TxDOT Research at UT Austin (plus other Universities)

Steel Quality Council
Austin, TX

Speaker: Todd A Helwig

UNIVERSITY OF TEXAS AT AUSTIN
Ferguson Structural Engineering Laboratory

November 12, 2024

Outline

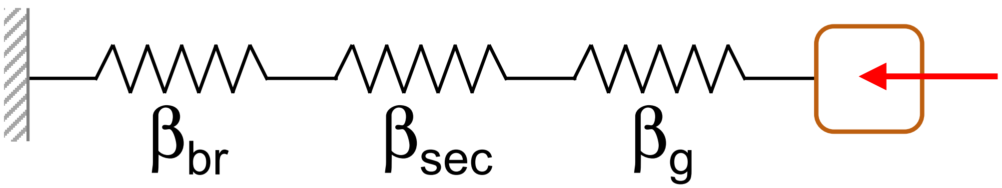
- Stability Bracing Studies (in-plane stiffness and TxDOT Project 0-7093) Refined Design Procedures for Lean-on Bracing
- TxDOT Project 0-7193: Mitigation and Repair of Ancillary Structures
- TxDOT Project 0-7213: Develop Design Methodologies and Efficient Details for Triple I-Girder Steel Straddle Caps

Recent and Ongoing Studies to Improve Torsional Stability Bracing Provisions

Researchers: David Fish – TxDOT
Aiden Bjelland – UT Austin

The Total System Stiffness Capacity (β_T)

A function of 3 stiffness components – and follows equation for springs in series



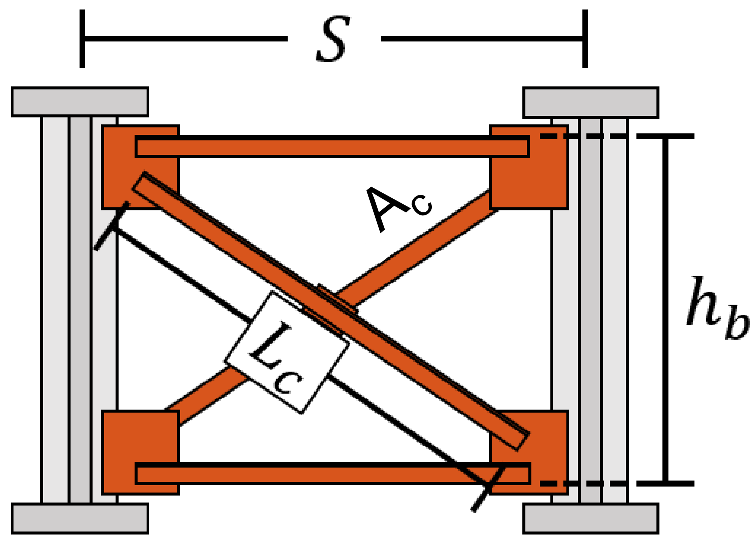
$$\frac{1}{\beta_T} = \frac{1}{\beta_{br}} + \frac{1}{\beta} + \frac{1}{\beta}$$

- β_T → torsional brace stiffness of the system
- β_{br} → brace stiffness
- β → cross-section stiffness
- β → in-plane girder stiffness

Note: β_T is smaller than smallest component

Brace Stiffness (β_{br})

- Each stability brace has a brace stiffness (β_{br}):
  - **X-frame:** $\beta_{br} = R\,\dfrac{A_c E S^2 h_b^2}{L_c^3}$
  - **Z-frame:** $\beta_{br} = R\,\dfrac{E S^2 h_b^2}{\dfrac{2L_c^3}{A_c}+\dfrac{S^3}{A}}$
  - **K-frame:** $\beta_{br} = R\,\dfrac{2E S^2 h_b^2}{\dfrac{8L_c^3}{A_c}+\dfrac{S^3}{A}}$

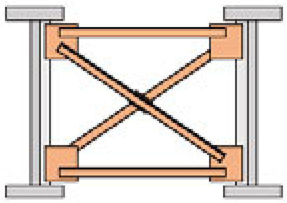


R n
(s)

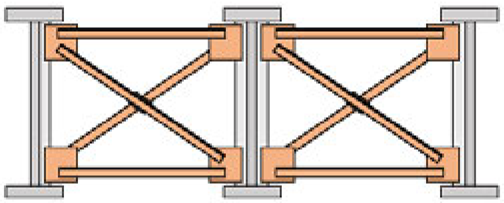
Recently Approved Ballots for AASHTO BDS

- Chapter 4 - Analysis for Cross-Frames comprised of single angles or WT sections.
  - A) During construction, reduce cross-frame area (ie. stiffness) by factor **R = 0.65**.
  - B) For composite girders, when evaluating fatigue – reduce cross-frame member area (stiffness) by factor **R = 0.75** (Based upon recent study published in NCHRP 962 and NCHRP 1045)

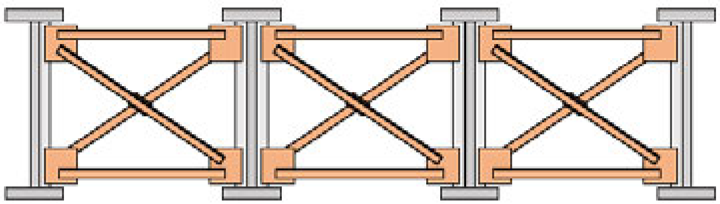
Benefits of More Cross-Frames in a Bracing Line



$0.5\ Brace/Girder \rightarrow C_{nc} = 1.00$



$0.67\ Brace/Girder \rightarrow C_{nc} = 1.21$



$0.75\ Brace/Girder \rightarrow C_{nc} = 1.35$

In-Plane Girder Stiffness

- The "current" (1993) β_g term for in-plane stiffness that has been used and is in the 10th Ed. AASHTO was developed for a single cross-frame at midspan of a twin girder – and extended to wider girder systems.

- While the expression recognized the impact of the strong-axis stiffness of the girder system on the stability bracing behavior, more recent computational studies have shown that the solution becomes unconservative with more bracing lines.

- The brace stiffness equations (β_{brace}) become more conservative with added bracing lines – so there is no need to get overly-excited about using the 10th ed. We have improved recommendations to improve these expressions as well.

- The 10th Edition Provisions are Conservative with the recommendations for adding top lateral truss panels at the end of the spans (ie. 30% reduction on required stiffness).

Improved Accuracy for β_G

- An effort to develop an improved solution was to utilize an approach consistent with the system mode of buckling that was based upon more of a continuous stiffness solution.

- David Fish (2022) developed a modification to the system mode equation (M_{gs}) that accounts for any number of girders.

- The equation was then used to develop an in-plane stiffness solution based upon a continuous formulation. The approach is much more applicable to a wide range of bracing applications.

Global LTB Moment Capacity (M_{gs})

- $M_{gs,2008}$ → Original simplified expression for twin girder system by Yura et al. (2008). C_{bs} → A moment gradient factor added by Han and Helwig (2020). $M_{gs,2021}$ → Update to existing expression by **Fish (2021).**

$$M_{\ ,2008} = \frac{\pi^2 sE}{2L^2}\sqrt{I_x I_{\ ff}} \rightarrow M_{\ ,2021} = C_b \frac{\pi^2 sE}{(KL)^2}\sqrt{I_x I_{\ ff}\frac{\alpha_x}{2n}}$$

The 2008 Eqn. was developed for twin girders. The updated 2021 equation is applicable to any number of girders (α_x, n_g). The "K-factor" reflects the use of warping restraint if a few panels of a lateral truss are applied near the ends of the span.

In-plane Girder Stiffness (β_g)

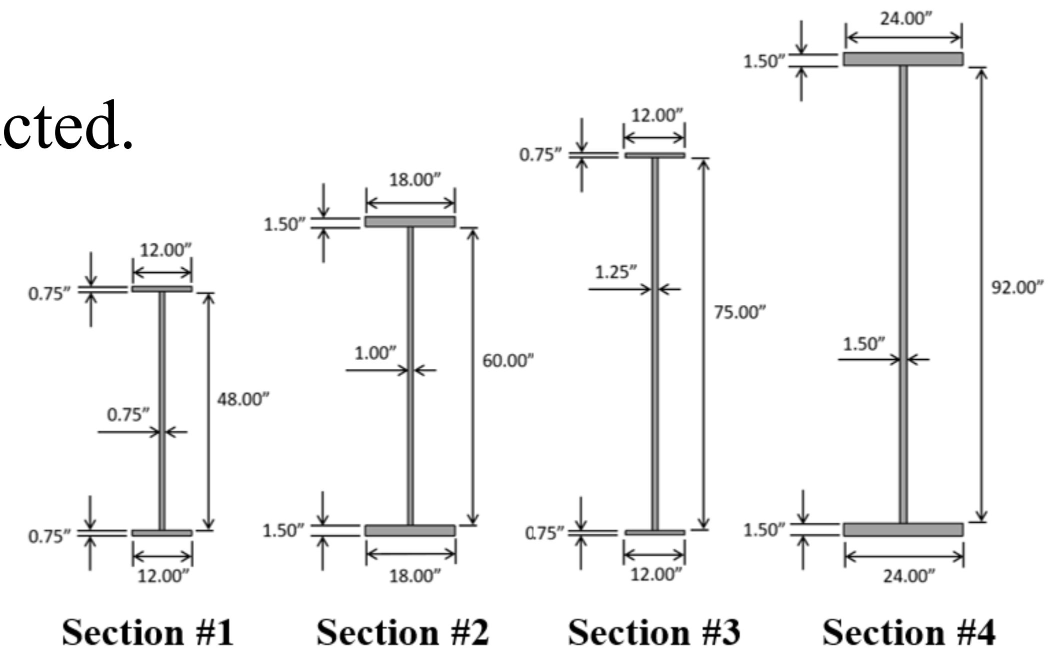
- $\boldsymbol{\beta}_{g,1993}$ → Original expression for twin girder system (1993).
- $\boldsymbol{\beta}_{g,2024}$ → Update to existing expression by Fish et al. (2024).

