Lateral Bending Stresses

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Purpose

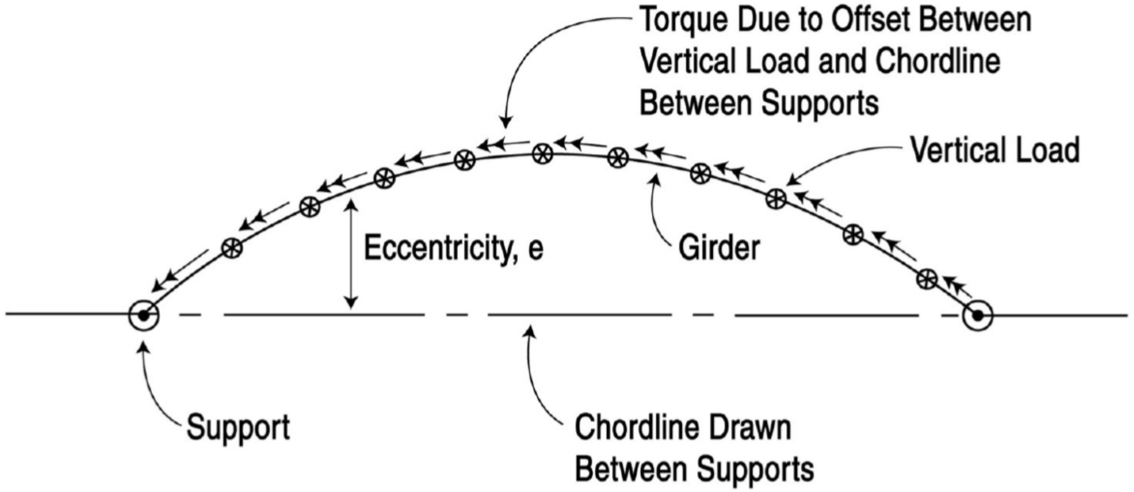
1. Understand **normal bending stresses** and **lateral bending stresses**, and what causes them.

2. Observe what are the **AASHTO constructability checks** for normal bending stresses and lateral bending stresses.

3. Illustrate how a large displacement (second-order) analysis in **mBrace3D** can provide **accurate estimations** of those stresses in a user-friendly fashion.

Curvature, torque and normal stresses (1/3)

On curved girders, the normal bending stress distribution is continuous between the **support points**, and the lateral bending stress distribution is continuous between the **brace points**. This is inherent to the system geometry to maintain equilibrium.



Plan view of the development of torque in a curved girder (Coletti & Yadlosky 2005)

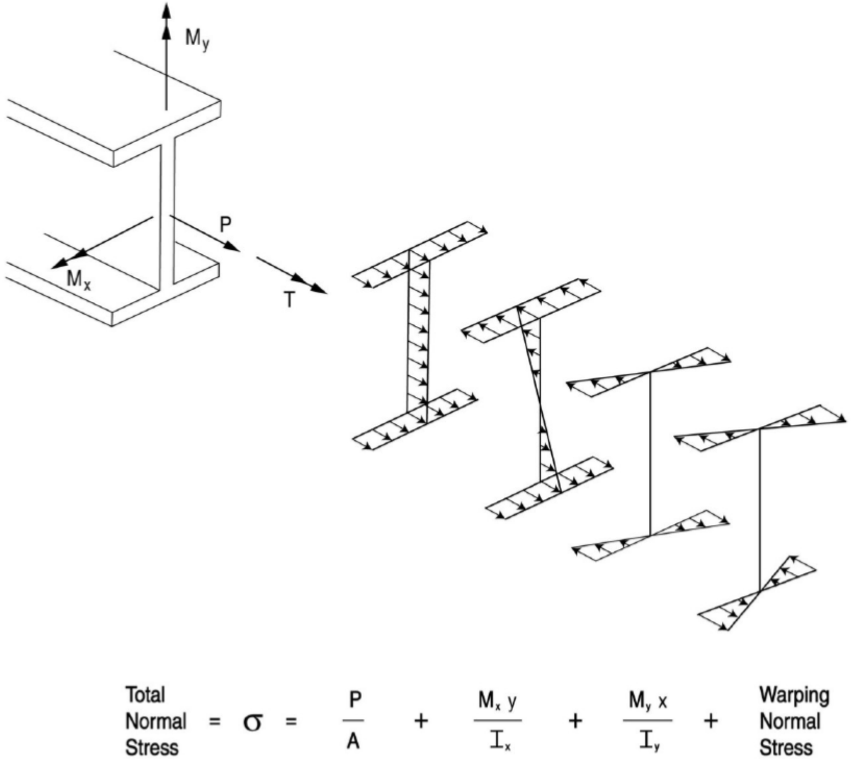
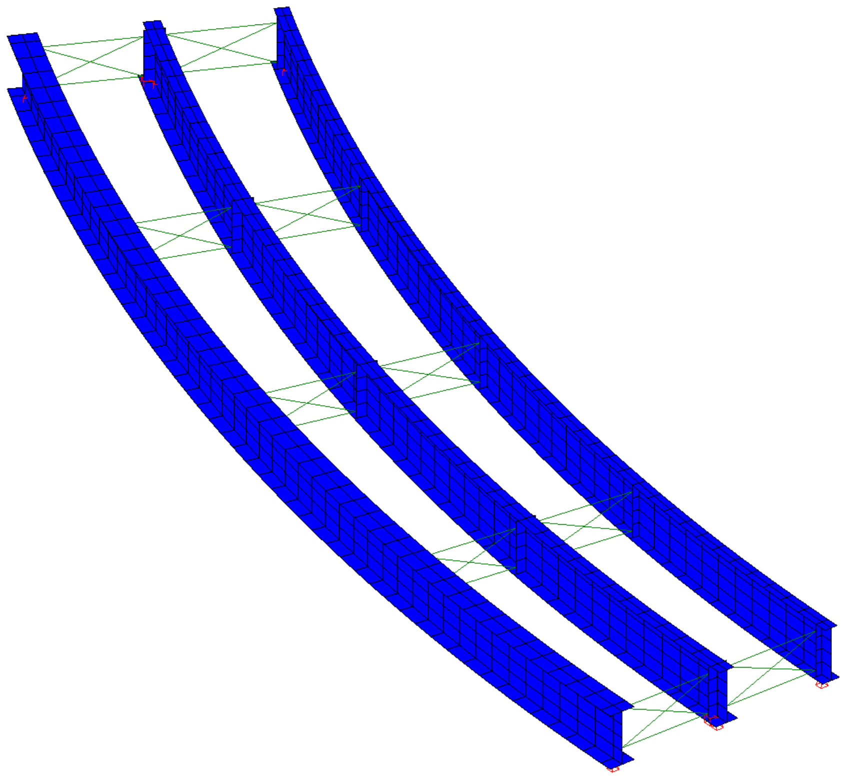


