Construction Simulation of Curved and Skewed Steel I-Girder Bridges

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Georgia Institute of Technology

Steel Bridges Session # 2

Western Bridge Engineers' Seminar

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psi Information To Build On
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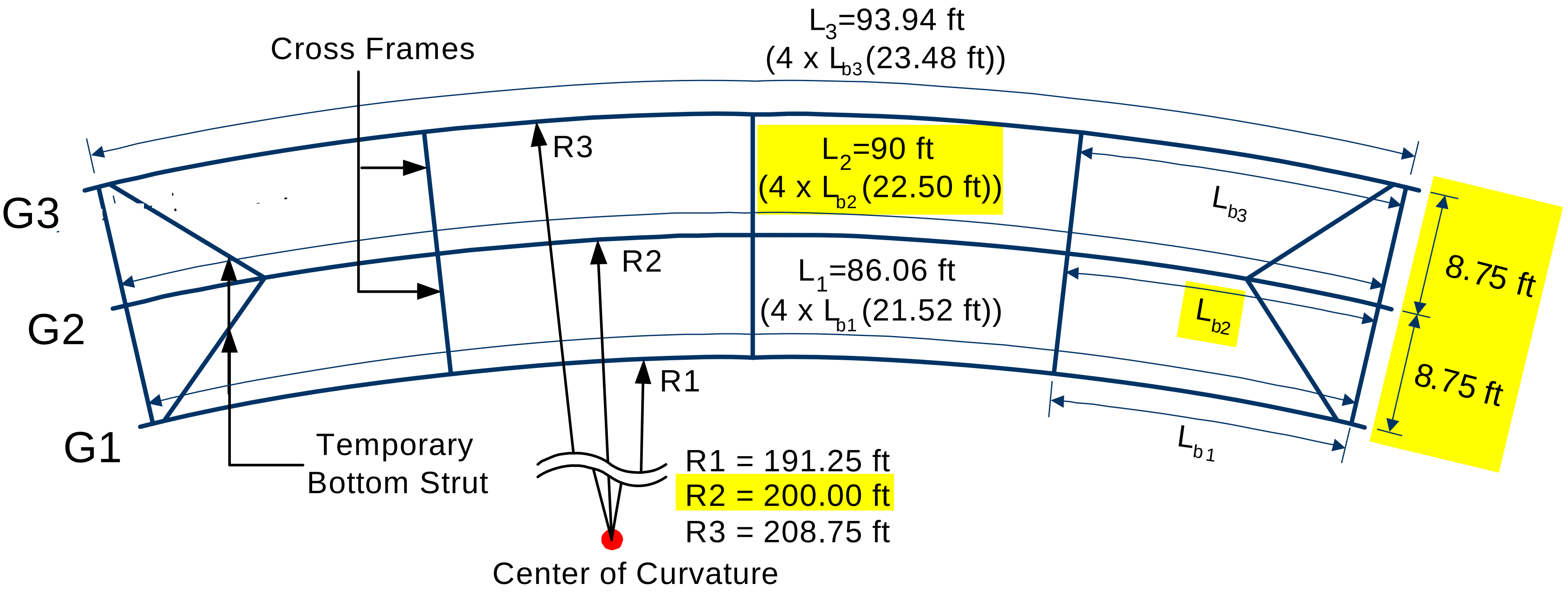
Organization

- Overview of interesting results from two horizontally curved bridges studied in the FHWA CSBRP research
  - FHWA TFHRC Composite Test Bridge
  - Representative curved bridge with substantial skew at the bearing lines
- Observations about behavior & best practices

QUIZ

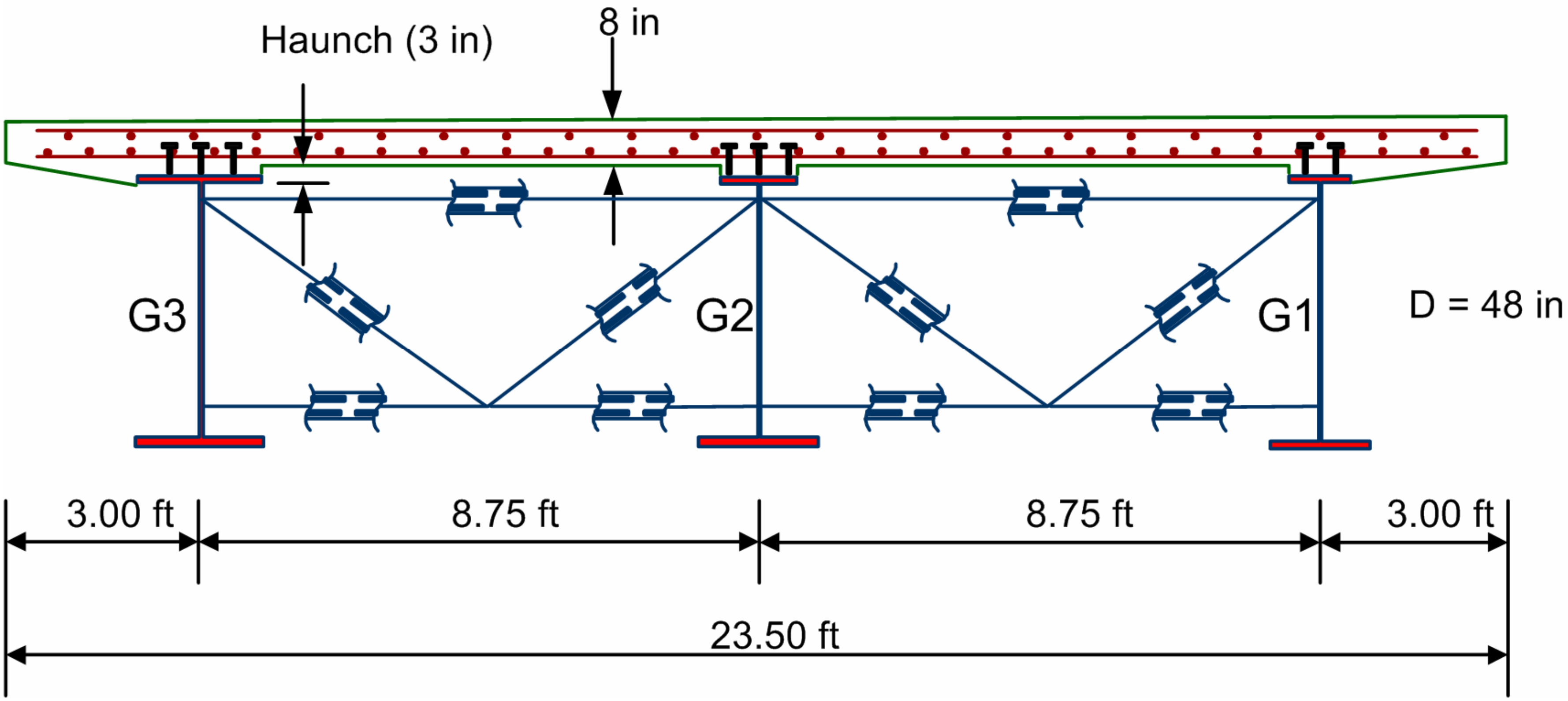
- What are the different ways that cross-frames can be detailed in curved &/or skewed I-girder bridges?
- What are the uses of the different methods?
- What is the impact of web out-of-plumbness on the strength of typical bridges?
- When should the different methods of cross-frame detailing be used?

