TxDOT 0-6816: Applications of Partial Depth Precast Concrete Deck Panels on Horizontally Curved Bridges

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Texas Department of Transportation

The University of Texas at Austin
Ferguson Structural Engineering Laboratory

Fundamental Questions

- Can Partial Depth Precast Concrete Deck Panels (PCPs) be used on horizontally curved bridges?
- Can the PCPs be relied up for bracing?

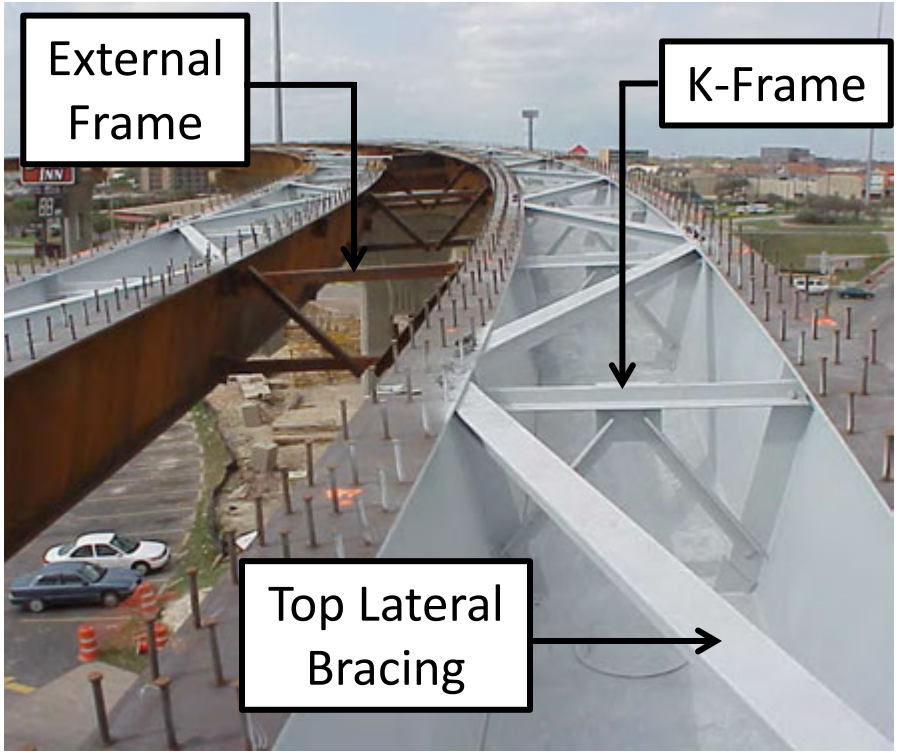
Outline

- Background
- Experiments
  - Shear Frame
  - Twin I-Girder
  - Tub Girder
- Parametric FEA Study
- Unconnected PCP Study
- UT Bridge
- Conclusions

Background

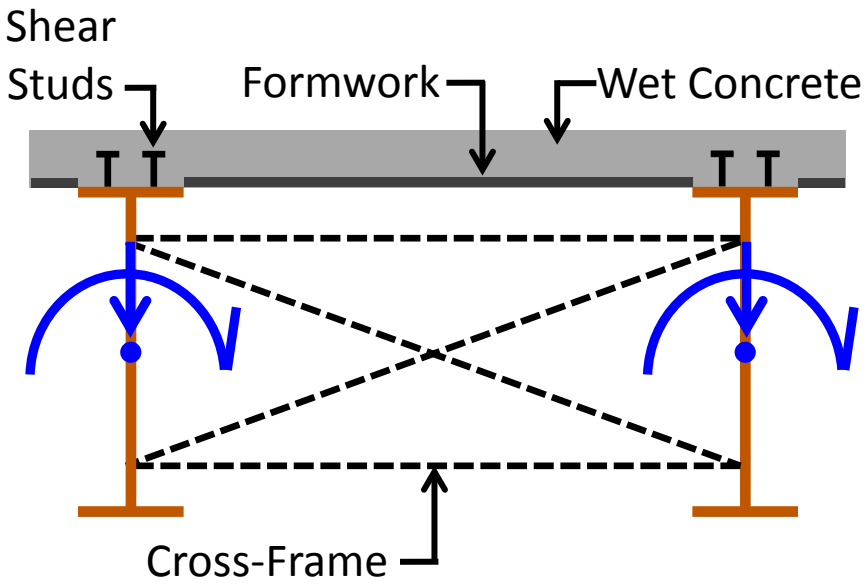
Background – Steel Girder Bracing

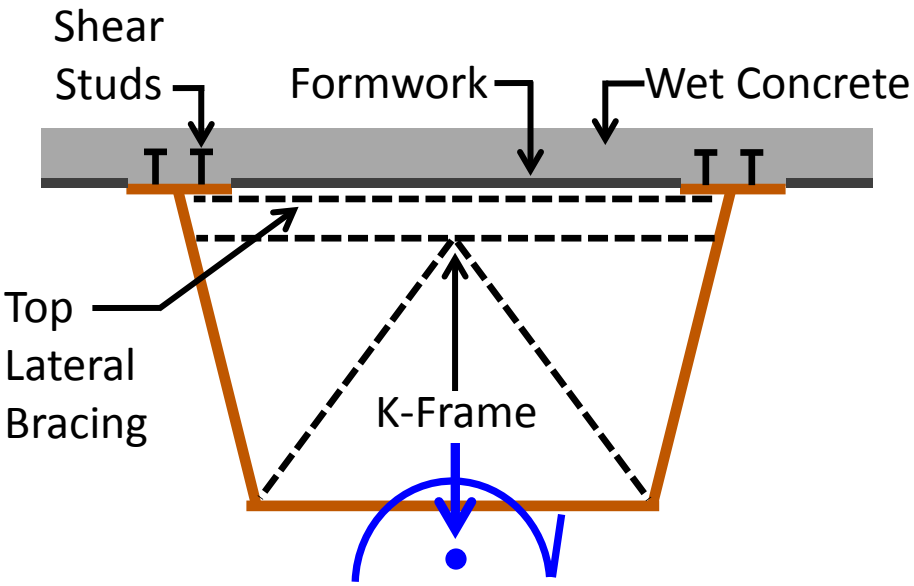
Curved I-Girder Bridge



Curved Tub Girder Bridge

Background – Steel Girder Bracing





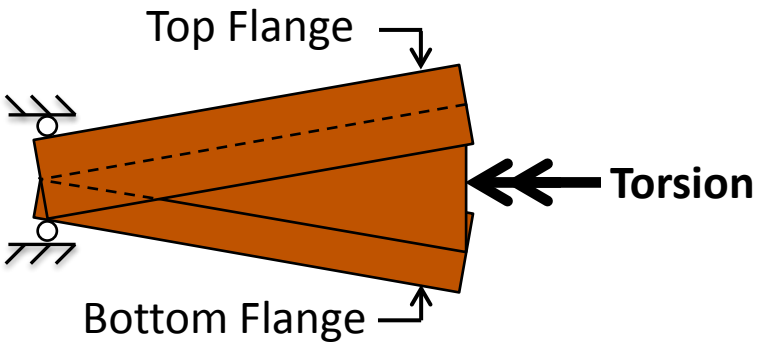
Can We Use Formwork as Shear Diaphragm Bracing?

Curved I-Girder Bridge

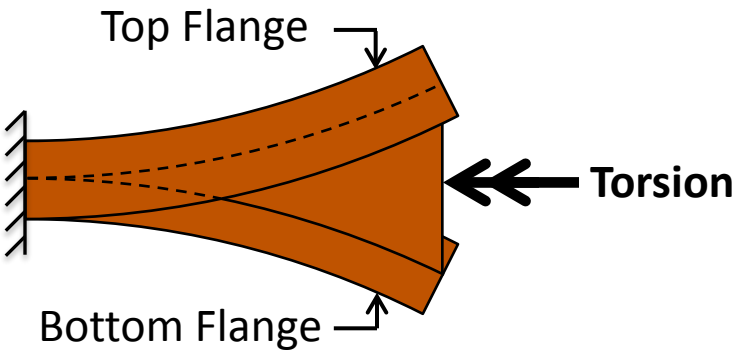
Curved Tub Girder Bridge

Background – I-Girder Torsion

- Saint-Venant Stiffness vs Warping Stiffness



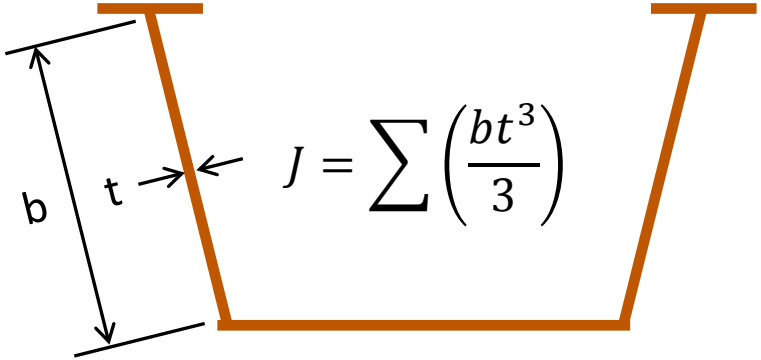
Warping Permitted



Warping Restrained

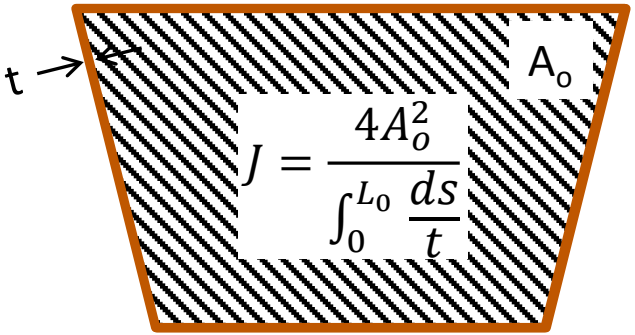
Background – Tub Girder Torsion

- Open Section Stiffness vs Closed Section Stiffness



$$J = \sum \left(\frac{bt^3}{3} \right)$$

Open Section

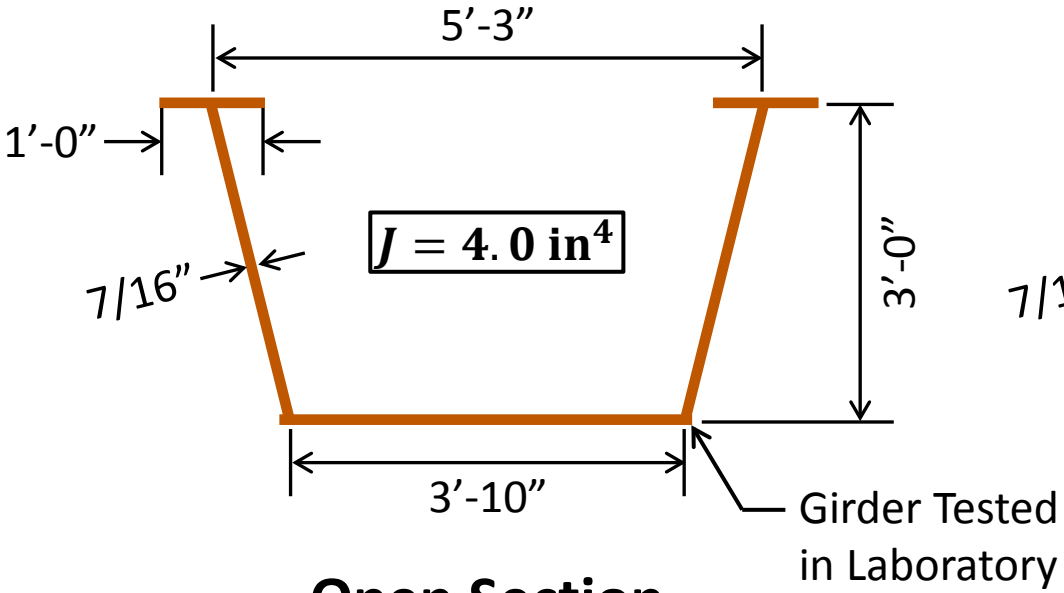


$$J = \frac{4A_o^2}{\int_0^{L_0} \frac{ds}{t}}$$

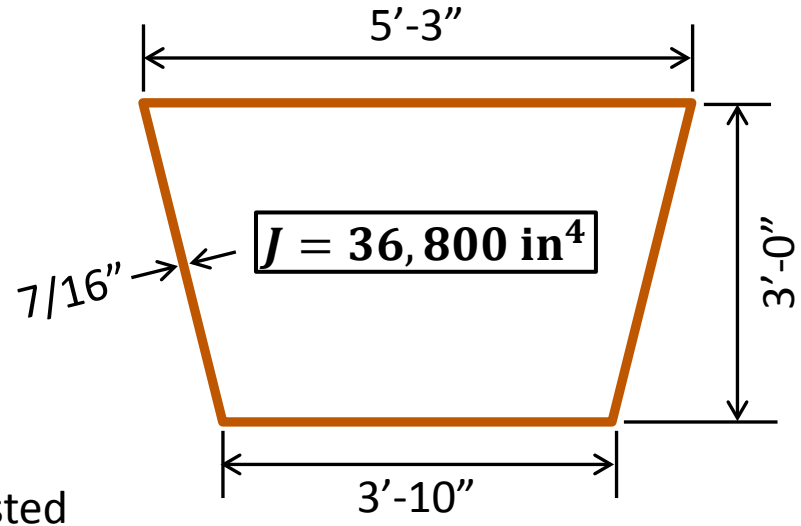
Closed Section

Background – Tub Girder Torsion

- Open Section Stiffness vs Closed Section Stiffness



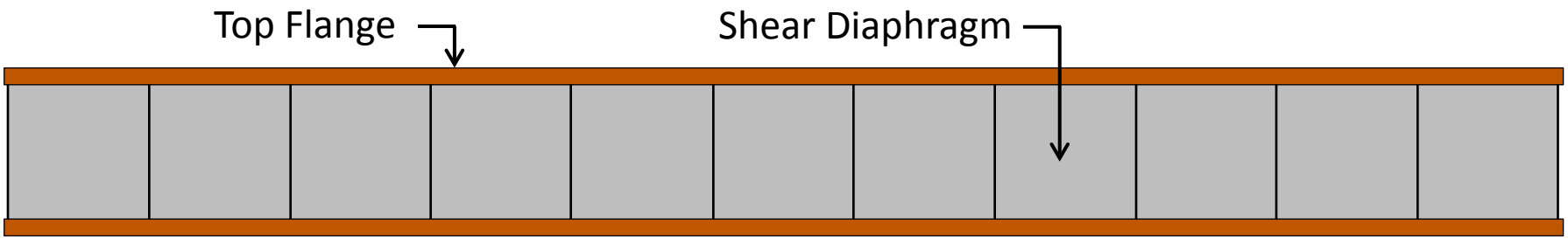
Open Section



Closed Section

Background – Steel Girder Bracing

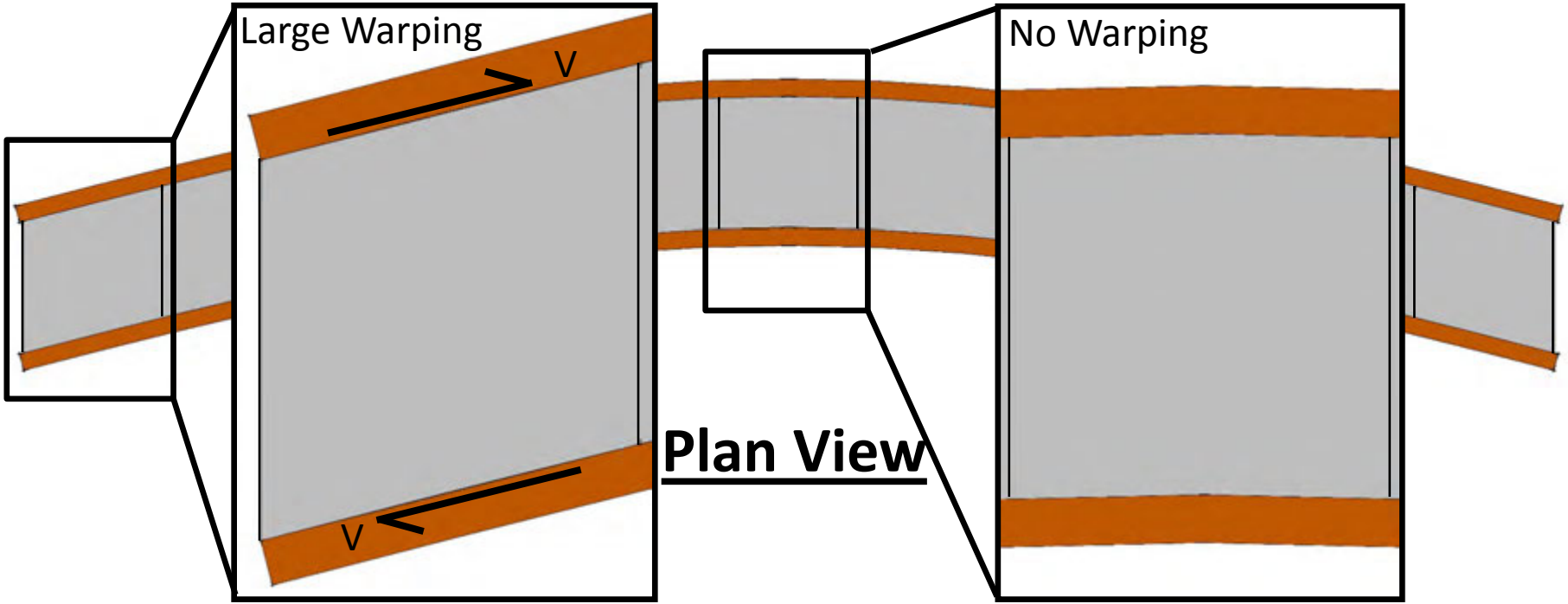
- Simply Supported Girder System w/ Shear Diaphragm Bracing



Plan View

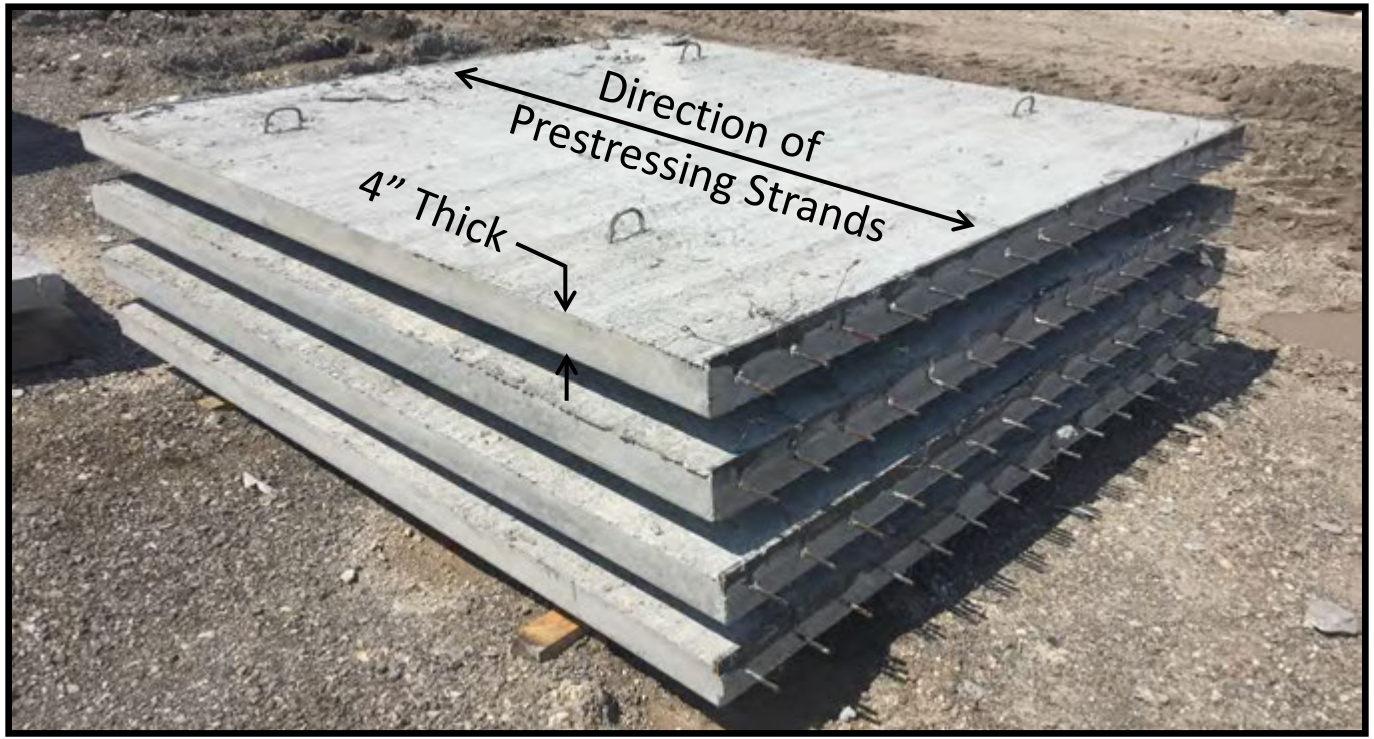
Background – Steel Girder Bracing

- Simply Supported Girder System w/ Shear Diaphragm Bracing



Background

- Partial Depth Precast Concrete Deck Panel (PCP)

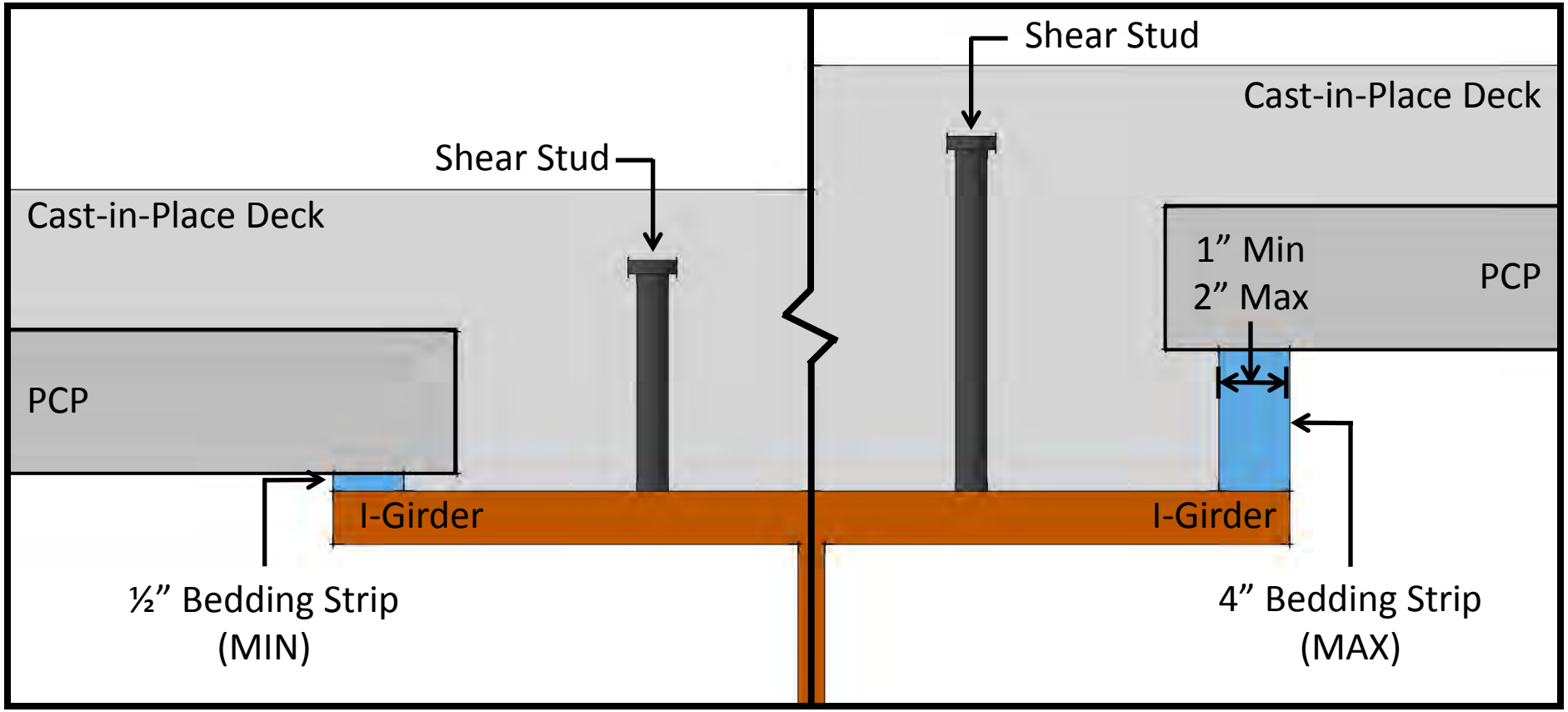


Project Goals

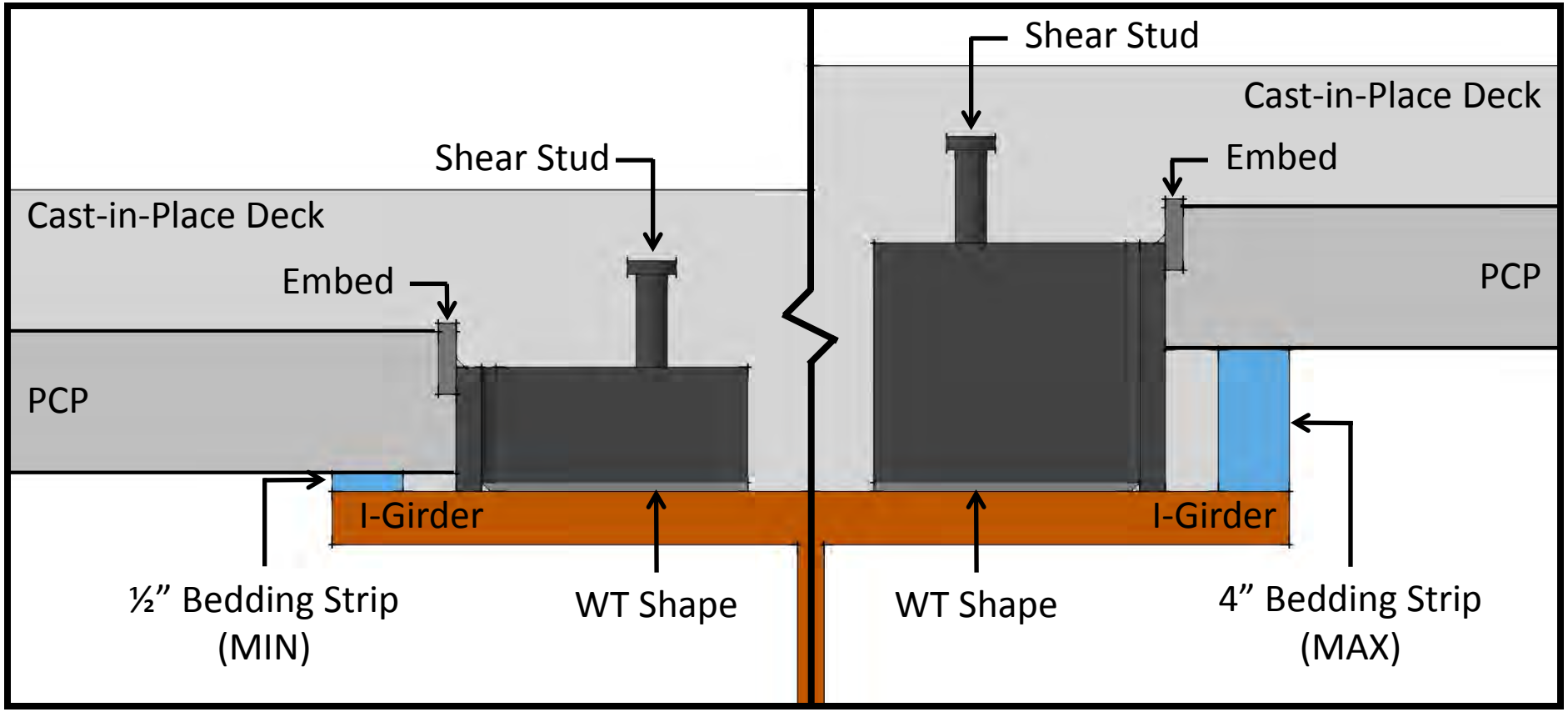
Project Goals

- Extend PCPs to Curved Systems
  - Steel I-girder & steel tub girder systems
- Evaluate Bracing Potential for PCPs During Construction
  - Provide adequate stiffness & strength
  - Develop Connection Details from PCPs to Steel Girders
- Requirements of Connection Details from PCPs to Steel Girders:
  - Accommodate difference in girder elevation
  - Avoid complicating the precasting & construction process
- UT Bridge Update (Totally new program)