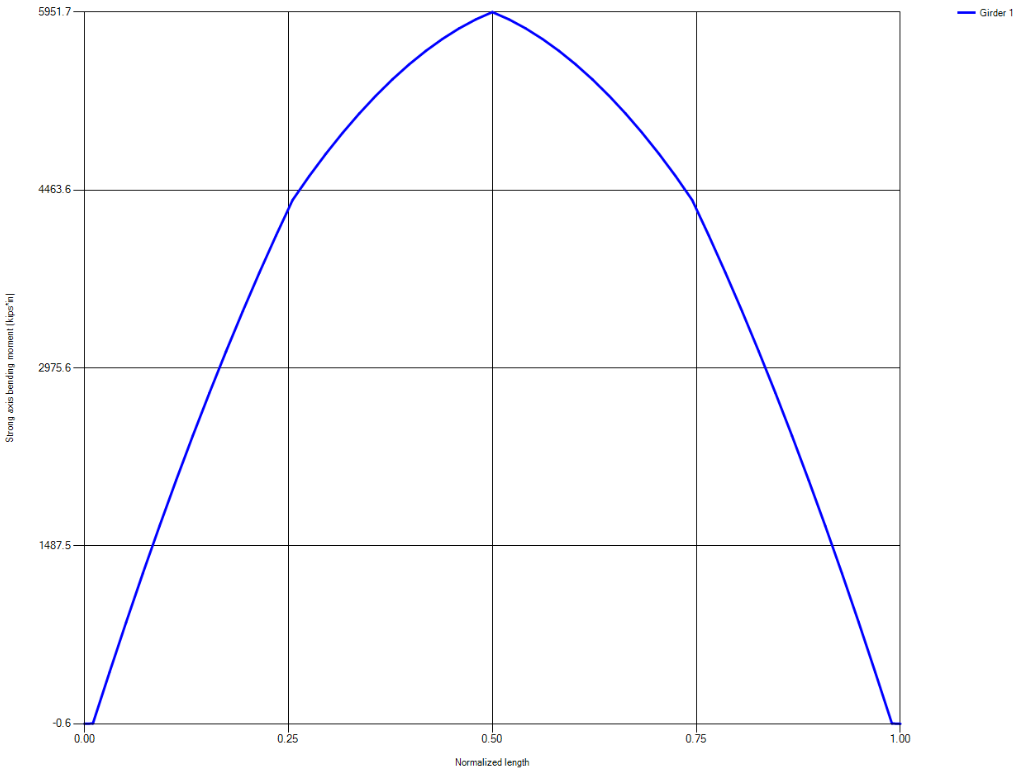
Illustration of the primary normal stresses which can occur in curved or skewed I-shaped girders (Coletti & Yadlosky 2005)

Curvature, torque and normal stresses (2/3)

Illustration on NCHRP Report 725 "EISCR1" Study Bridge: one span, well-known major axis bending diagram.