$$\beta_{\ ,1993} = \frac{24(n\ \ -1)^2 E I_x s^2}{n\ \ L^3} \quad \rightarrow \quad \beta_{\ ,2024} = \frac{\pi^4 E I_x s^2}{(n+1)(KL)^3} \frac{\alpha_x}{2n}$$

2024 expression applies for any number of girders, any number of bracing lines, and more accurately represents stiffness.

Solution Validation Through Parametric FEA Studies

- To study β_{br} and β_G, parametric studies were conducted.



Bridge Parameters:

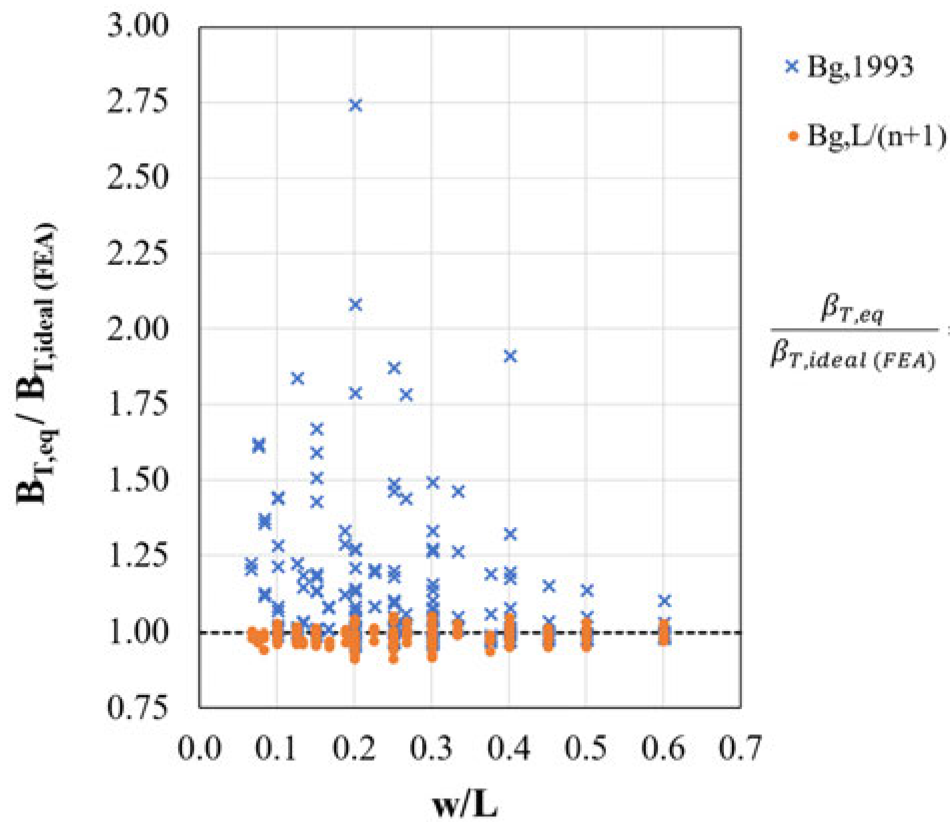
\# Girders lines: 2, 3, 4, 5
\# Bracing lines: 1, 2, 3, 5
Unbraced Length: 20 ft., 40 ft.
4 Girder Sections: ranging properties
Girder Spacing: 8, 10, 12 ft.

Girder Depths ranging from 4~7.7 ft.
$b_f/d = 0.16\sim0.30$

Comparison of $\beta_{g,1993}$ and $\beta_{g,2024}$

- By accounting for the number of girders and the vertical warping restraint generated by girder pairs, the 2024 equation more accurately predicts the in-plane girder stiffness.

- The new equation predicted results that were within 5% of the FEA solution.



$$\frac{\beta_{T,eq}}{\beta_{T,ideal\,(FEA)}} = \frac{\left(1+\frac{\beta_{br,eff}}{\beta_{g,FEA}}\right)}{\left(1+\frac{\beta_{br,eff}}{\beta_{g,eq}}\right)}$$

Combined Lateral and Torsional Bracing

- Improvements have been developed for both the effective brace stiffness and in-plane girder stiffness that have good agreement with a wide range of geometries modelled.
- Significant work has also been conducted for longer-span systems that show the systems often have inadequate in-plane stiffness and require additional bracing.

Preliminary results show that the addition of a few truss panels near the ends will **allow ~0.7L** to be **used in β_G expression**. (that is a $(0.7L)^3$ in expression.

TXDOT PROJECT NO. 0-7093

REFINED DESIGN METHODS FOR LEAN-ON BRACING

Project Terminated on Jan. 31,2024 – Still Refining Final Report

RESEARCH TEAM

UT Austin Dr. Todd Helwig, Dr. Michael Engelhardt, Dr. Eric Williamson, Dr. Matthew Hebdon, Aidan Bjelland, David Fish, Dr. Sunghyun Park, and Xiaoyi Chen

Texas A&M Dr. Stefan Hurlebaus, Dr. Matthew Yarnold (Auburn), Claire Gasser (Auburn), and Shrey Patel

Objective of Project 0-7093

"Develop refined methods for designs utilizing lean-on bracing concepts"

- Instrumented and field-tested bridges utilizing lean-on bracing
- Used field data to validate finite element models
- Performed parametric study using validated models
- Refined existing design expressions

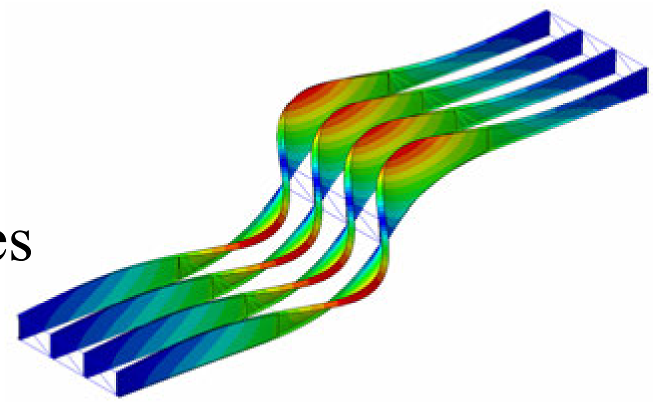
Lean-on Bracing Implementation Study (TxDOT Project 5-1772)

"Improve the economy and application to Texas bridges"

Parametric Study Statistics

- girder cross-section
- girder spacing
- top flange truss
- bracing layout
- skew angle
- unbraced length
- number of girders
- span length

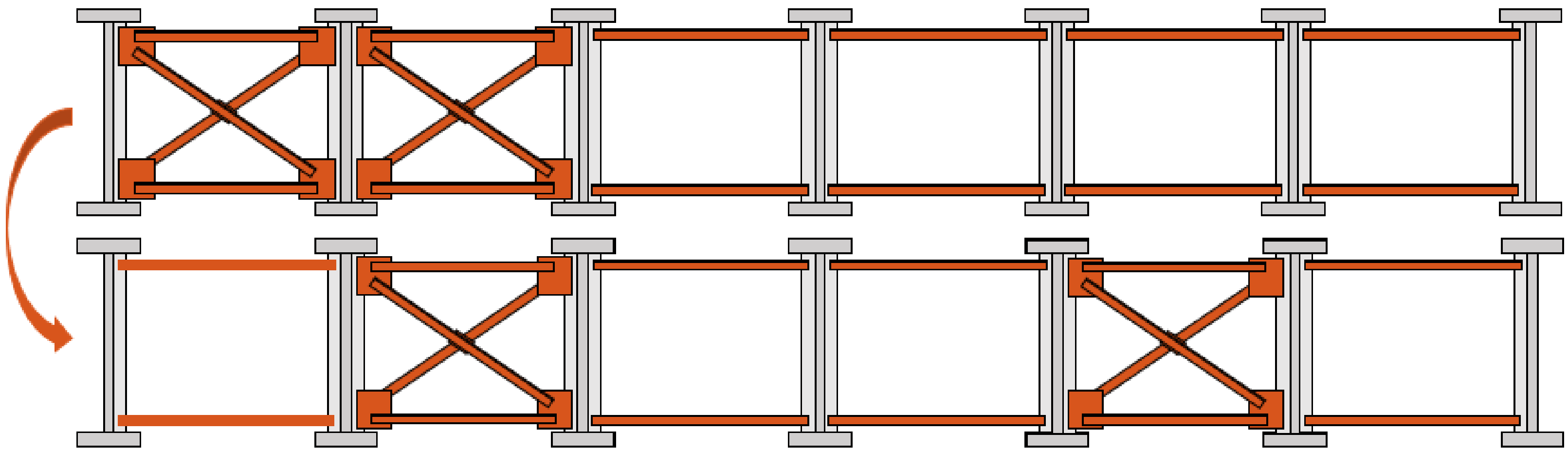
- Thousands of analyses have been conducted on a wide array of girder systems.
- The goal of the study is to provide detailed recommendations on the layout of the cross-frames and improved design equations
- Design examples are provided