FHWA TFHRC Test Bridge – Plan View



$L_i/R_i = 0.45$ $L_{bi}/R_i = 0.112\ (6.45^o)$

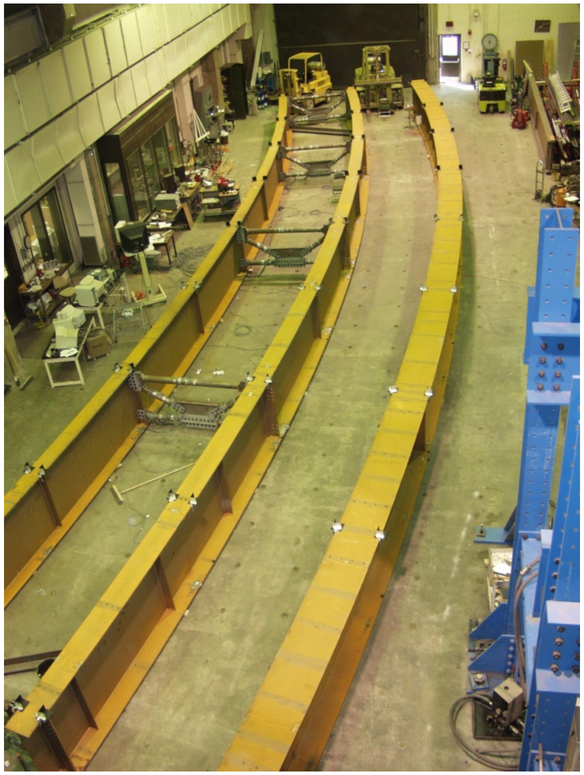
Test Bridge Cross-Section



Center of Curvature →

Test Bridge Construction Sequence

1. Block G1, G2 & G3 to the camber profiles.
   Drill holes & assemble the cross-frames.
   Attach bottom flange diagonals between G1 and G2.



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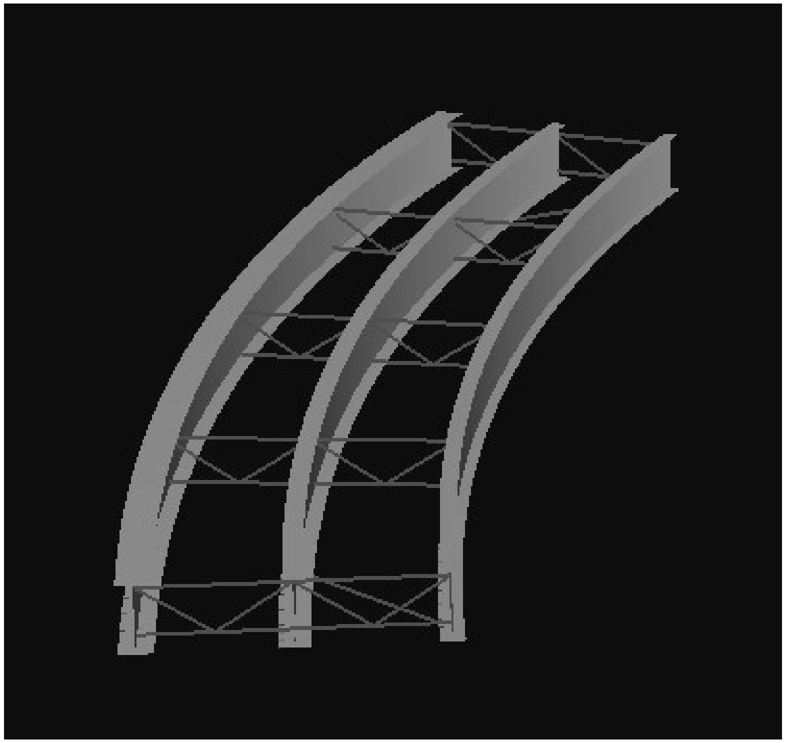
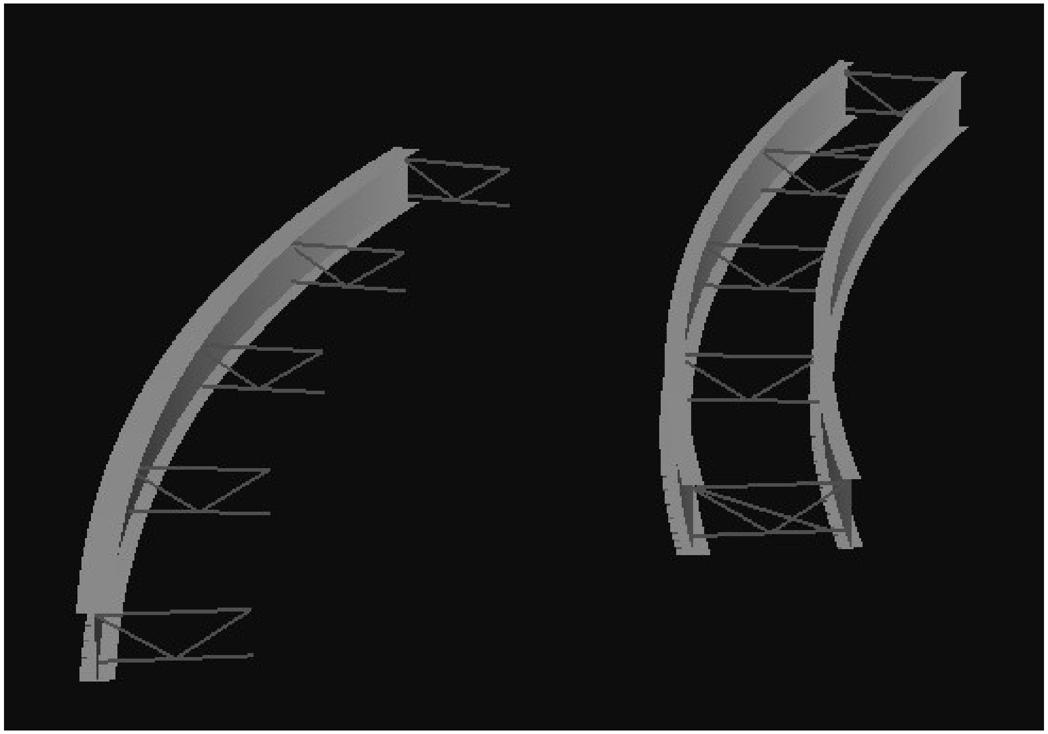


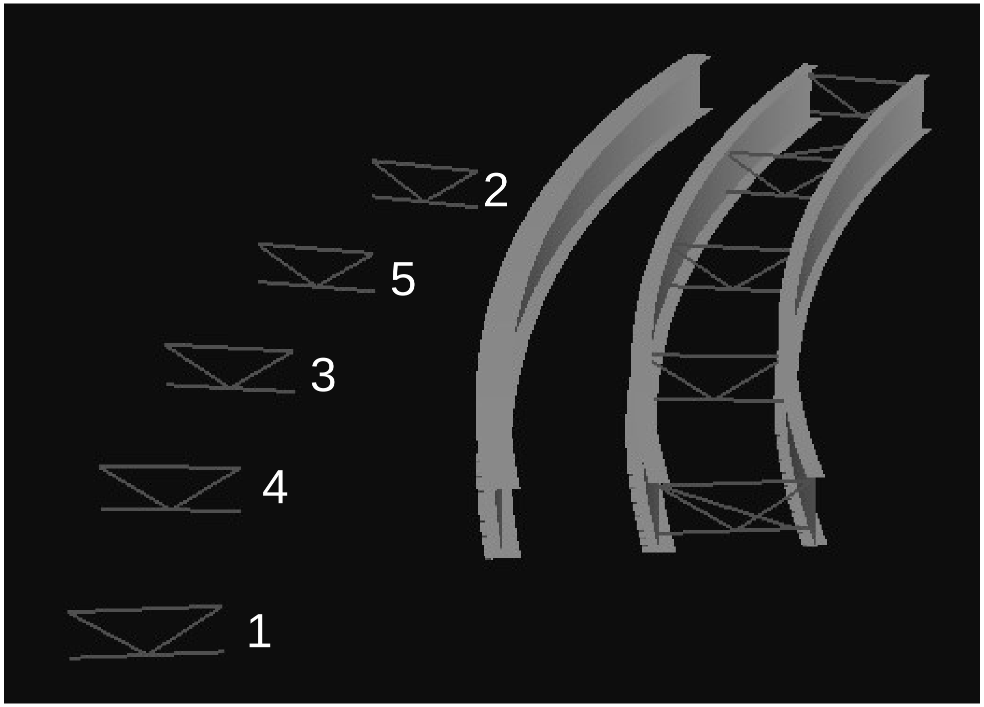
Test Bridge Construction Sequence

2. Disassemble the cross-frames between G2 and G3.
   Leave G3 blocked in its camber profile.
   Set the G1-G2 pair on the abutments.



