Placement analysis of a curved, variable depth, single tub girder bridge

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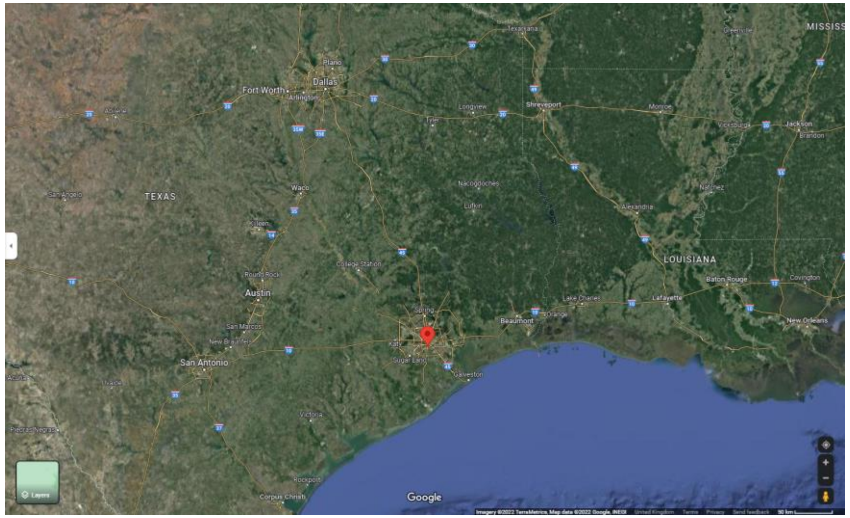
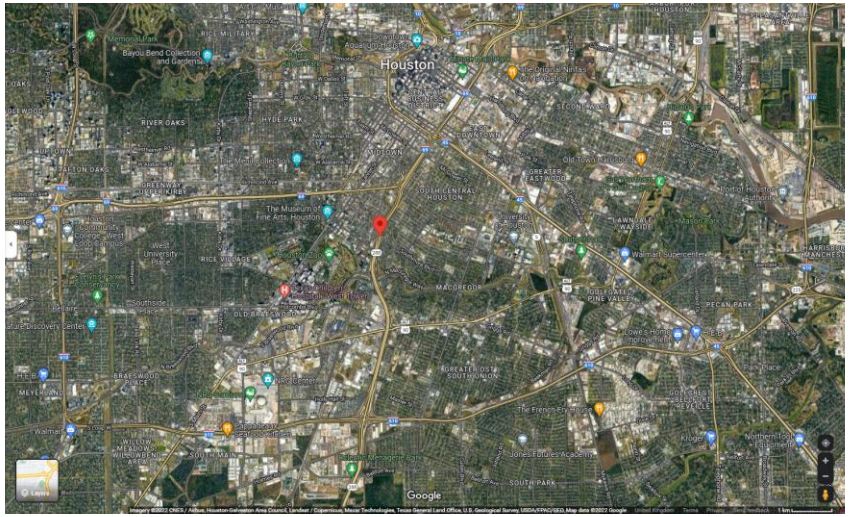
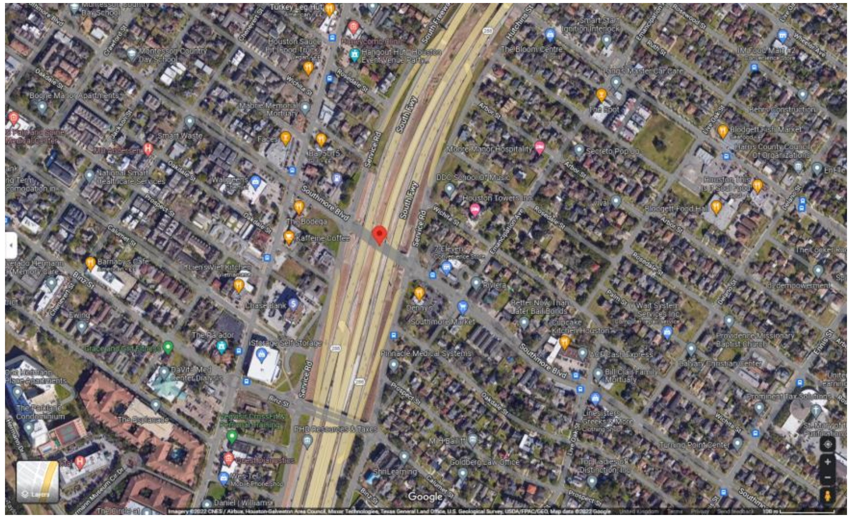
Case study

- Bridge located in the Museum District, **Houston**, TX
- "The aesthetic concept was **chosen by TXDOT** as a unique **"signature" bridge** that serves as a gateway to the northern limit of the SH 288 toll lane project in Houston which is a heavily travelled corridor in Houston with a confluence of three freeways."
- "A steel box girder was chosen over concrete to meet the requirement of **variable depth superstructure**, provide a **pre-fabricated** option to erect and **minimize impact to traffic** under the bridge and be the most **cost-effective** option for these bridges."
- Spans: 105-ft. – 88-ft. – 108-ft. Box girder depth varying between 72-in. (abutments & piers) and 36-in. (mid-span)