Lean-on Layout Design Recommendations

Bridges with **Normal** Supports:

- **Recommended layouts…**
  1. Distribute cross-frames about bridge centerlines (layout effects)
  2. Link adjacent bracing lines with girder pairs (layout effects)
  3. **Minimize the number of adjacent leaning girders**



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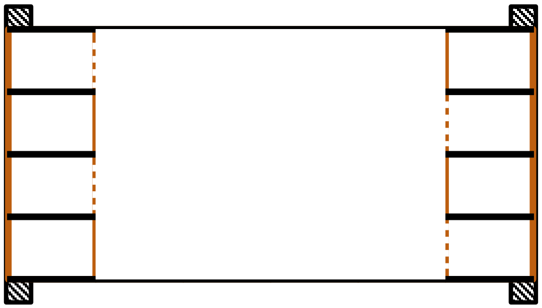
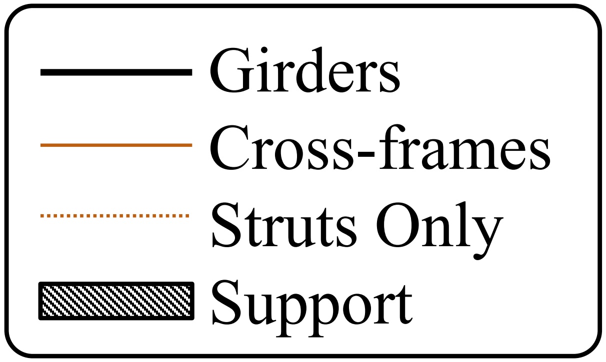
  4. **Include a cross-frame in every bay along the entire span (no fully leaning girders)**





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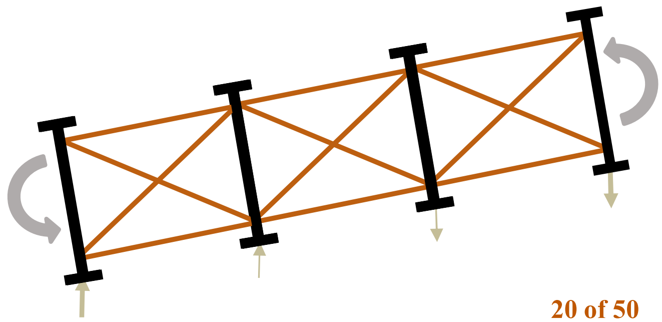
  4. Include a cross-frame in every bay along the entire span (no fully leaning girders)
  5. **Include a full cross-frame line at midspan**



Combined Lateral and Torsional Bracing

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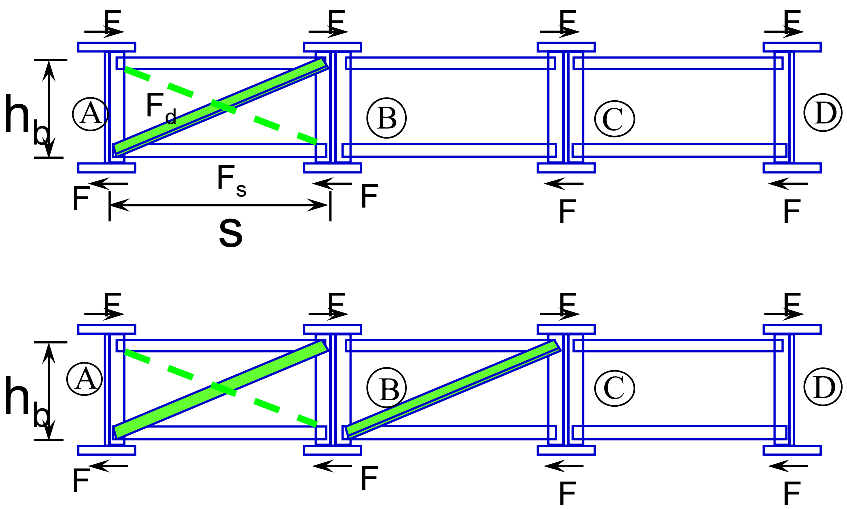
Preliminary results show that the addition of a few truss panels near the ends will **allow ~0.7L** to be **used in β_G expression**. (that is a $(0.7L)^3$ in expression.

Effective Bracing Stiffness in Lean-on Bracing Applications



$$\beta_{br,lean} = R\frac{ES^2h_b^2}{C_{CF}(n_{g,eff}-n_{c,eff}+1)\frac{L_d^3}{A_d}+\left(n_{lean,eff}+1\right)^2\frac{S^3}{A_s}}$$

C_{CF} = 1.0 for Z-Frames
0.5 for X-Frames
2.0 for K-Frames

$n_{c,eff}$ = effective number of cross-frames

$n_{g,eff}$ = effective number of girders

$n_{lean,eff}$ = effective number of lean-on bays

Adjustments to β and M for Layout Effects

- C_{LO} → Layout (LO) factor taking into account reduction $M_{,2024}$ and $\beta_{,2024}$ from the removal of cross-frames in a lean-on layout.

$$M_{,2024} = C_{LO} C_b \frac{\pi^2 s E}{(KL\ )^2} \sqrt{I_x I_{\ ff} \frac{\alpha_x}{2n}}$$

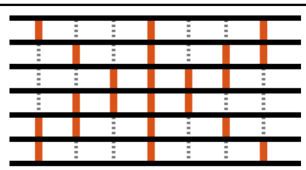
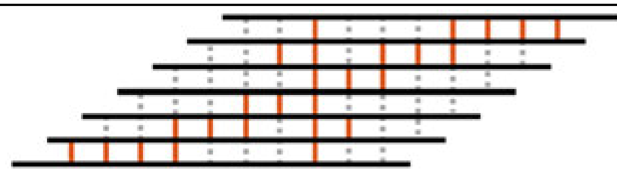
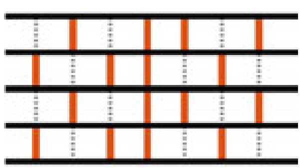
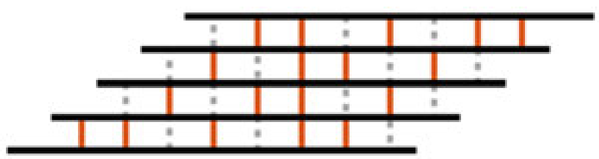
$$\beta_{,2024} = C_{LO}^2 C_b^2 \frac{\pi^4 E I_x s^2}{(KL\ )^3 (n+1)} \frac{\alpha_x}{2n}$$

$$C_{LO} = \frac{M_{,l\ an}}{M_{,\ onv\ ntional}}$$

- $C_{LO} = 0.95$ for normal systems.
- $C_{LO} = 0.85$ for skew systems.

Conservative based on data distributions for recommended layouts!

Recommended Cross-frame Layouts

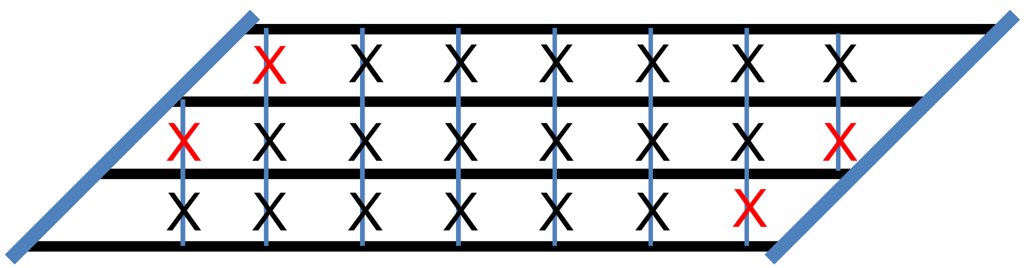
Layout Designation	Sample Image Nonskew	Sample Image Skew	Applicable # of Girders	Applicability
Diagonal	-		4, 5	Shorter Spans
ZigZag		-	4, 5	Longer Spans
X			6+	Reducing Adjacent Leaning Girders
Checkerboard			4, 5	Shorter Spans Erection Stability Issues

Additional Layout Recommendations

- Lean-on layouts should not be used in systems with 3 girders.
  - Reductions in β are too significant to be practical.