Test Bridge Construction Sequence

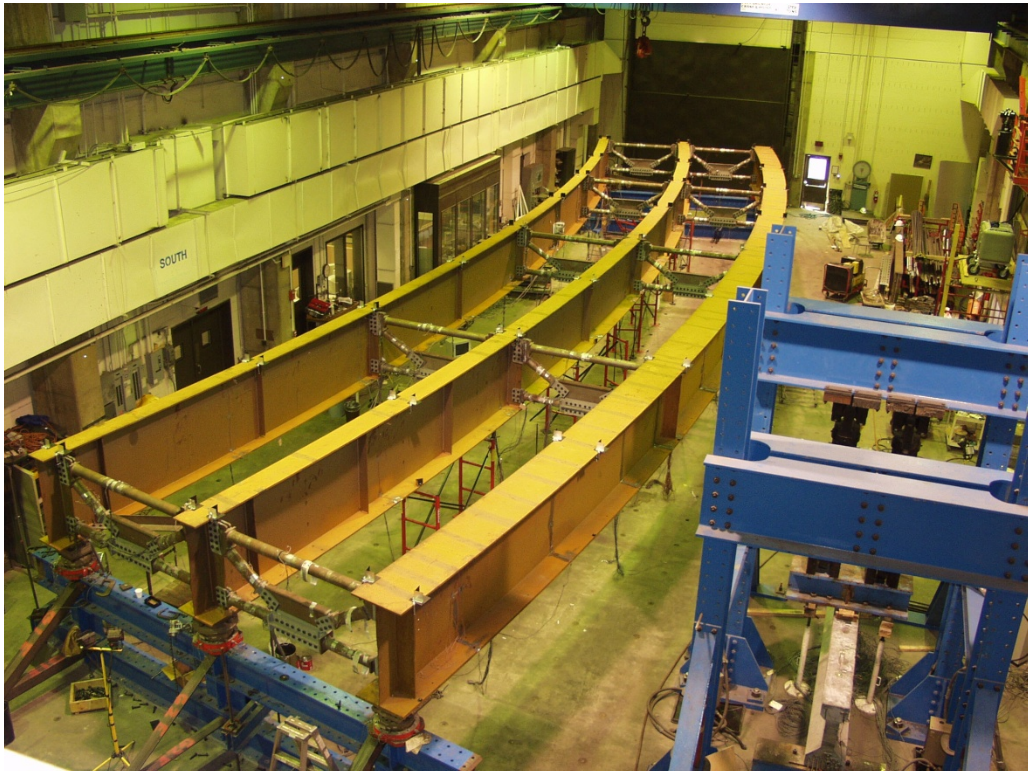
3. Set girder G3 on the abutments & hold with crane.



4. Install the cross-frames in the order of 1, 2, 3, 4 & 5. Install bottom flange diagonals between G2 & G3.

Test Bridge Construction Sequence

5. Release all cranes.



Test Bridge Construction Sequence

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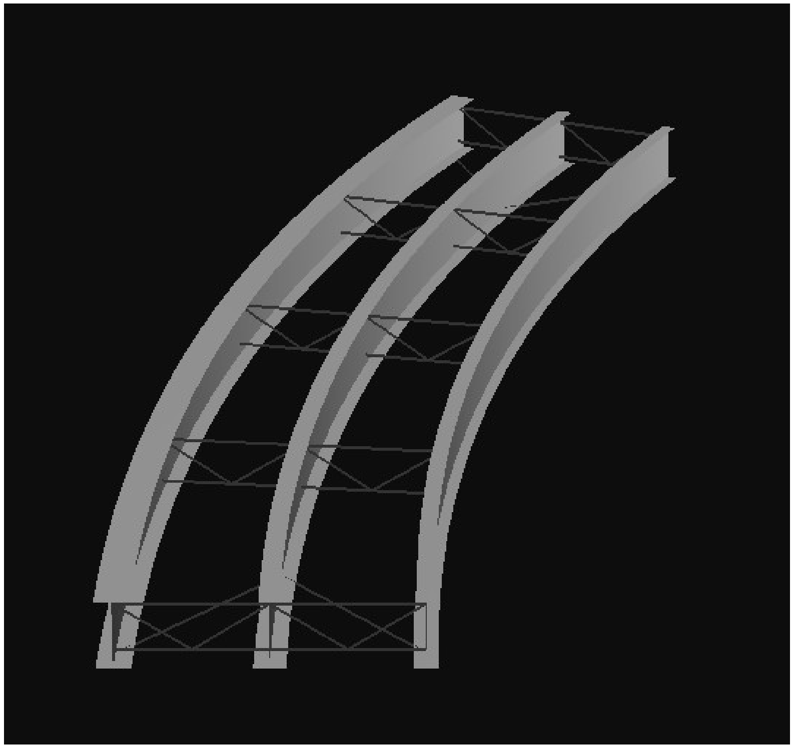
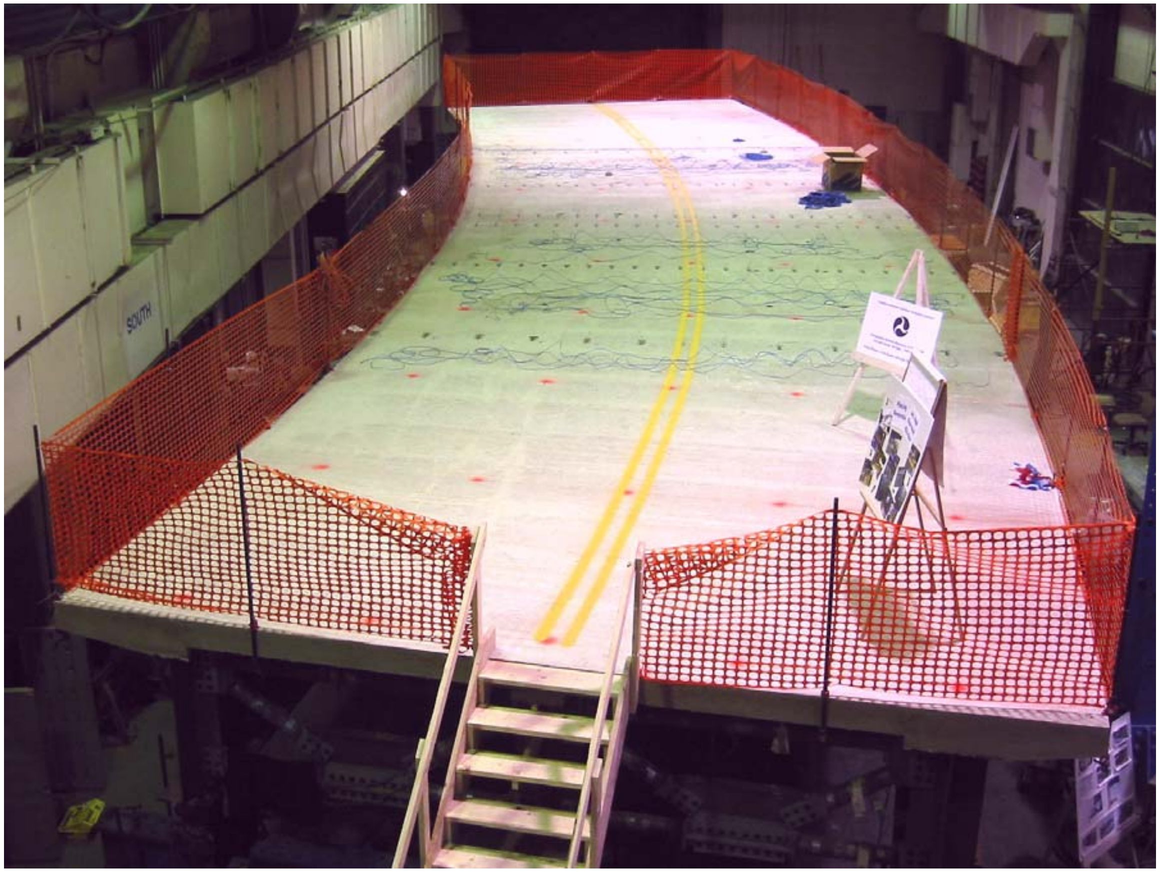