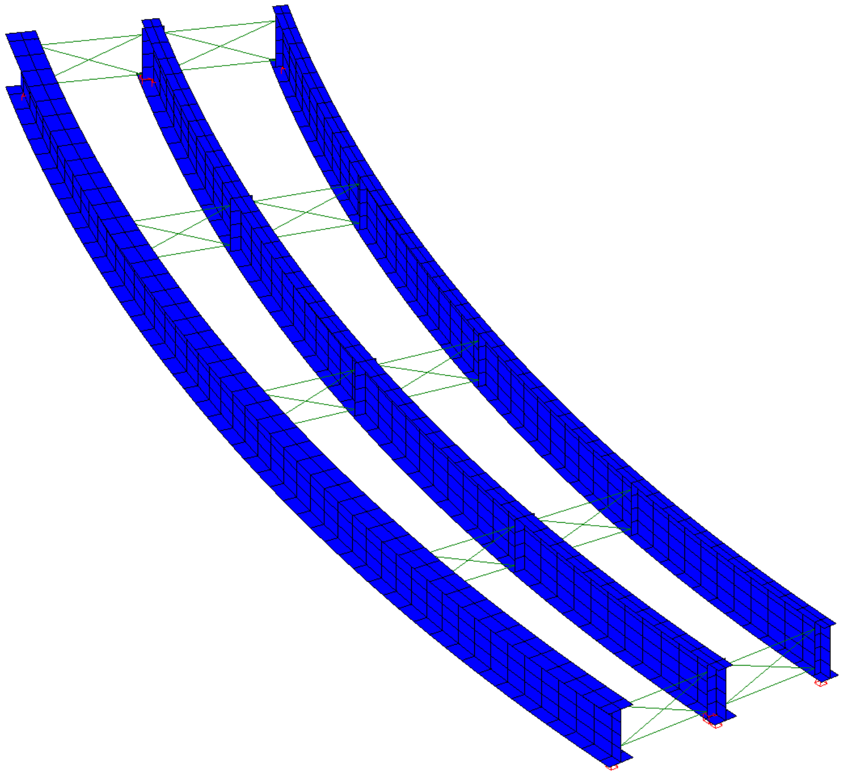
Study Bridge EISCR1 Geometry



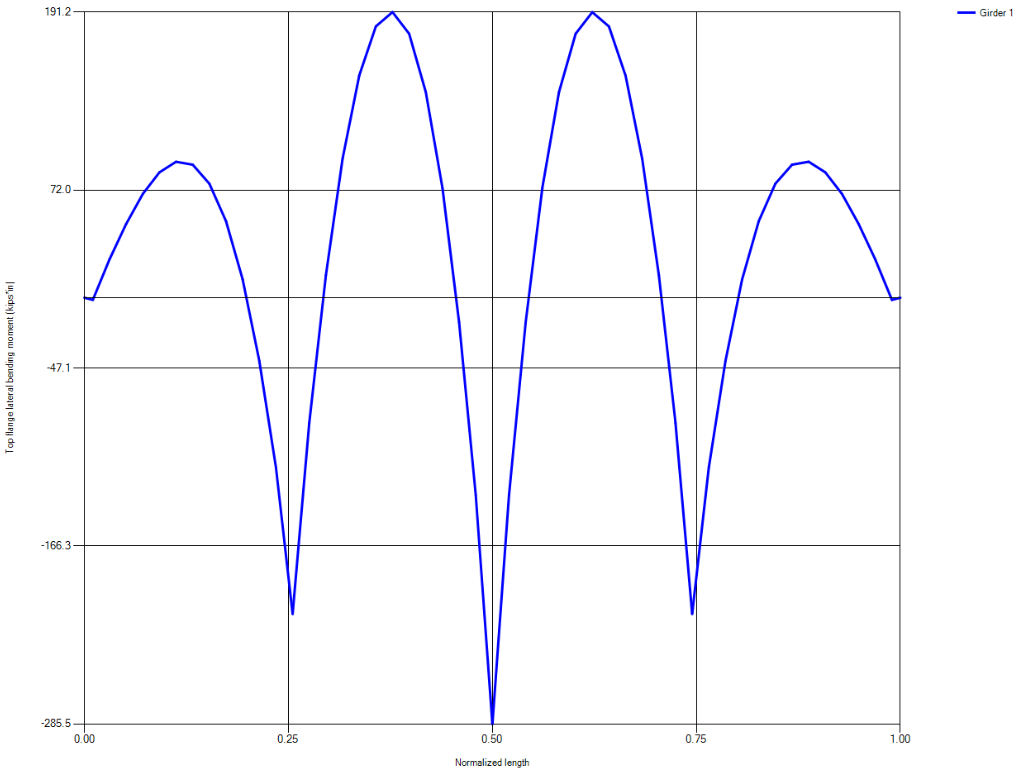
Moment diagram (exterior girder)

Curvature, torque and normal stresses (3/3)

Illustration on NCHRP 725 “EISCR1” Study Bridge: five brace points, i.e. four “spans” for the lateral bending diagram.