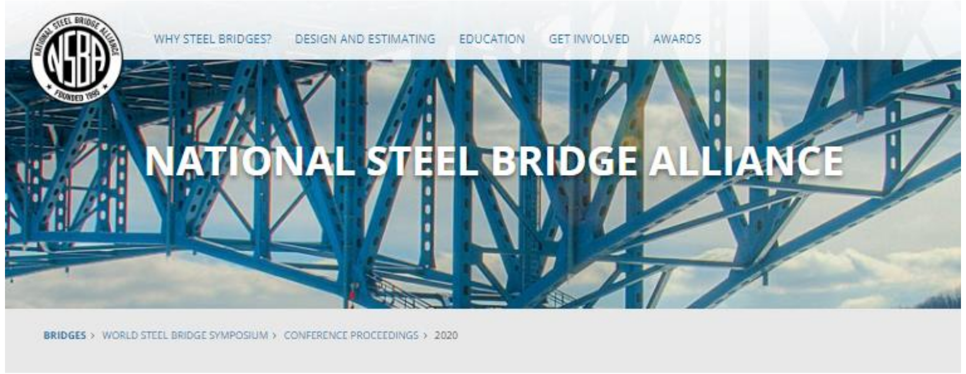




Reference

K. Ramanathan, A. Ahmed, S. Sok, Curved, Variable Depth, Single Steel Trapezoidal Box Girder Pedestrian Bridges, World Steel Bridge Symposium, 2020

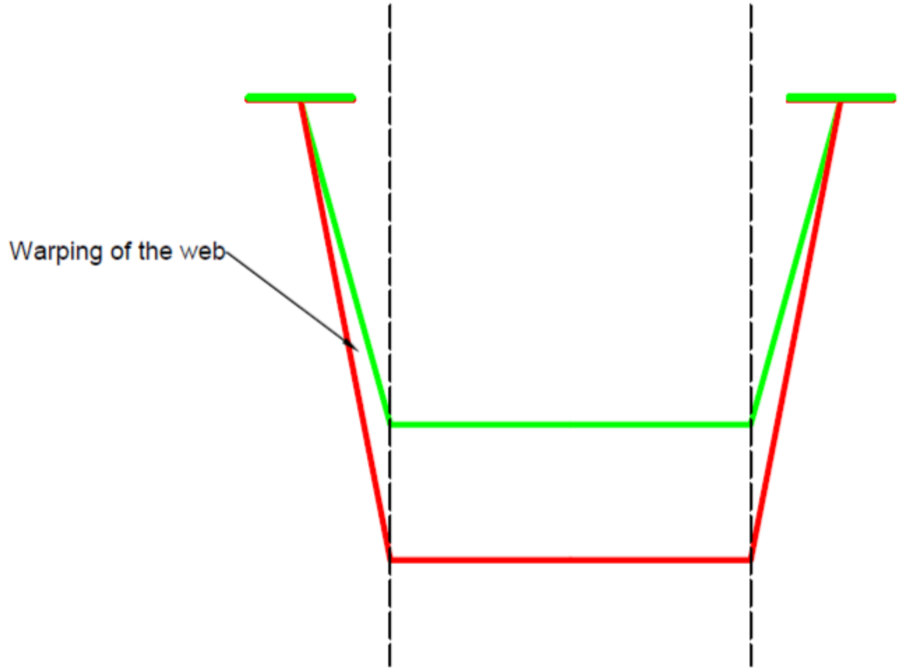
(Source: https://www.aisc.org/globalassets/nsba/conference-proceedings/2020/ramanathan_ahmed_sok.pdf)



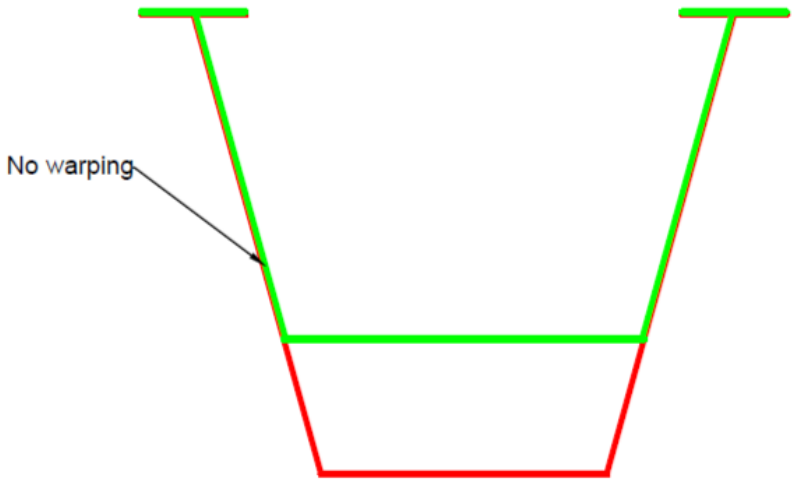
Presentation Title	Author(s)/Speaker(s)
A CM/GC Approach for the Design of a Two-Girder Horizontally Curved Pedestrian Bridge	Irvin J. Lopez, PE; Ken Price, PE, SE, PEng; Rachel Cullen, CPEng; Joshua Sletten, PE, SE; Joseph Smith, PE, SE
A Collaboration in Steel to Across Borders	Vincent Gastoni
Bayonne Bridge Main Span Demolition Case Study	Thomas Rabinko
Considerations for Rehabilitating a Steel Self-Anchored Suspension Bridge -- A Case Study	Aaron Colorito, PE
Development of Analytical Framework for Strength Assessment of Corroded Steel Bridges	Georgios Tzortzinis; Brendan T. Knickle; Simos Gerasimidis, PhD; Alexander Bardow; Sergio F. Brena, PhD
Development of the Design to Fabrication Information Delivery Manual (IDM) for Model-Based Information Exchange	Aaron Costin, PhD; Ronald Medlock, PE
Evaluation and Retrofit for the Second Widening of the P.R. Olgiati Bridge	Frank Artmont, PE, PhD; Philip A. Ritchie, PE, PhD; Thomas P. Murphy, PE, PhD
High Load Multi-Rotational Disk Bearings for Steel Plate Girder Bridges	Ronald J. Watson
Horizontally Curved, Variable Depth Single Steel Trapezoidal Box Girder Pedestrian Bridge	Karthik Ramanathan, PE; Annus Ahmed, PE; Seng Sok, PE
Network Tied-Arch Bridge: Efficient Solutions with High-Strength Jumbo Shapes as Arch Member	Ricardo Zanon, SE; Mehdi Assad, SE; Dennis Rademacher, SE, PhD; Wojciech Lorenc, SE, PhD
Rapid Reconstruction of BNSF Br. 482.1 West Approach	Ashley Cook, PE; Temple Overman, PE
Streamlining Steel Box and Arch Erection Through BrIM and 3-D Modeling for the I-59/20 Bridge Replacement	Patrick Noble, PE, SE
Structural Behavior and Fatigue Rehabilitations of the I-64 Steel Delta Frame Bridges over Kerrs Creek and Maury River in Virginia	Loai El-Gazairly, PE, PhD; Rex L. Pearce, PE