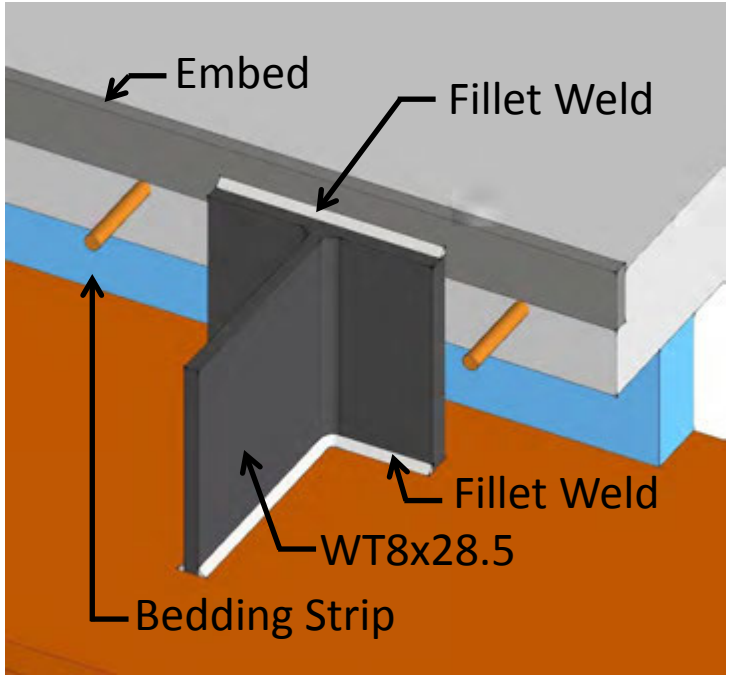
Current PCP Connection Detail

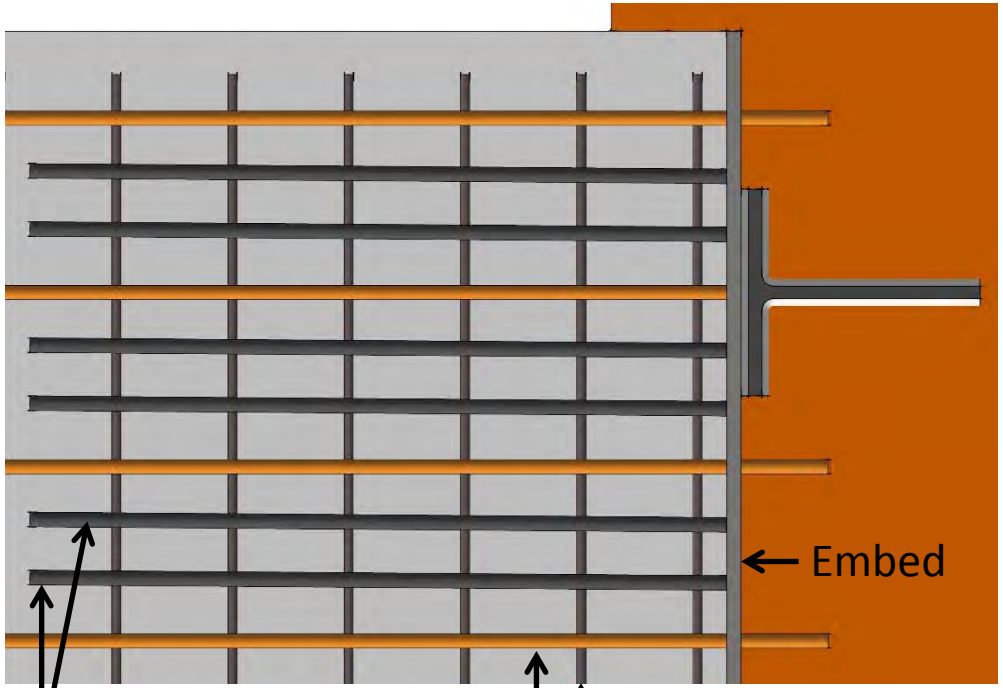


Proposed PCP Connection Detail



Proposed PCP Connection Detail

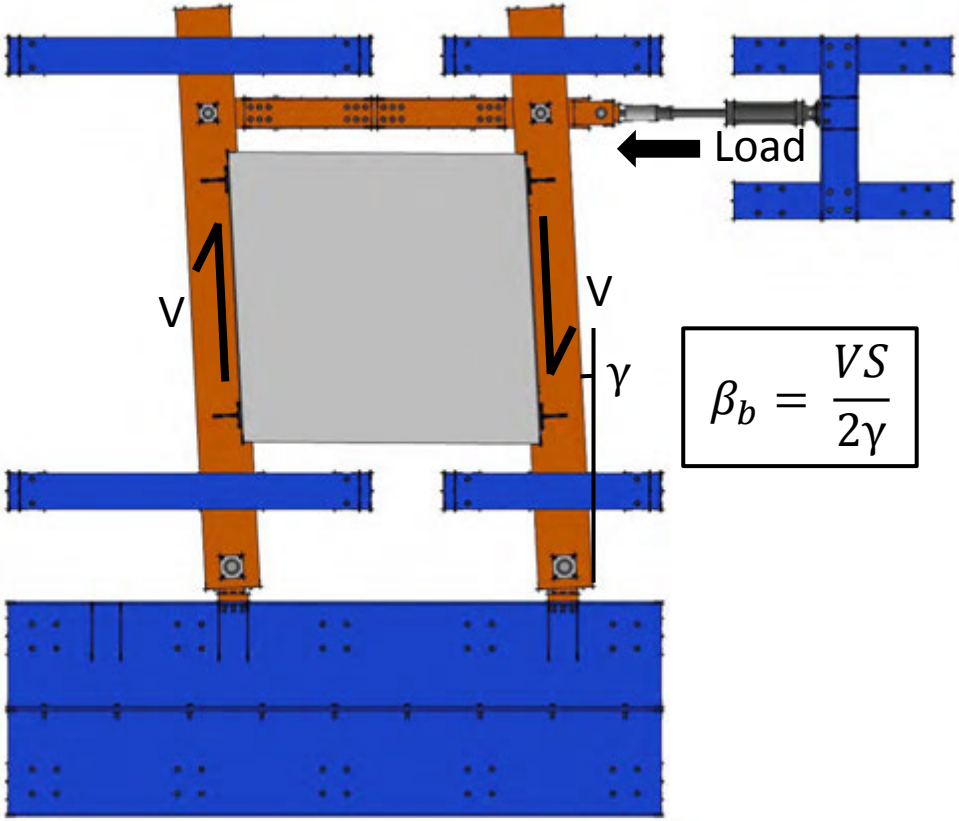




Shear Frame Study

Shear Frame Tests

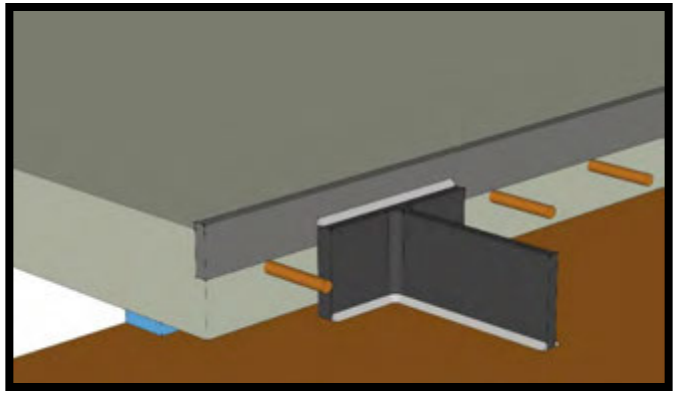
- Load Test Full Scale PCP & Connection System
- Determine Systems Stiffness & Strength
- Observe Behavior and Failure Mechanism



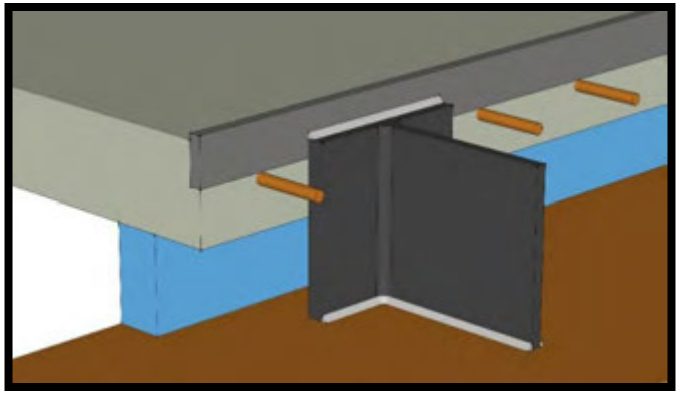
$$\beta_b = \frac{VS}{2\gamma}$$

Eight Shear Frame Tests

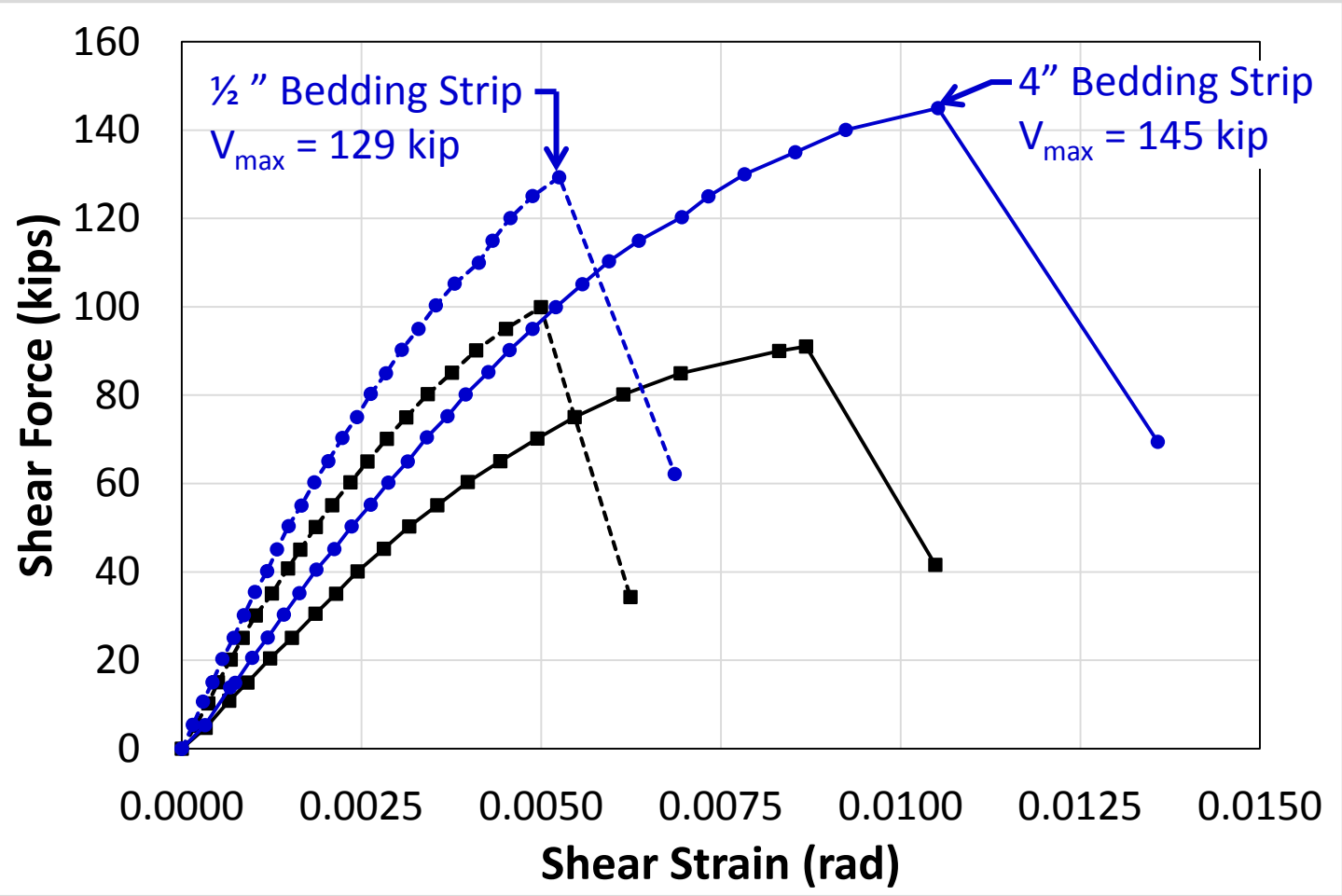
Detail	Bedding Strip		Anchors per Corner	Embed Size	WTs per Corner
A.1	Min = ½”	Max = 4”	(6) 1/2" Ø x 2'-0" Long	2"x1/2"	(1) WT8x28.5
B.1	Min = ½”	Max = 4”	(6) 5/8" Ø x 2'-6" Long	2"x5/8"	(1) WT8x28.5
C.2	Min = ½”	Max = 4”	(10) 1/2" Ø x 2'-0" Long	2"x5/8"	(2) WT8x28.5
D.2	Min = ½”	Max = 4”	(8) 5/8" Ø x 2'-6" Long	2"x3/4"	(2) WT8x28.5



Min Bedding Strip = ½”

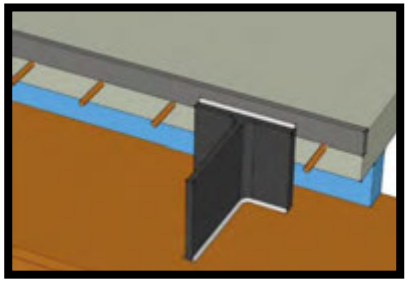


Max Bedding Strip = 4”