Study Bridge EISCR1 Geometry



Lateral bending diagram (exterior girder)

AASHTO Constructability Checks (1/3)

During erection of the steel superstructure and placement of the concrete deck, the bridge is **not fully braced** and **AASHTO 6.10.3** Constructability provisions apply.

For **discretely braced flanges in compression**, AASHTO 6.10.3.2.1:

$$f_{bu} + f_{\ell} \leq \phi_f R_h F_{yc}$$

$$f_{bu} + \frac{1}{3} f_{\ell} \leq \phi_f F_{nc}$$

$$f_{bu} \leq \phi_f F_{crw}$$

For **discretely braced flanges in tension**, AASHTO 6.10.3.2.2:

$$f_{bu} + f_{\ell} \leq \phi_f R_h F_{yt}$$

AASHTO Constructability Checks (2/3)

Lateral bending stresses determined from a **first-order analysis** may be used in discretely braced compression flanges for which:

$$L_b \leq 1.2L_p\sqrt{\frac{C_bR_b}{f_{bu}/F_{yc}}}$$ AASHTO Article 6.10.1.6

This **limit on the unbraced length** is often not satisfied, hence Article 6.10.1.6 requires that **second-order** elastic compression-flange lateral bending stresses be determined. Generally, this is done by **amplifying** the first-order lateral bending stress values as follows:

$$f_\ell = \left(\frac{0.85}{1-\frac{f_{bu}}{F_{cr}}}\right)f_{\ell 1} \geq f_{\ell 1} \quad \text{(second-order analysis)}$$ AASHTO Equation 6.10.1.6-4

AASHTO Constructability Checks (3/3)

However, many researchers, including D. White and his students at Georgia Institute of Technology, have found that this amplification factor can be quite inaccurate:

"It is clear that **the AASHTO amplification factors are not capturing the system behavior**. This is due to the complex interactions between the girders in the three-dimensional bridge structural system."(Ozgur 2007)

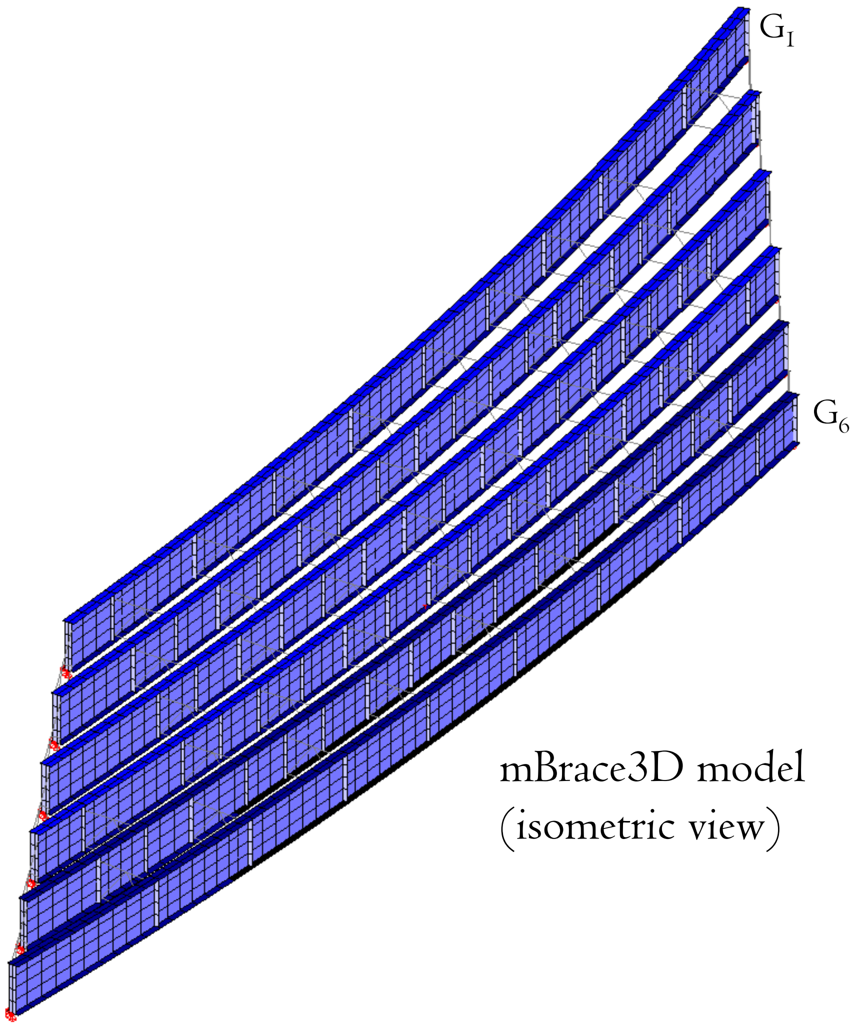
-> The only way to determine lateral bending stresses on curved and/or skewed I-girder bridges is to **conduct a large displacement analysis** (second-order analysis).