Constructability and aesthetics

"If the bottom flange was constant width the web slope would have to vary resulting in **warping in variably cut web plates**. With a variable width bottom flange, it would allow the web slope to be constant throughout the bridge and would keep the developed elevation of web to remain **planar**. This would eliminate warping otherwise developed due to variable web slope. To prevent web warping and to have a **uniform visual appearance** in elevation for the webs, **it was determined that the web slope would be constant while the width of the bottom flange would vary.**"

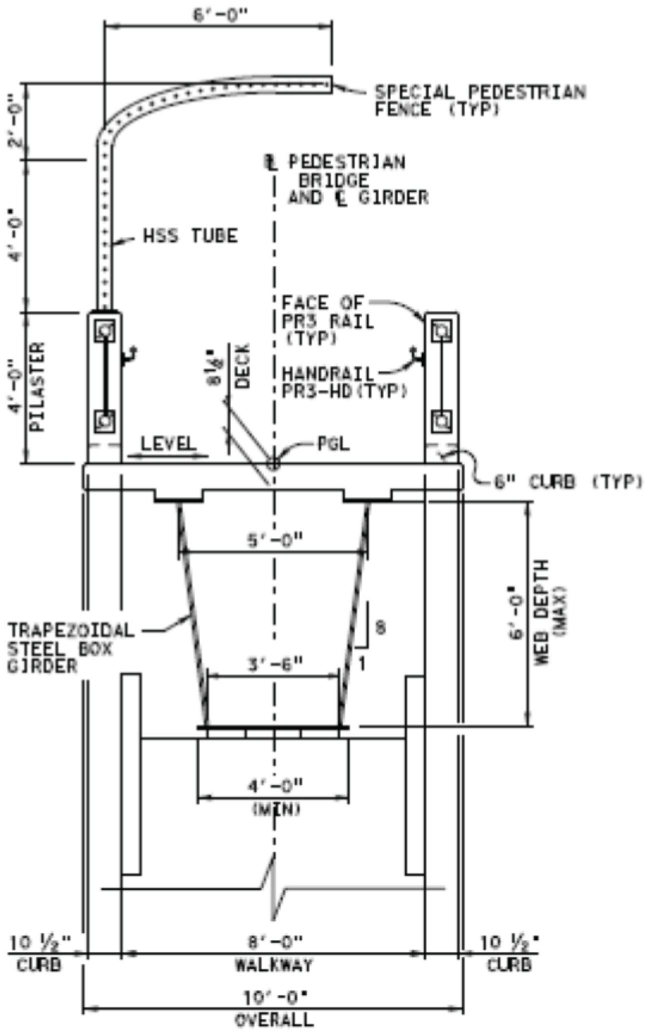


Initial solution: constant bottom flange width

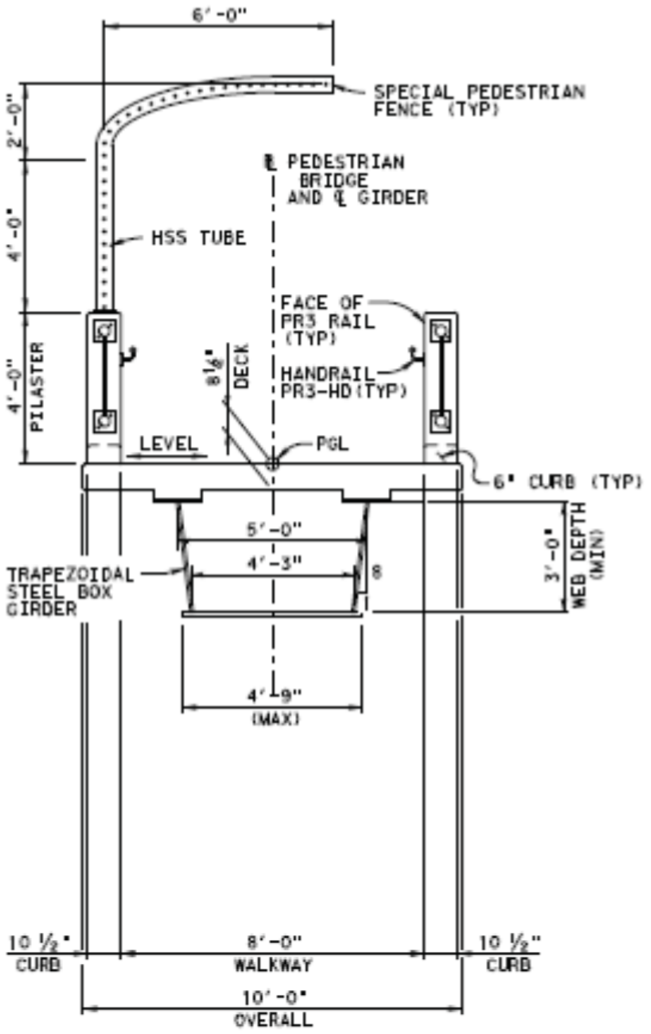


Preferred solution: varying bottom flange width (for constructability and aesthetics)

Bridge cross-sections at bents/abutments (left) and at mid-span (right)



SECTION A-A
(AT BENTS/ABUTMENTS)



SECTION B-B
(AT MID SPAN)

Challenges

- Overall design challenge:

"The primary challenge was to fit all required details such as cross-frames, lateral bracing, splices, access holes, jacking stiffeners, bearings, end diaphragms and bearing stiffeners within the room available, while satisfying all the design requirements."