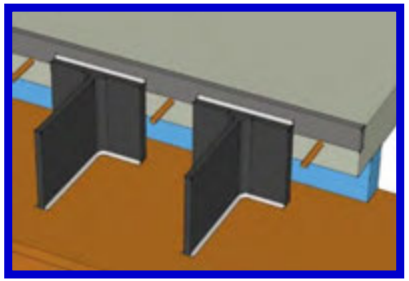
A.1.MAX

A.1.MIN



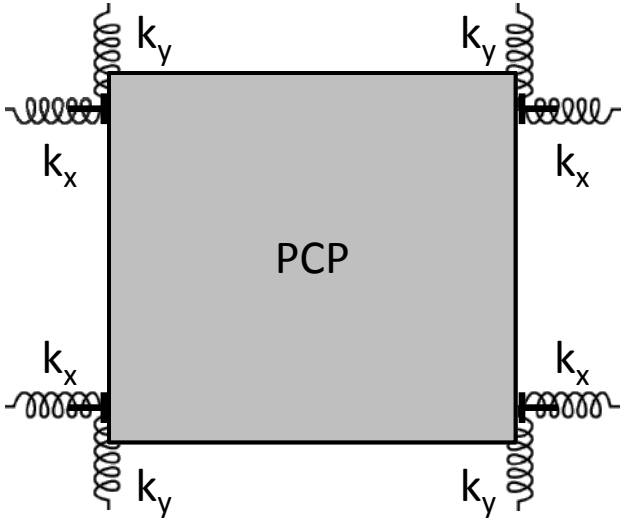
C.2.MAX

C.2.MIN



Failure Mechanism

Stiffness of PCP/Connection System
Extensive FEA modelling carried out



$$\frac{1}{\beta_b} = \frac{1}{\beta_{PCP}} + \frac{1}{\beta_{con}}$$

β_b= Brace Stiffness

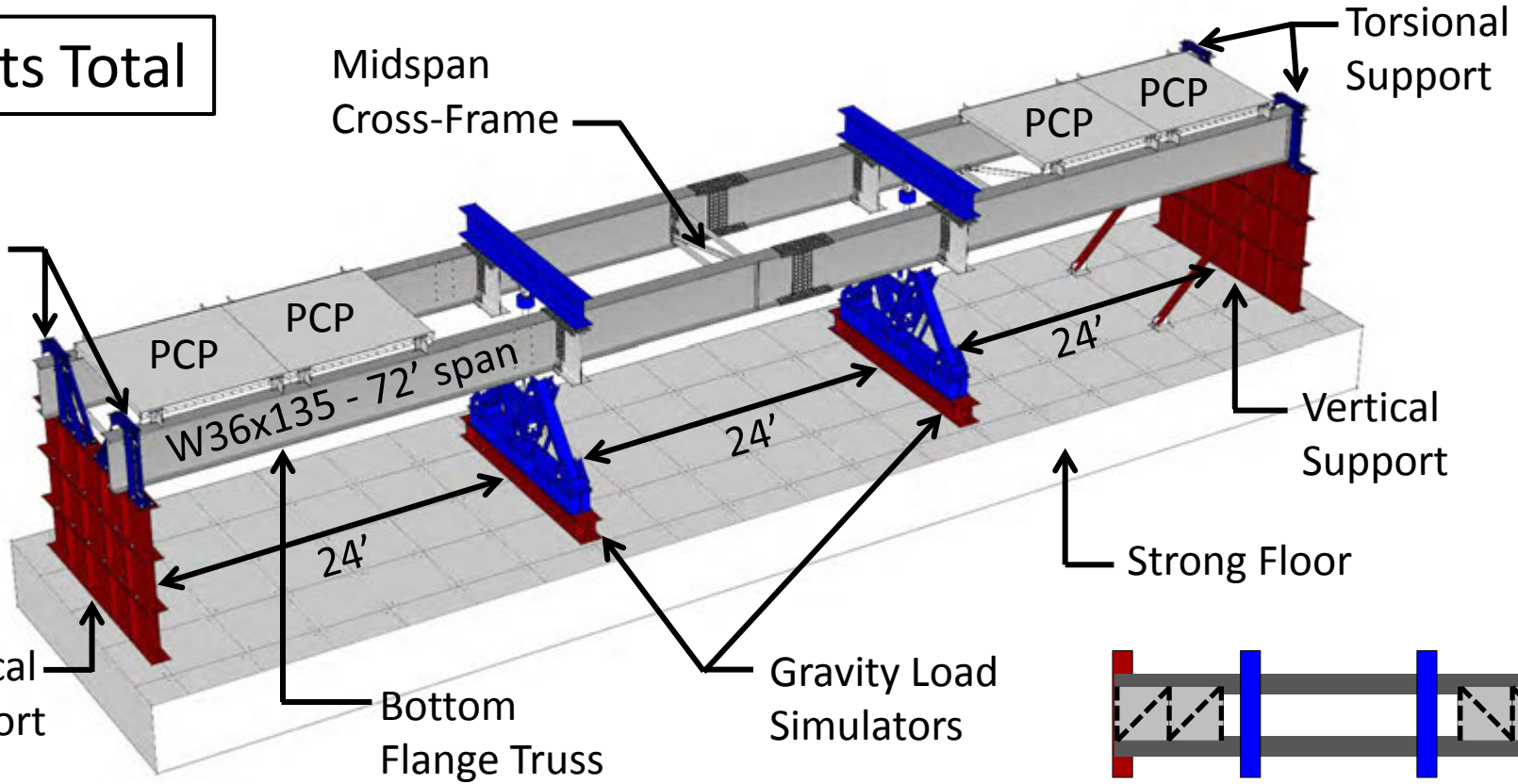
β_{PCP}= PCP Stiffness

β_{con}= Connection Stiffness

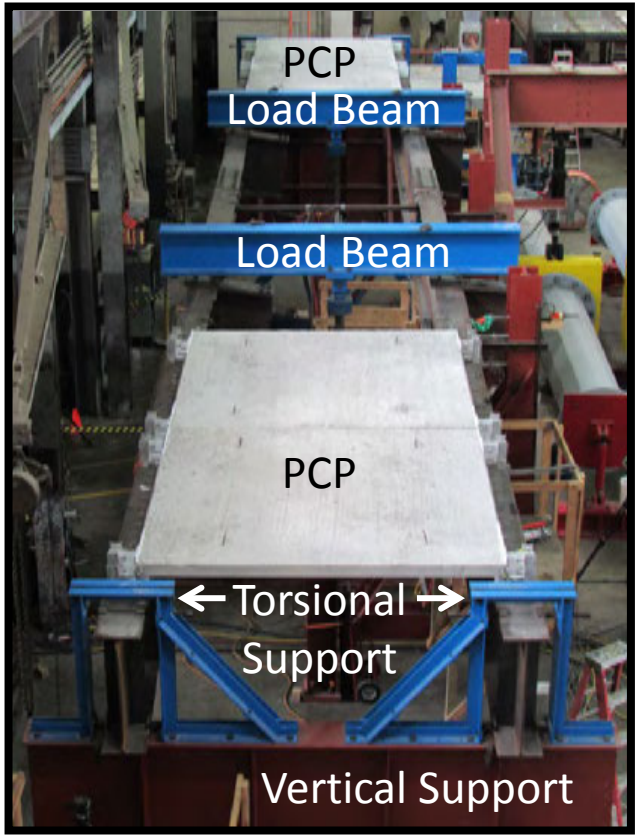
Twin I-Girder Study

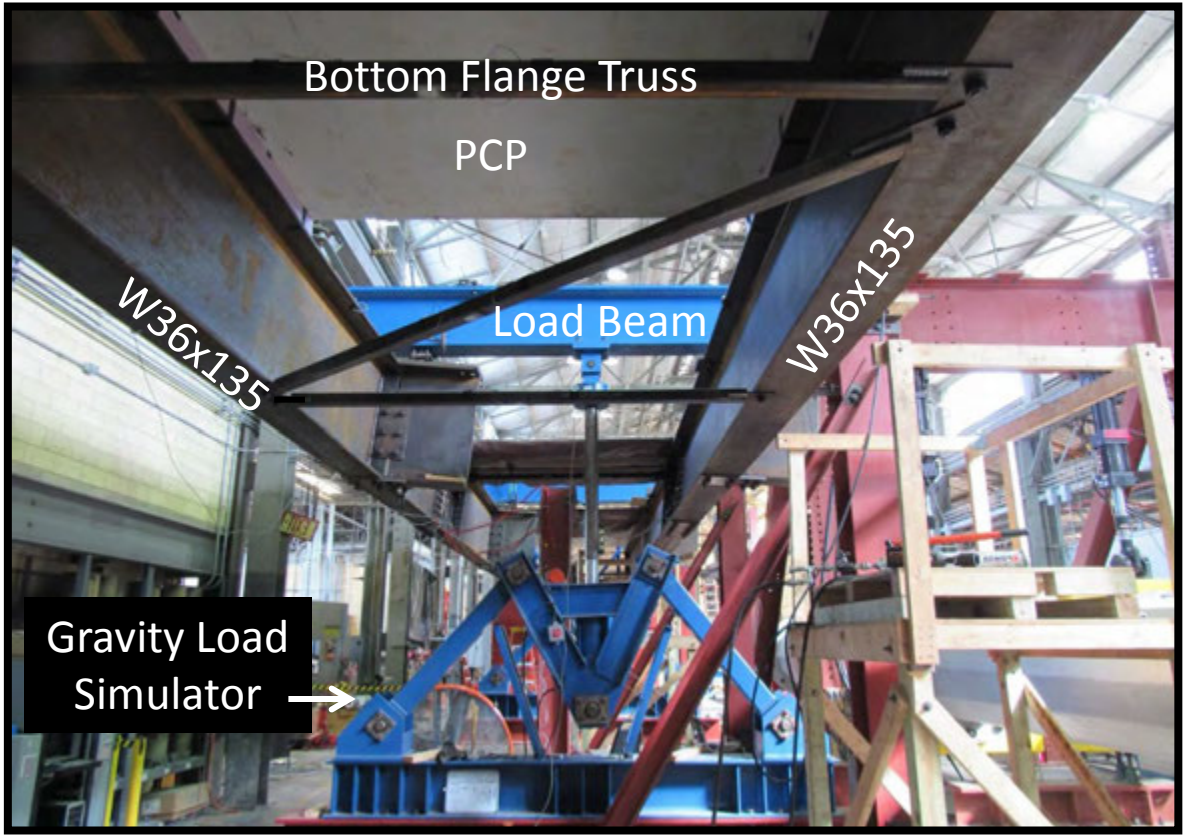
Twin I-Girder Setup – Simply Supported

22 Tests Total

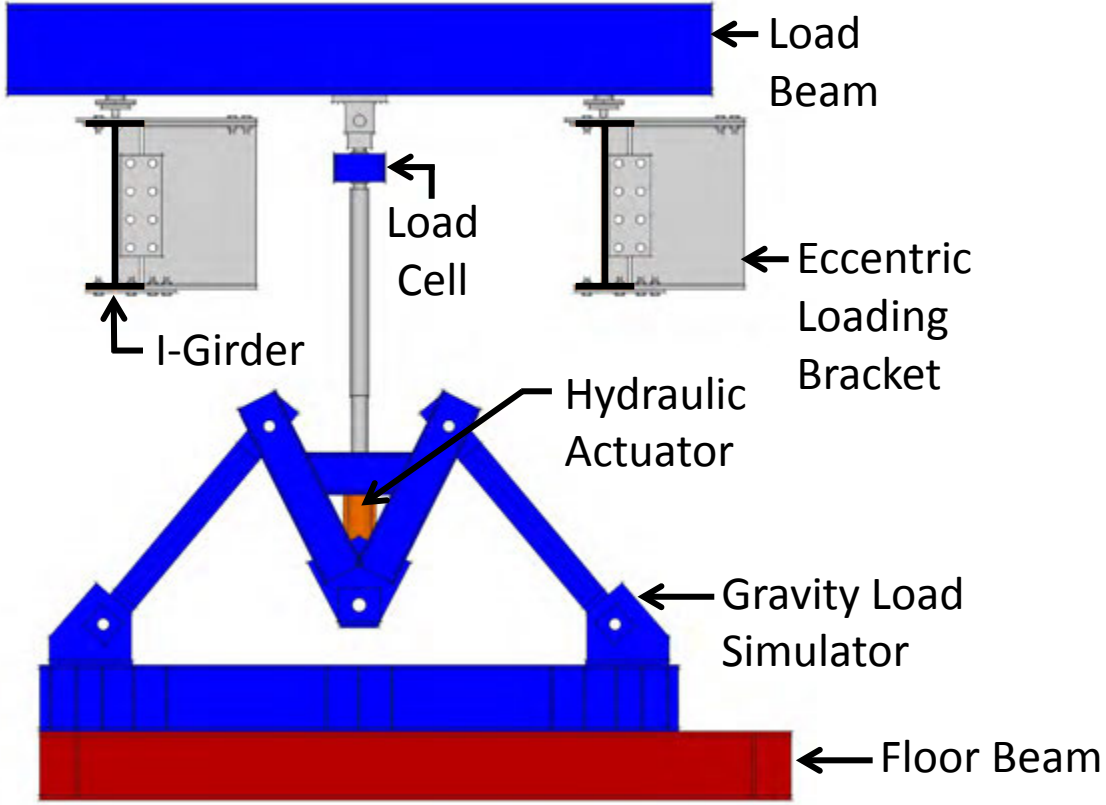


Twin I-Girder Setup – Photographs

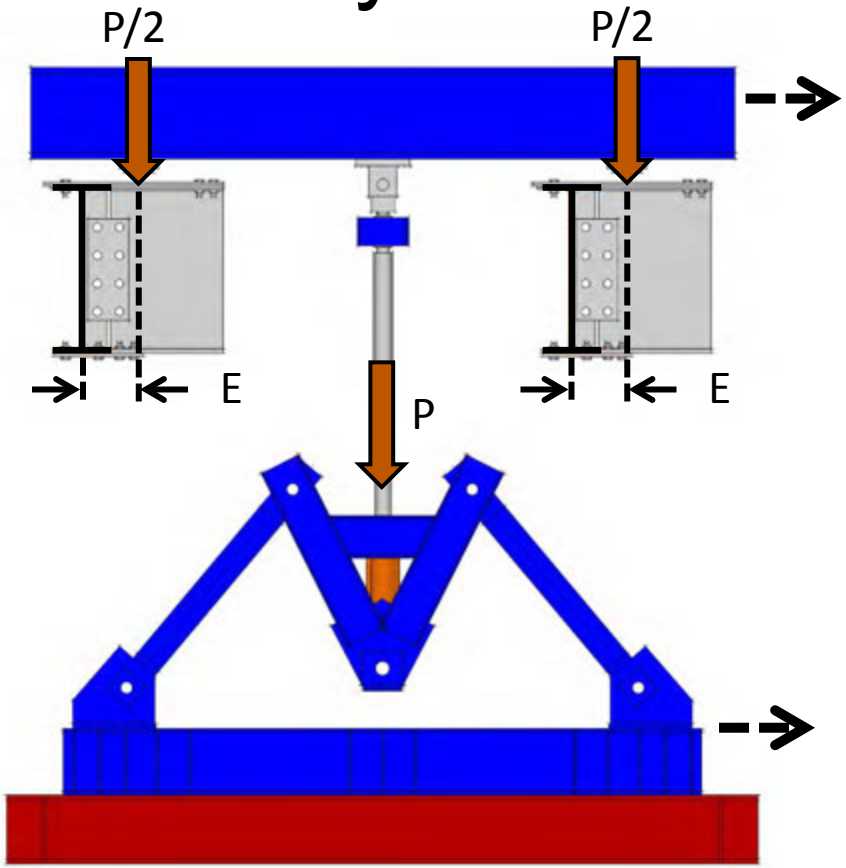


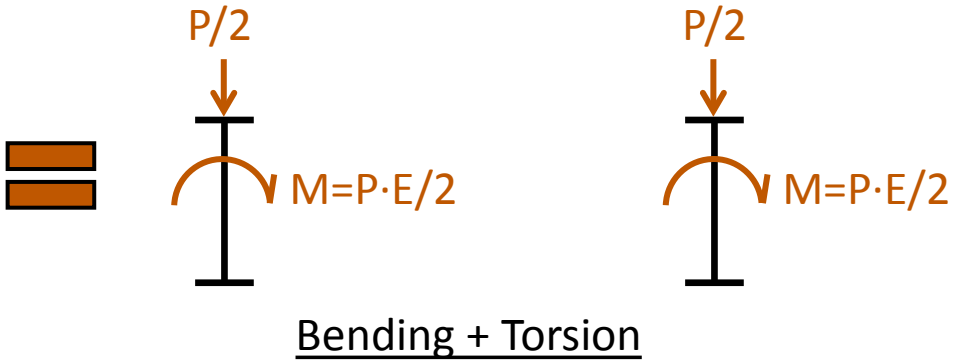


Gravity Load Simulator – Twin I-Girder



Gravity Load Simulator – Twin I-Girder

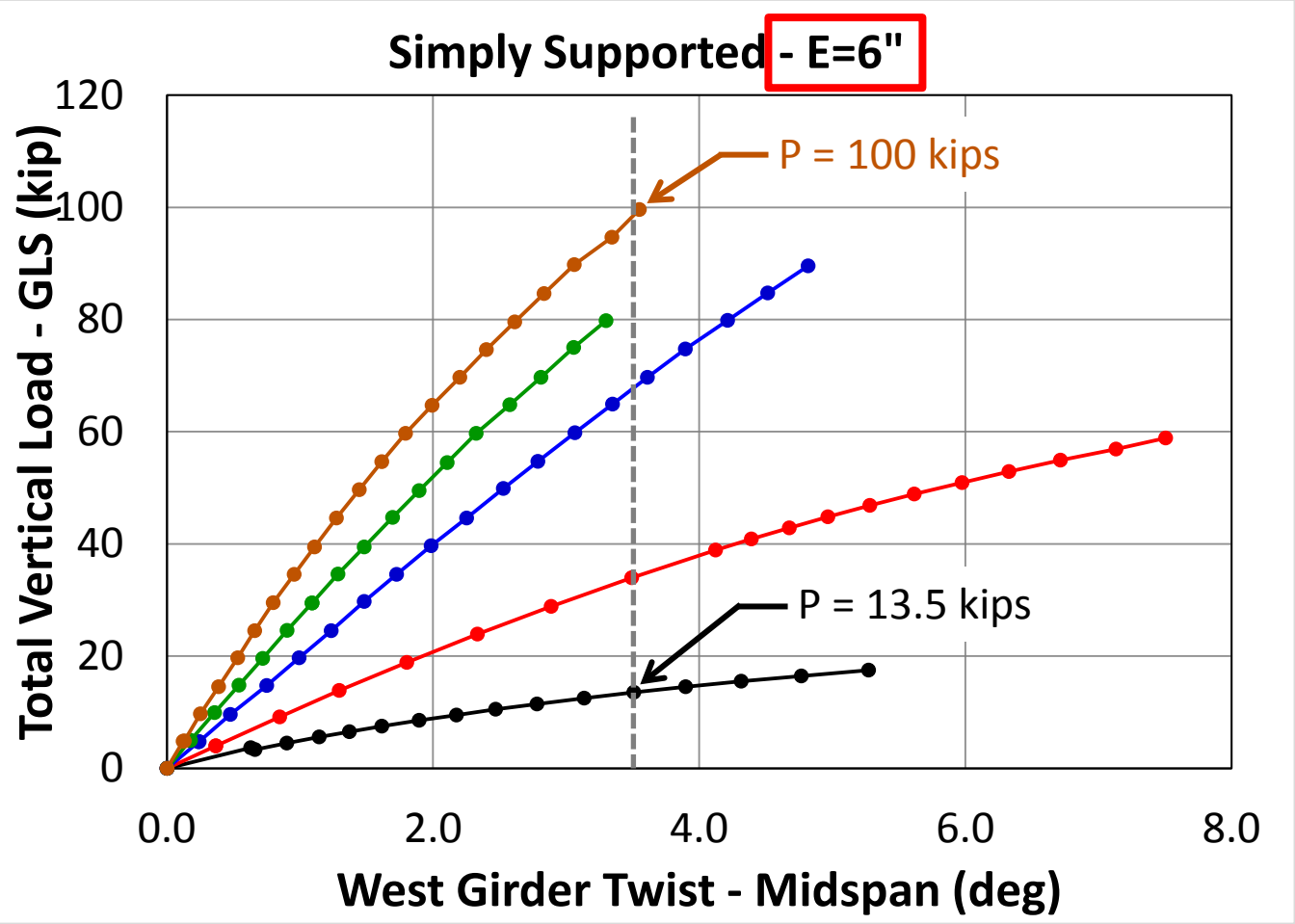


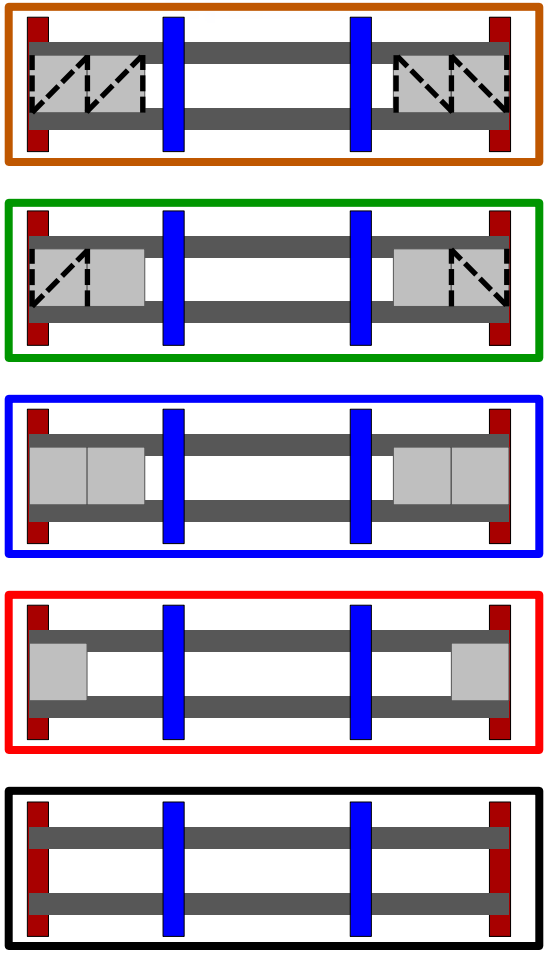


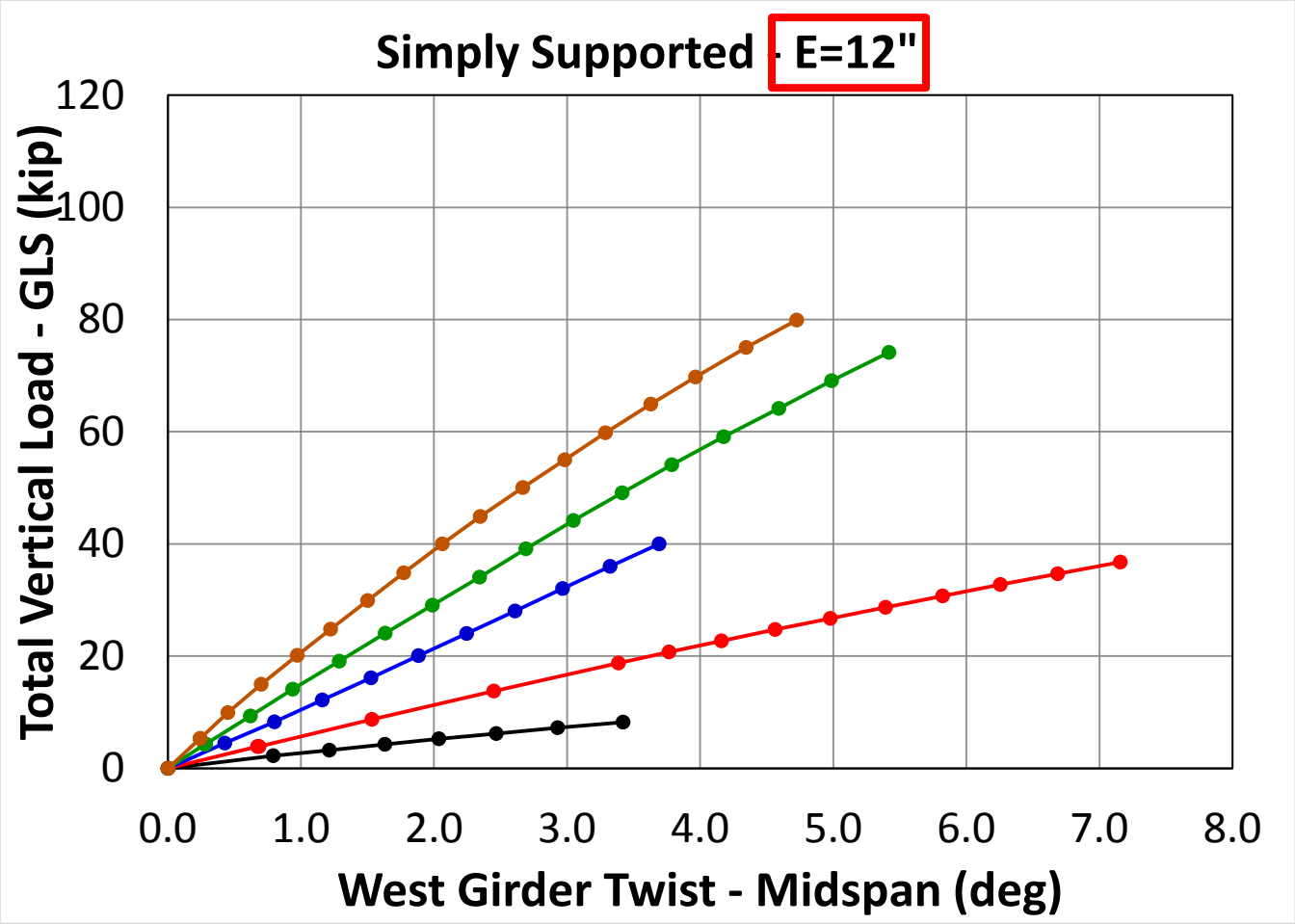
E = 0” → R = ∞

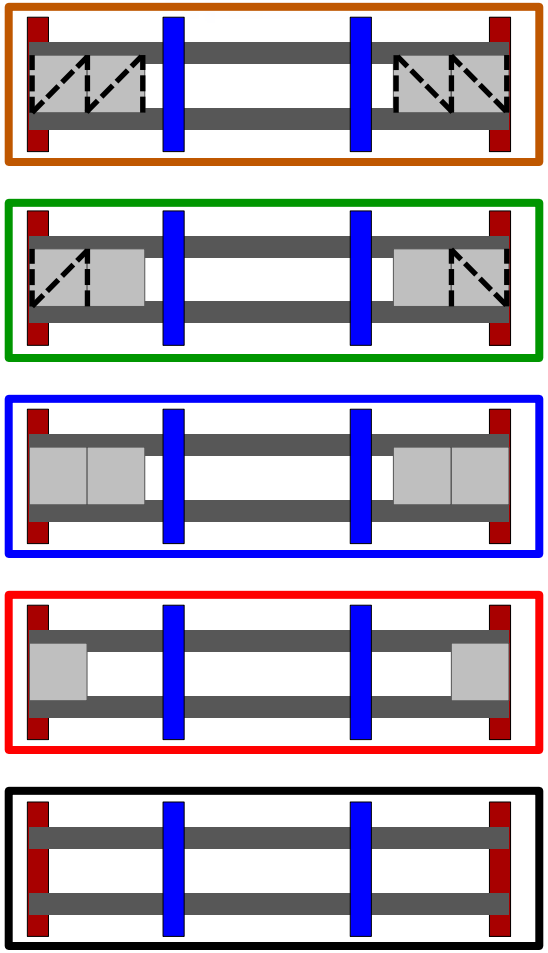
E = 6” → R ≈ 1200 ft

E = 12” → R ≈ 600 ft

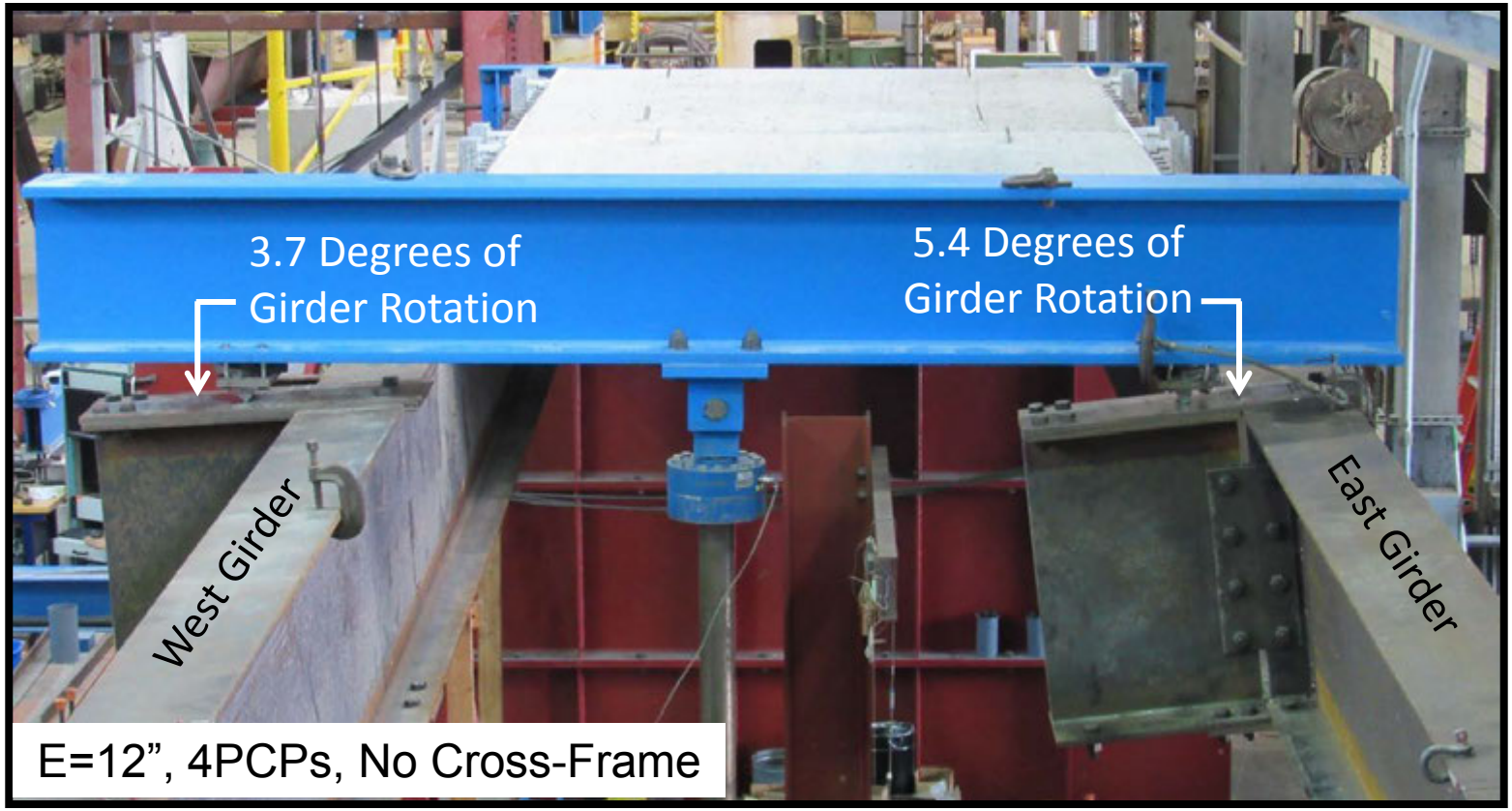

Simply Supported - E=6"
P = 100 kips
P = 13.5 kips
Total Vertical Load - GLS (kip)
West Girder Twist - Midspan (deg)
0
20
40
60
80
100
120
0.0
2.0
4.0
6.0
8.0



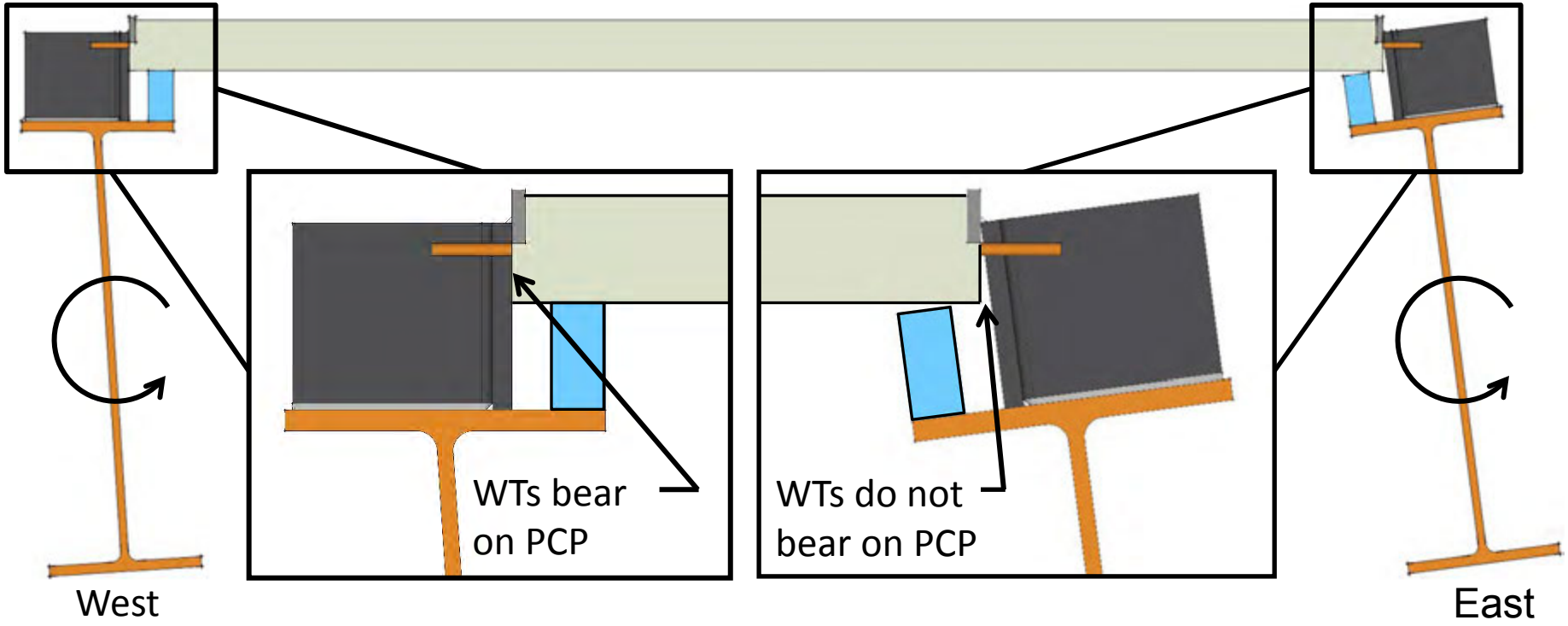

Simply Supported - E=12"
Total Vertical Load - GLS (kip)
0
20
40
60
80
100
120
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
West Girder Twist - Midspan (deg)



Twin I-Girder – West vs East Rotation

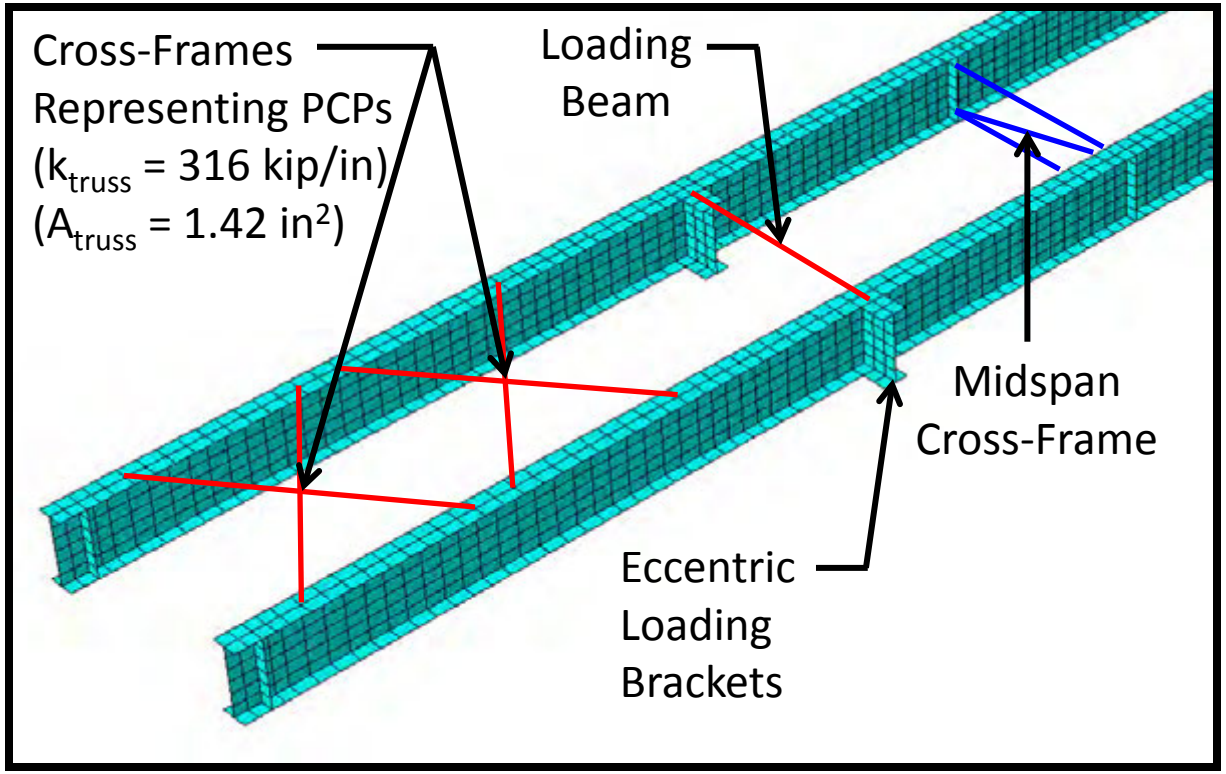


Twin I-Girder – West vs East Rotation



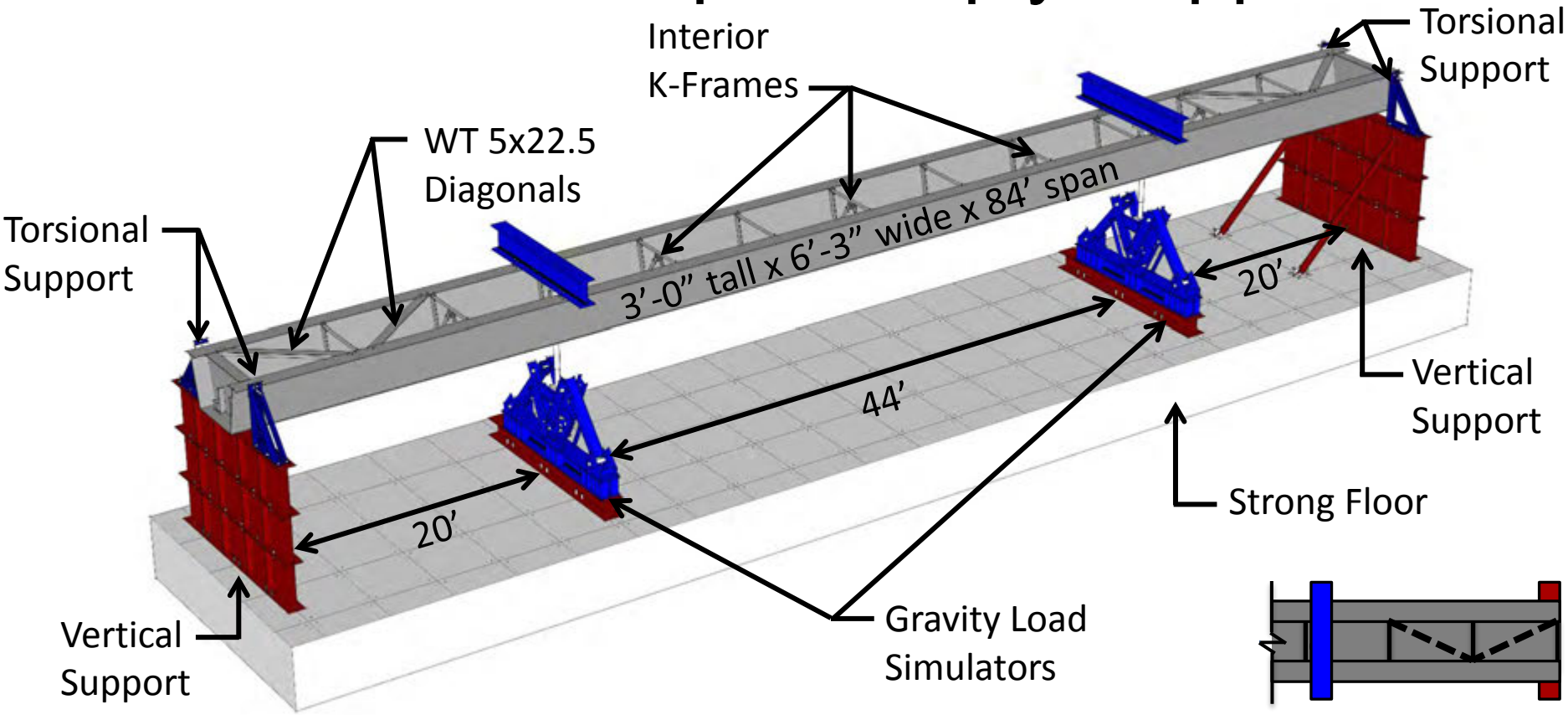
Twin I-Girder – Finite Element Model

- Abaqus 6.14
- S8R5 Shells
- Course & Fine Mesh
- 1.6 Max Aspect Ratio
- T3D2 Truss - PCPs
- Connection A.1.MAX
- Modified Boundary Conditions