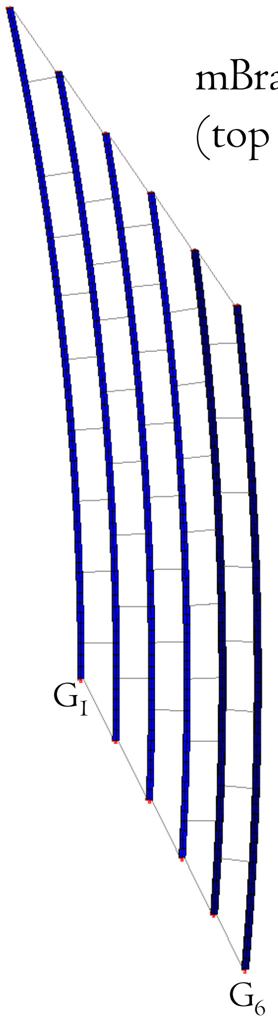
This, however, is usually NOT conducted routinely by bridge engineers due to the **complexity of creating 3D shell models**.

-> mBrace3D fills this gap and aims to improve the way curved steel bridges are routinely analyzed and designed.

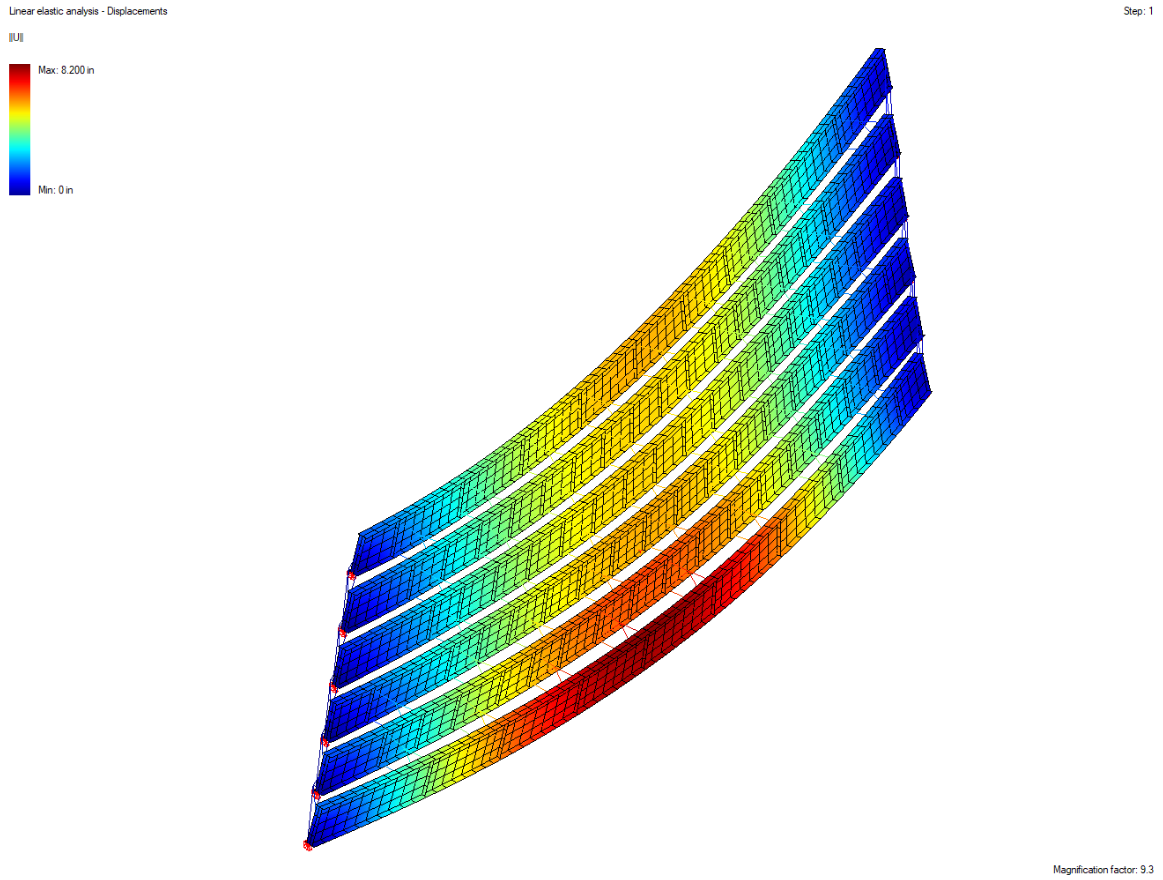
mBrace3D – Large displacement analysis (1/4)

Case study: Curved, skewed, 6-girder bridge under DC1 (self-weight + wet concrete load), adapted from Ozgur 2007