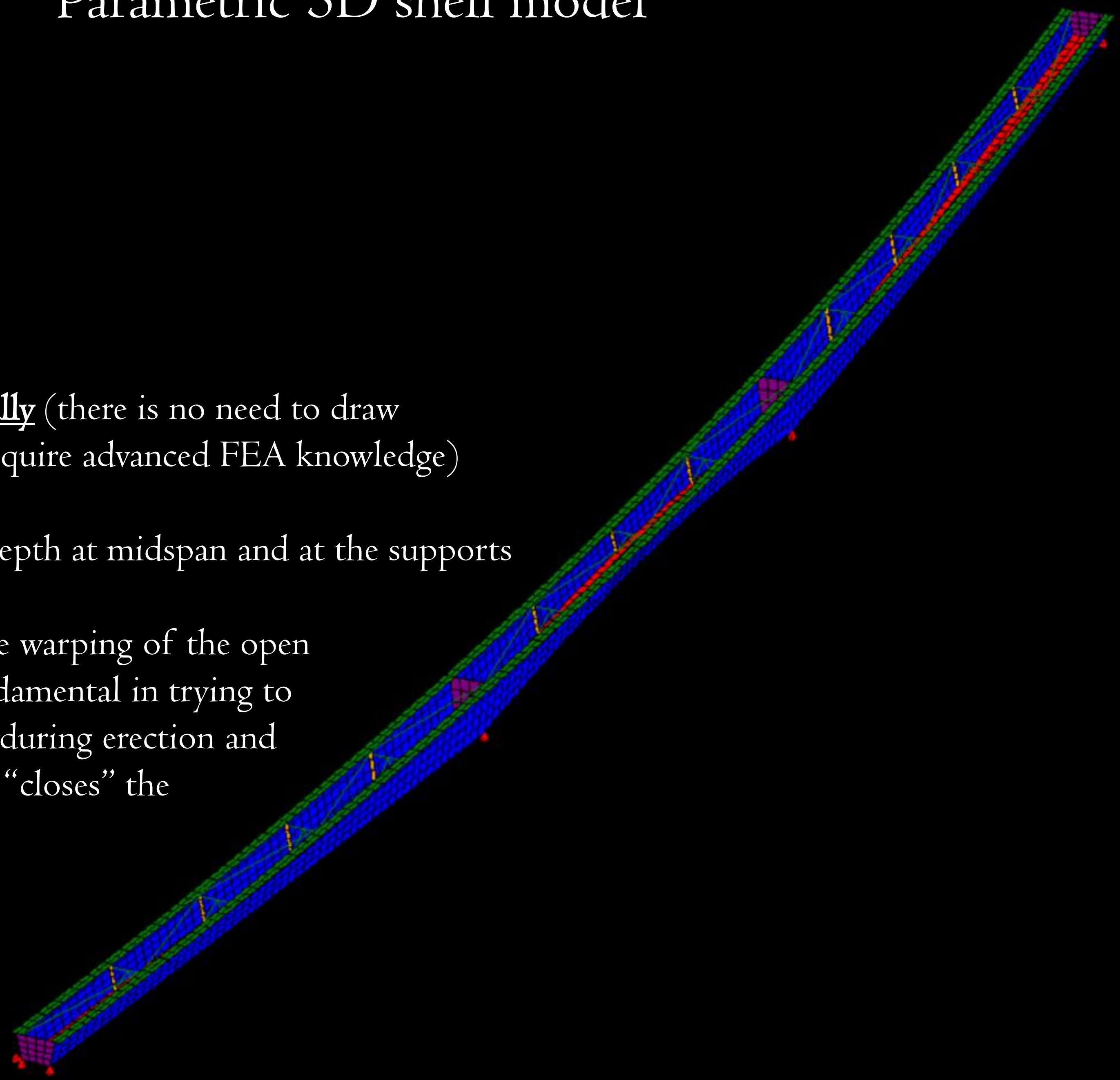
- Construction analysis challenge:

"It is vital to note that no commercially available program completely covered the interim loading/deck pour considerations that come into play for single steel trapezoidal boxes."

"Given the challenging geometry of the steel tub as described, it was difficult to capture all the aspects of the tub girder typically used industry standard software such as MDX."

-> The ability to address such complex geometries and creating 3D shell models (in lieu of 1D line models or 2D grid models), particularly for the erection and deck placement stages, is the precise reason why mBrace3D was developed.