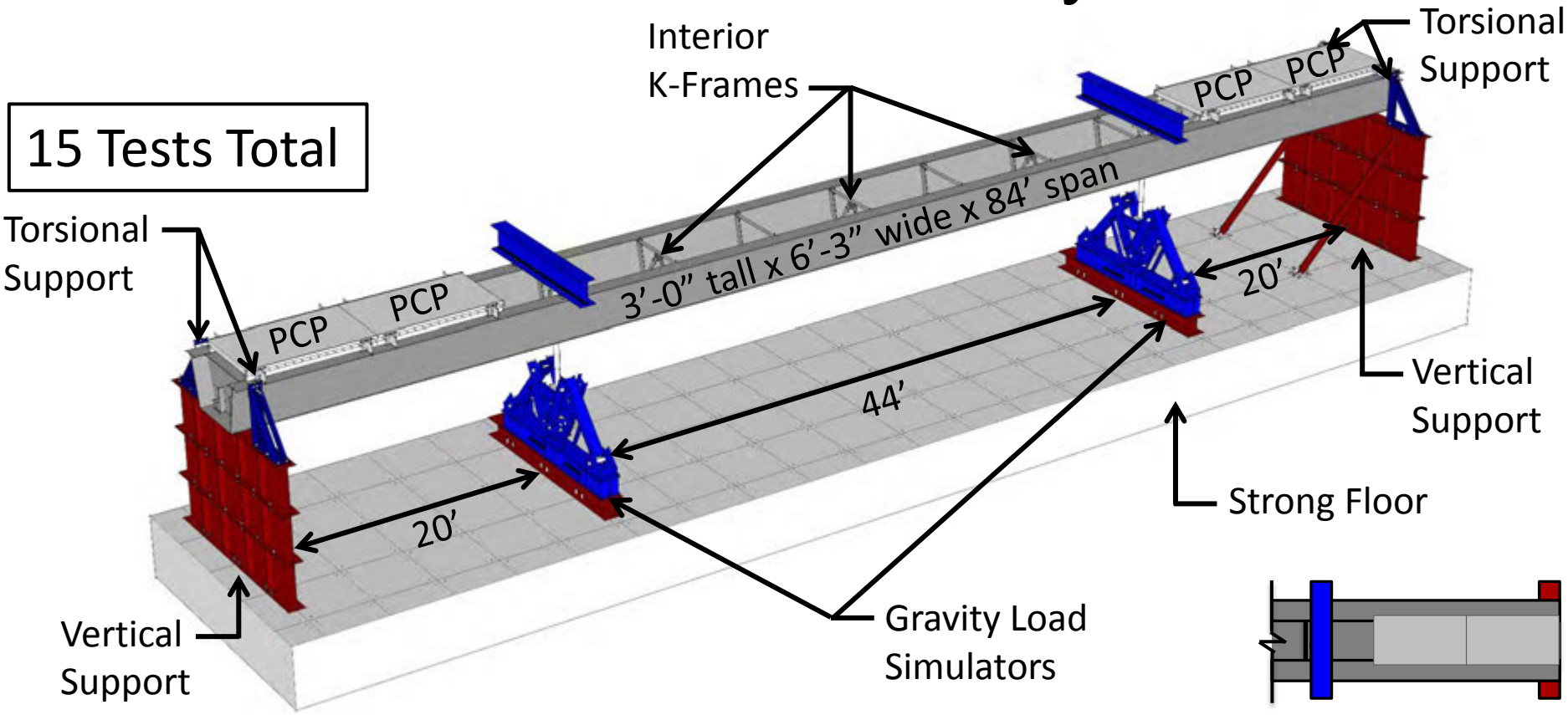
Tub Girder Study

Tub Girder Setup – Simply Supported

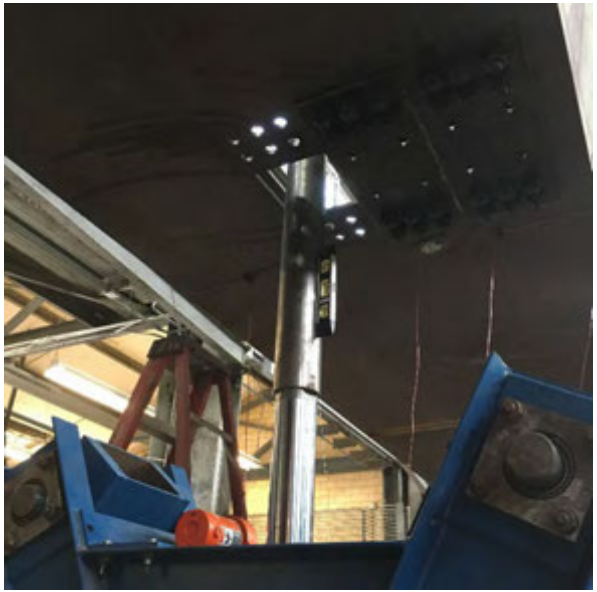


Tub Girders – Fabricated by Hirschfeld

15 Tests Total



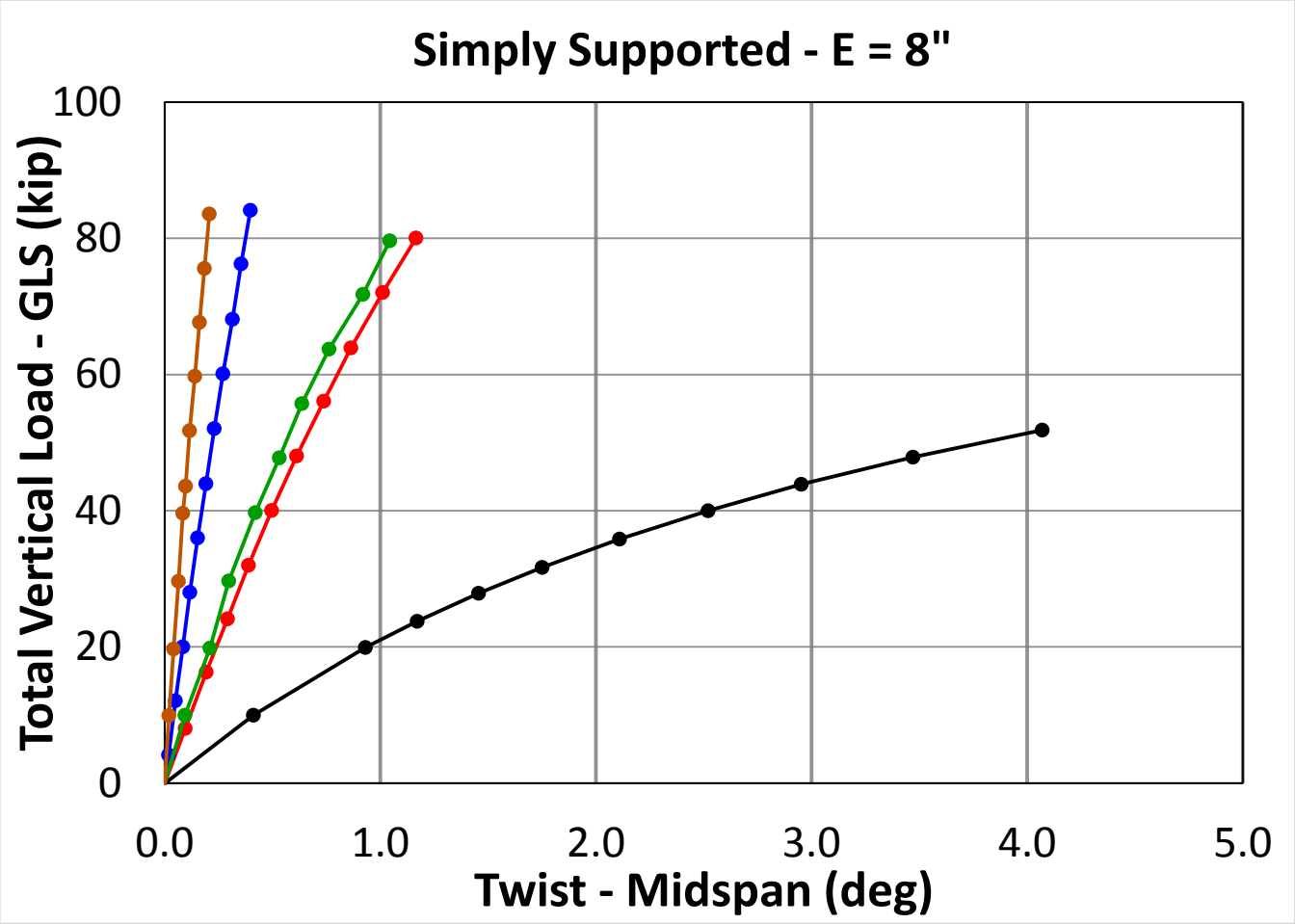
Experimental Study – Elastic Buckling Tests
Improved Tub Girder Details Study

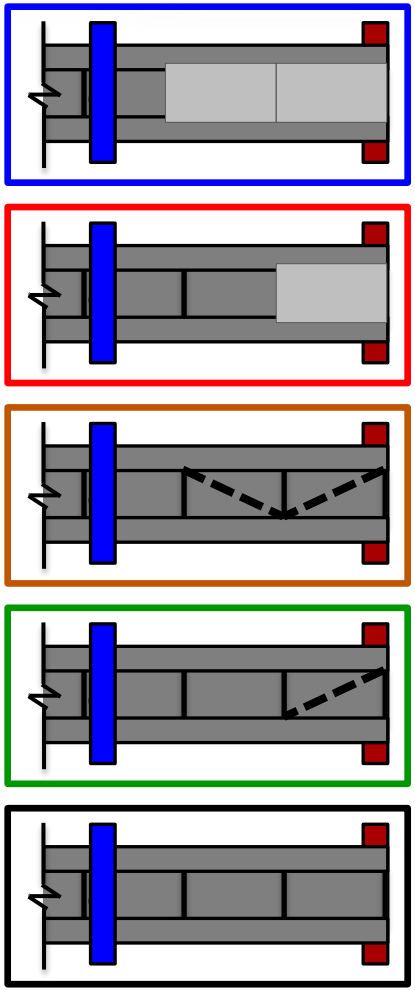


GLS concentric

GLS eccentricity=8”

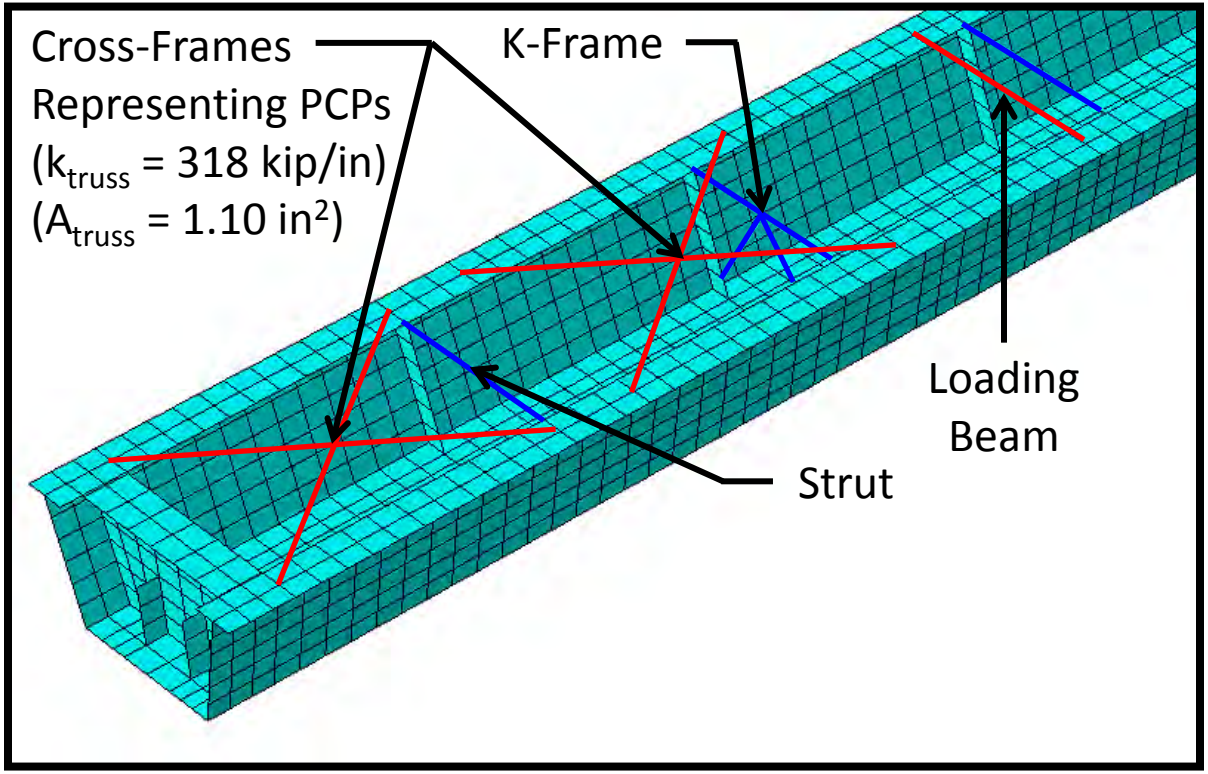
GLS eccentricity=16”


Simply Supported - E = 8"
Total Vertical Load - GLS (kip)
100
80
60
40
20
0
0.0
1.0
2.0
3.0
4.0
5.0
Twist - Midspan (deg)



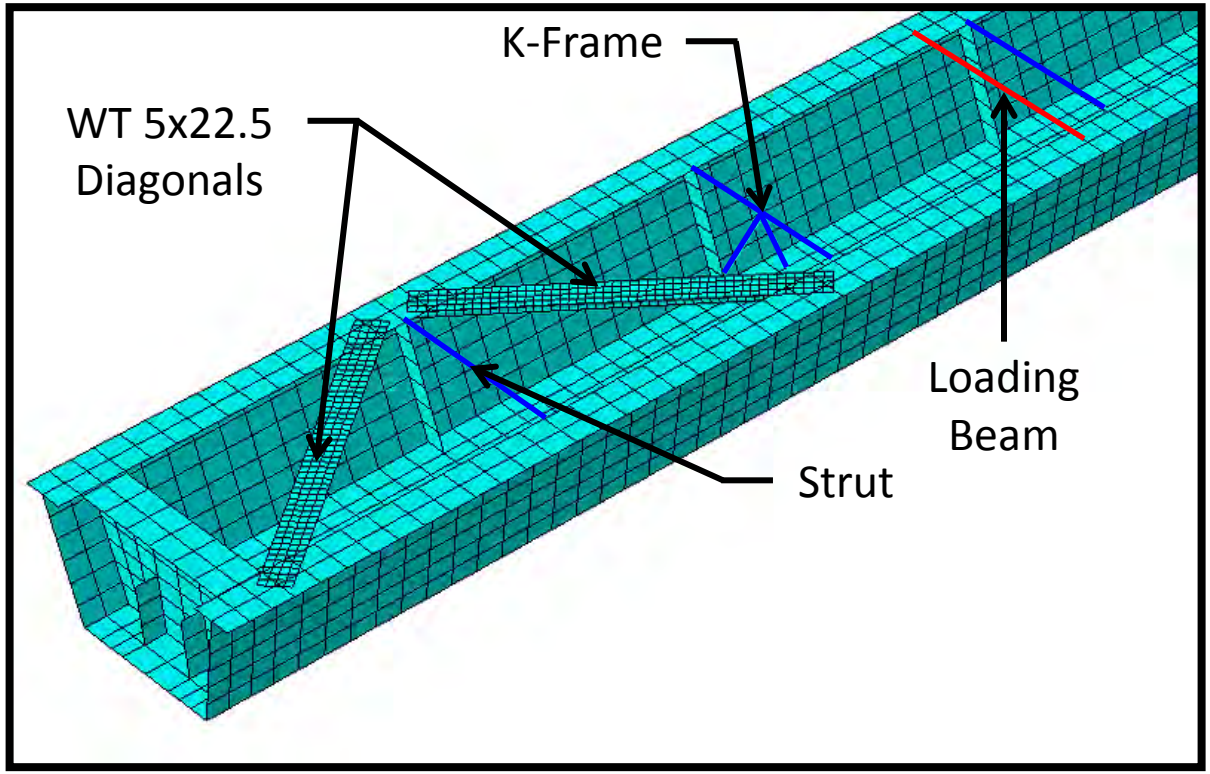
Tub Girder – Finite Element Model

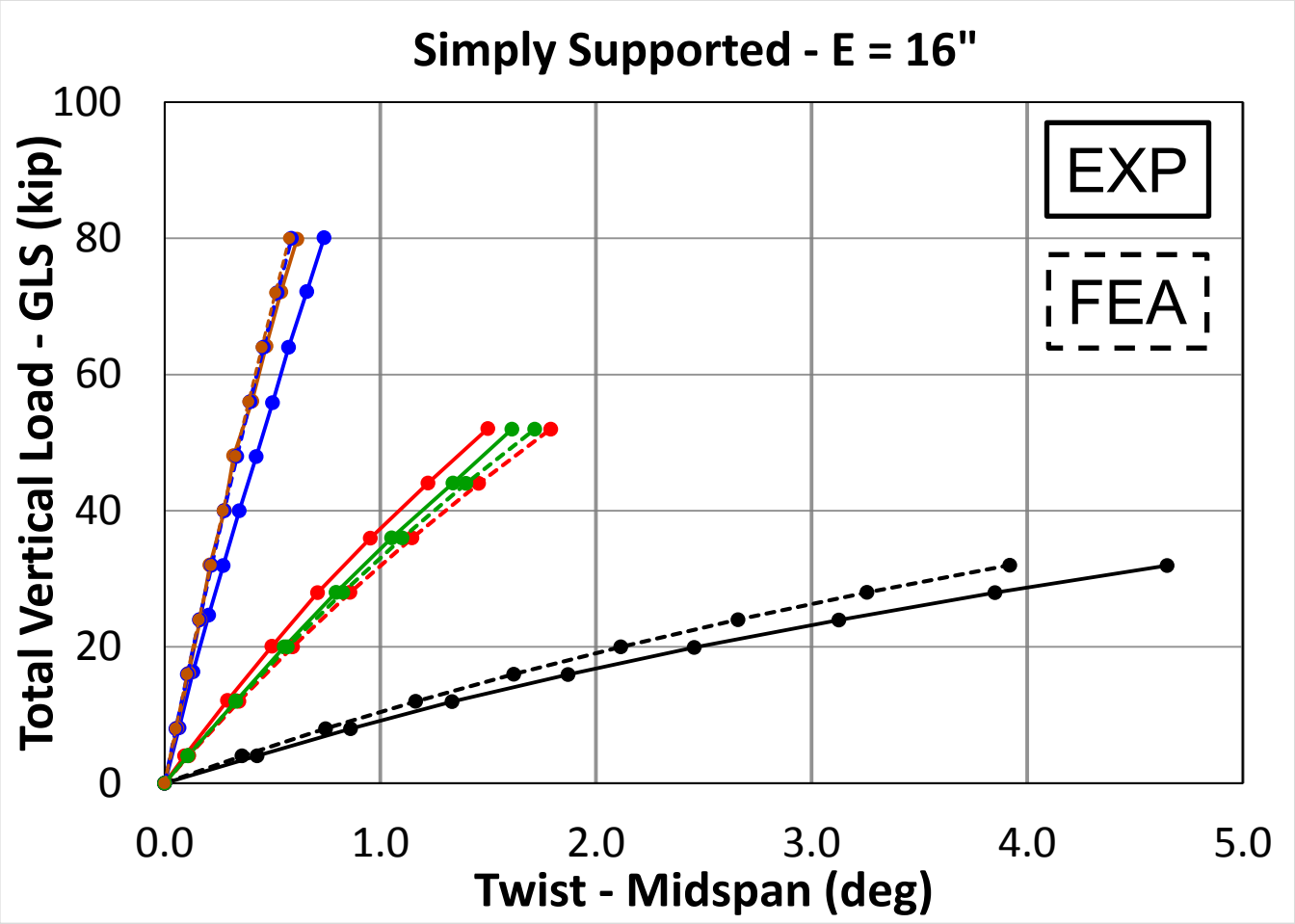
- Abaqus 6.14
- S8R5 Shells
- Course & Fine Mesh
- 2.1 Max Aspect Ratio
- T3D2 Truss - PCPs
- Connection A.1.MAX
- Modified Boundary Conditions

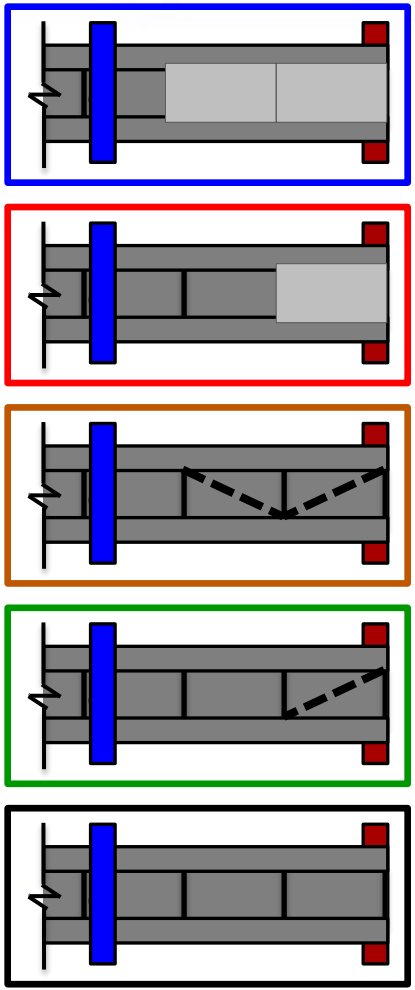


Tub Girder – Finite Element Model

- Abaqus 6.14
- S8R5 Shells
- Course & Fine Mesh
- 2.1 Max Aspect Ratio
- S8R5 Shells - WTs
- Connection A.1.MAX
- Modified Boundary Conditions

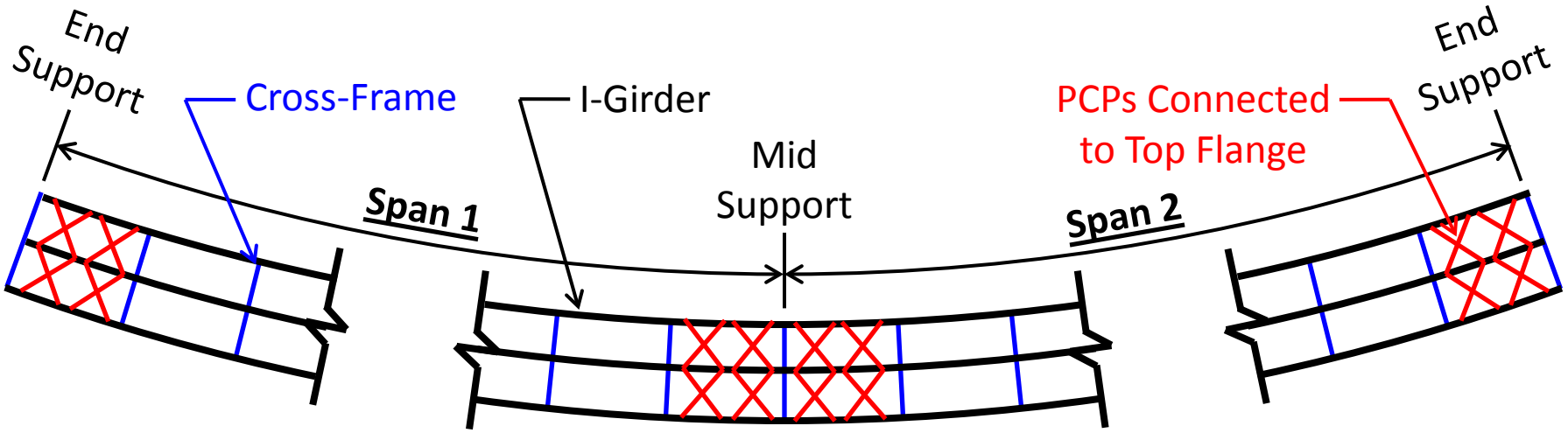



Simply Supported - E = 16"
Total Vertical Load - GLS (kip)
100
80
60
40
20
0
0.0
1.0
2.0
3.0
4.0
5.0
Twist - Midspan (deg)
EXP
FEA



Parametric FEA Study

I-Girder Parametric FEA

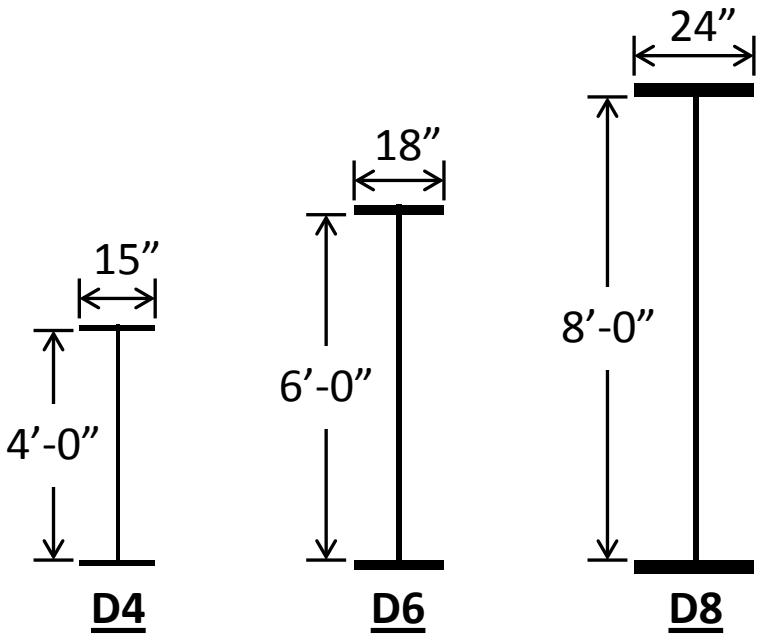


Plan View

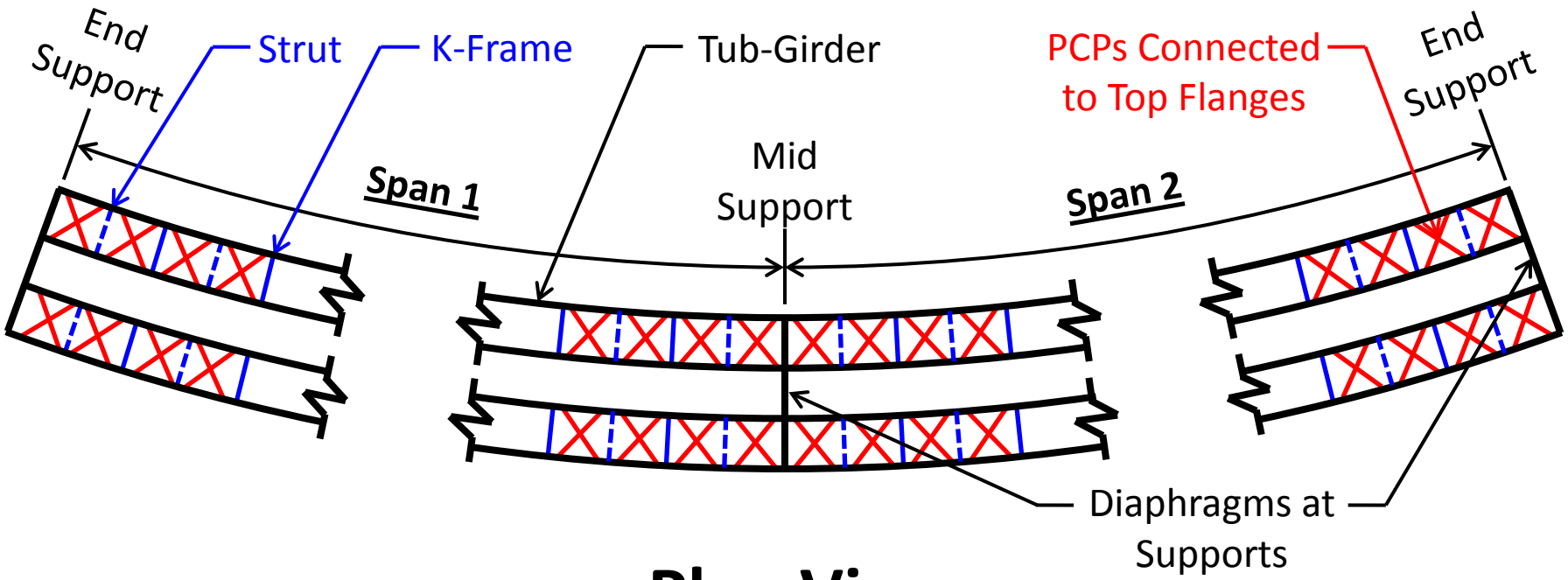
I-Girder Parametric FEA

Parameters

- Radius of Curvature: 1800′, 1200′, & 600′
- I-Girder Sections: D4, D6, & D8
- PCP Location: 2 @ End of Span
- X-Frame Spacing: 20′ & 40′
- Unequal Span: L/D = 20 & 30
- Equal Span: L/D = 30
- Load Steps: 5