- Designers can strategically remove up to 10% of cross-frames with minimal behavioral changes – avoid removing adjacent cross-frames in a given line.

  - Useful for difficult to install braces for bridge systems with high skew.



TXDOT PROJECT NO. 0-7193

DEVELOP ASSESSMENT AND MITIGATION GUIDANCE FOR ANCILLARY HIGHWAY STRUCTURES WITH EXISTING CRACKS

RESEARCH TEAM

UT Austin Junghoon Sohn (PhD Student), Dr. Mojtaba Aliasghar, Dr. Aidan Bjelland, Dr. Todd Helwig, Dr. Matthew Hebdon, Dr. Salvatore Salamone

Texas A&M HanGil Kim (PhD Student), Emily Bruening, Mike Nitsche, Dr. Arash Rockey, Dr. Stefan Hurlebaus, Dr. Peter Keating, Dr. Kinsey Skillen

Research Objectives

- This study is focused on the assessment and mitigation/repair guidance of cracked ancillary structures

Traffic Signal Structure
(TSS)

Cantilever Overhead Sign Structures
(COSS)

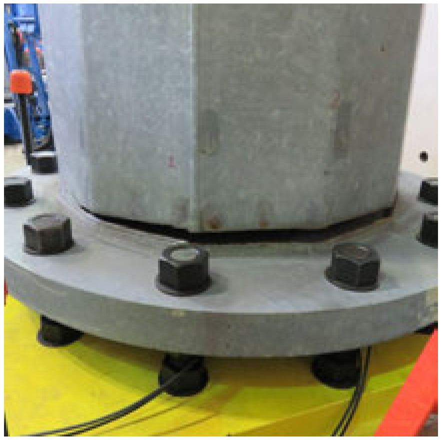
High Mast Illumination Pole
(HMIP)

Research Background

- There have been a number of previous studies related to damage and fatigue performance of HMIP/COSS/TSS poles.
- The poles are all galvanized to improve the long-term corrosion performance.
- Galvanizing has been found to potentially initiate cracks in welds of components.
- Current practice inspects welds for cracks during fabrication after galvanization.
- Still existing inventory likely has cracks in welds resulting in a need to inspect/monitor and potentially repair.

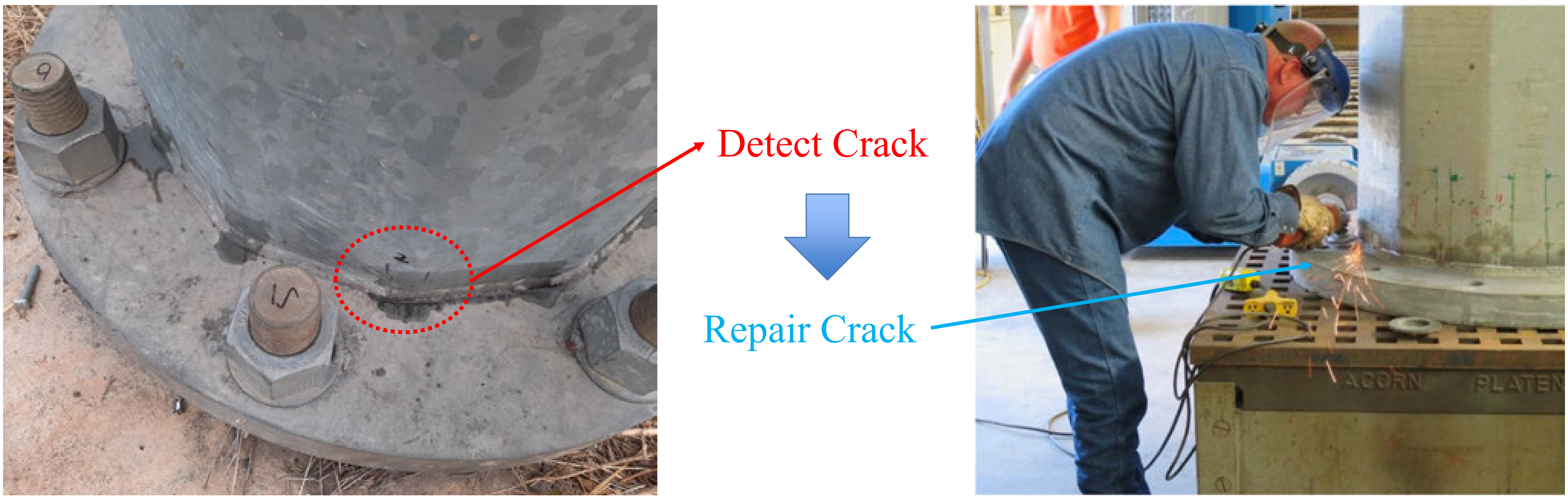
Research Background

Laboratory Testing at UT Austin (Pool – 2010, Belivanis – 2013, Morovat et. al, 2018)



Research Objectives

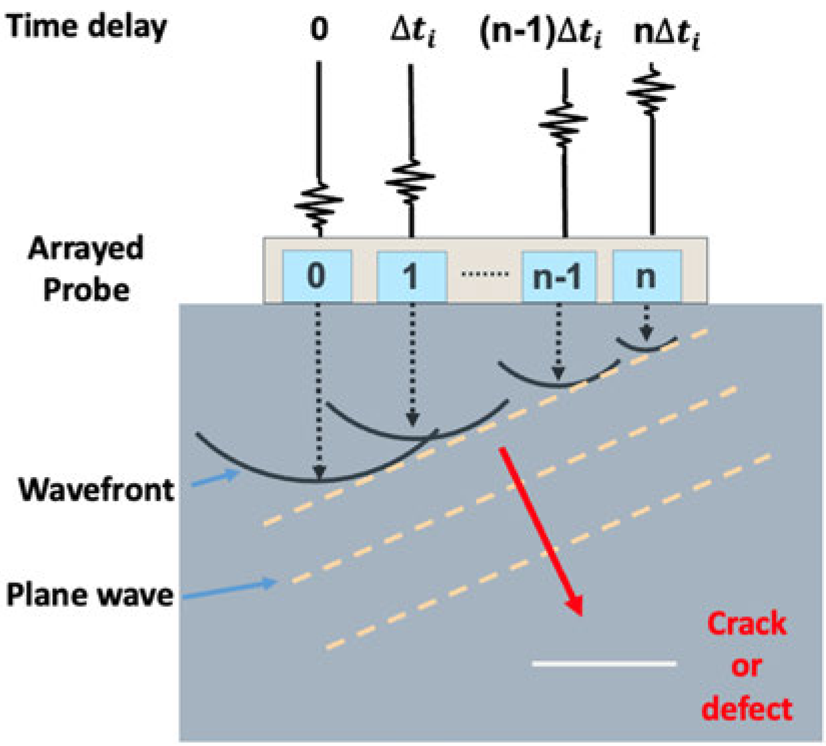
- Detect and repair weld cracks often initiated from galvanizing and potentially growing from fatigue in TSS, COSS, and HMIP

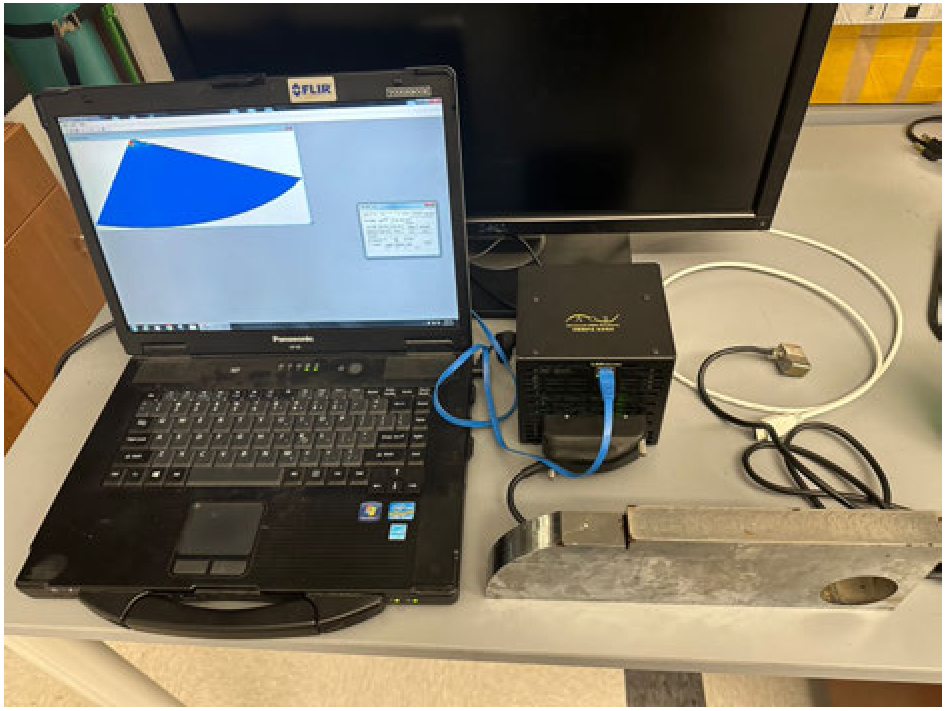


Field Assessment of COSS, HMIP, and TSS Structures

Methodology

- Phased Array Ultrasonic Testing (PAUT)