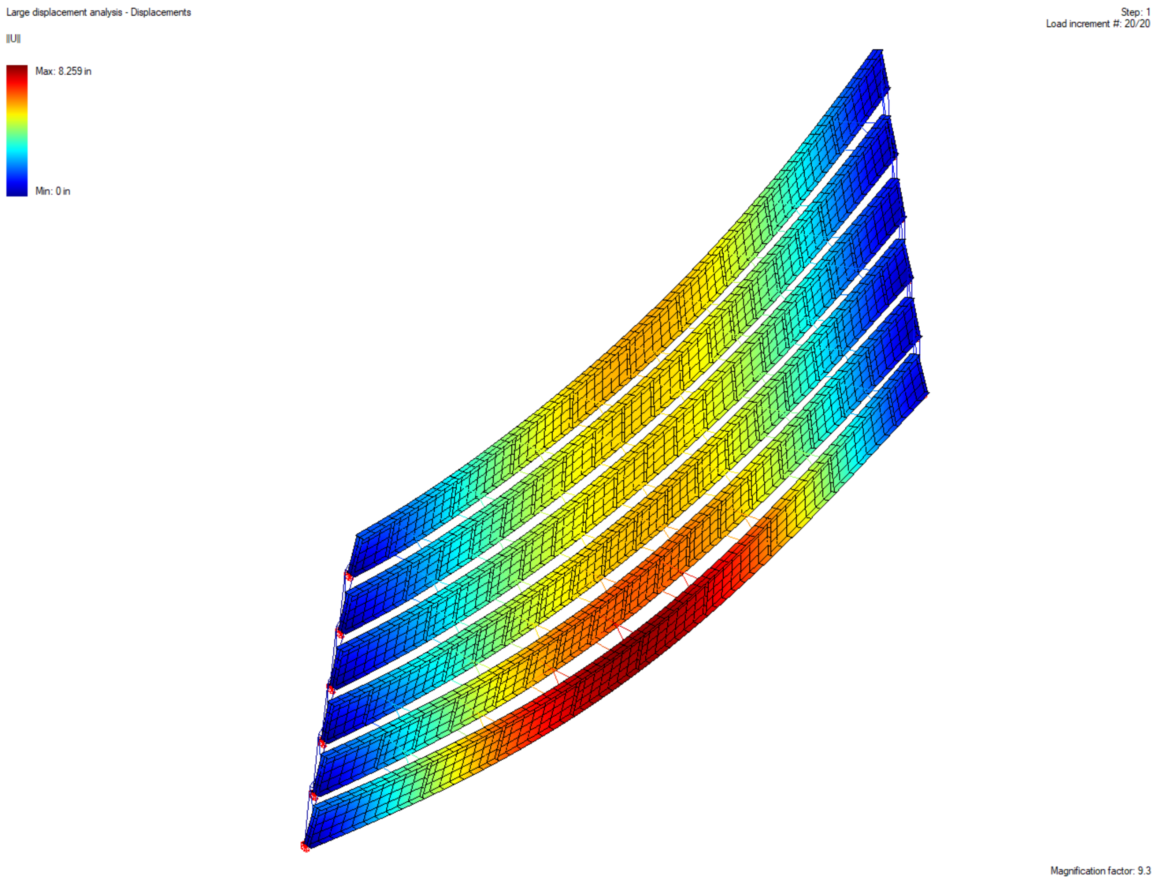




mBrace3D – Large displacement analysis (2/4)