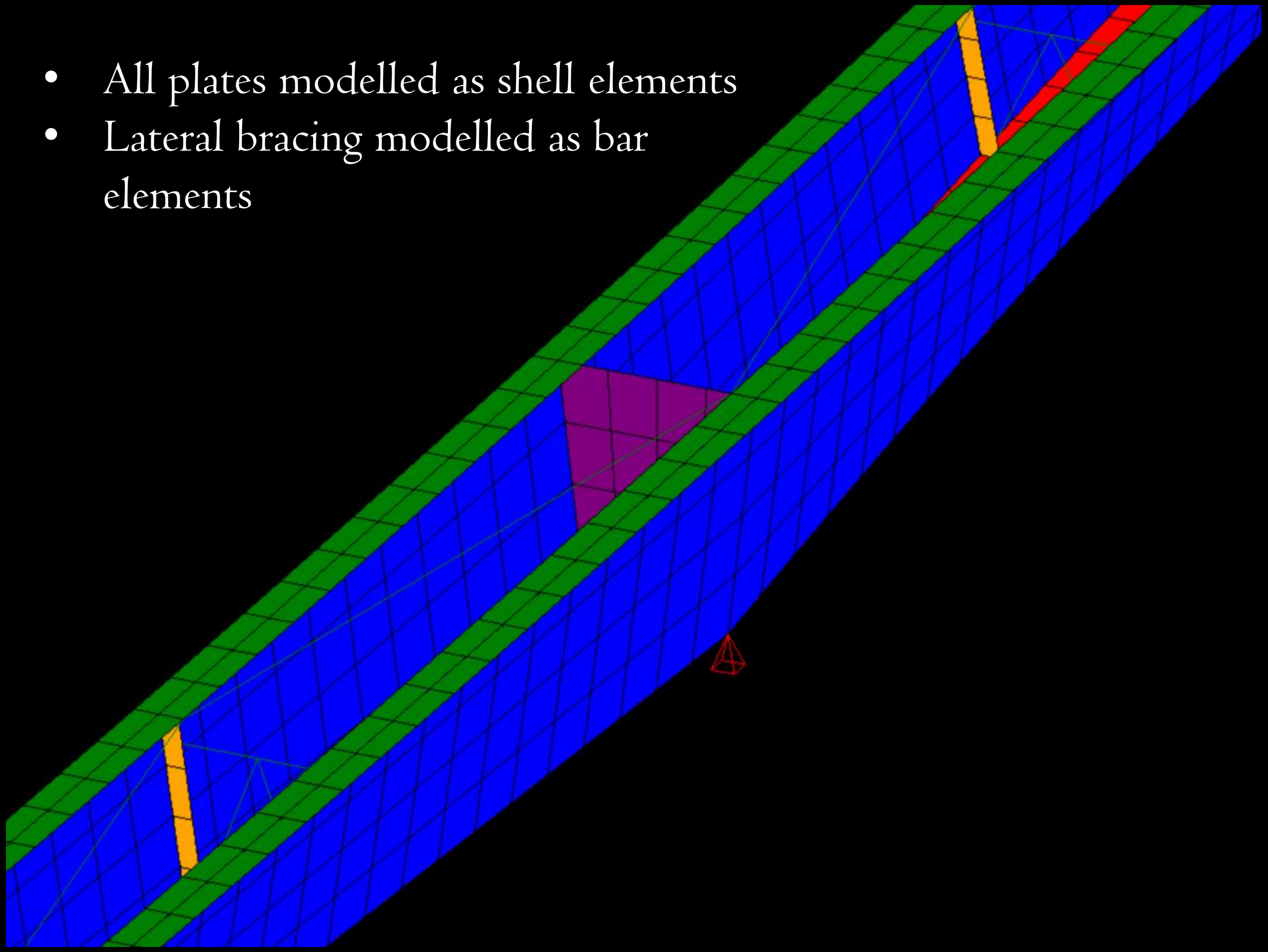
Parametric 3D shell model



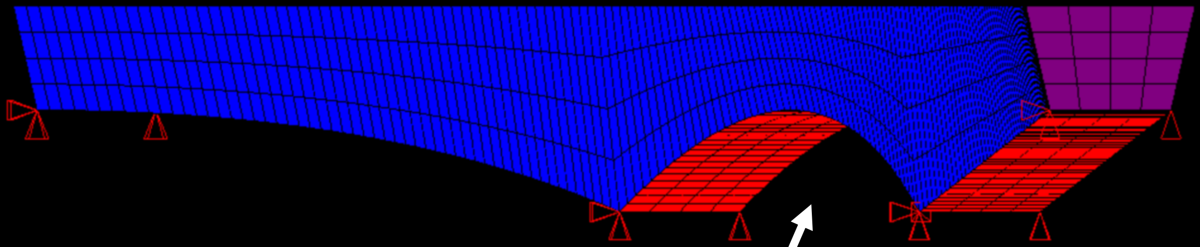
Note:

- This 3D shell is produced **parametrically** (there is no need to draw anything manually and this does not require advanced FEA knowledge)
- The only input for the haunch is the depth at midspan and at the supports
- Only 3D shell models can fully capture warping of the open trapezoidal cross-section, which is fundamental in trying to understand the "true" bridge behavior during erection and construction, before the concrete deck "closes" the section and makes it torsionally stiff.

Close-up views of the parametric 3D shell model



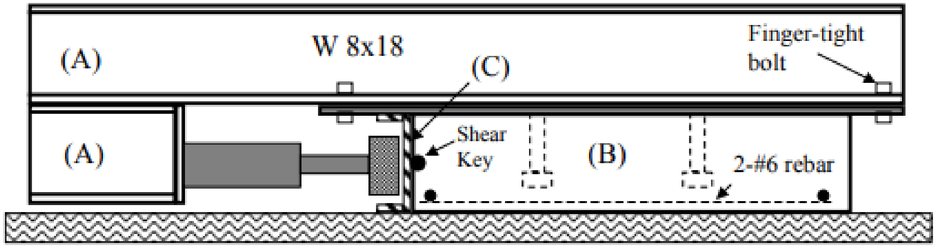
- All plates modelled as shell elements
- Lateral bracing modelled as bar elements