Tub Girder Parametric FEA

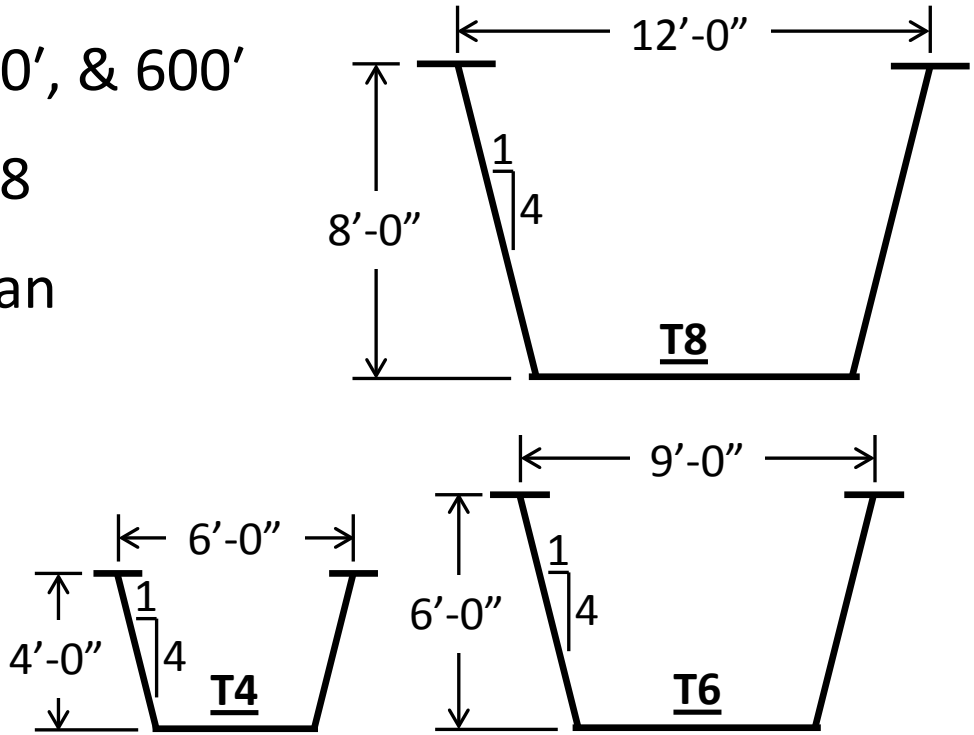


Plan View

Tub Girder Parametric FEA

Parameters

- Radius of Curvature: 1800′, 1200′, & 600′
- Tub Girder Sections: T4, T6, & T8
- PCP Location: 25% @ End of Span
- Equal Span: L/D = 32
- Load Steps: 5

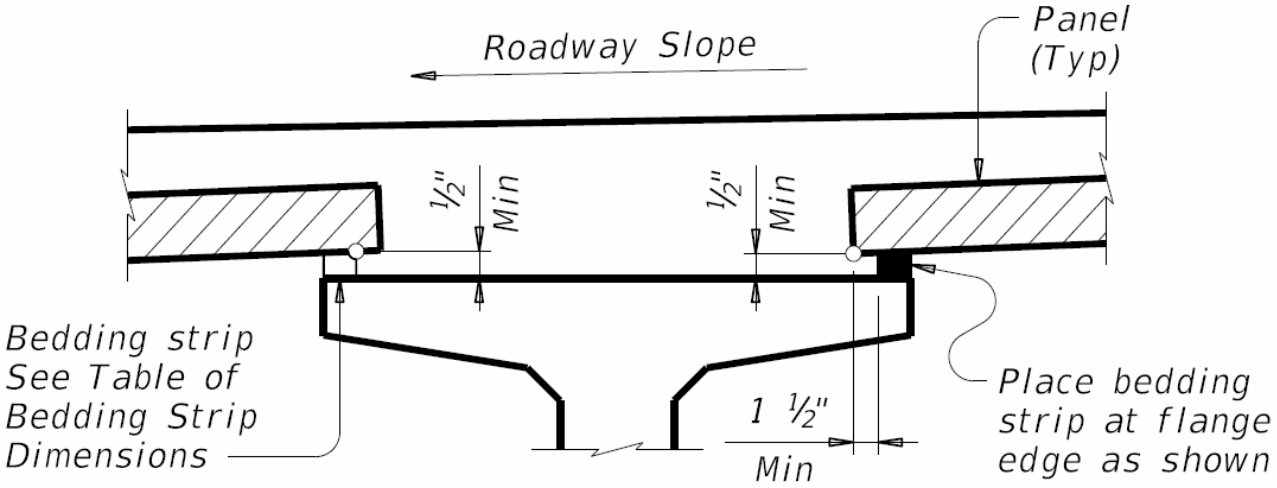


Conclusion - Steel Girder Parametric Study

- PCPs Connected to Curved I-Girders
  - PCPs did not significantly reduce forces of **all** cross-frames
  - PCPs did not significantly reduce twist of system (system was still an open girder and bottom flange kicks out)
  - PCPs will not allow significant increases for cross-frame spacing
  - **Therefore – PCPs not recommended for bracing in long-span I-girders (shorter spans – rolled beam bridges may work well).**
- PCPs Connected to Curved Tub Girders
  - Lifting and construction sequence issues
  - Partial top flange bracing only for mildly curved systems
  - Improved Tub Girder Details Project – Should result in reduced bracing
  - **Therefore – PCPs not recommended for bracing in steel tub girders**

Unconnected PCP Study

Current TxDOT PCP Connection Detail



NORMAL GRADING DETAIL (1)

Showing Prestressed Concrete I-Girders.
(Other Beam Types Similar)

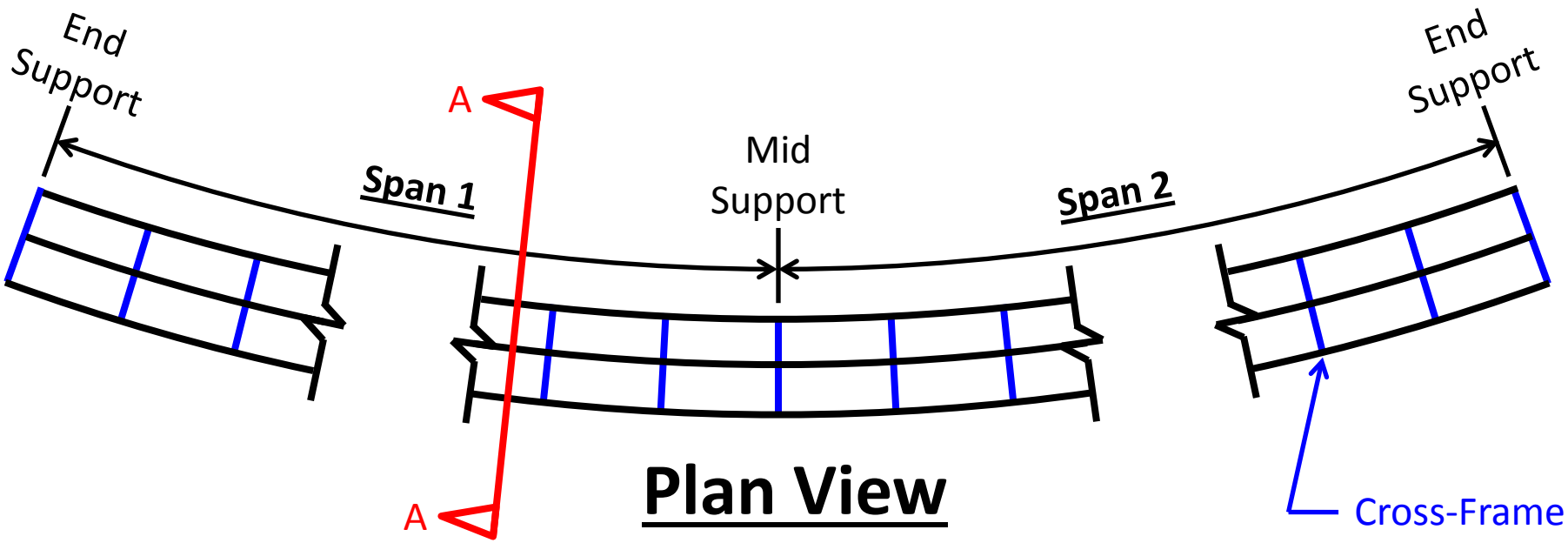
TABLE OF BEDDING STRIP DIMENSIONS

WIDTH	HEIGHT (2)	
	Min	Max
1" (Min)	½"	2"
1 ¼"	½"	2 ½"
1 ½"	½"	3"
1 ¾"	½"	3 ½"
2" (Max)	½"	4"

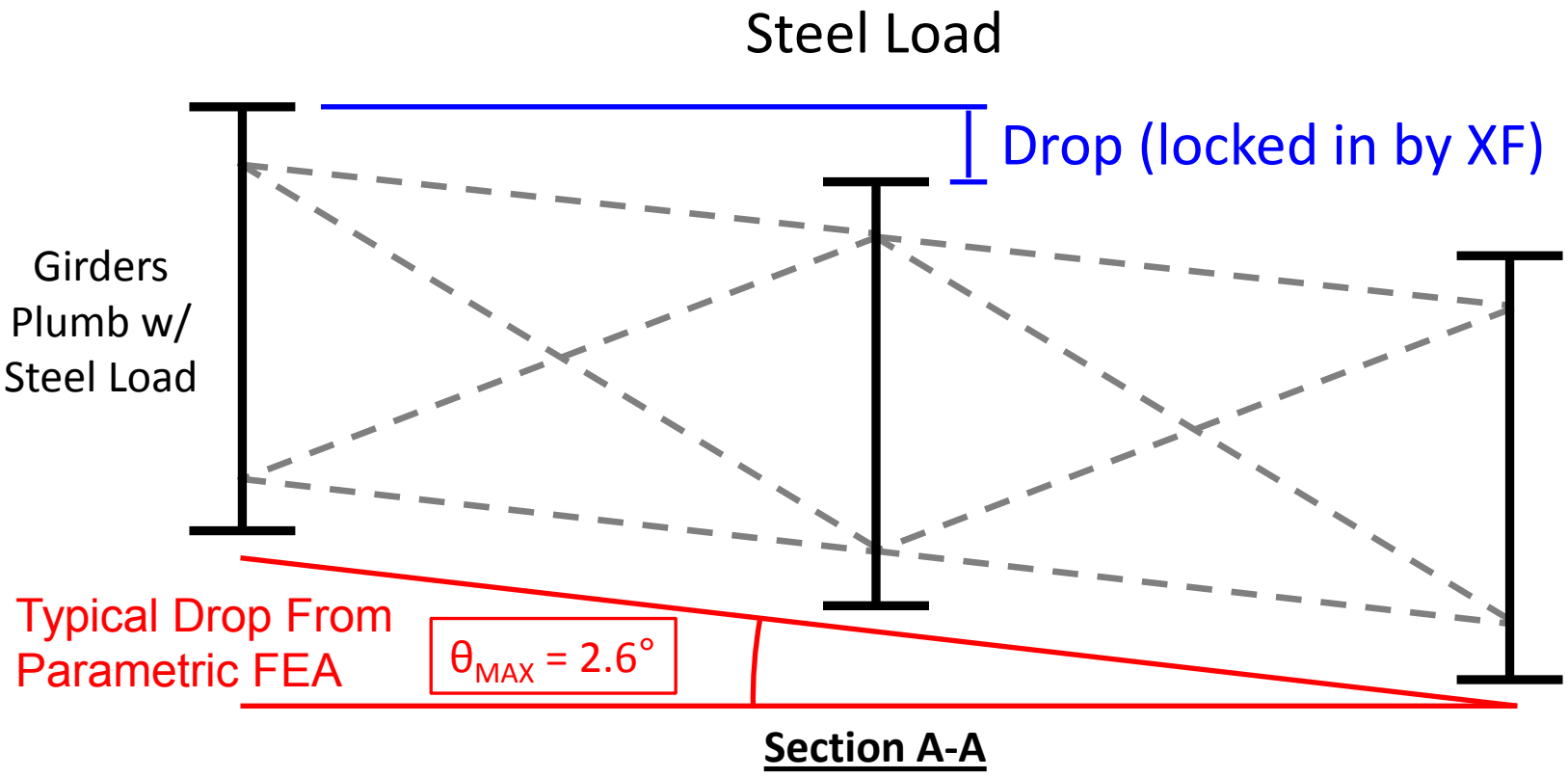
GENERAL NOTES:

Use of Prestressed Concrete Panels is not permitted for horizontally curved steel plate or tub girders.