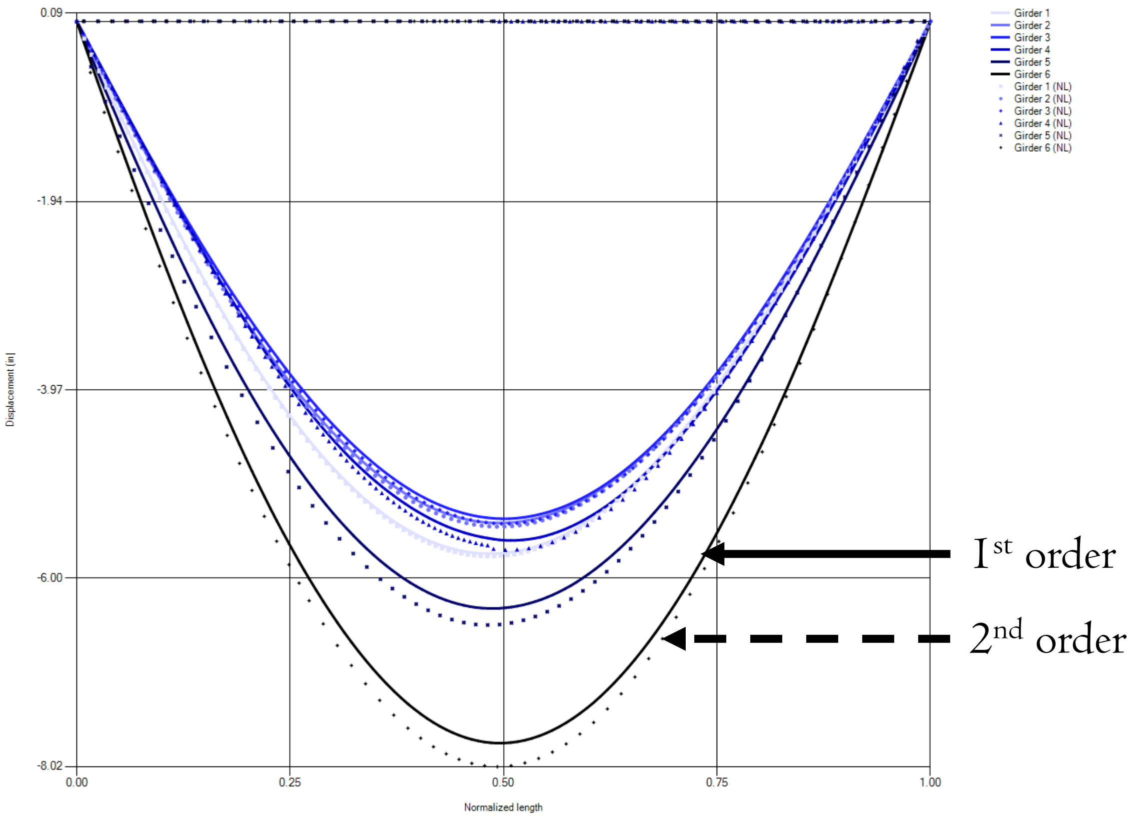


First-order deflections

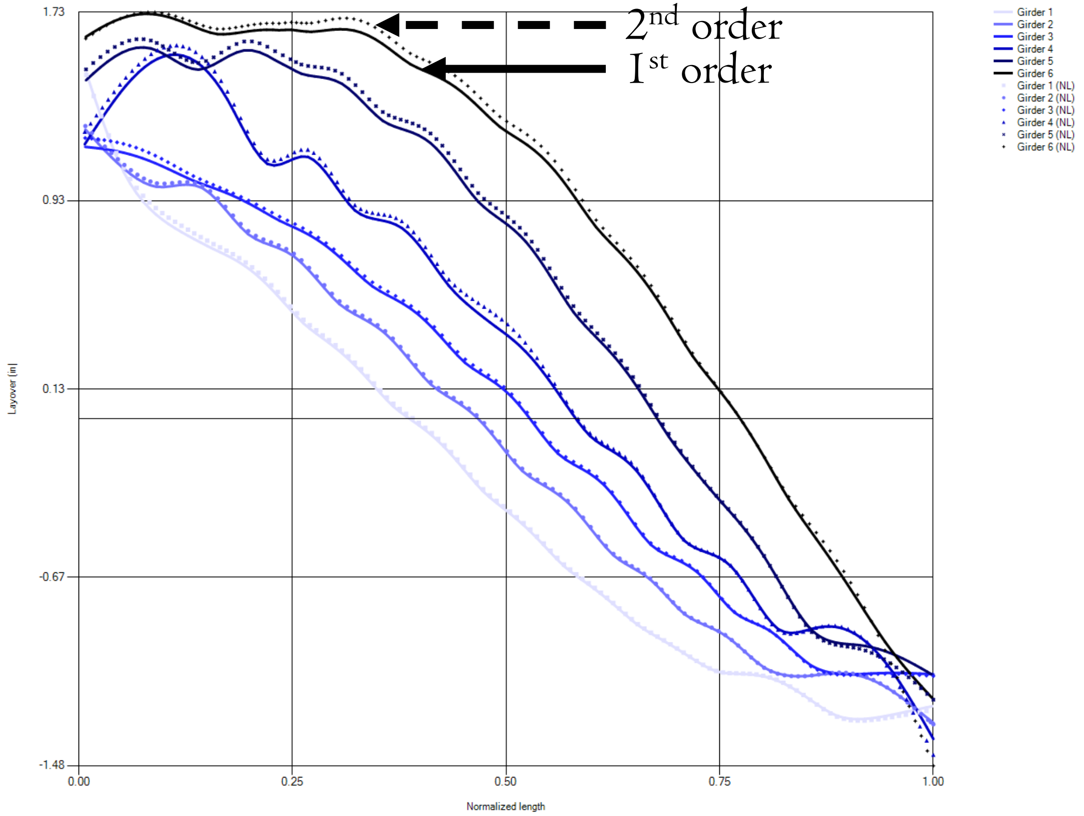


Second-order deflections
(visually, very similar to first-order deflections)

mBrace3D – Large displacement analysis (3/4)