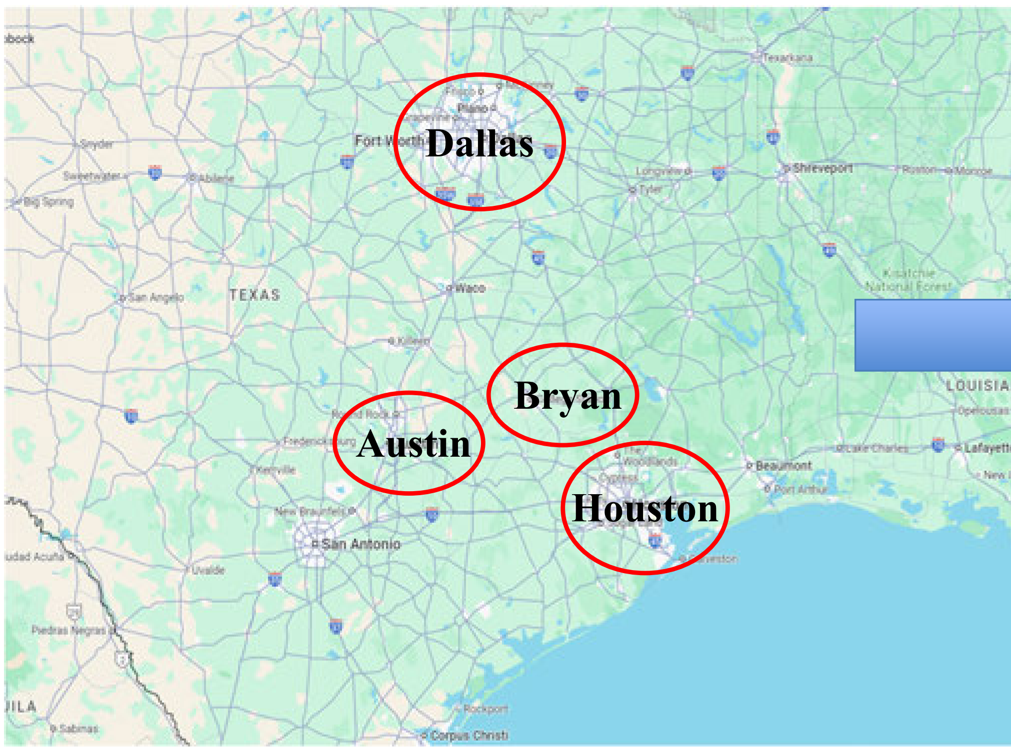




PAUT system

Field Assessment

- 10 TSS, 10 COSS, and 10 HMIP samples per region

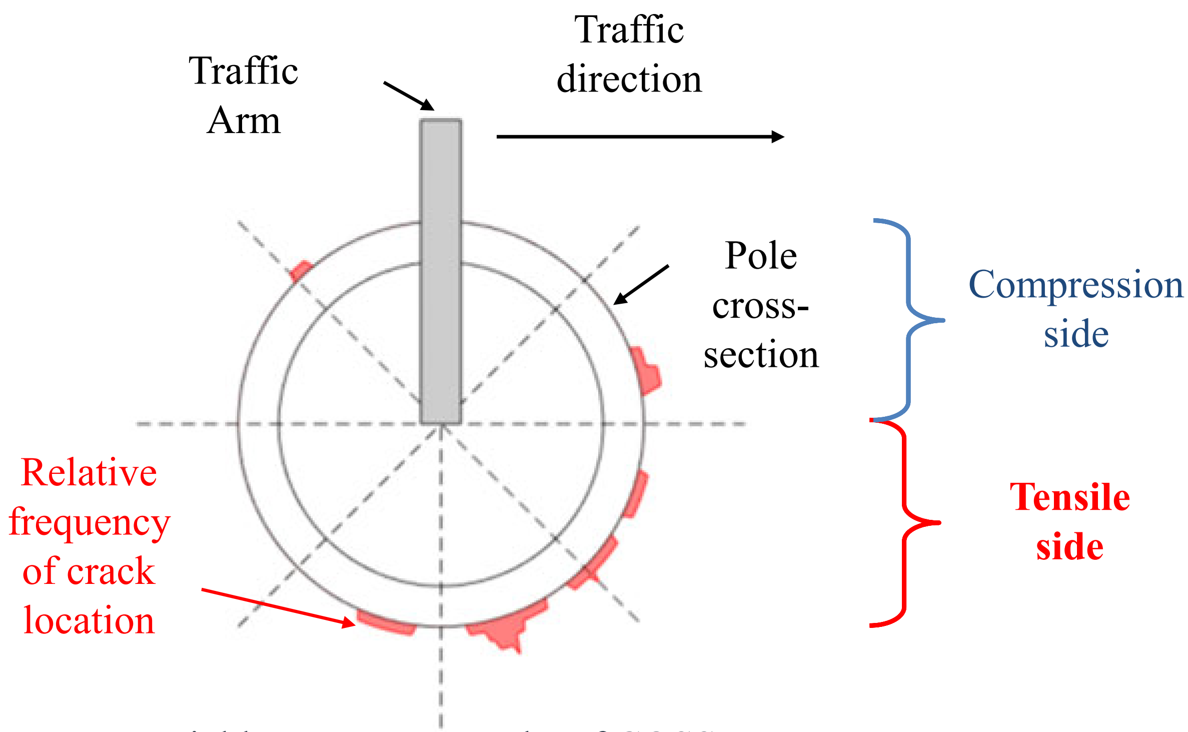


Total 120 Poles (HMIP, COSS, TSS)

- Geometry
- PAUT results

Field Assessment Results – COSS, HMIP, TSS

- Crack locations and their frequency on COSS (similar data for TSS, HMIP)



Field assessment results of COSS

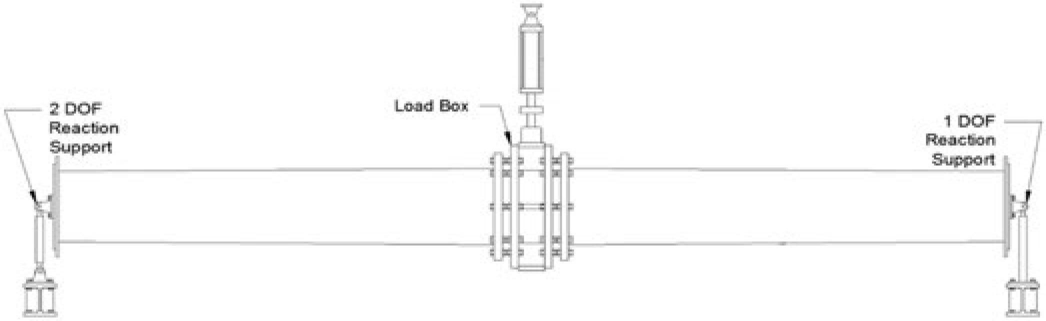
Gravity-induced Stress

Laboratory Experiments on HMIP, TSS, and COSS Structures

Upcoming Lab Tests

- Induce and/or extend fatigue cracks by applying cyclic loading to the specimens

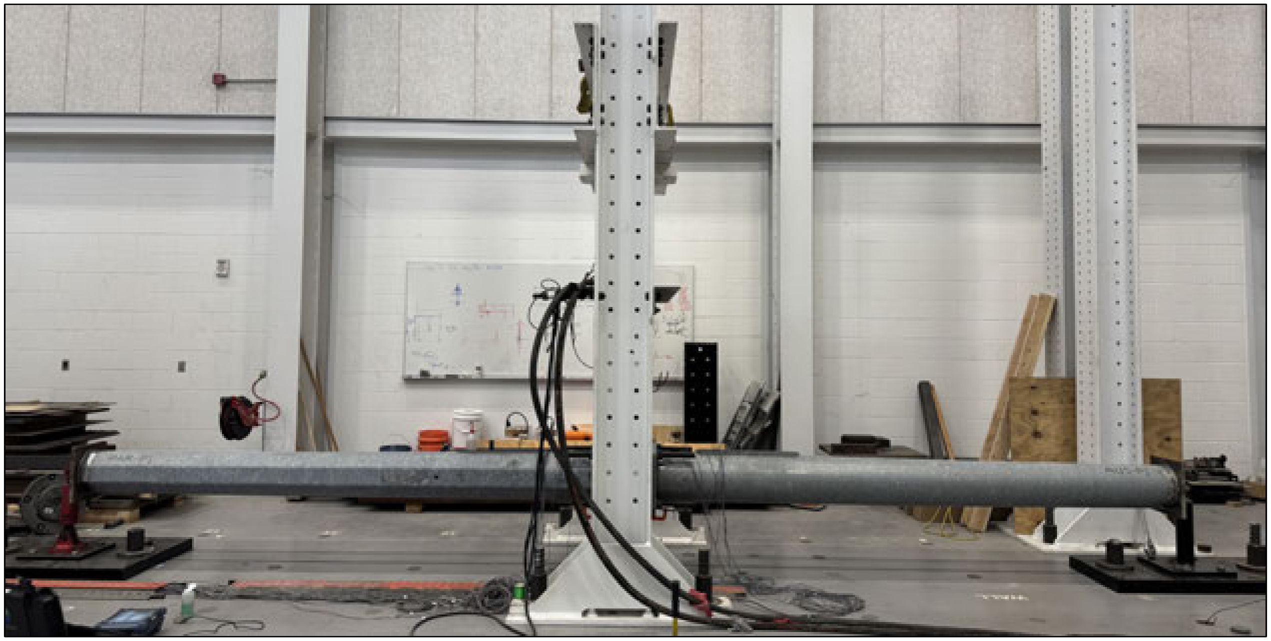
Tests at both UT and A&M on HMIP, COSS, and TSS Specimens. Cyclic loading to obtain cracks, study weld repair techniques and performance.