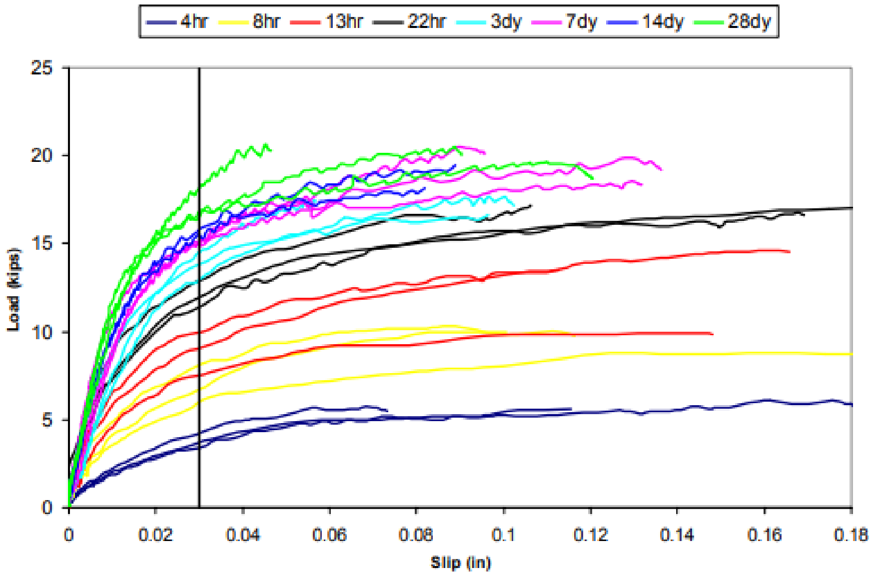
True parabolic profile

Deck placement analysis in mBrace3D

- mBrace3D is state-of-the-art in that it captures the **partial composite action** as the concrete deck hardens
- Shear studs are modelled as **link elements**, whose **time-varying stiffness** was determined **experimentally** based on push-out tests