Test Bridge Construction Sequence

6. Construct forms & cast slab in one continuous stage.
7. Remove formwork & bottom flange diagonals.



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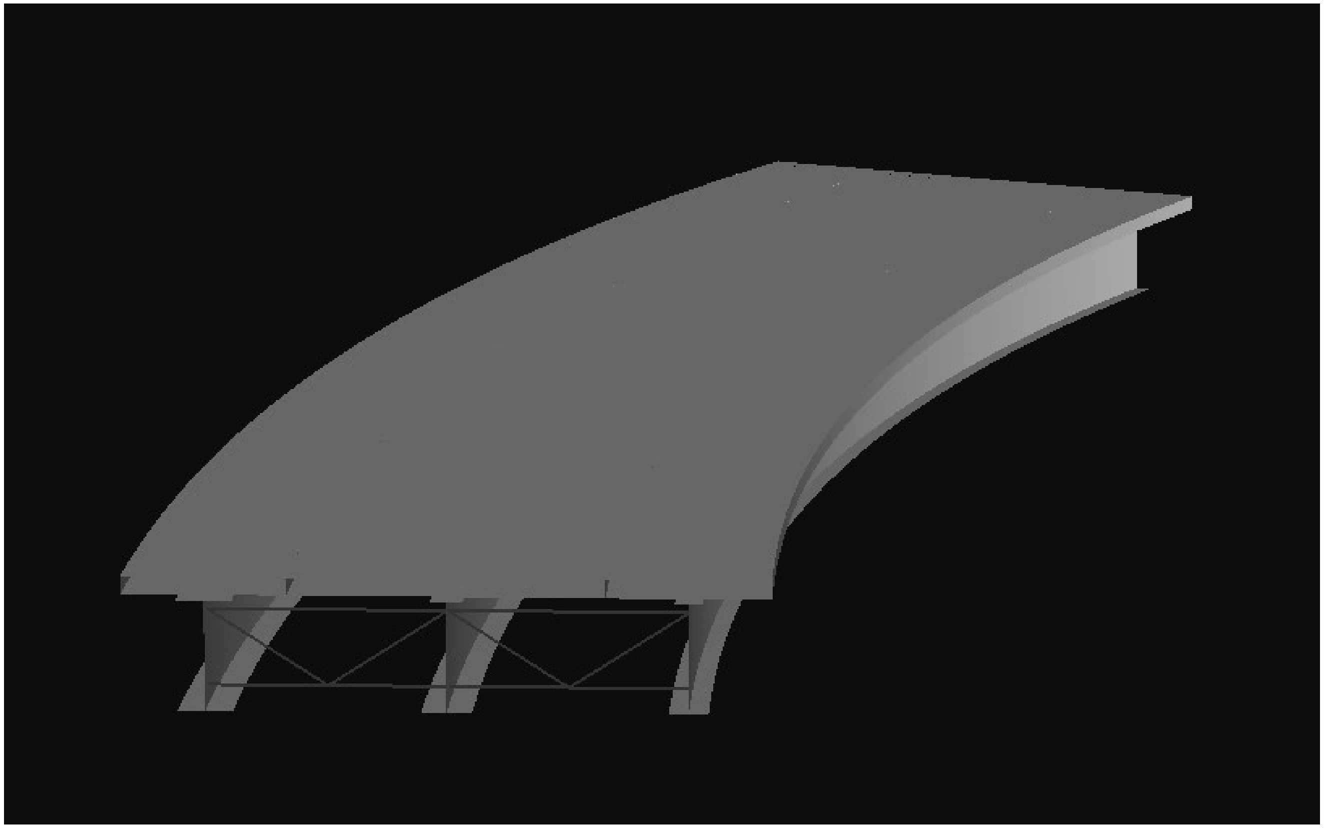


Uniqueness

- The displacements, internal stresses & reactions in the completed structure are unique (independent of the construction sequence) within the following limits:
  - The structure is kept elastic
  - The connections are made ideally with zero tolerance
  - The displacement boundary conditions are unaffected by the sequence
  - The no-load geometry of all the components is unique

Implications of Uniqueness

- Most I-girder bridges can be analyzed without needing to simulate the sequence of erection
- Staged casting of the slab ***does*** make the response ***non-unique*** (the no-load geometry of the slab depends on the deformations of the bridge at each stage)
- Potential lack-of-fit (in the no-load geometry) due to detailing of the cross-frames affects the bridge response, but the response is unique to the specific initial no-load geometry

Cross-Frame Detailing

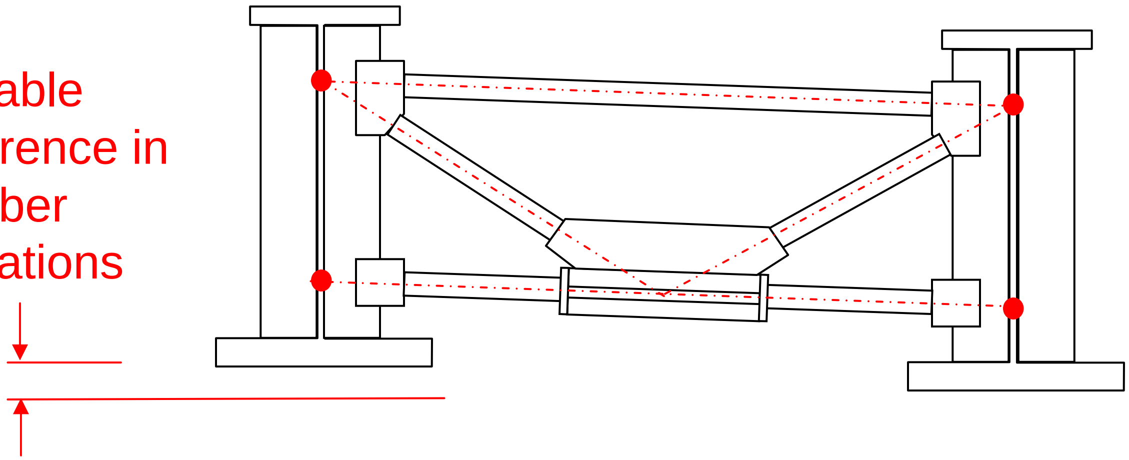
- No-Load Fit (NLF)

  The girders are cambered vertically to offset the dead load deflections. The cross-frames are detailed to ***connect to the girders in their cambered, plumb, no-load geometry without inducing any stresses due to fit-up.***

- Total Dead Load Fit (TDLF)

  The girders are cambered vertically to offset the dead load deflections. The cross-frames are detailed to ***connect to the girders in their idealized total dead load geometry (plumb and with the cambers removed due to the dead load deflections).***

Cross-Frame Detailing, No-Load Fit



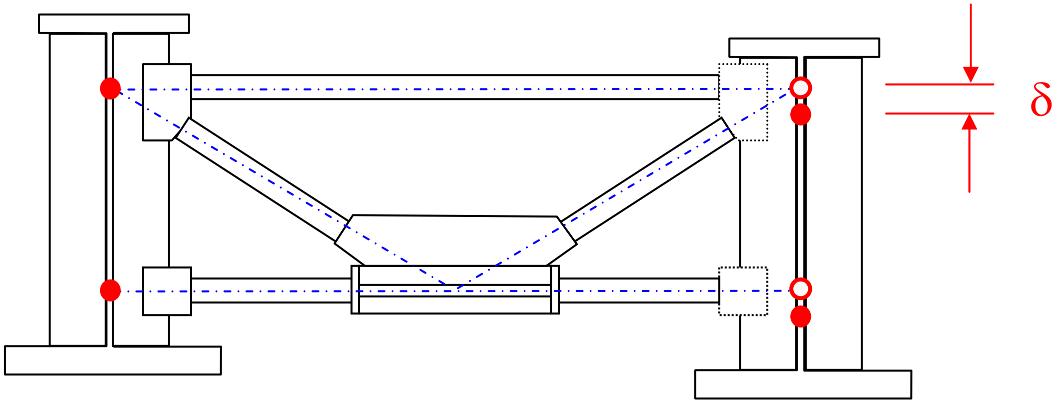
Variable difference in camber elevations

The drop in the cross-frames is detailed to fit the differential camber between the girders at all locations