Texas A&M Tests - TSS

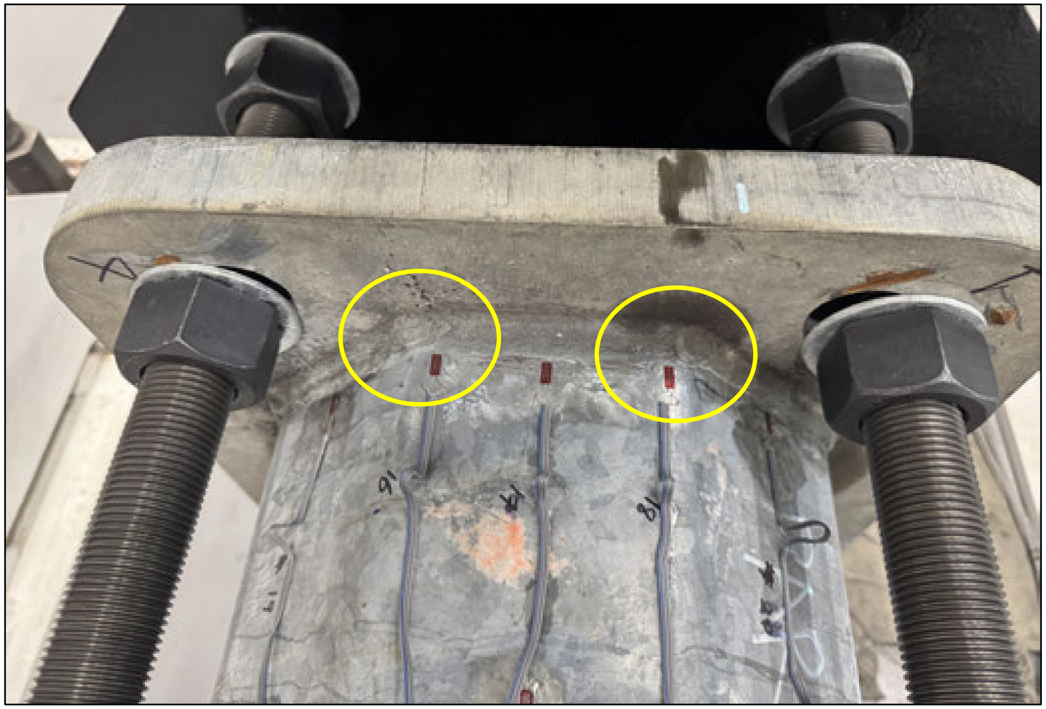
Loading Stress*: 2 – 17 ksi
Stress range: 15 ksi
Displacement: 0.16 – 1.33 in.
No. of Cycles: 7,500 cycles

* Average stress applied to the poles



Texas A&M Tests - TSS

Cyclic Loading Began Last Week



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Summary

- The field assessment of HMIP, COSS, and TSS Poles have been completed.
- HMIP and TSS Specimens have been obtained from the field for laboratory testing and repair studies. Additional COSS specimens from the field are desireable – but will be fabricated within the coming months if field specimens are unavailable.
- While the research team has become proficient in PAUT methods, additional information will be obtained during experiments since cracks can be "opened" from applied loading to improve understanding of resolution on readings.
- Experiments are underway at A&M (TSS) and will be at UT in the coming months (HMIP – COSS). If you know of **COSS poles** from the field that are being dismantled – **PLEASE LET US KNOW!!**

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TEXAS TECH

TXDOT PROJECT NO. 0-7213

DEVELOP DESIGN METHODOLOGIES AND EFFICIENT DETAILS FOR TRIPLE I-GIRDER STEEL STRADDLE CAPS

RESEARCH TEAM

UT Austin – PhD Student: Baran Koyuk, Post Docs: Aidan Bjelland, Mojtaba Aliasghar, Supervisors: Todd Helwig, Matthew Hebdon

Texas Tech – PhD Student: Shrijan Dhakal, Supervisor: Sunghyun Park

BACKGROUND: PROJECT 0-7012 – DEVELOPMENT OF NON-FRACTURE CRITICAL STEEL BOX STRADDLE CAPS

THREE-GIRDER CAPS - CONNECTICUT

A) Assembled at Fabrication Yard

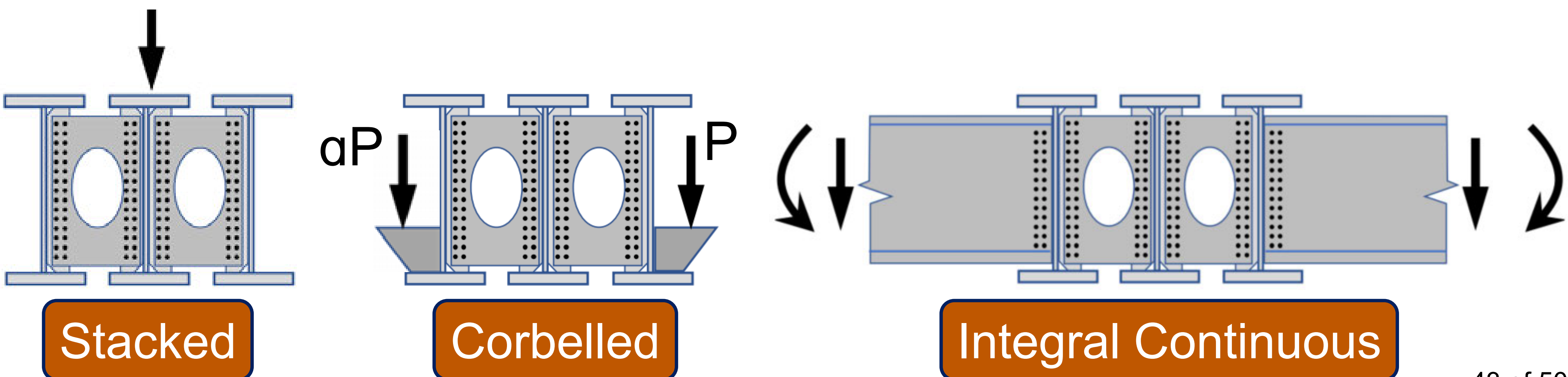
B) Erected by Single Crane in Field

C) Fully Erected Cap - Bridge Under Construction

Mike Culmo – Cha Consulting, Inc.
Ronnie Medlock – High Steel Structures

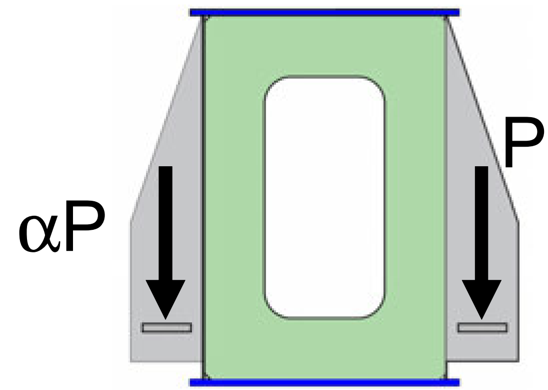
TxDOT Project No. 0-7213 – Objectives

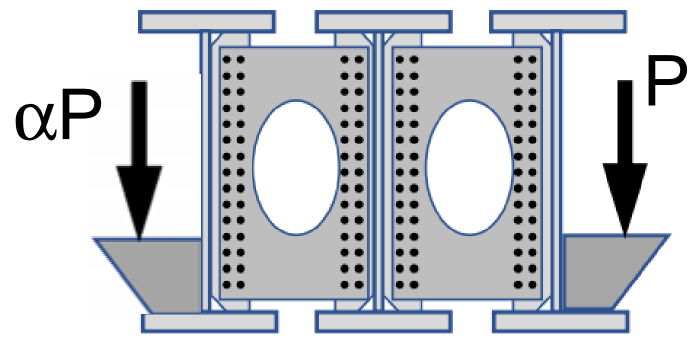
- Investigate the behavior of triple I-girder straddle caps with various configurations.
- Develop efficient and economical details that provide high resistance capacity for bending, torsion, and shear loads.