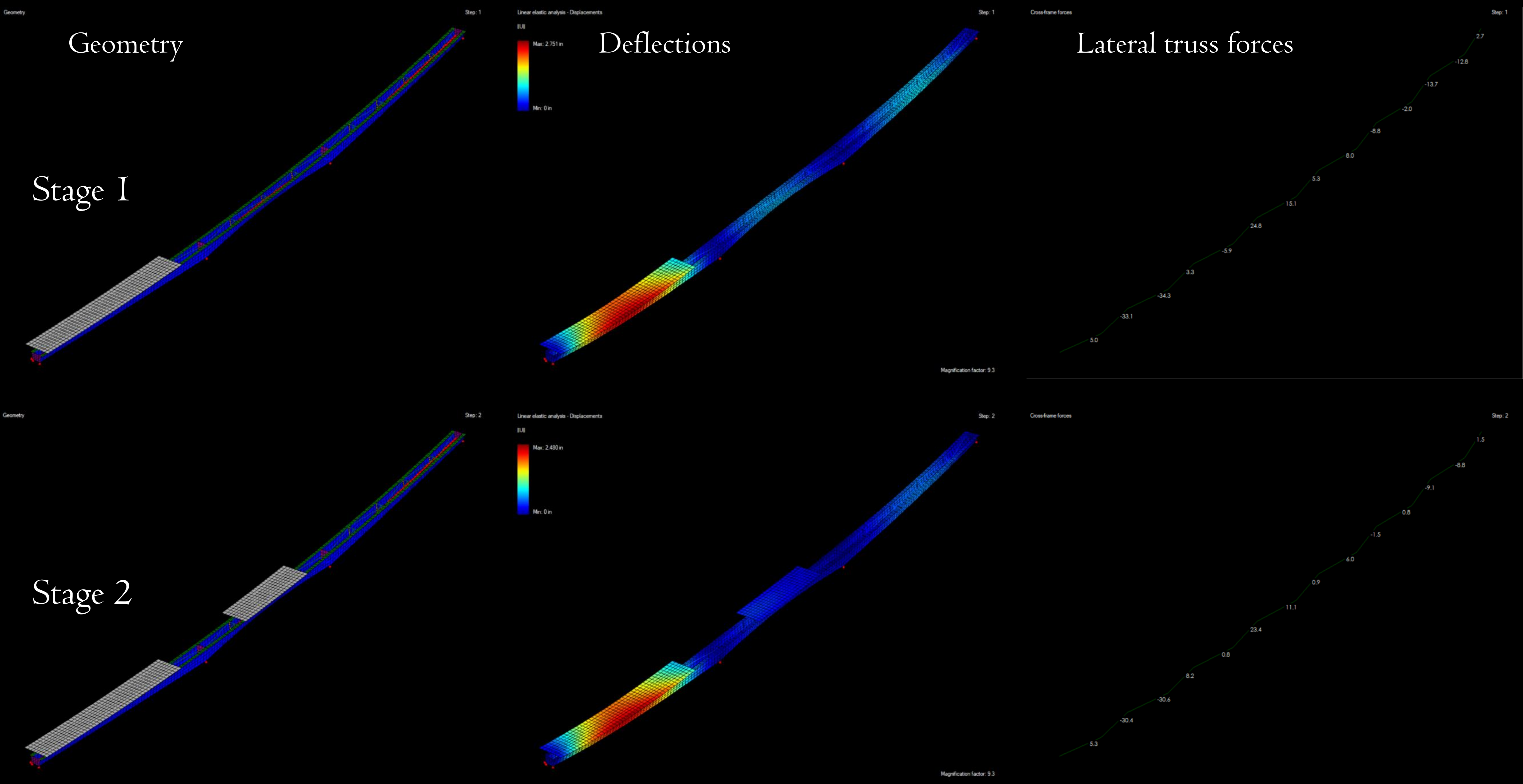


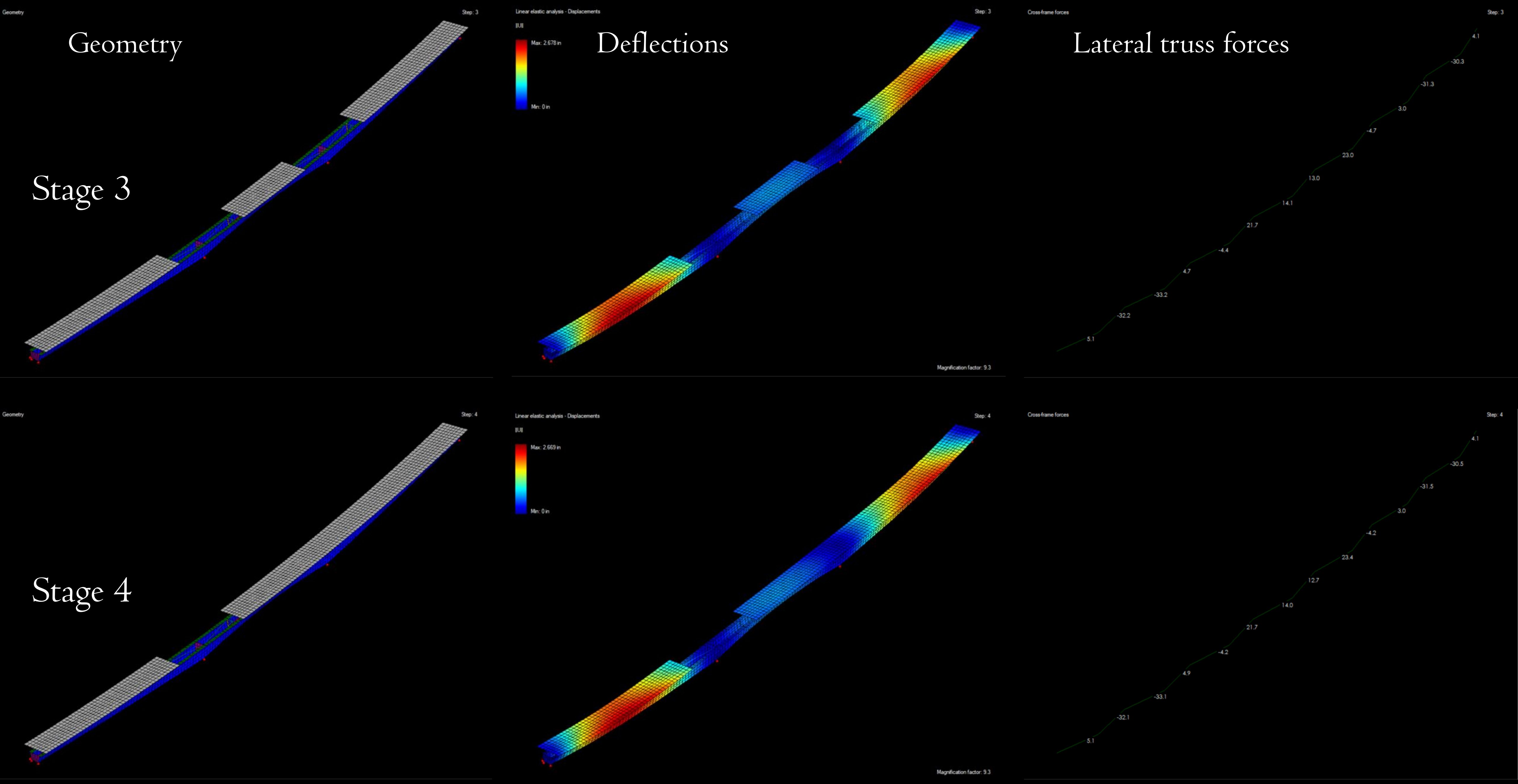
Schematic of the Push-Out Test Setup



Load-Slip Relationship from Push-Out Tests

Source: C. Topkaya, Behavior of Curved Steel Trapezoidal Box Girders During Construction, PhD Dissertation, The University of Texas at Austin, 2002 (available at: https://repositories.lib.utexas.edu/bitstream/handle/2152/998/topkayac026.pdf)

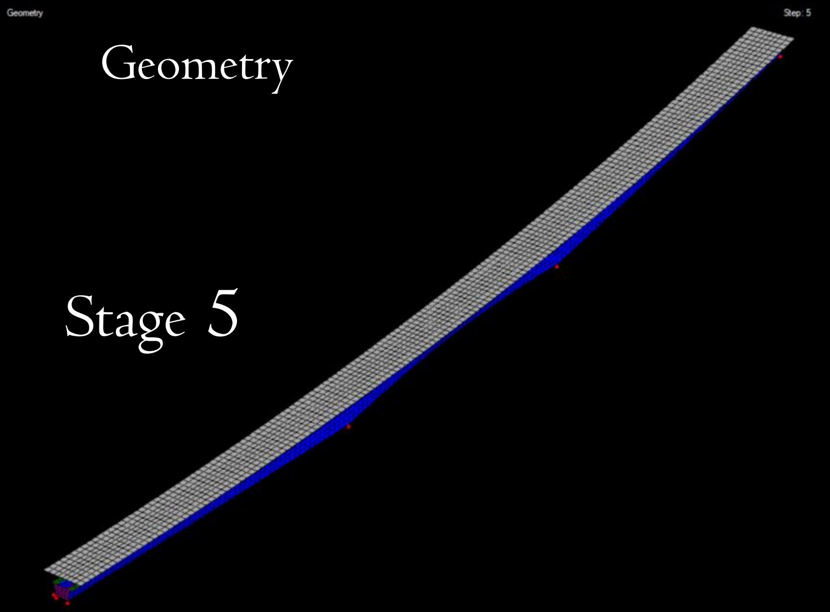

Geometry
Deflections
Lateral truss forces
Stage 1
Stage 2
Geometry
Step: 1
Linear elastic analysis - Displacements
|U|
Max: 2.751 in
Min: 0 in
Magnification factor: 9.3
Cross-frame forces
2.7
-12.8
-13.7
-2.0
-8.8
8.0
5.3
15.1
24.8
-5.9
3.3
-34.3
-33.1
5.0
Geometry
Step: 2
Linear elastic analysis - Displacements
|U|
Max: 2.480 in
Min: 0 in
Magnification factor: 9.3
Cross-frame forces
1.5
-8.8
-9.1
0.8
-1.5
6.0
0.9
11.1
23.4
0.8
8.2
-30.6
-30.4
5.3



