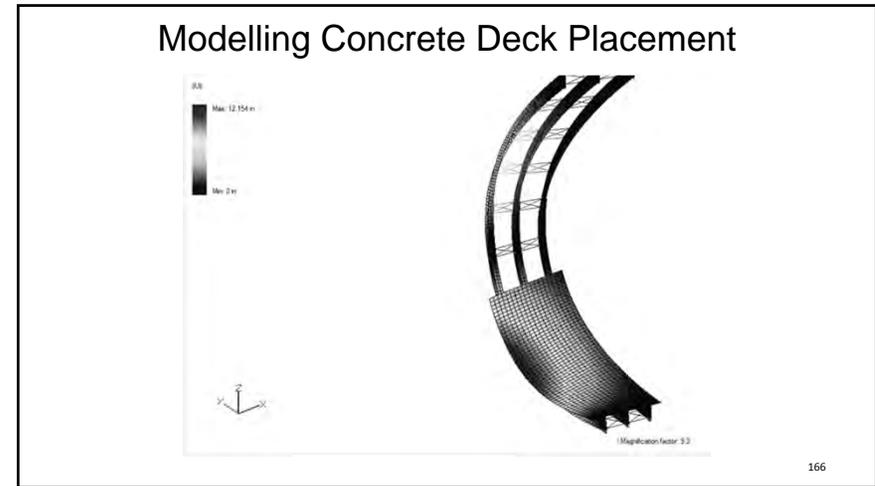

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Modelling Erection Stages

Modelling Erection Stages

Modelling Erection Stages

Modelling Erection Stages

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Modelling Concrete Deck Placement
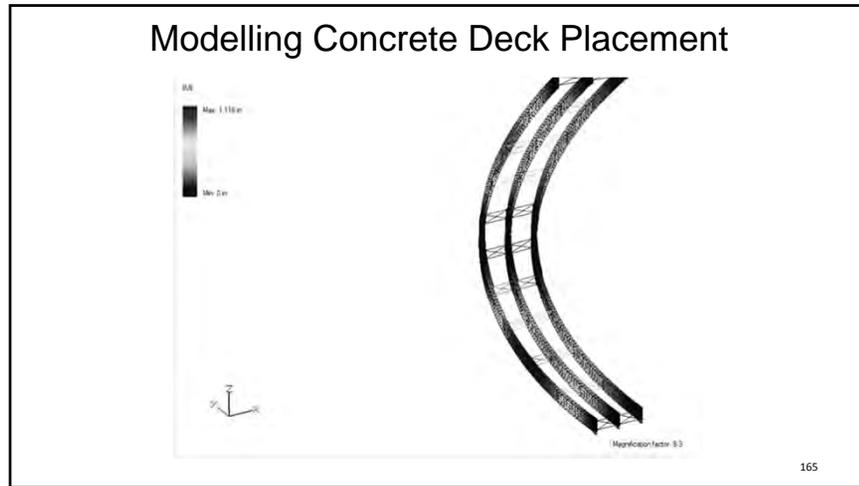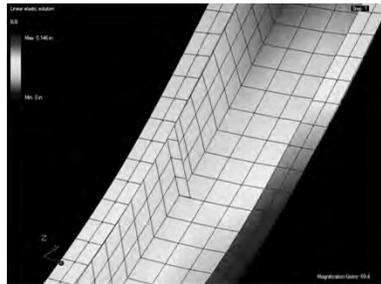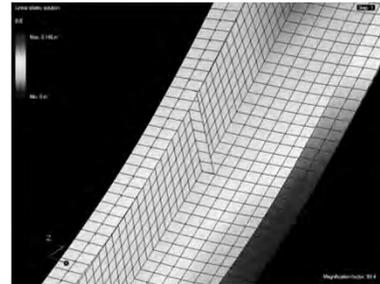
CURVED TUB GIRDER

Coarse mesh

Fine mesh

169

UT BRIDGE V2.2 CAPABILITIES

- **Types:** I-girder and tub girder bridges
- **Geometries:** Straight, curved, point of tangency
- **Special features:** Dapped ends, tapered sections
- **Loads:** Self-weight, wind loads, point loads, top flange uniform loads
- **Boundary conditions:** Standard pin and roller supports, temporary supports (shore towers or cranes), arbitrary
- **Braces:** X-frames, K-frames, lateral trusses, springs, diaphragms (tub girders)
- Eigenvalue Buckling, First Order, Second Order

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UT Bridge Software

Free Download from Ferguson Lab Website
(Google UT Bridge)

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Summary

- Connection eccentricity can have a dramatic impact on the stiffness of braces. It's interesting to note that this was the most significant discovery of that particular research study – and wasn't a focus of the investigation.

- System buckling is a mode we have become aware of relatively recently that impacts narrow girder systems.

- Lean-on bracing techniques, split pipe stiffeners, and other details can lead to improved efficiency and behavior in many bracing systems.

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Thank - You

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.

There's always a solution in steel.

Thank You

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

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