Corbelled Geometry – Torsion on Straddle Caps

- Eccentric loading of bridge girders.
- Box-shaped straddle cap:
  - Closed section
  - Torsional stiffness ~ area enclosed by section.
- Triple I-Girder straddle cap:
  - Pseudo-Open section
  - Torsional stiffness < Full Box-shaped
  - Combination of Batten plates and diaphragms likely provide "effective-stiffness" of pseudo box shape





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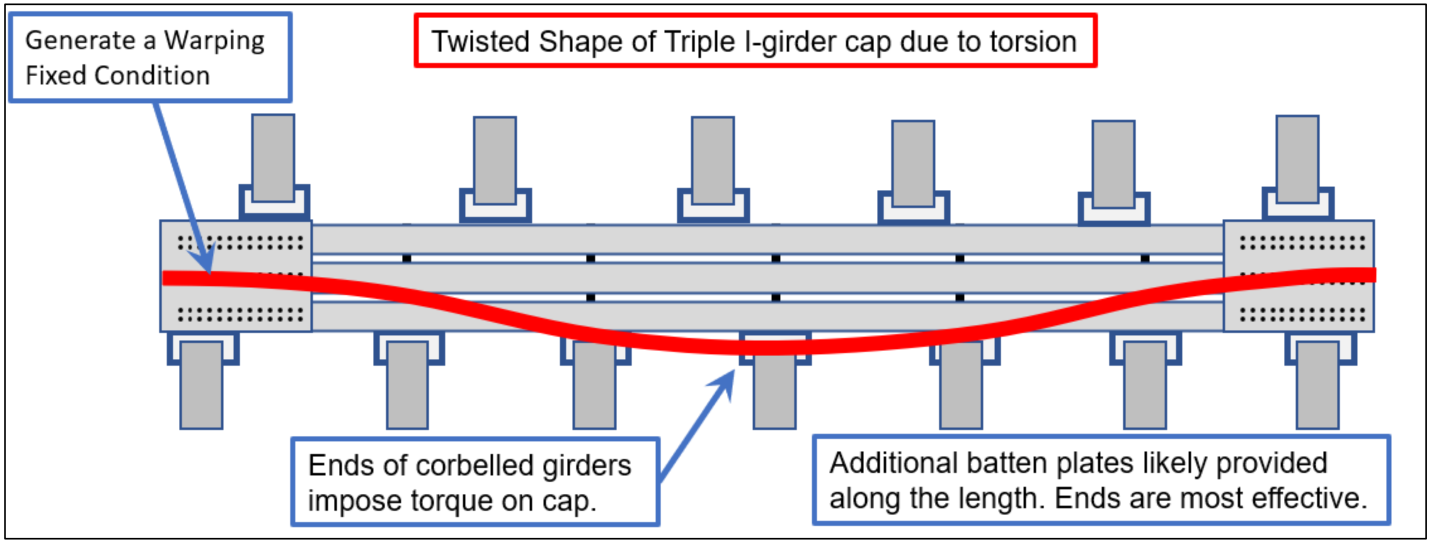
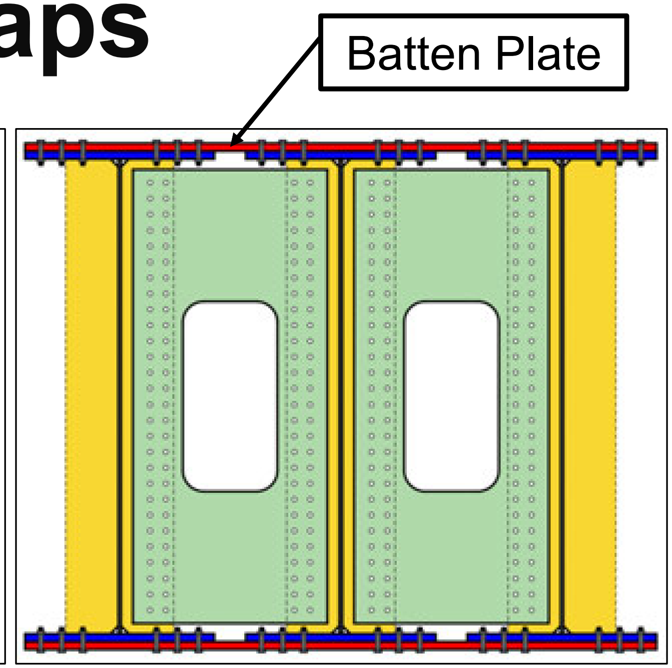
TEXAS TECH

Torsion on Triple I-Girder Caps

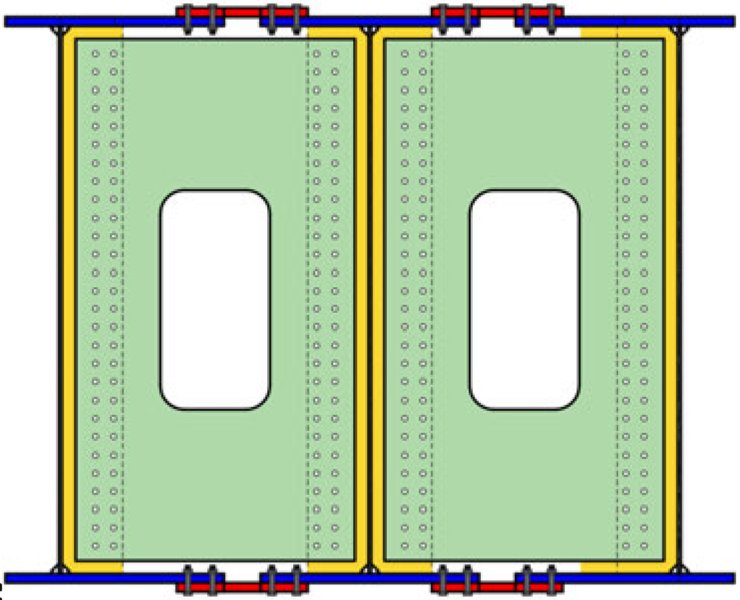




- Use bolted flange batten plates → pseudo-closed box section
- Potentially increase torsional stiffness

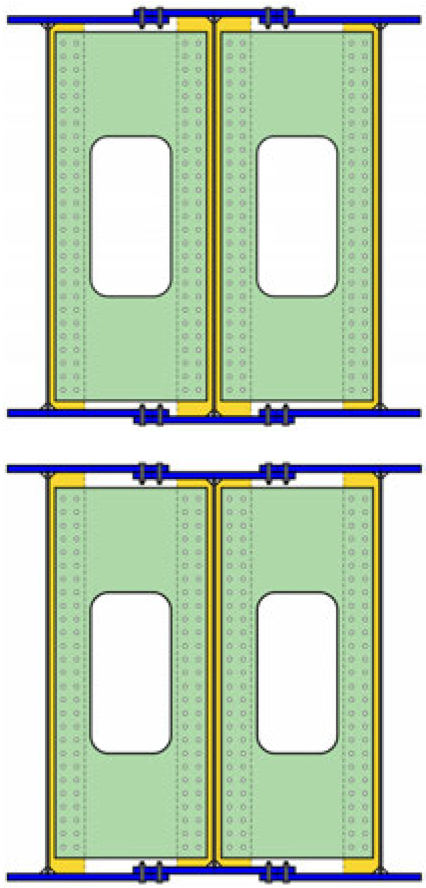
Potential Detail 1: Shift Webs Outwards

- Improve performance, aesthetics, and accessibility.
  - Appearance similar to the box-shaped straddle caps.
  - Improved accessibility, inspection,etc.
  - 3 primary members → Redundant
  - b/t increases → Local flange buckling
  - Potential increase in torsional stiffness by using flange connection plates.