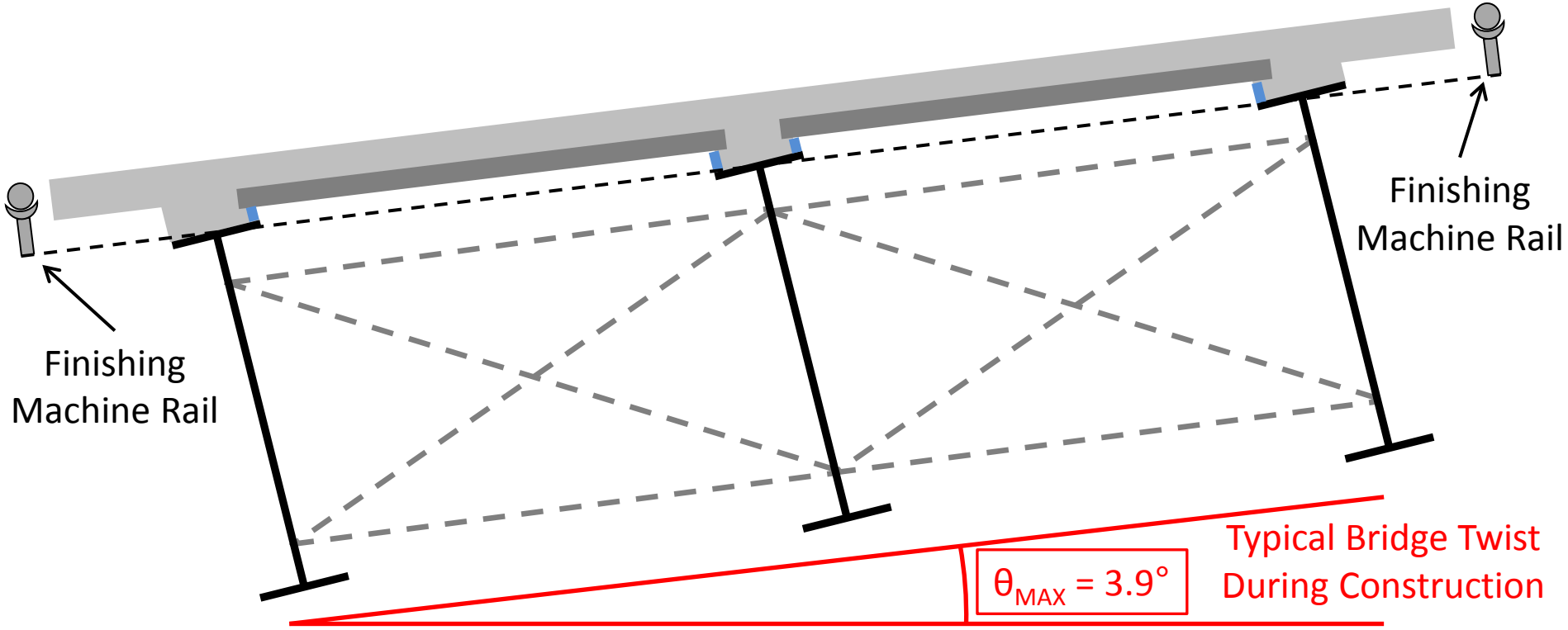
Unconnected PCPs on Curved I-Girders



Unconnected PCPs on Curved I-Girders

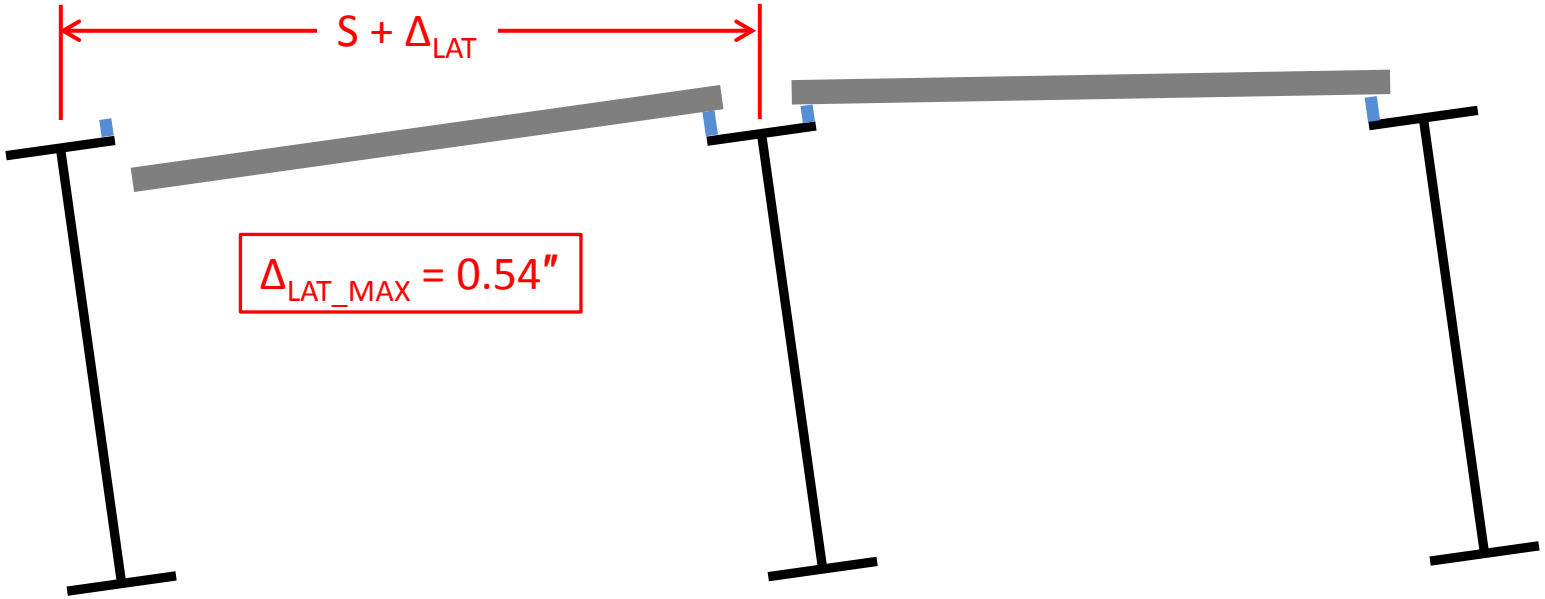


Unconnected PCPs on Curved I-Girders



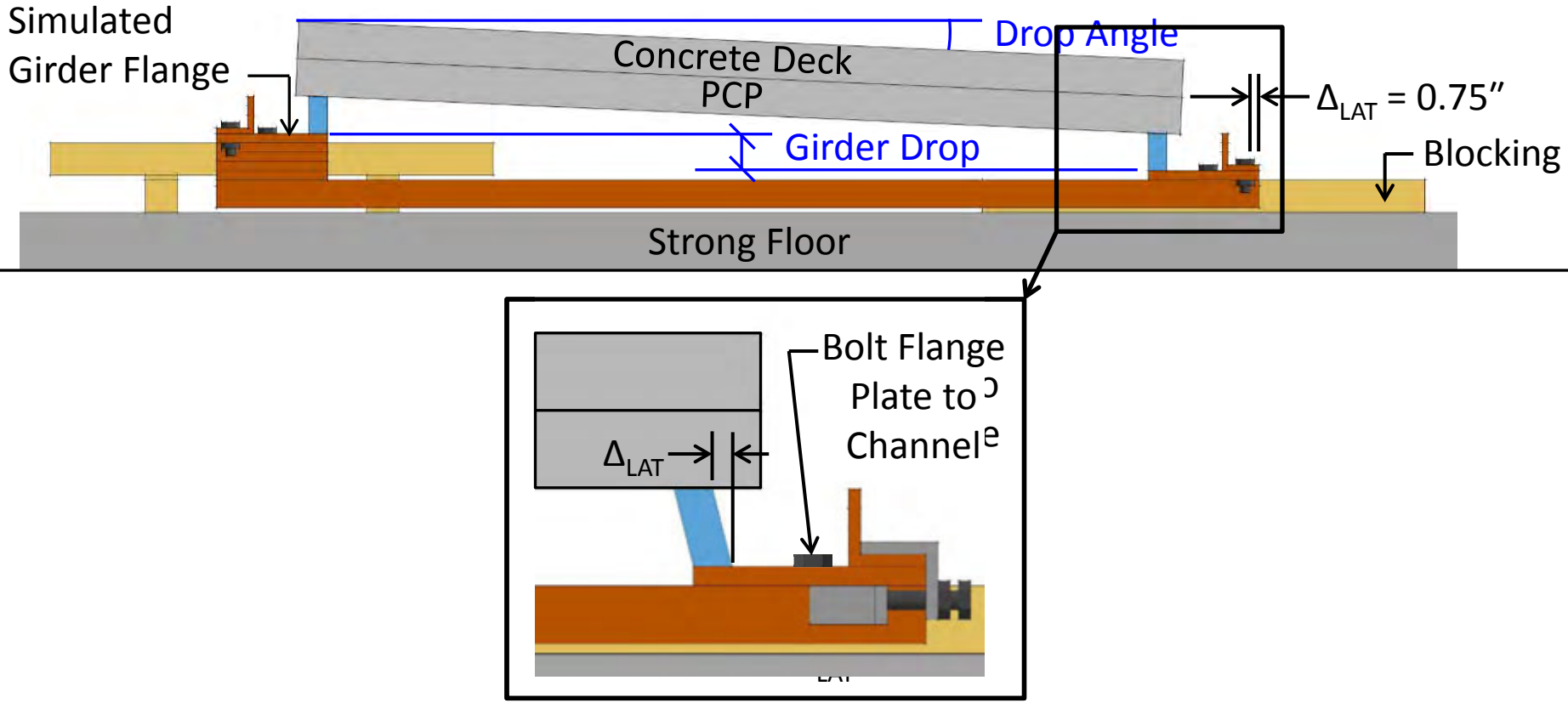
Section A-A

Unconnected PCPs on Curved I-Girders

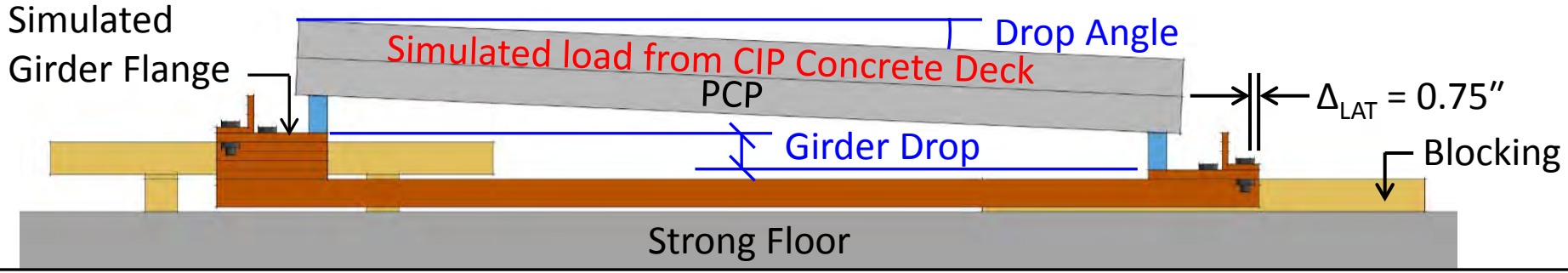


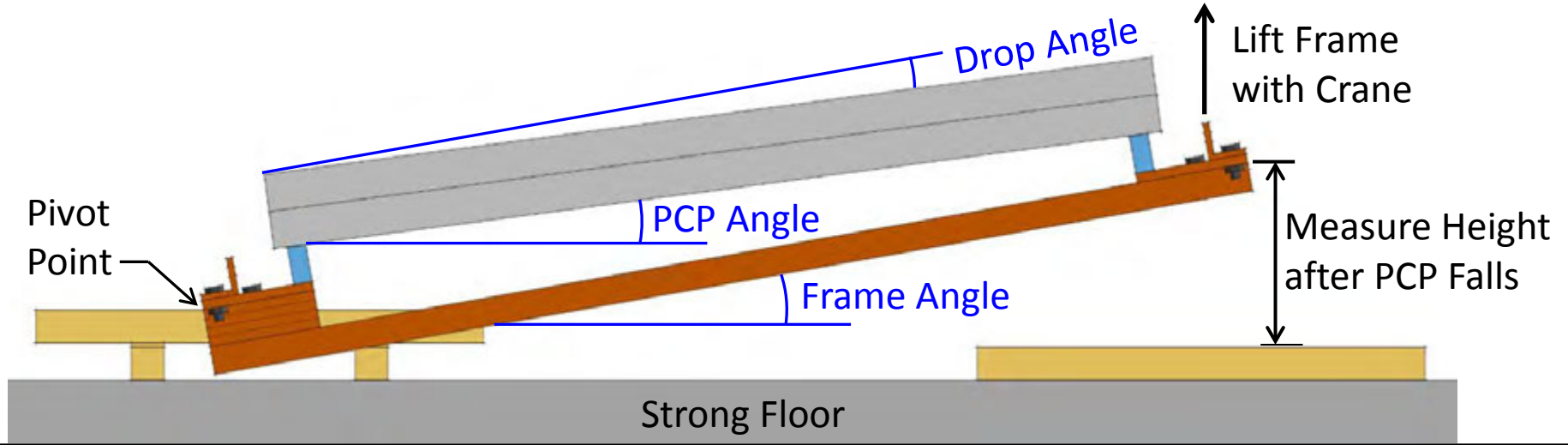
Section A-A

Tipping of PCPs on Curved Girders

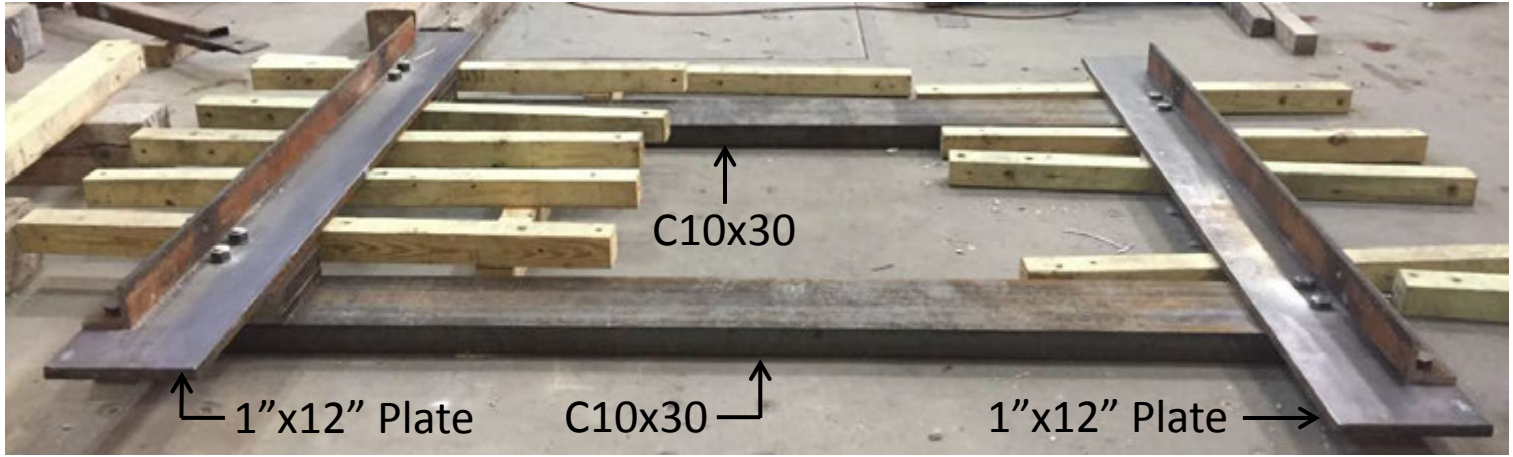


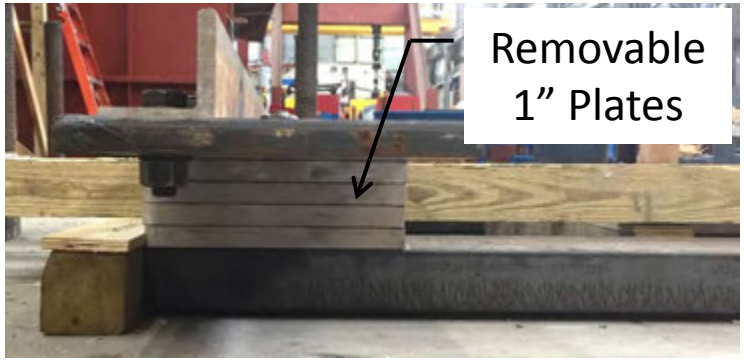
Tipping of PCPs on Curved Girders





Tipping of PCPs on Curved Girders





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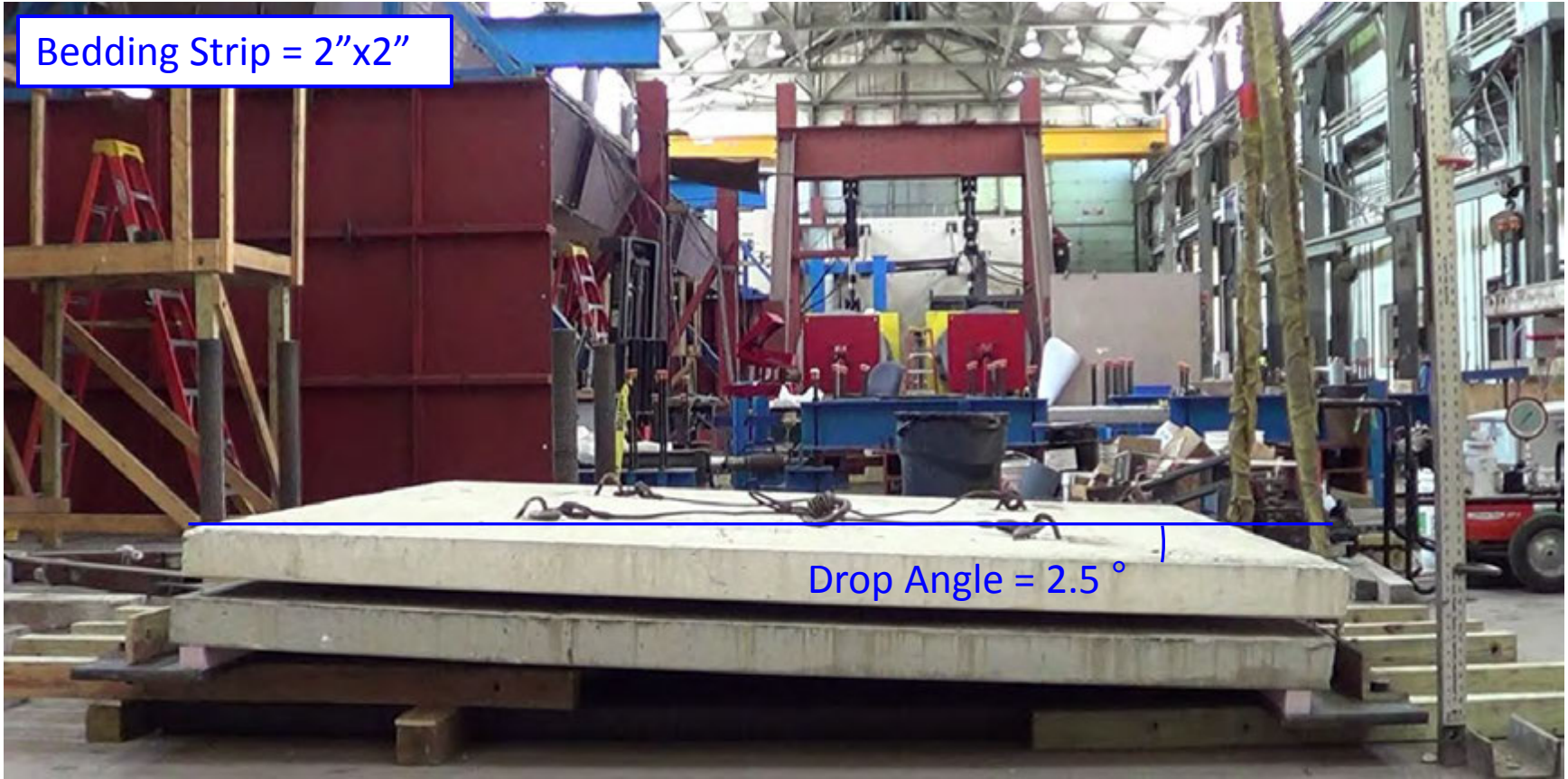

Tipping of PCPs on Curved Girders

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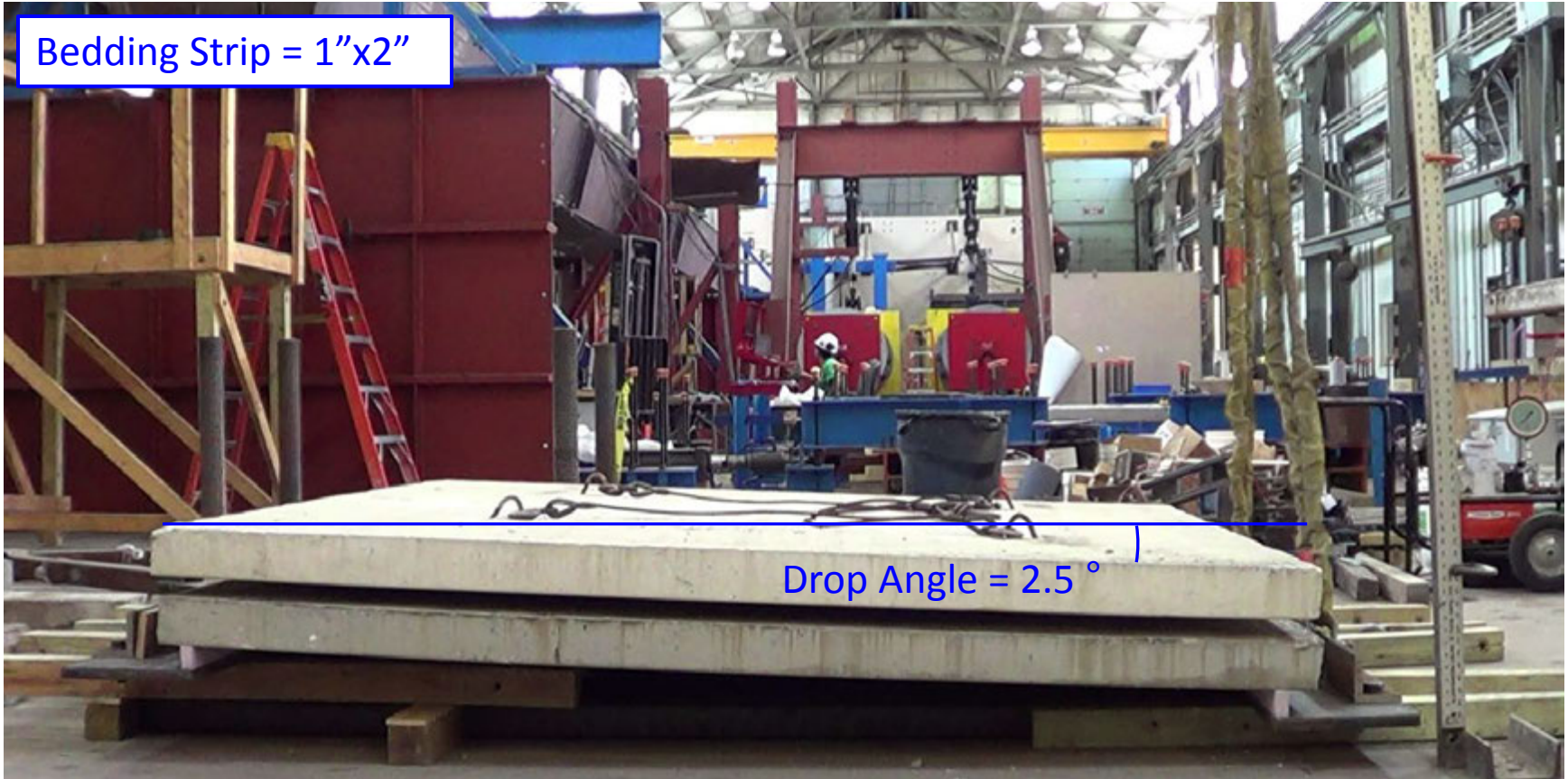


Tipping of PCPs on Curved Girders

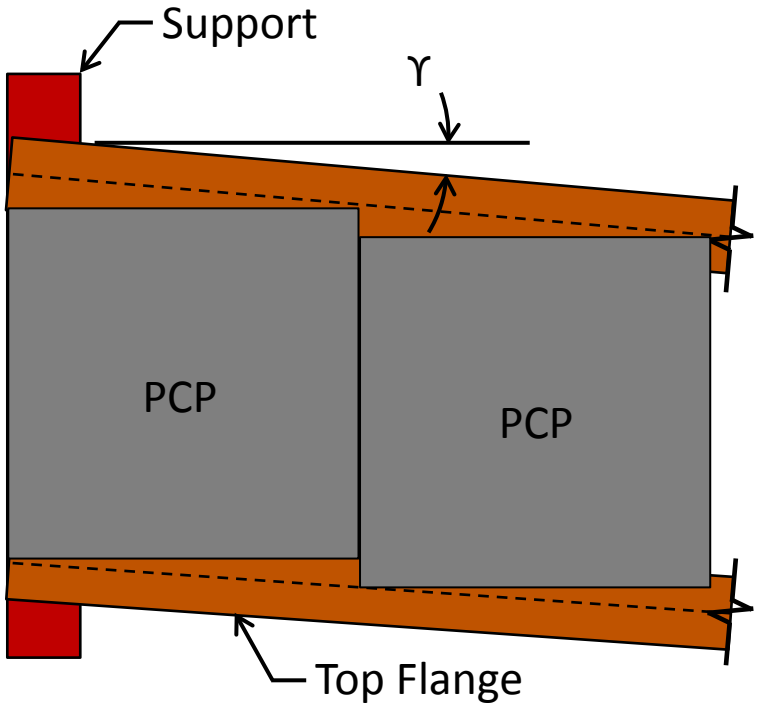
Tipping of PCPs on Curved Girders

Maximum PCP Inclination Angle (deg) for Design (FS = 3.0)

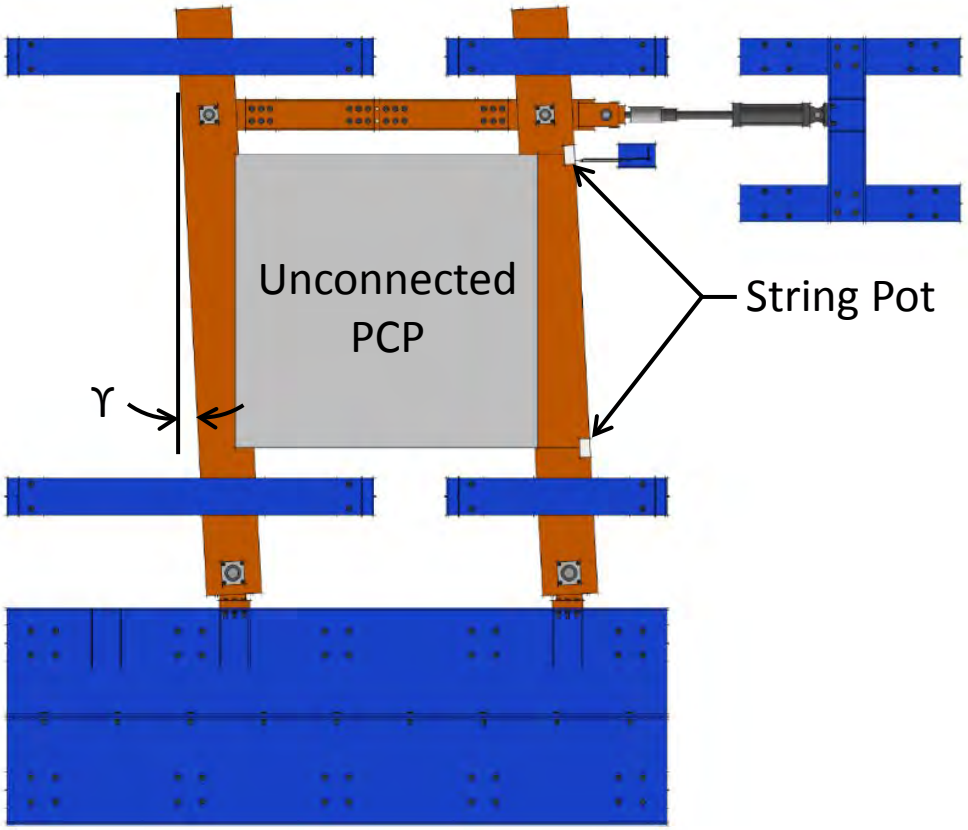
Bedding Strip	Height														
Width	½"	¾"	1"	1 ¼"	1 ½"	1 ¾"	2"	2 ¼"	2 ½"	2 ¾"	3"	3 ¼"	3 ½"	3 ¾"	4"
1"	9.4	9.4	9.4*	7.1	4.7	2.4	0*	-	-	-	-	-	-	-	-
1 ¼"	9.6	9.6	9.6	9.6	8.0	6.5	4.9	3.4	1.9	-	-	-	-	-	-
1 ½"	9.7	9.7	9.7	9.7	9.7*	8.7	7.7	6.7	5.7	4.7	3.7*	-	-	-	-
1 ¾"	10.0	10.0	10.0	10.0	10.0	10.0	9.1	8.3	7.5	6.6	5.8	5.0	4.2	-	-
2"	10.2	10.2	10.2	10.2	10.2	10.2	10.2*	9.5	8.8	8.1	7.4	6.7	6.0	5.3	4.6*

*Minimum values from labortory test with drop angle = 0° and 2.5° & Δ_{LAT} = 0.75" divided by FS = 3.0

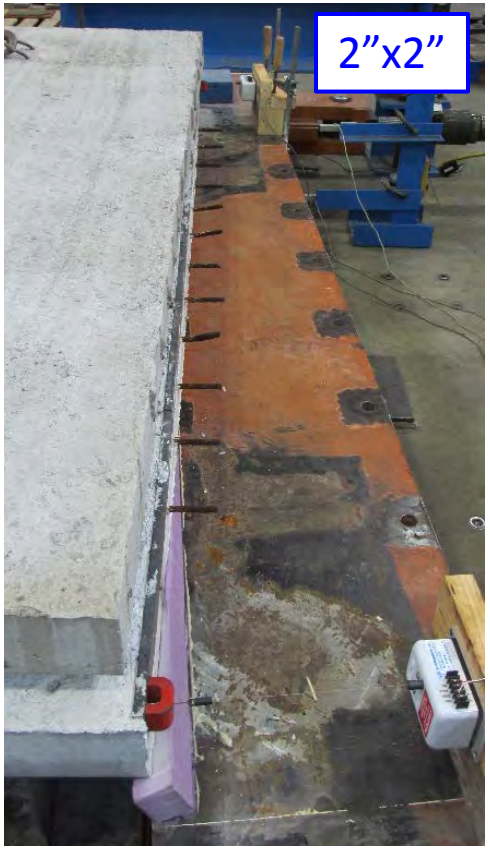
Warping of Curved I-Girders



$\Upsilon_{MAX} = 2.0°$



Warping of Curved I-Girders



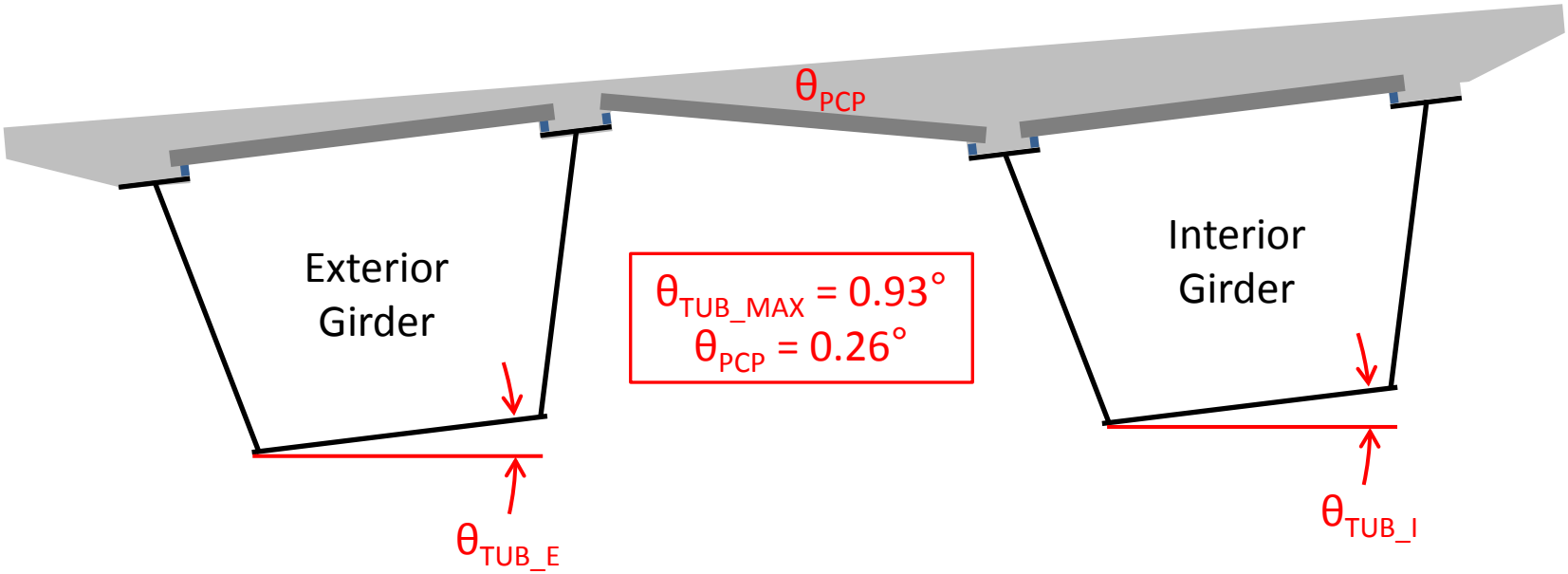
Warping of Curved I-Girders

Maximum Warping Angle (deg) for Bedding Strip Size for Design (FS = 3.0)

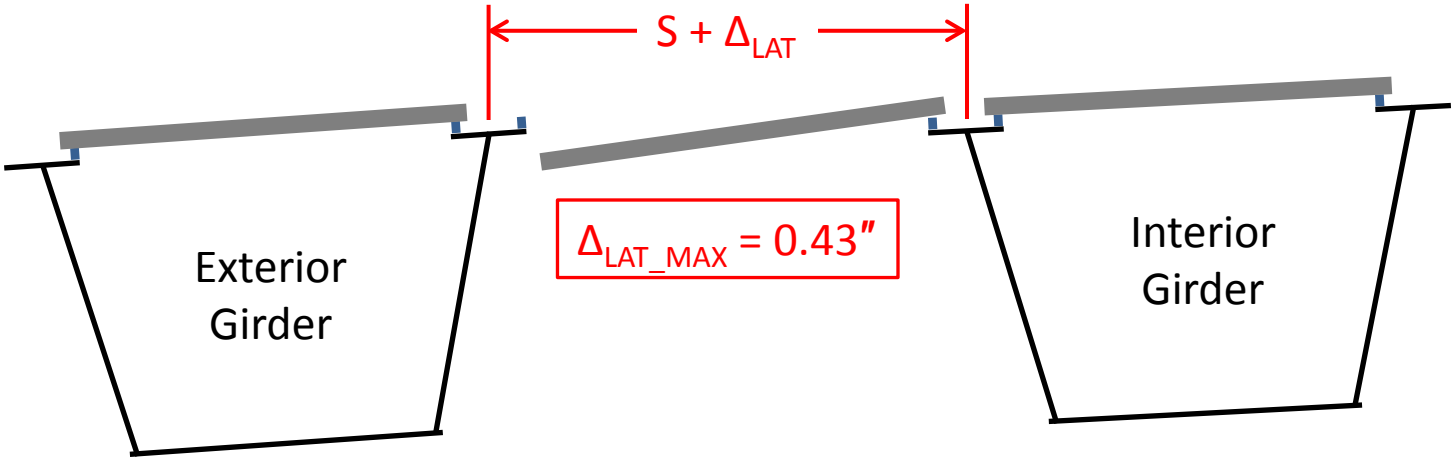
Bedding Strip	Height														
Width	½"	¾"	1"	1 ¼"	1 ½"	1 ¾"	2"	2 ¼"	2 ½"	2 ¾"	3"	3 ¼"	3 ½"	3 ¾"	4"
1"	1.33	1.33	1.33*	1.07	0.80	0.53	0.27*	-	-	-	-	-	-	-	-
1 ¼"	1.33	1.33	1.33	1.33	1.15	0.96	0.77	0.59	0.40	-	-	-	-	-	-
1 ½"	1.33	1.33	1.33	1.33	1.33*	1.20	1.07	0.93	0.80	0.67	0.53*	-	-	-	-
1 ¾"	1.33	1.33	1.33	1.33	1.33	1.33	1.26	1.18	1.10	1.03	0.95	0.88	0.80	-	-
2"	1.33	1.33	1.33	1.33	1.33	1.33	1.33*	1.30	1.27	1.23	1.20	1.17	1.13	1.10	1.07*

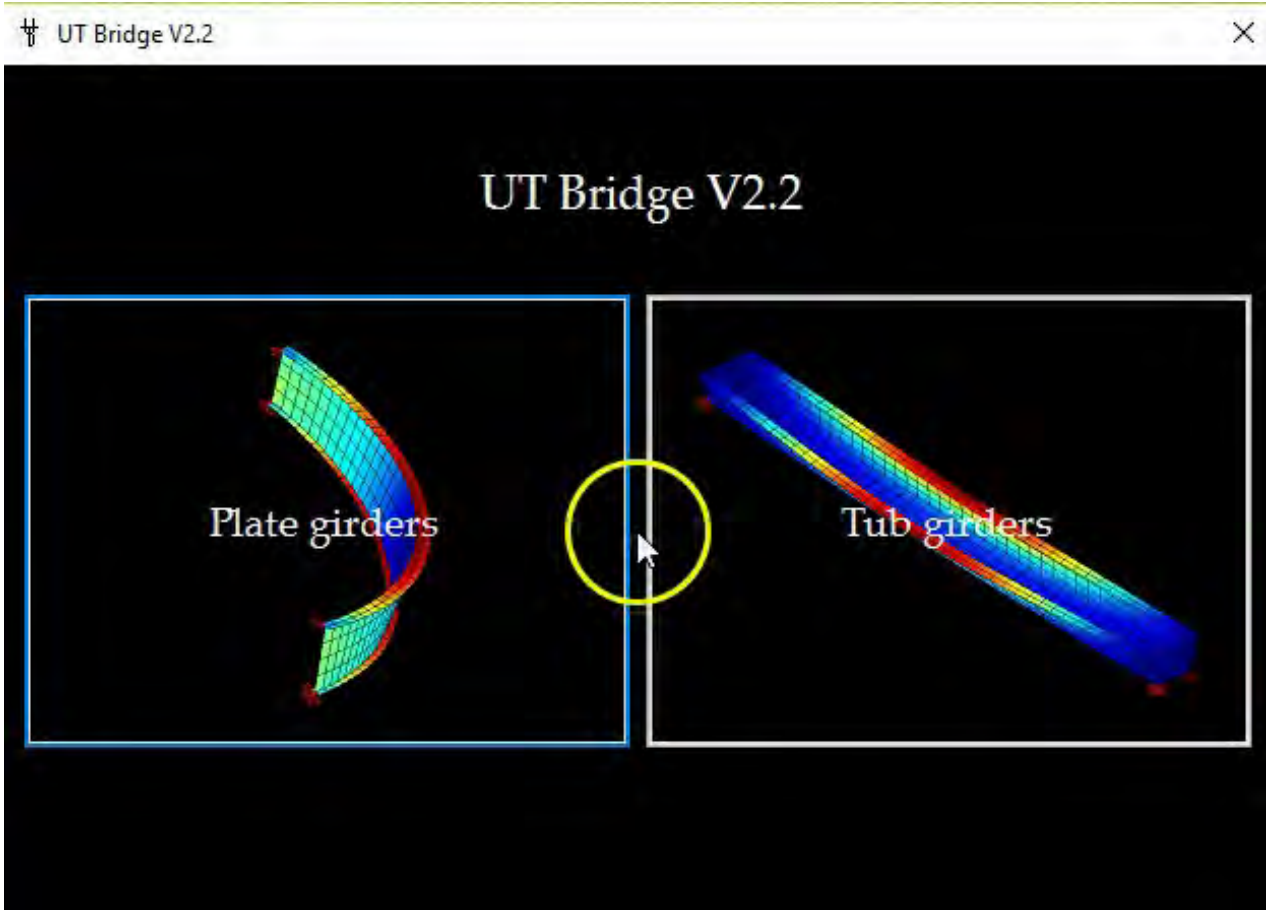
*Minimum values from labortory test divided by FS = 3.0

Unconnected PCPs on Curved Tub Girders



Unconnected PCPs on Curved Tub Girders





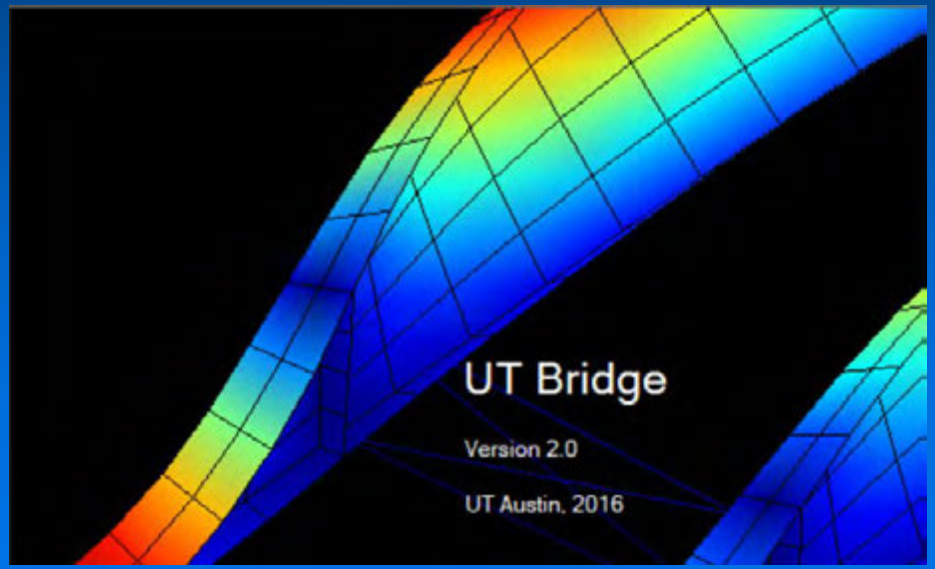
Version 2.3 (or 3.0)

New 64-bit version should raise problem size from about 170,000 DOF to 750,000 DOF.