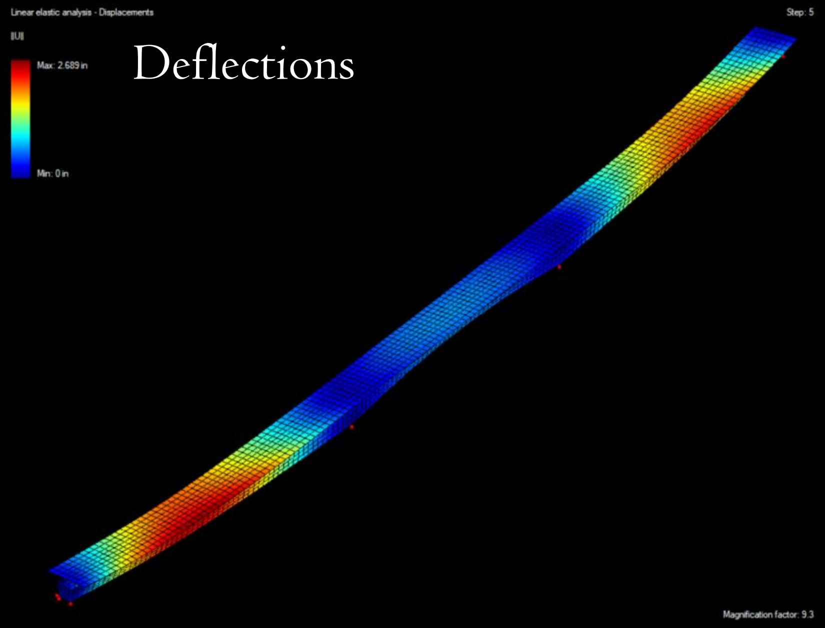
Geometry
Deflections
Lateral truss forces
Stage 3
Stage 4
Geometry
Step: 3
Linear elastic analysis - Displacements
|U|
Max: 2.678 in
Min: 0 in
Step: 3
Magnification factor: 9.3
Cross-frame forces
Step: 3
5.1
-32.2
-33.2
4.7
-4.4
21.7
14.1
13.0
23.0
-4.7
3.0
-31.3
-30.3
4.1
Geometry
Step: 4
Linear elastic analysis - Displacements
|U|
Max: 2.669 in
Min: 0 in
Step: 4
Magnification factor: 9.3
Cross-frame forces
Step: 4
5.1
-32.1
-33.1
4.9
-4.2
21.7
14.0
12.7
23.4
-4.2
3.0
-31.5
-30.5
4.1

Stage 5

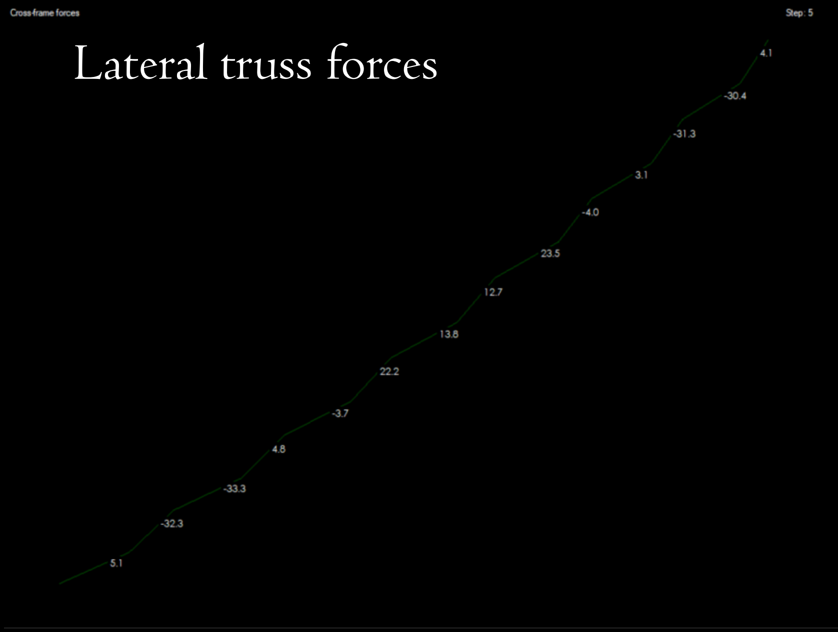
Geometry



Deflections



Lateral truss forces



View of the bridge under construction

Source: https://www.houstonchronicle.com/news/houston-texas/houston/article/Damaged-pavement-shuts-down-part-of-Texas-288-16110760.php

Further references

- G. Kochersperger and A. Crozier, Current design practices for curved trapezoidal steel box girders – A case study, World Steel Bridge Symposium 2012, Dallas, TX

- D. Coletti, Z. Fan, W. Gatti, J. Holt, and J. Vogel, Practical Steel Tub Girder Design, National Steel Bridge Alliance (NSBA), 2005

- Z. Fan and T. Helwig, Behavior of Steel Box Girders with Top Flange Bracing, ASCE Journal of Structural Engineering, Vol. 125, No. 8, August, 1999

- Z. Fan and T. Helwig, Distortional Loads and Brace Forces in Steel Box Girders, ASCE Journal of Structural Engineering, Vol. 128, No. 6, June, 2002

- P. Biju-Duval, Development of Three-Dimensional Finite Element Software for Curved Plate Girder and Tub Girder Bridges During Construction, PhD Dissertation, The University of Texas at Austin, 2017

<u>Final note:</u> For the placement analysis conducted in mBrace3D and presented in earlier slides, in absence of further publicly available information, assumptions were made in terms of deck placement sequence (which may not reflect the actual sequence), lateral bracing member sizes, boundary conditions, etc. This can be quickly addressed if the appropriate information is received.