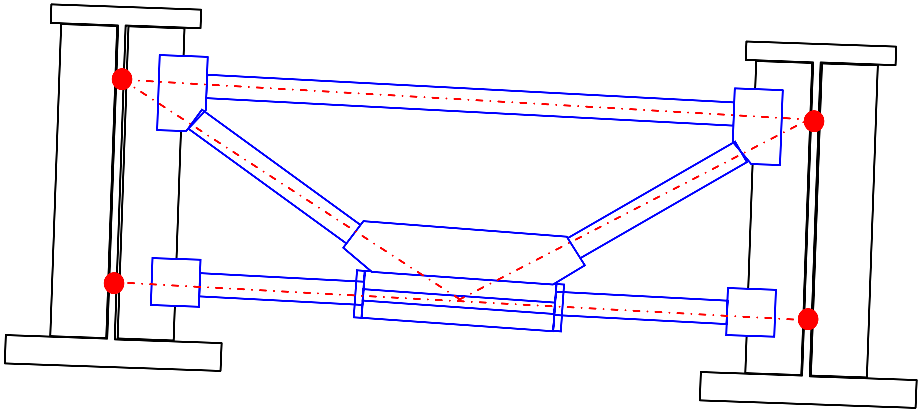
Therefore, the cross-frames fit-up “perfectly” with the girders in their no-load geometry

Cross-Frame Detailing, Total Dead Load Fit

Lack of fit between girders and cross-frames in no-load geometry



The girders are forced/twisted into position to connect the cross-frames

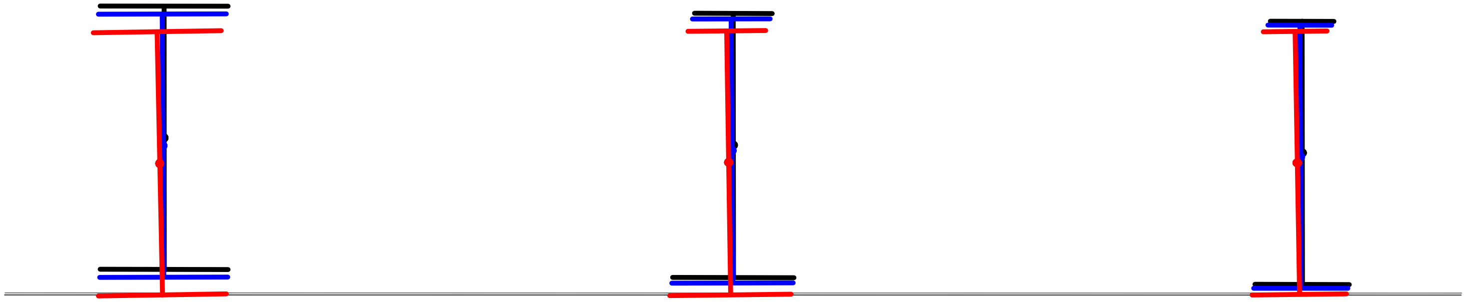


Internal stresses are introduced

Total Dead Load Fit Concepts

- Primary goal: plumb girder webs under the total dead load
- The girders must be twisted from their idealized no-load position to connect the cross-frames
- This ***lack-of-fit*** in the no-load geometry induces additional stresses and influences the deflections (e.g., the required cambers) in the completed bridge system
- The above ***lack-of-fit*** also tends to increase the forces required to connect the deformed components during erection

Girder Mid-Span Positions/Displacements for Test Bridge – ***No Load Fit (NLF)***



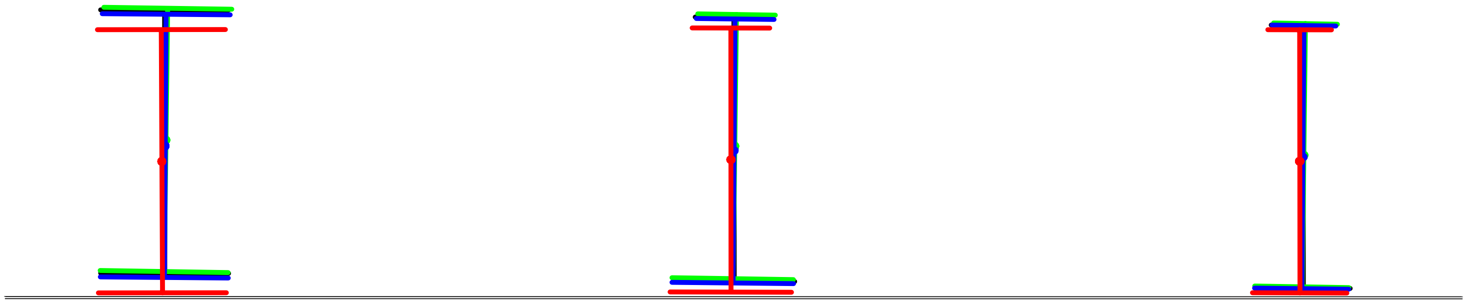
steel self-weight + concrete dead load

Girder	Load Condition	Elevation (in)	Twist Angle (degrees)	Radial Deflection top / bottom flgs**
G1	Initial no-load cambered position	1.478	0.000	0.000
	Steel + concrete dead load	0.024	-0.770º	-1.120 / -0.450
G2	Initial no-load cambered position	2.805	0.000	0.000
	Steel + concrete dead load	-0.010	-0.837º	-1.156 / -0.426
G3	Initial no-load cambered position	4.300	0.000	0.000
	Steel + concrete dead load	-0.051	-1.039 º	-1.253 / -0.338

**** Positive toward center of curvature**

Girder Mid-Span Positions/Displacements for Test Bridge – ***Total DL Fit (TDLF)***