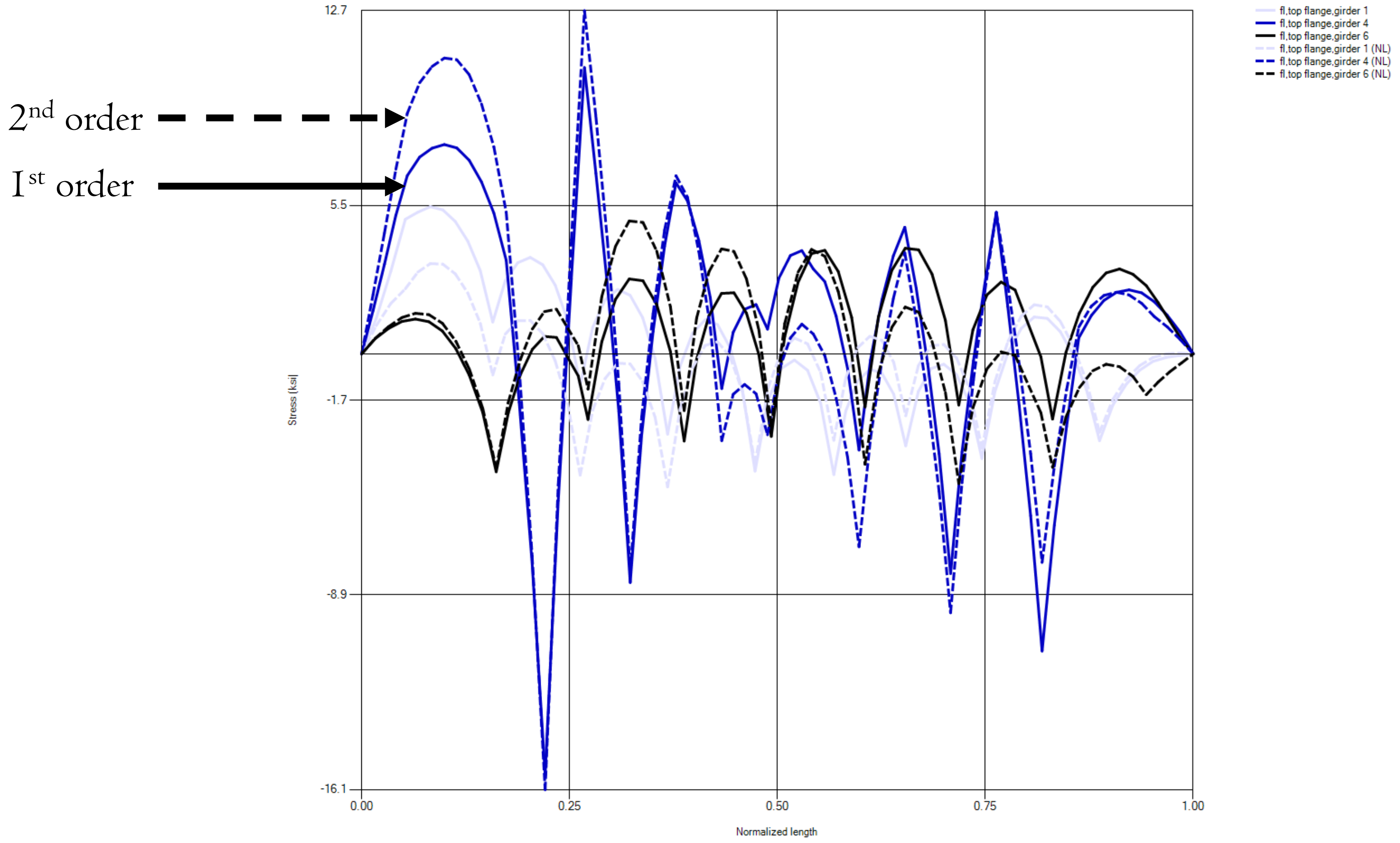


First-order vs. second-order vertical deflections



First-order vs. second-order vertical layovers (cross-sectional rotations)

mBrace3D – Large displacement analysis (4/4)



First-order vs. second-order vertical top flange (compression) lateral bending stresses
(Girders 1, 4 and 6 shown only, for clarity)

Concluding remarks

1. Flange lateral bending stresses are **inherent to curved systems** and are **paramount to evaluating the stability and strength of curved and/or skewed bridges during construction**.

2. For some cases, AASHTO requires **second-order lateral bending stresses** to be evaluated. However, **the amplification factors proposed by AASHTO are often inaccurate** as these do not account for the bridge system behavior as a whole.

3. The only way to properly assess second-order lateral bending stresses is to conduct a **large displacement analysis**.

4. mBrace3D can smoothly perform large displacement analyses in a **user-friendly** way:
   - 3D shell models are generated **parametrically**
   - Lateral bending and principal bending stress components are **computed automatically** from the normal stress results
   - Lateral bending and principal bending stresses are **plotted directly** within the software (no need to export results to Excel)

References

Coletti and Yadlosky, Behavior and Analysis of Curved and Skewed Steel Girder Bridges, World Steel Bridge Symposium, April 2005, available at: https://www.aisc.org/globalassets/nsba/conference-proceedings/2005/coletti---2005-wsbs-final.pdf

AISC, NSBA Design Example 3: Three-Span Continuous Horizontally Curved Composite Steel I-Girder Bridge, February 2022, available at: https://www.aisc.org/globalassets/nsba/design-resources/steel-bridge-design-handbook/b954_sbdh_appendix3.pdf

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