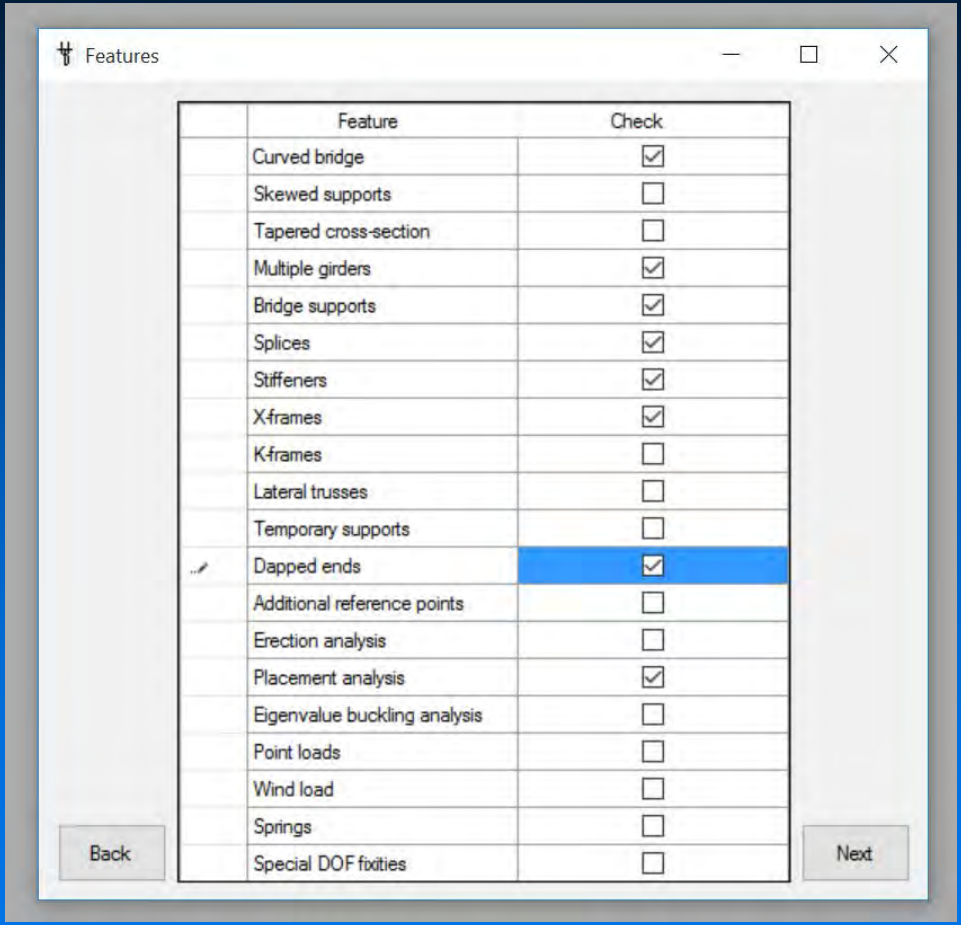
UT Bridge Version 2.0 Release in January 2017

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

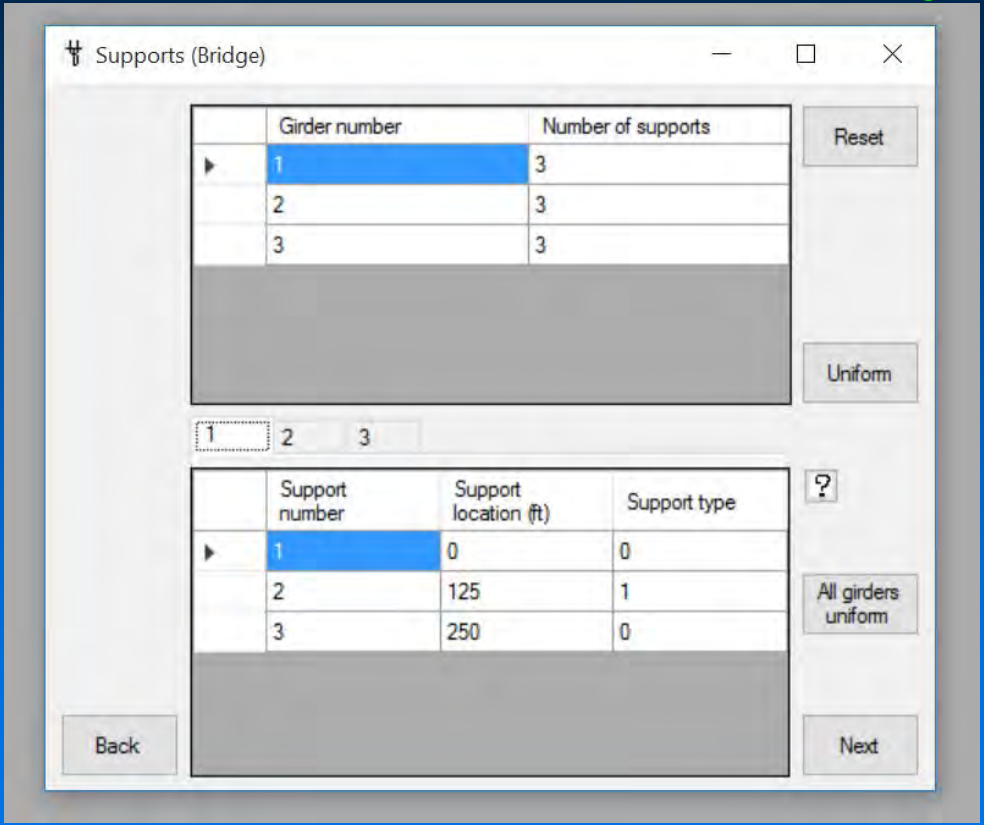
Co-PIs: Eric Williamson, Mike Engelhardt, Karl Frank, and Tricia Clayton



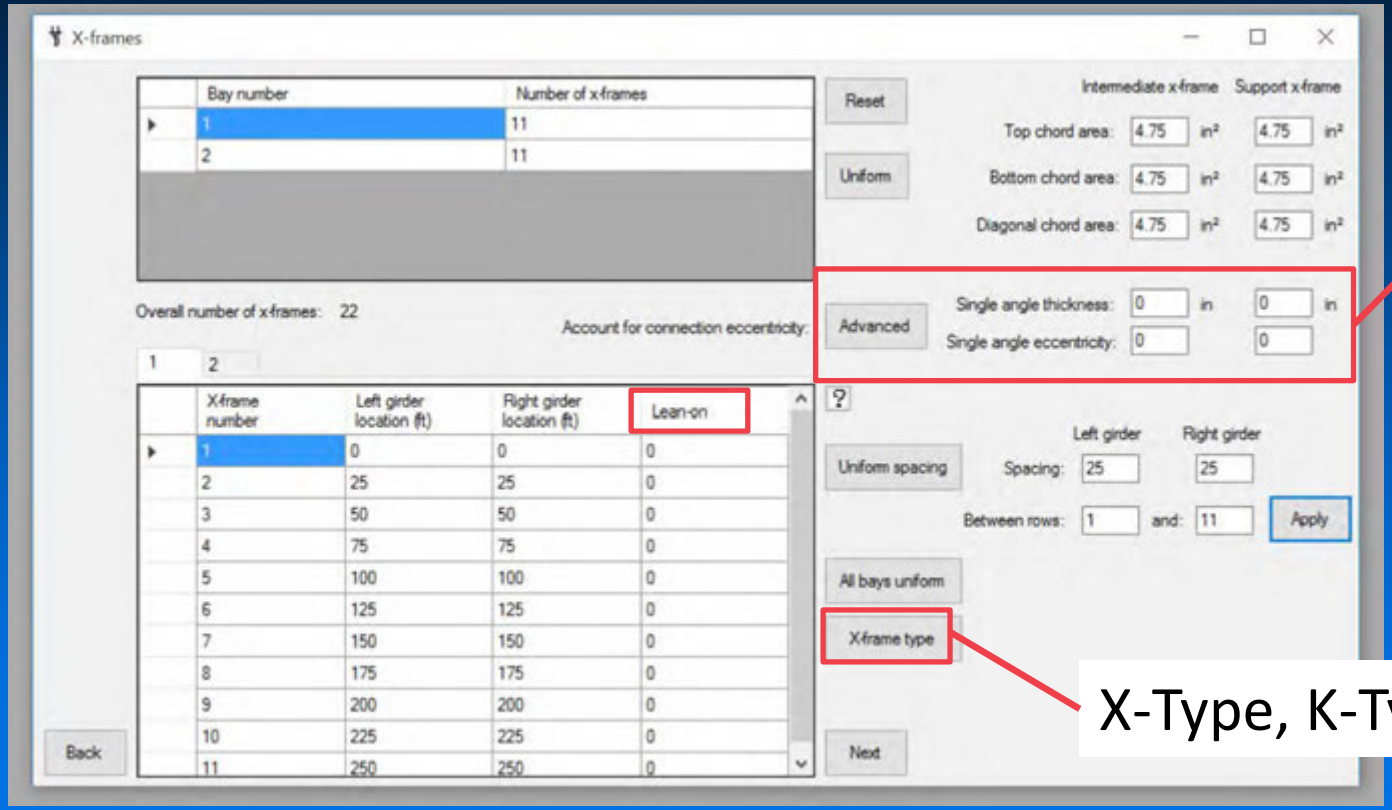
Specify “Features” of the Analysis



Pop-up Panels Prompt User for Basic Model Geometry



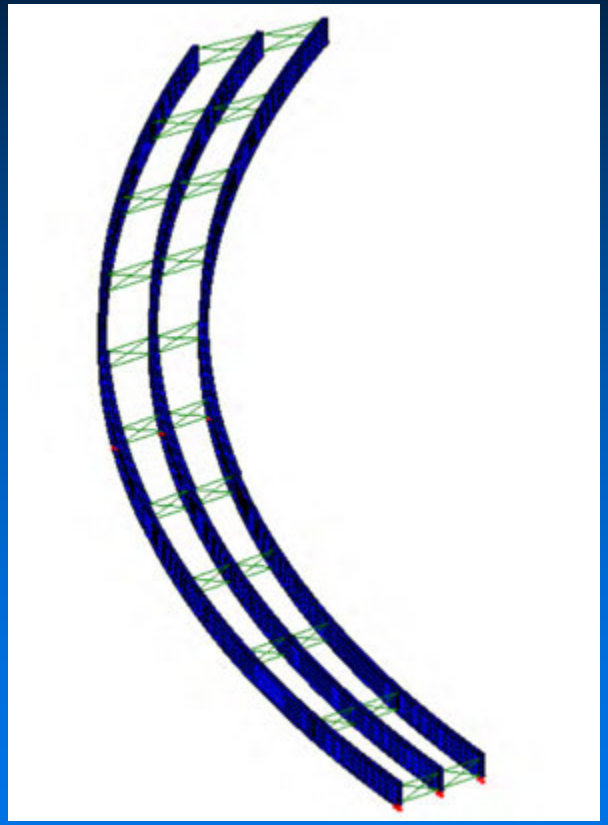
Cross Frame Properties and Spacing



R- Factor

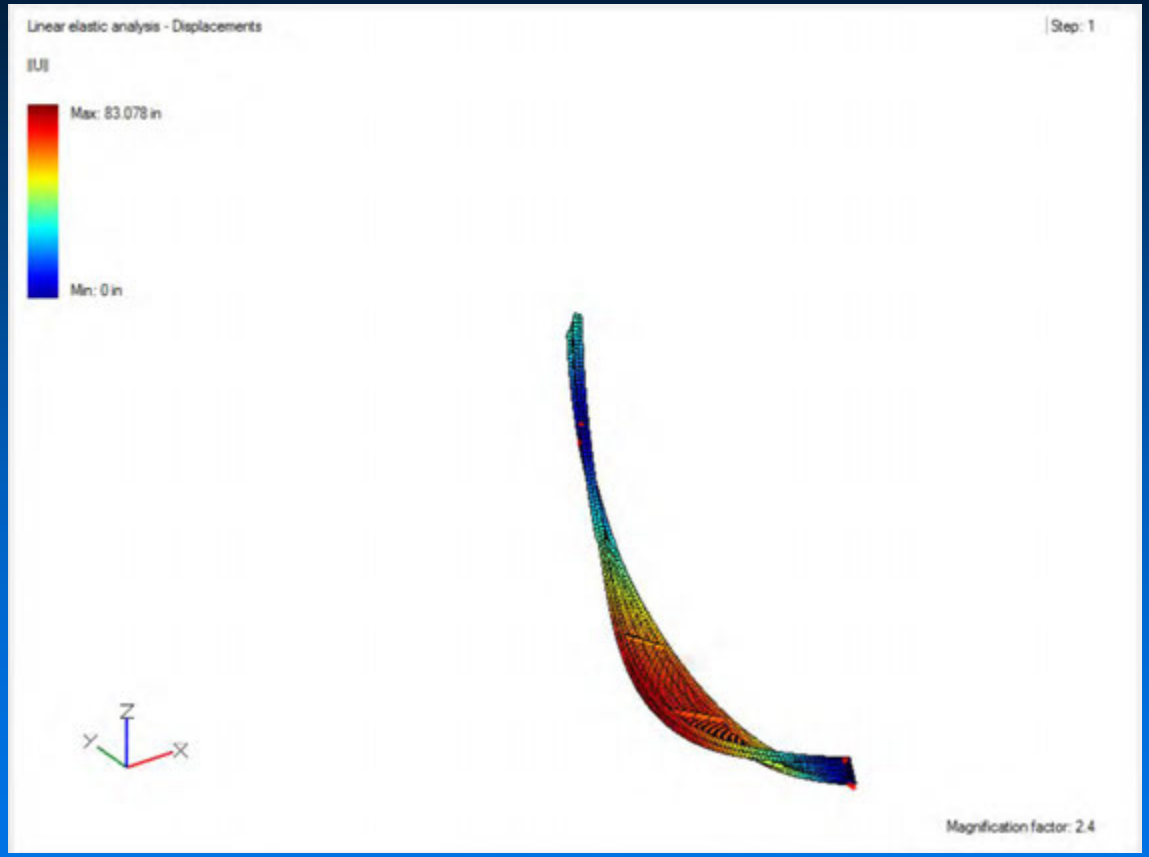
X-Type, K-Type, Lean On

Modelling Erection Stages

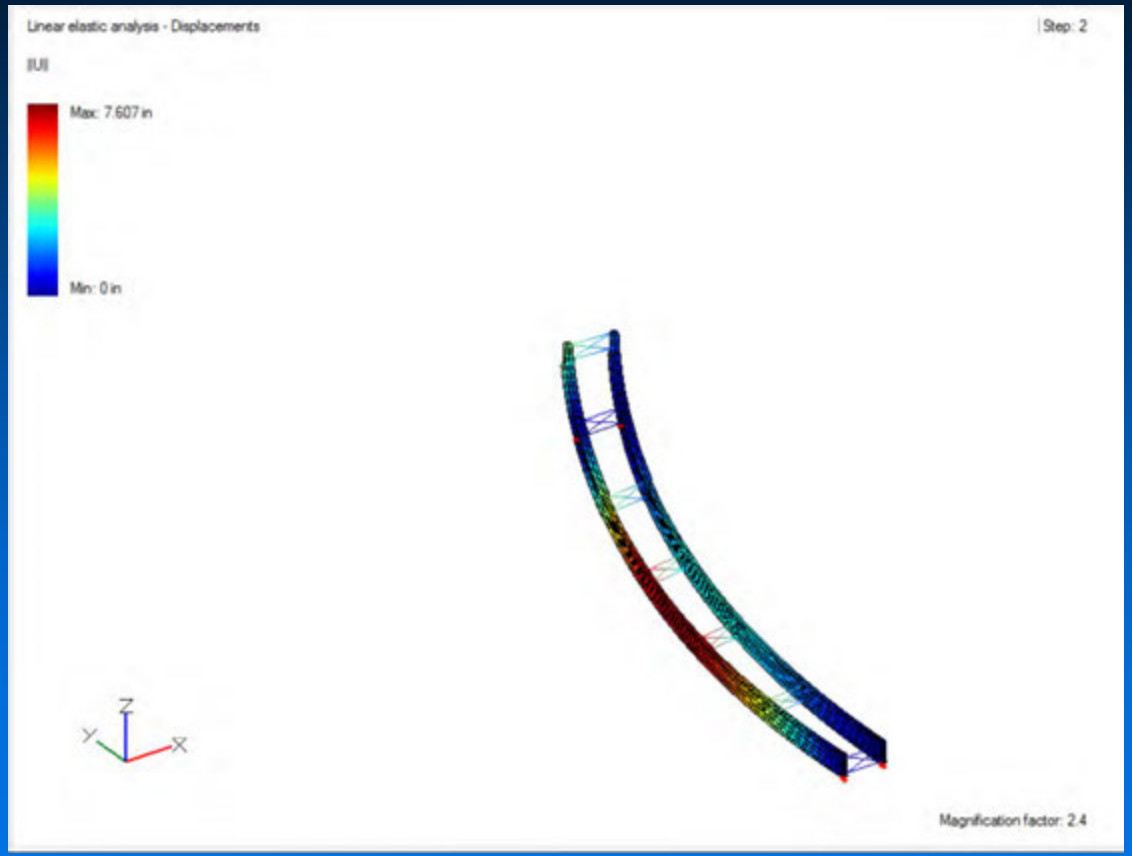


- Once the model is fully defined, the program can be used as a tool to evaluate various erection stages.
- The need for temporary supports such as shore towers or holding cranes can be easily evaluated.