*** Girder cambers based on NLF**



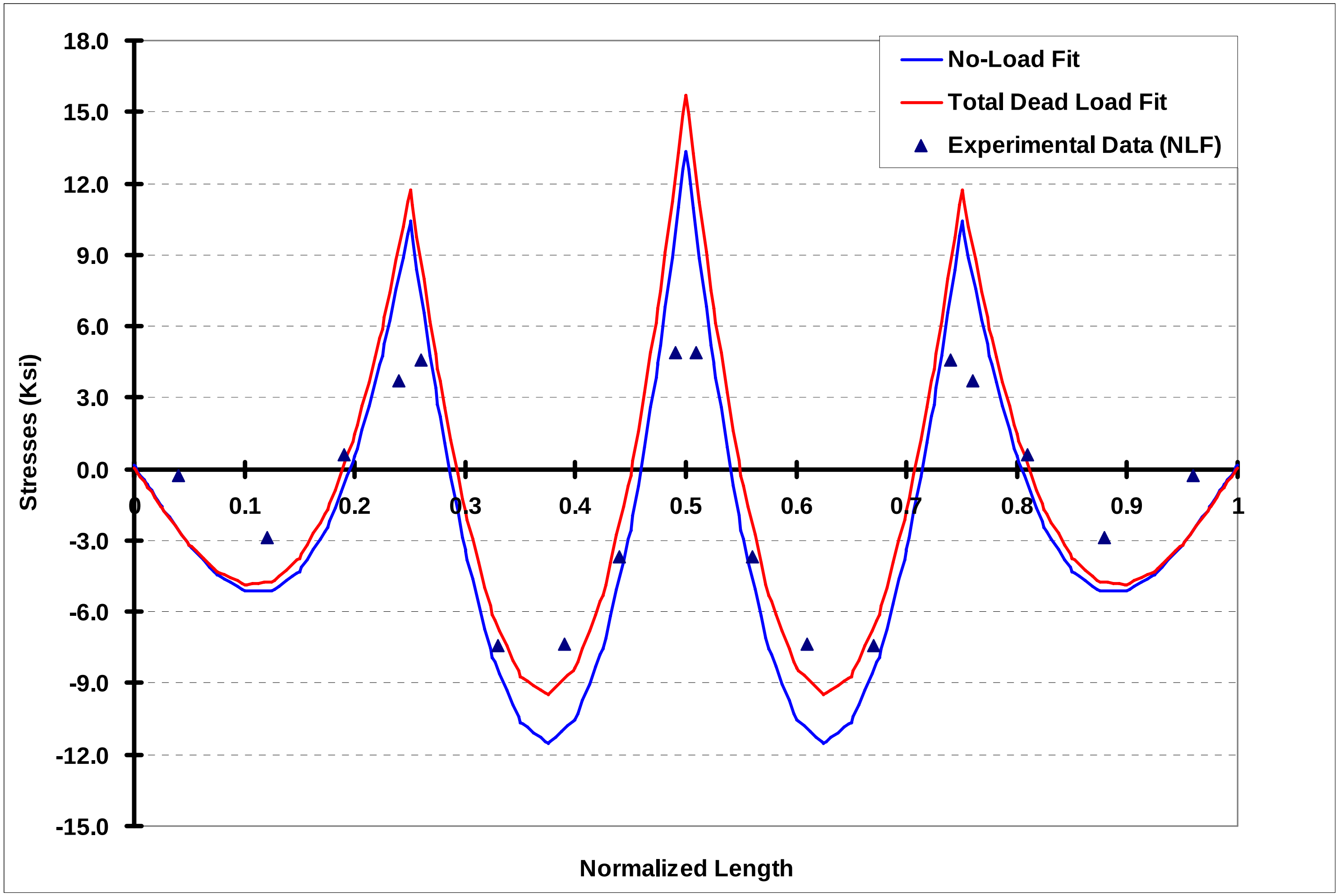
steel self-weight + concrete dead load

Girder	Load Condition	Elevation (in)	Twist Angle (degrees)	Radial Deflection top / bottom flgs**
G1	Initial no-load cambered position	1.478*	0.000	0.000
	Steel + concrete dead load	0.647	0.024º	-0.371 / -0.392
G2	Initial no-load cambered position	2.805*	0.000	0.000
	Steel + concrete dead load	0.743	-0.038º	-0.397 / -0.364
G3	Initial no-load cambered position	4.300*	0.000	0.000
	Steel + concrete dead load	0.676	-0.210º	-0.469 / -0.285

**** Positive toward center of curvature**

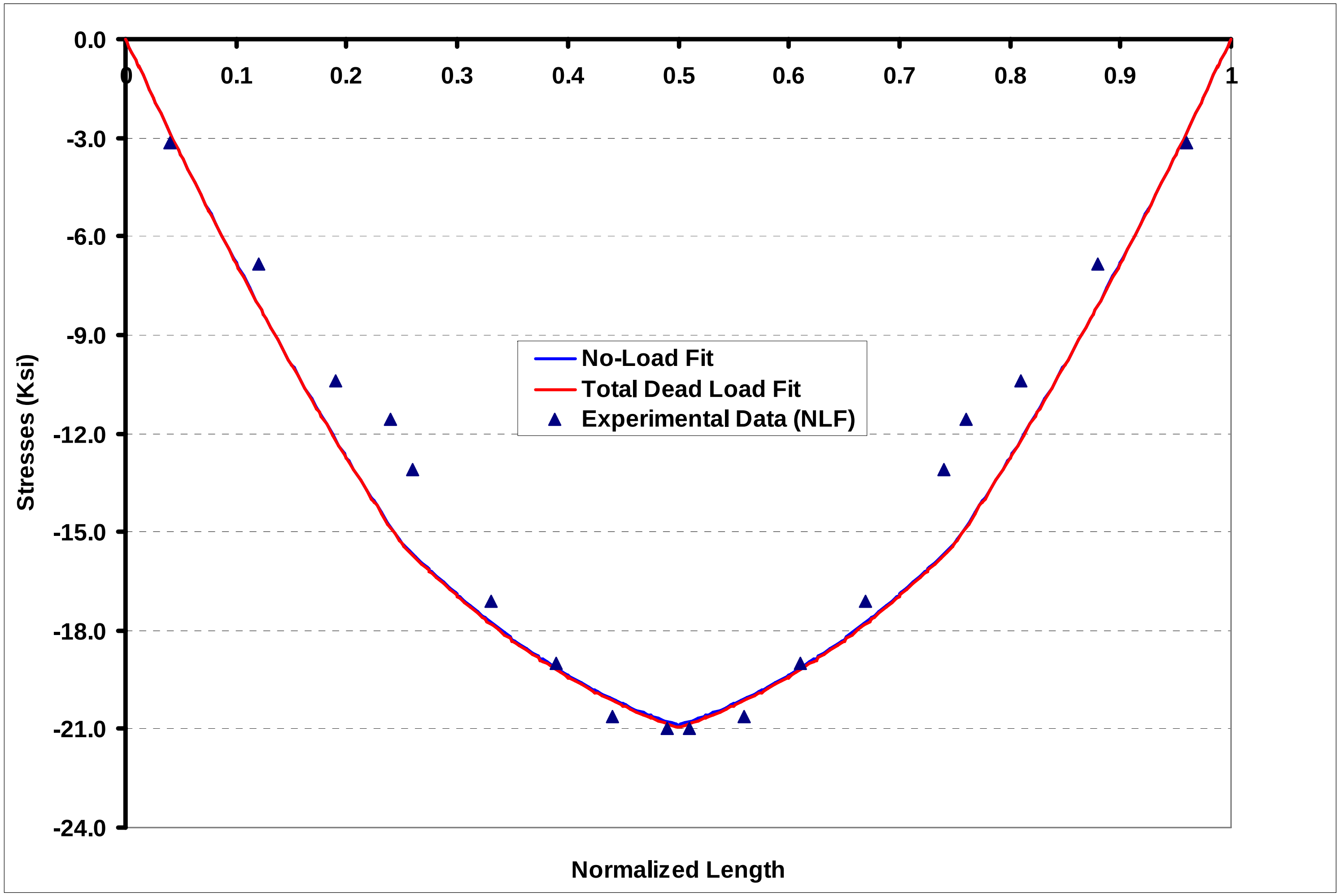
Influence of NLF vs TDLF, Final Results

– Girder G3 Top Flange Lateral Bending Stresses



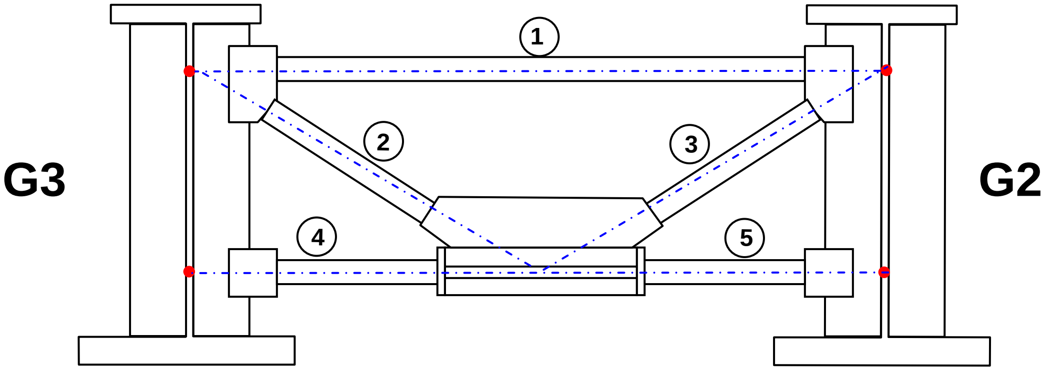
Influence of NLF vs TDLF, Final Results

– Girder G3 Top Flange Major-axis Bending Stresses



Influence of NLF vs TDLF, Final Results

– Mid-span Cross-Frame Forces (kips)



CF members / Models	1	2	3	4	5
No-Load Fit	55.34	49.02	-47.57	-95.74	-14.63
Total Dead Load Fit	54.76	49.13	-48.29	-94.97	-14.59