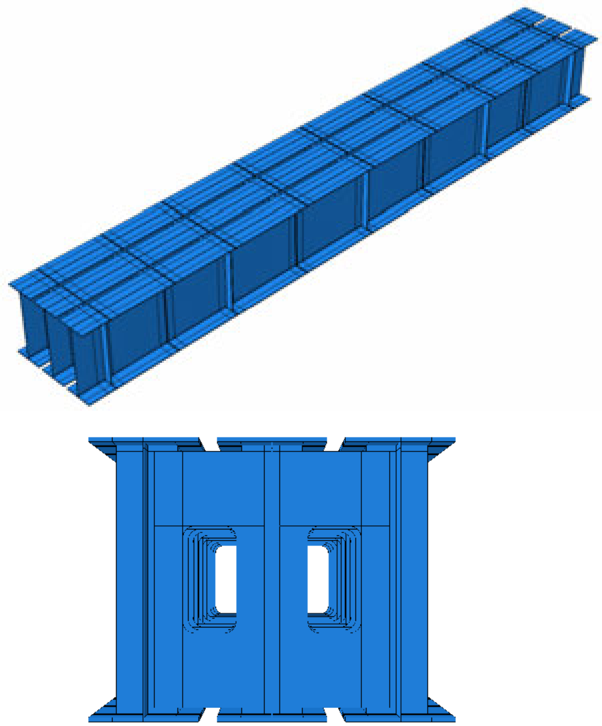
Potential Detail 2: Overlapped Flanges

- Slight increase/decrease the depth of the interior girder → flanges overlap
- Improved accessibility.
- Decrease overall width.
- 3 Primary members with mechanical separation → Redundant
- No need for flange connection/batten plates.
- Significant increases in bolting options/distribution

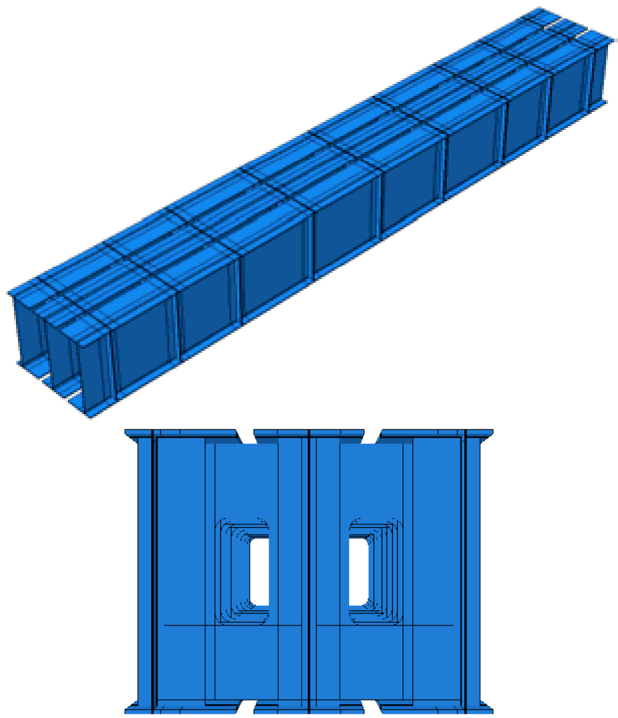


Preliminary FEA Studies – Abaqus Models

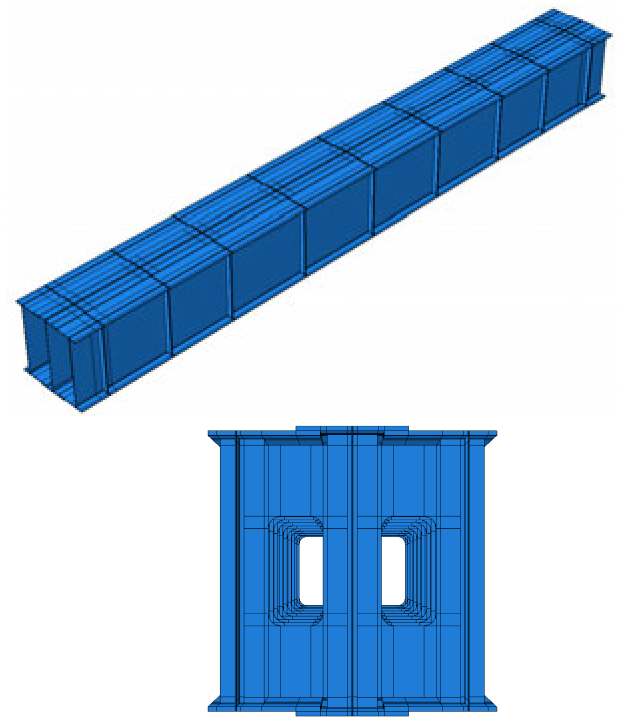
The initial analysis used the exact same plate sizes for each geometry.



Base Model

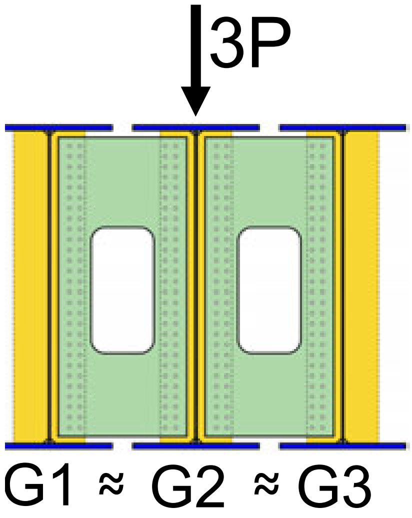


Shift Webs Outwards

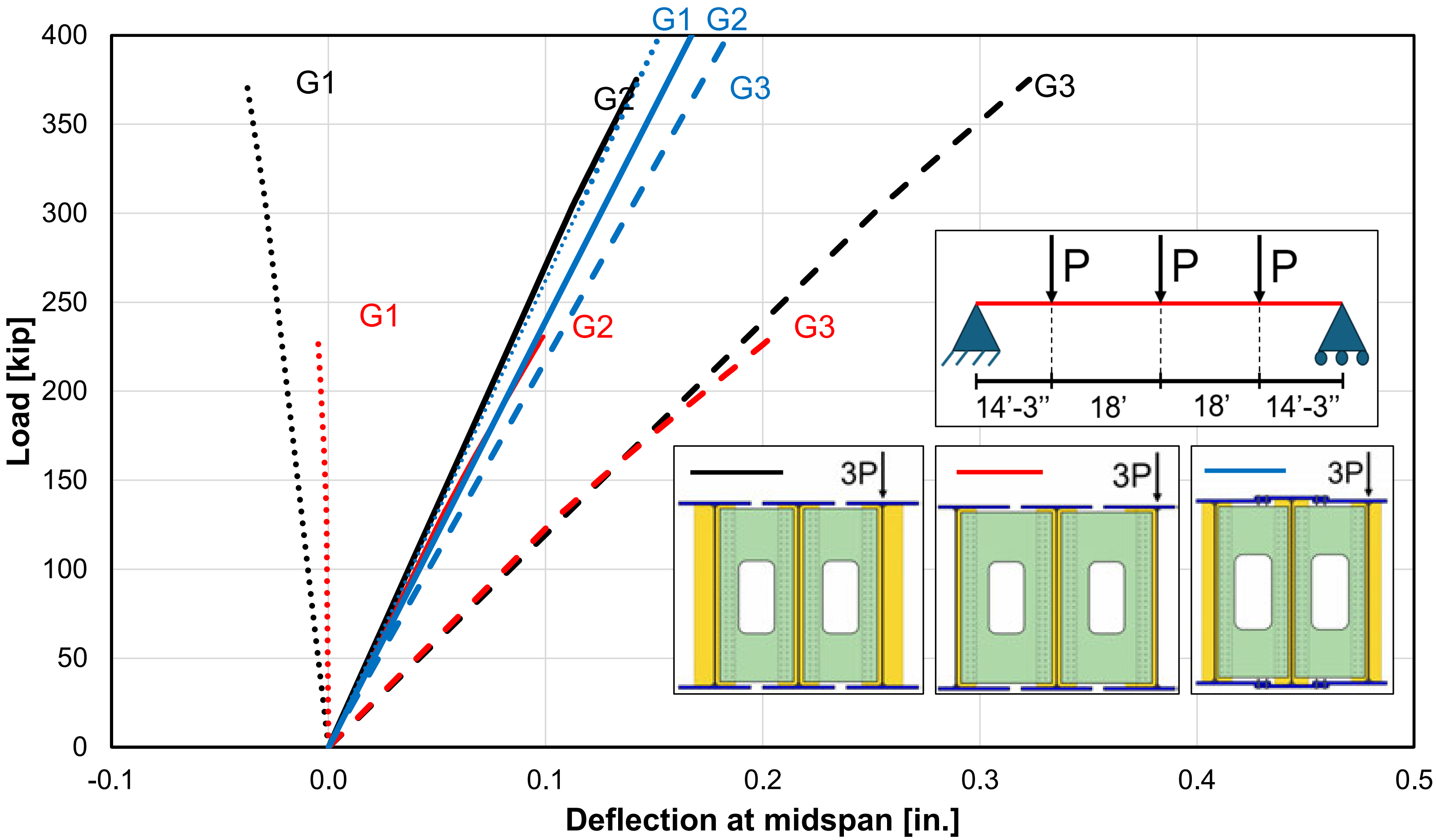


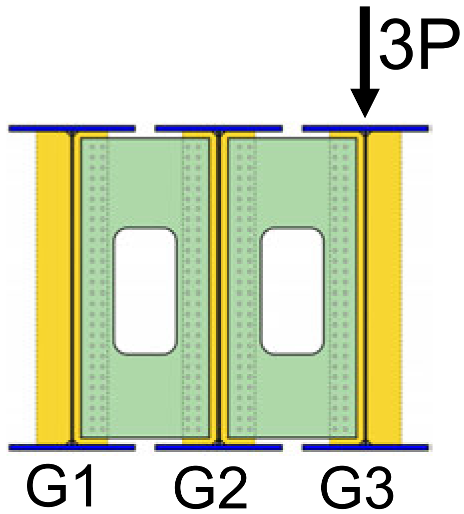
Overlapped Flanges

Preliminary FEA Studies – Flexural Bending



Preliminary FEA Studies – Combined Bending and Torsion





Thank-you!

For any question, please contact:

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