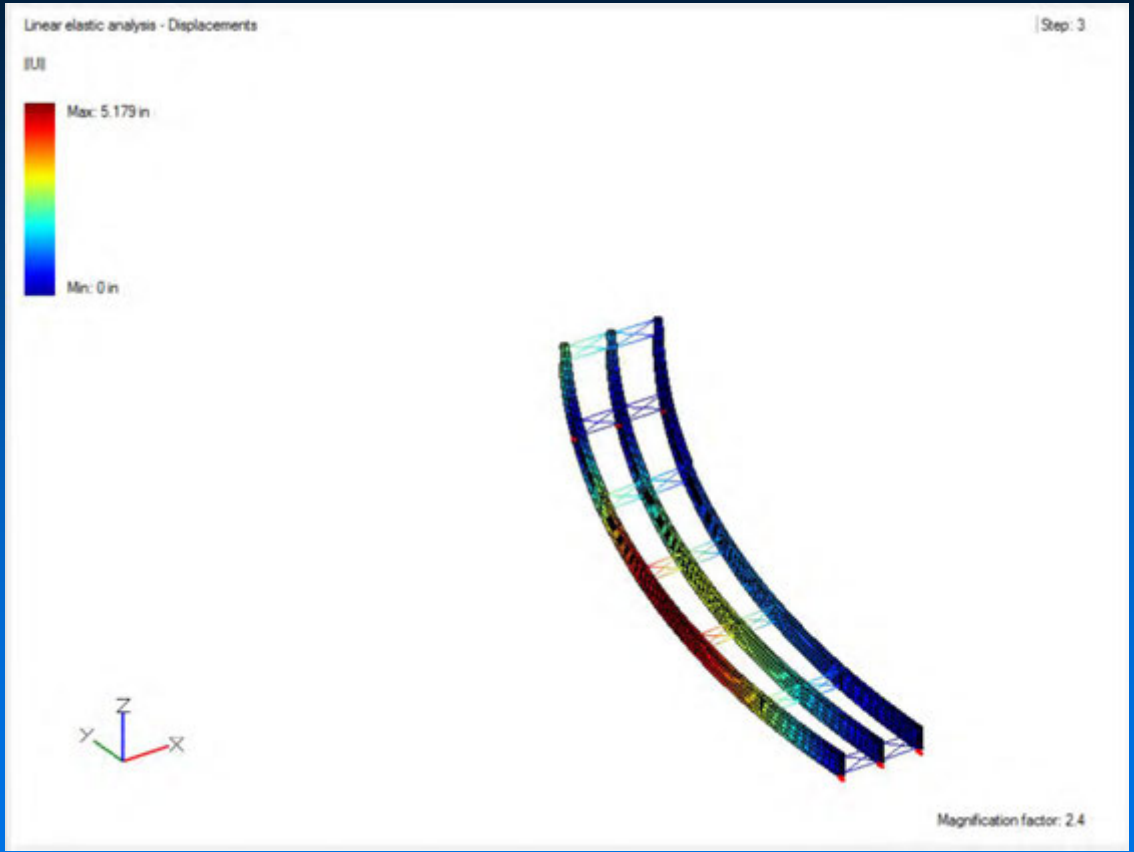
Modelling Erection Stages



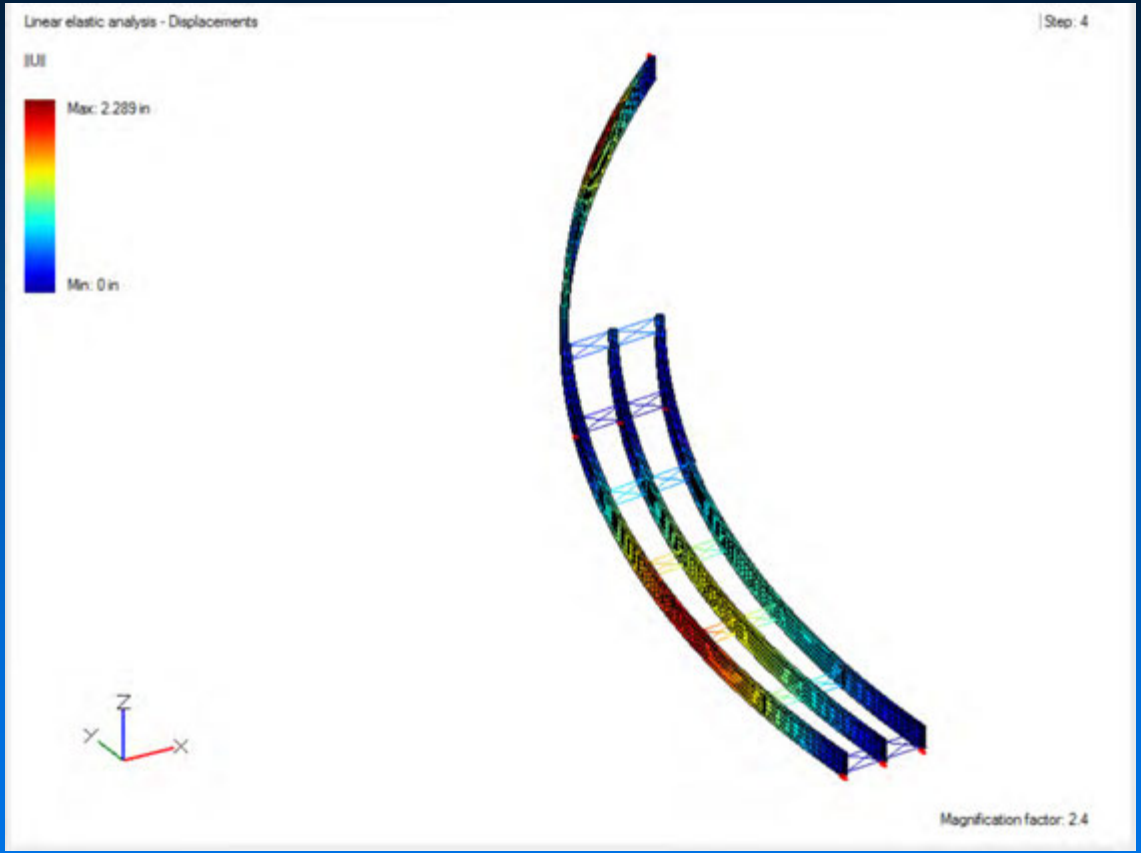
Modelling Erection Stages



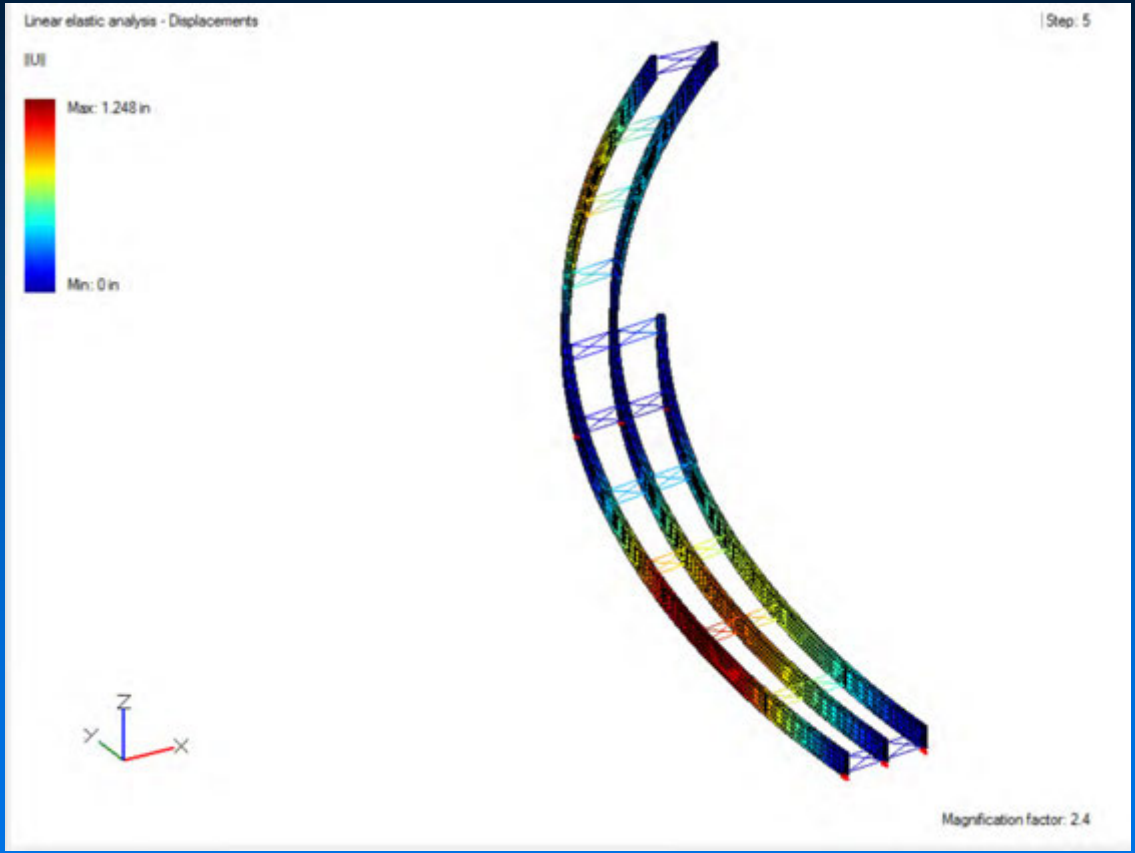
Modelling Erection Stages



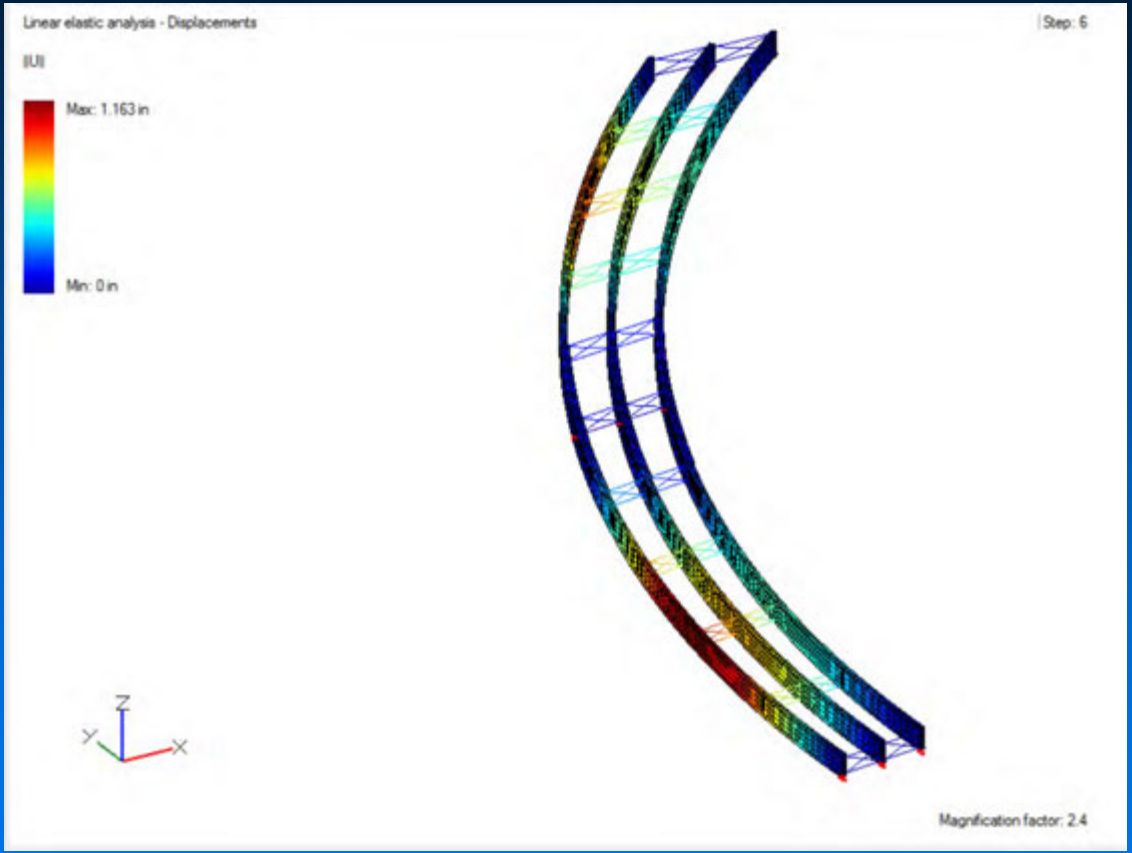
Modelling Erection Stages



Modelling Erection Stages

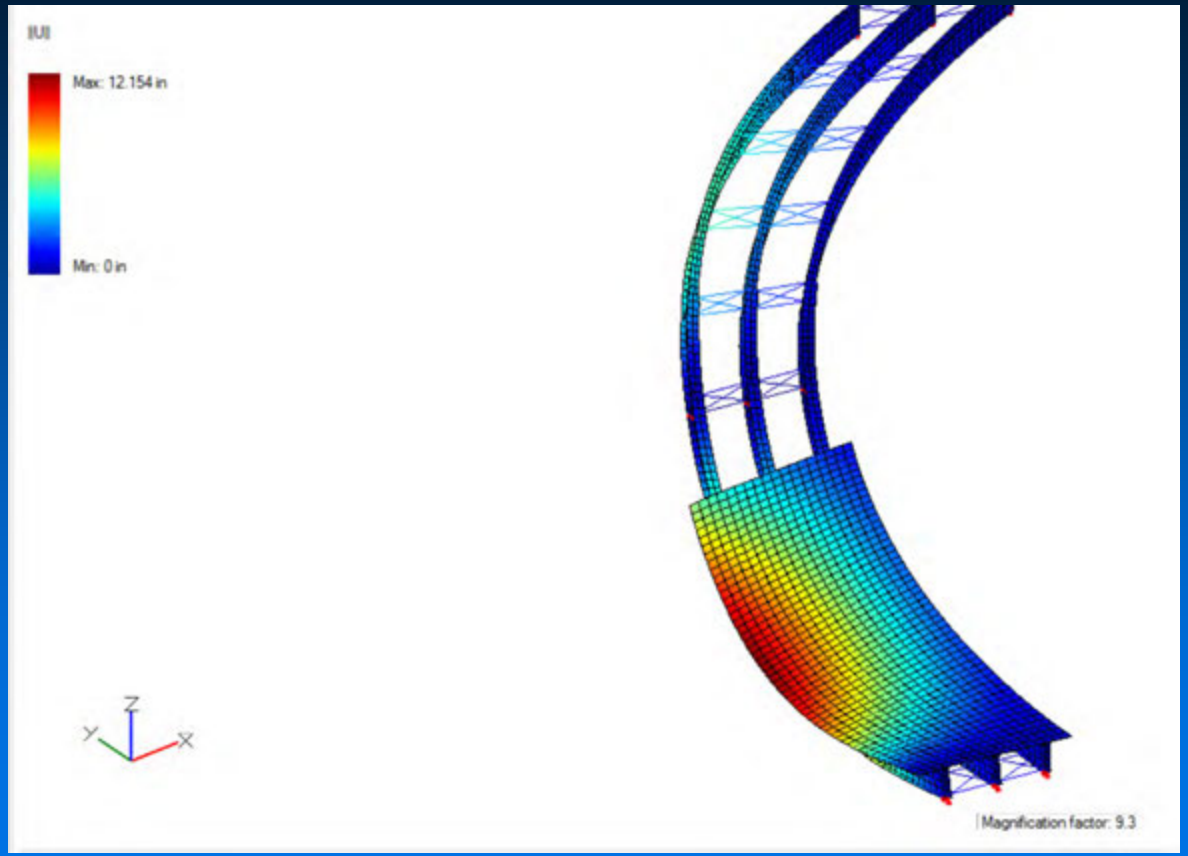


Modelling Erection Stages

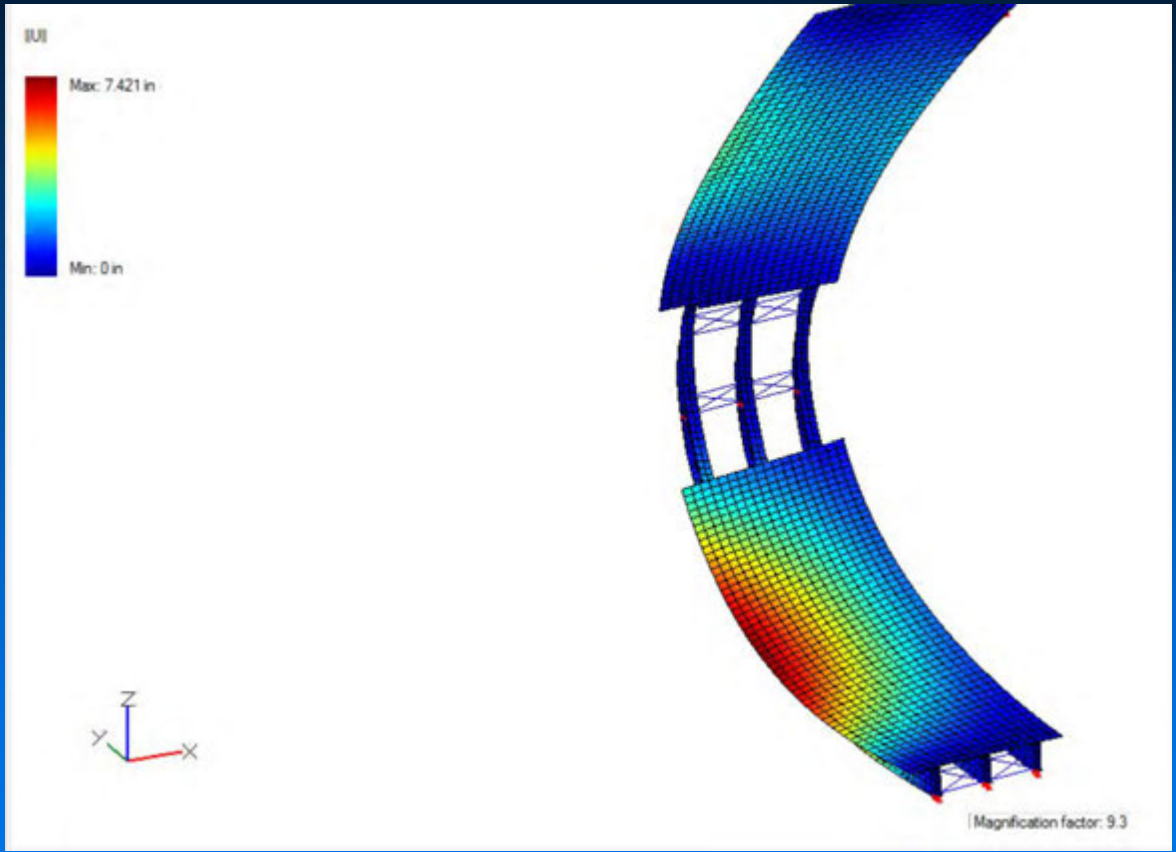


Modelling Concrete Deck Placement

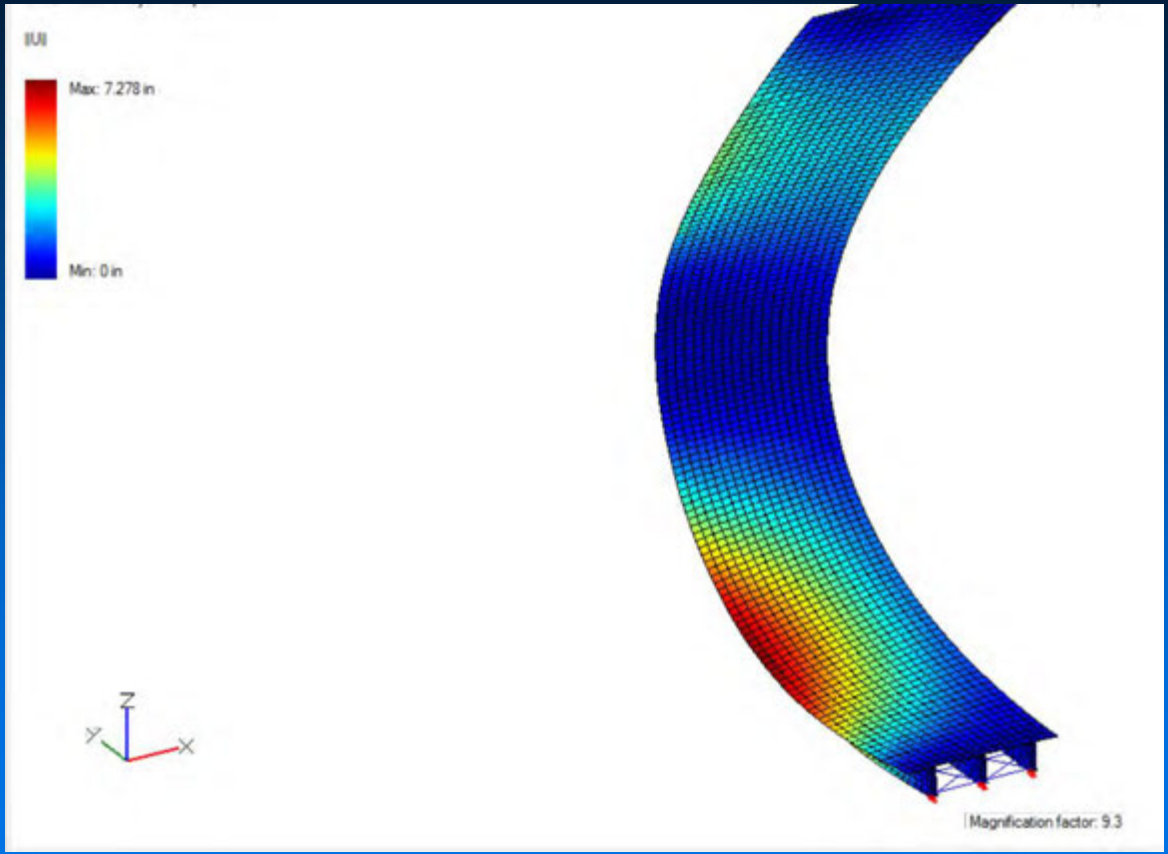
Modelling Concrete Deck Placement

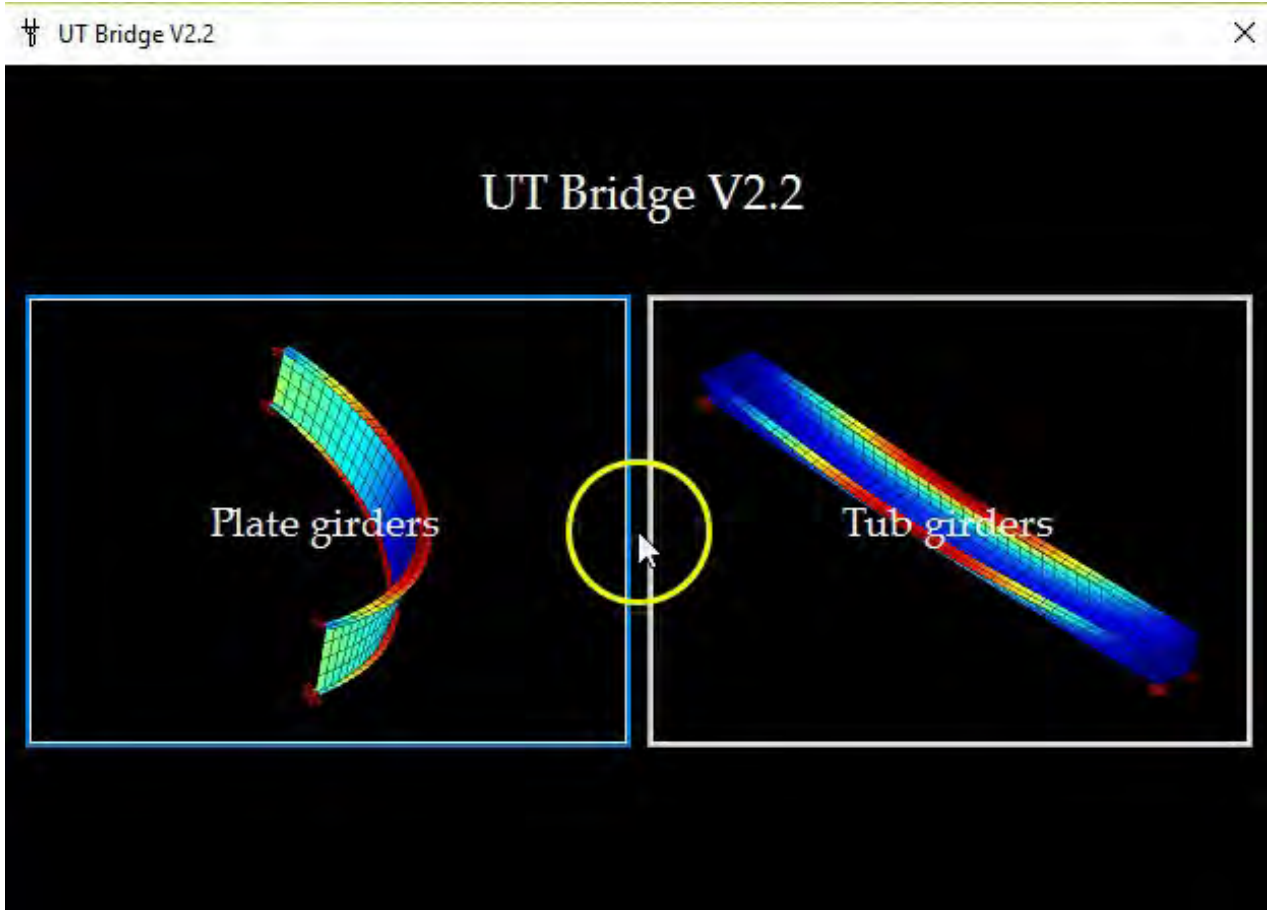


Modelling Concrete Deck Placement

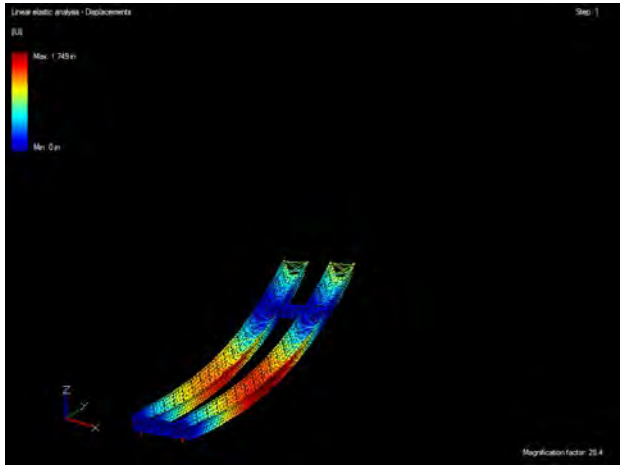


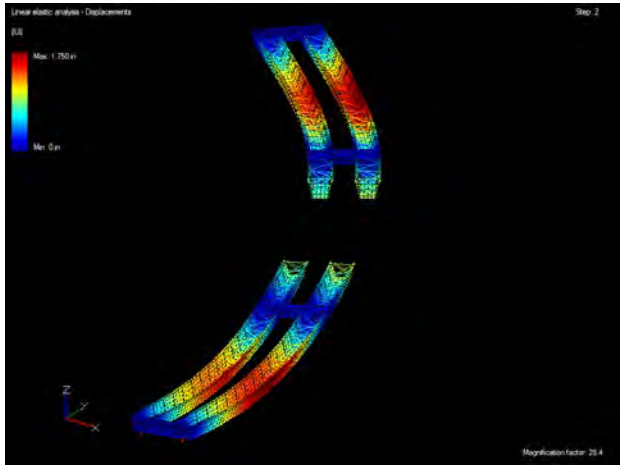
Modelling Concrete Deck Placement

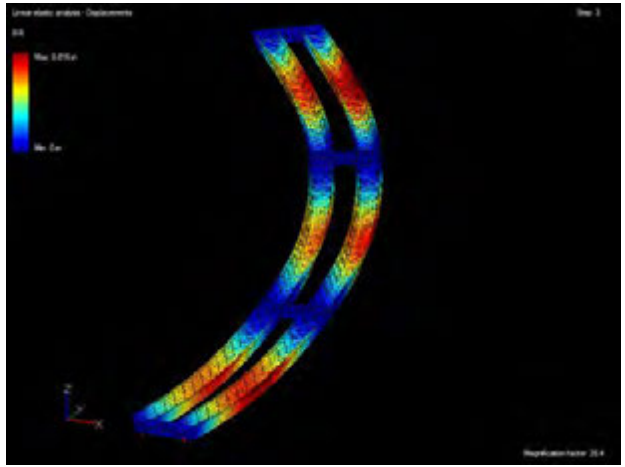



UT Bridge V2.2
UT Bridge V2.2
Plate girders
Tub girders

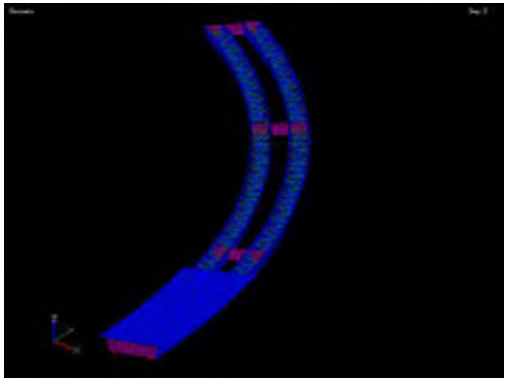
Erection sequence:

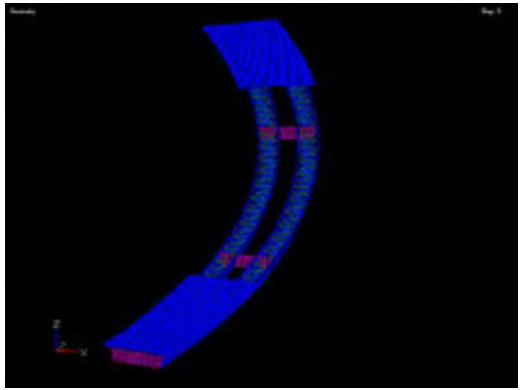


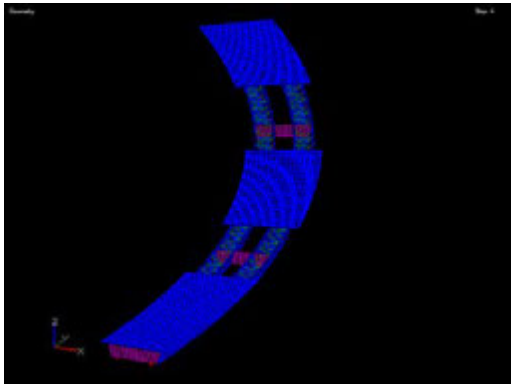


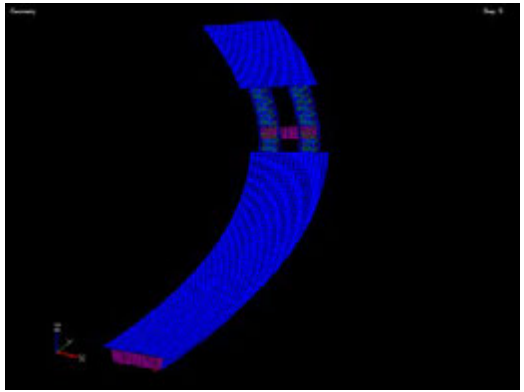


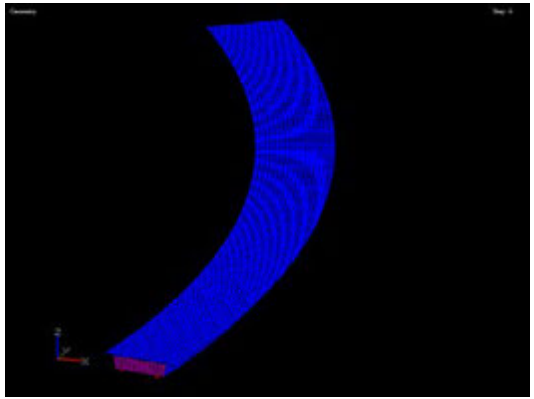
Deck placement sequence:

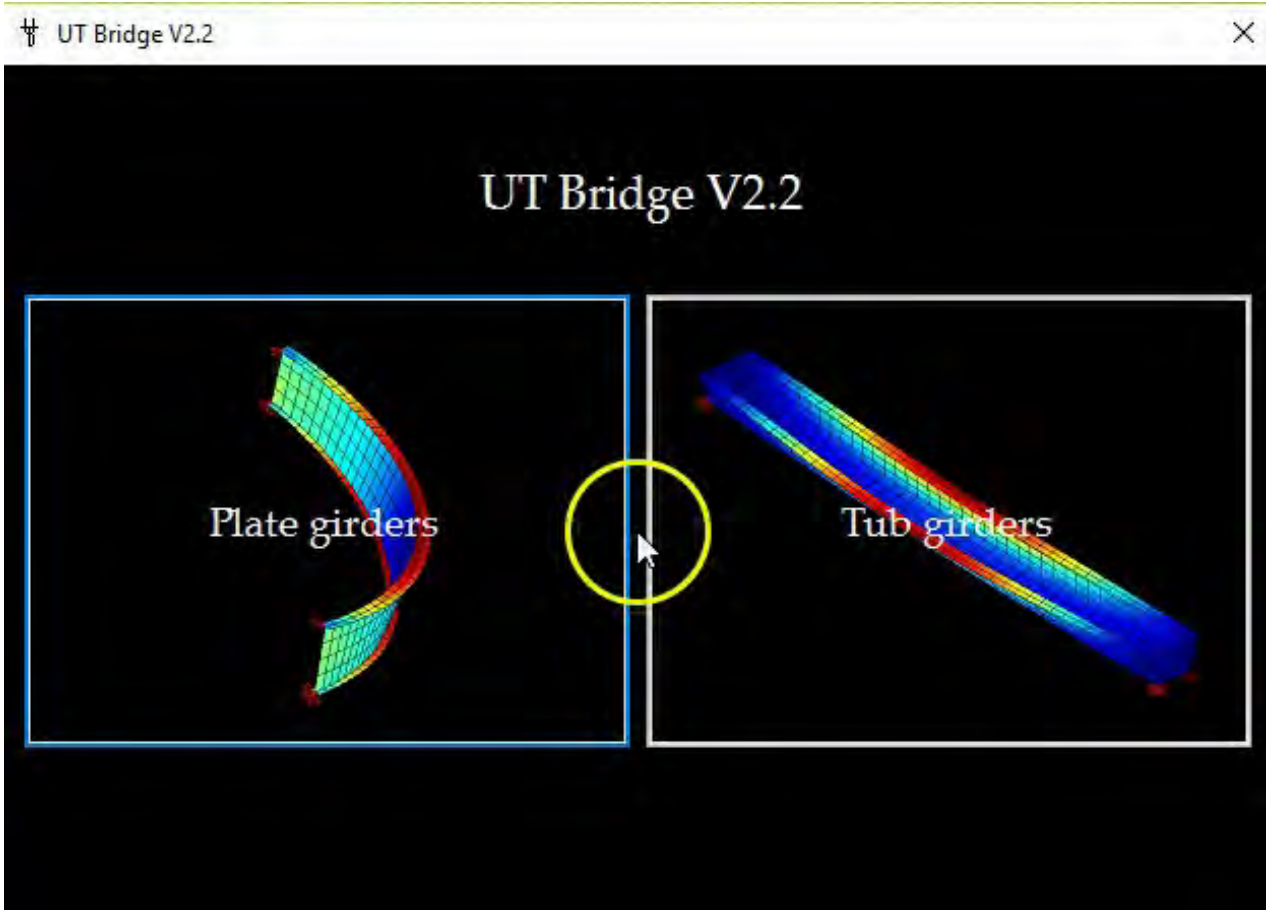












Version 2.3 (or 3.0)

New 64-bit version should raise problem size from about 170,000 DOF to 750,000 DOF.

Improved Solver Optimization – Much faster on large-displacement solutions

Paul Biju-Duval is considering commercializing the software

Conclusions

Conclusions – Experimental Study

- Developed Connection Details from PCPs to Steel Girders
  - Measured stiffness & strength
- Investigated PCPs as U-Beam Bracing Elements
  - Measured stiffness & strength
- PCPs Connected to Girder Systems
  - Increase load carrying capacity
  - Reduce girder deformations & cross-frame forces
- Unconnected PCPs on Curved Girders
  - Measured tipping of PCPs on bedding strips
  - Measured I-girder warping w/ PCPs on bedding strips

Conclusions – Parametric Study

- PCPs Connected to Curved I-Girders
  - PCPs do not significantly reduce forces of **all** cross-frames
  - PCPs will not allow significant increases for cross-frame spacing
- PCPs Connected to Curved Tub Girders
  - Lifting and construction sequence issues
  - Potential capacity issues for design
- Unconnected PCPs are Stable on Curved Systems
  - PCPs performed well for very significant deformations
  - Limitations for size of bedding strips (recommended minimum bedding strip width is 2” for curved girder applications.)

Comments on Future Bridge Research

- Research is the driving force behind the success of every University.
- 20 years ago – there were as many as 8-10 bridge related projects per year. The past few years there have been 1-2 bridge related projects.
- Historically, Texas has led the country in innovative bridge systems and the research program plays a big role in this.
- Beyond the technological advances – the educational aspects of research have played a huge role in developing the design expertise in the state.

Comments on Future Bridge Research

- Successful problem statements generally require a TxDOT Champion at the ROC meeting (and to get out of the FAP meetings).
- Not having bridge related projects saves exactly $0. The research money is always spent.
- In my opinion, the entire research program should be related to steel bridge research ☺.
- If 5 projects per year are desired, 10-15 statements should make their way to the ROC.

Questions?