↑ Units: kips

Experimental Data (NLF): 94.9 kips

Influence of NLF vs TDLF Detailing on System Strength

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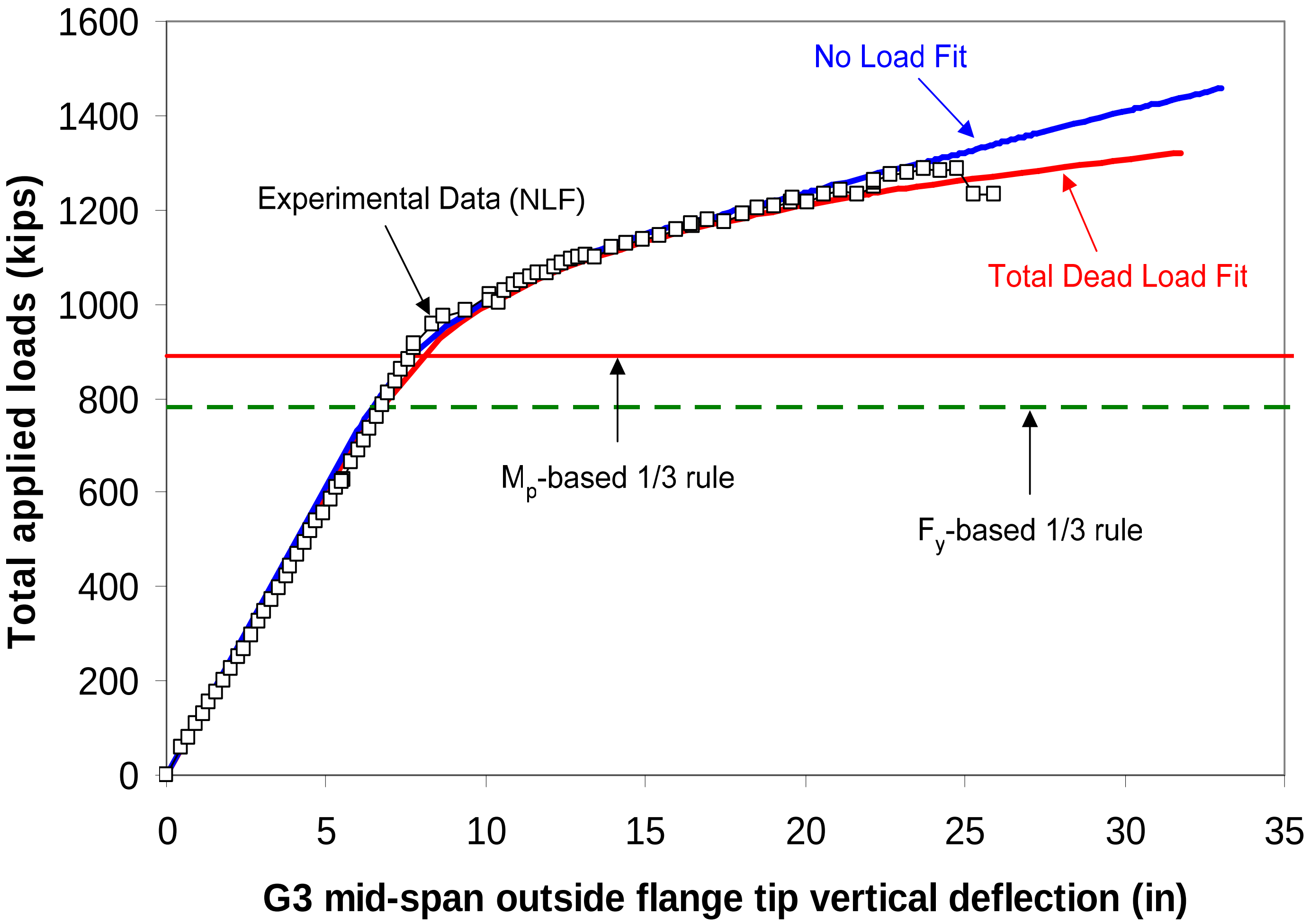
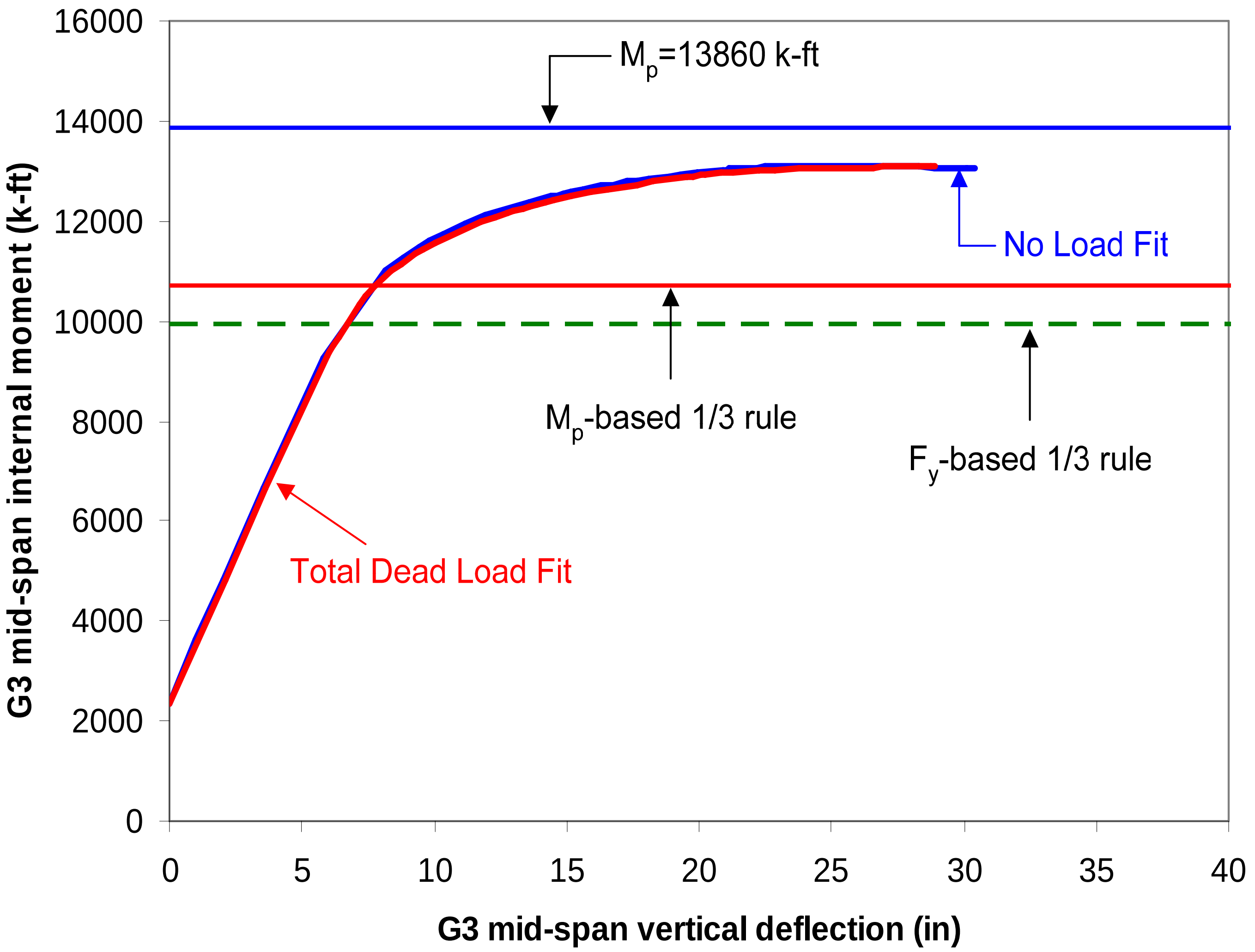
Total Applied Load vs. G3 Mid-Span Outside Flange Tip Vertical Deflection



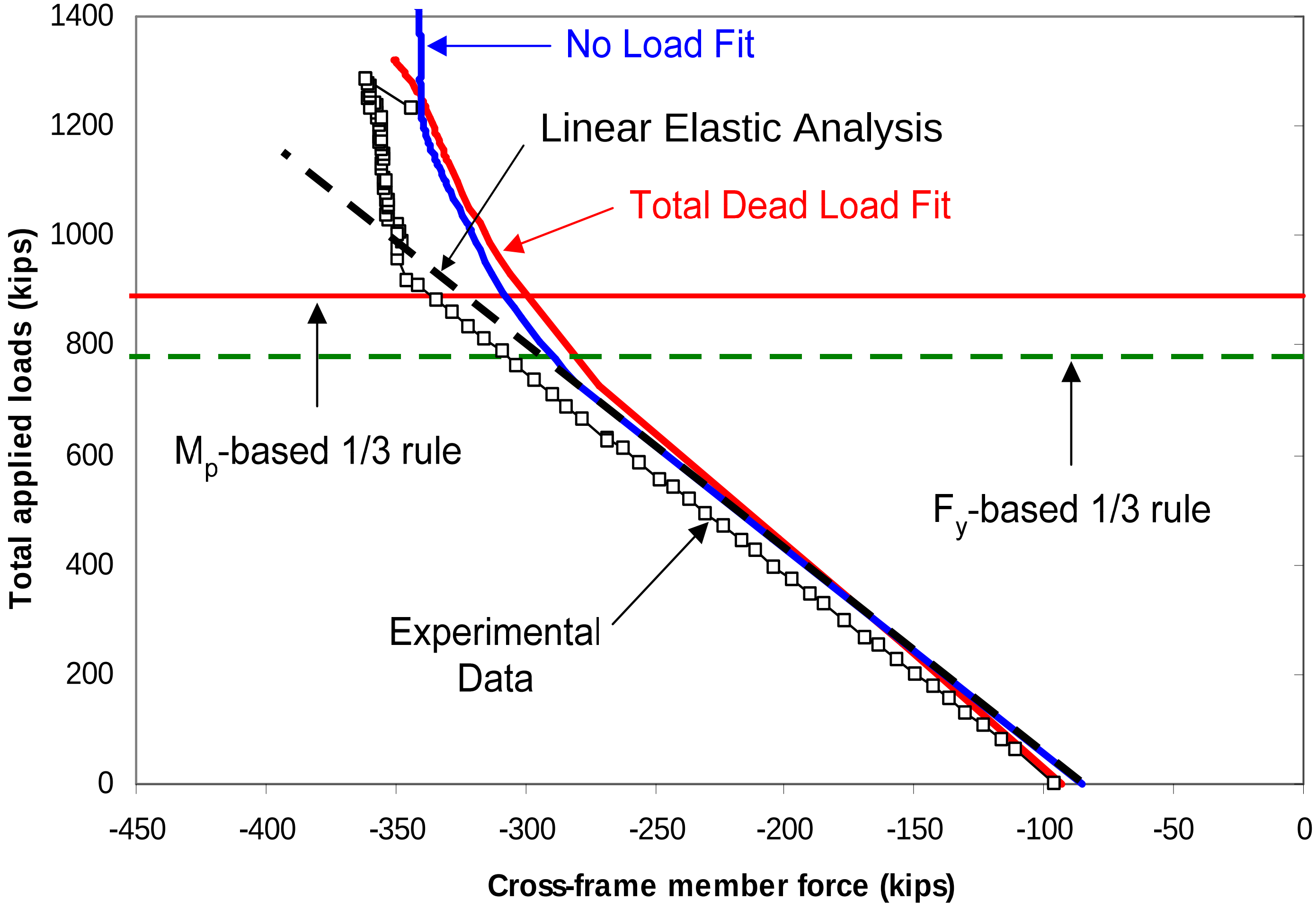
Test Bridge Just Prior to Slab Crushing

G3 Mid-Span Internal Moment vs. Vertical Deflection



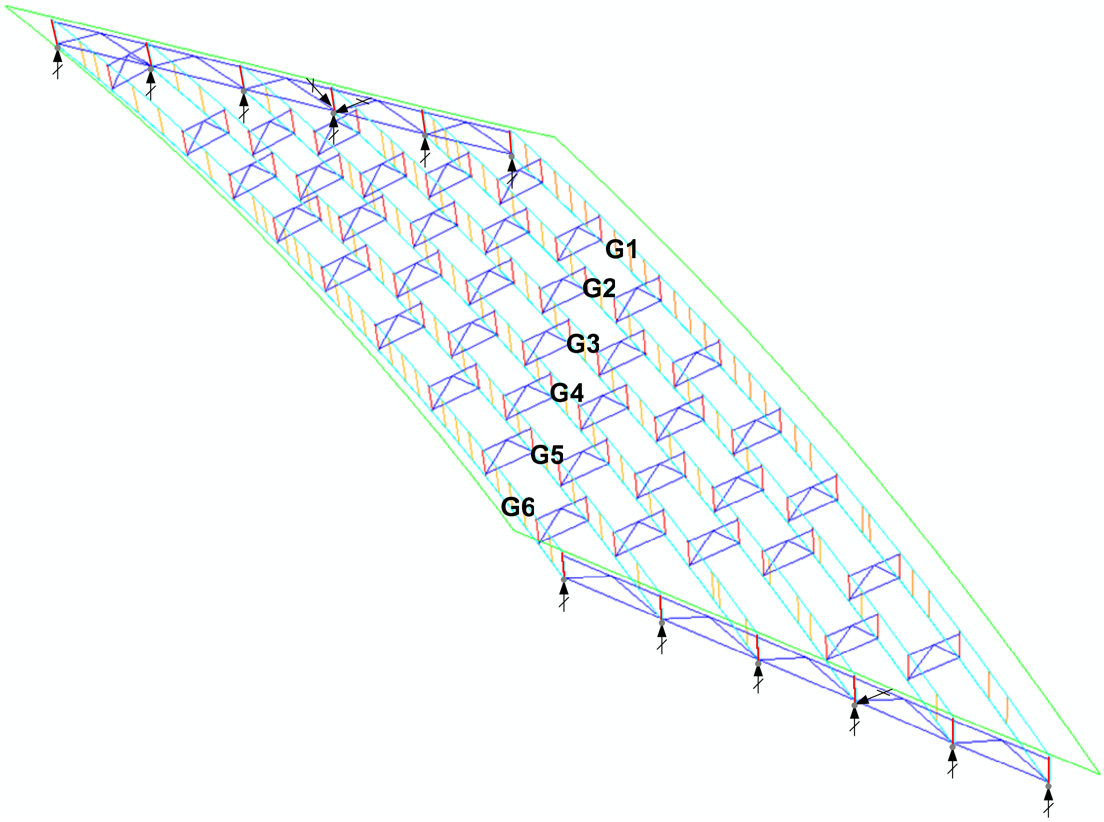
Total Applied Load vs. Cross-Frame Bottom Chord Force

(Mid-span cross-frame)



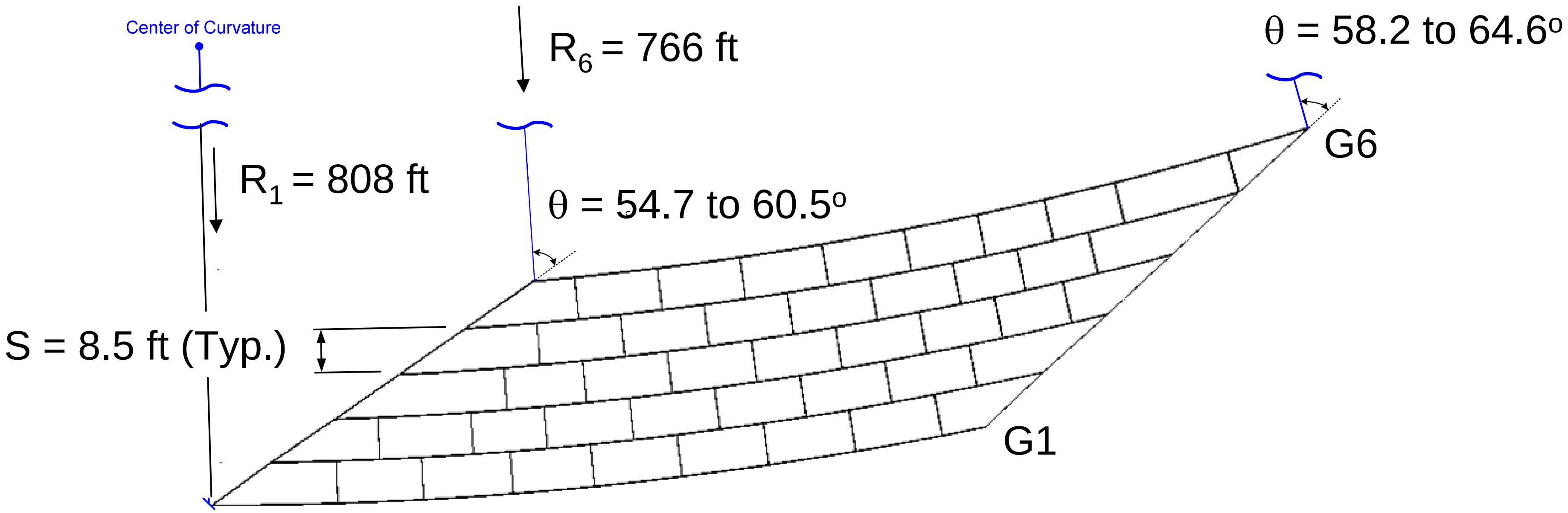
Representative Curved Bridge with a Severe Skew

Bridge configuration suggested by Mr. Dann Hall, BSDI Inc.



Girders and cross-frames detailed for no-load fit

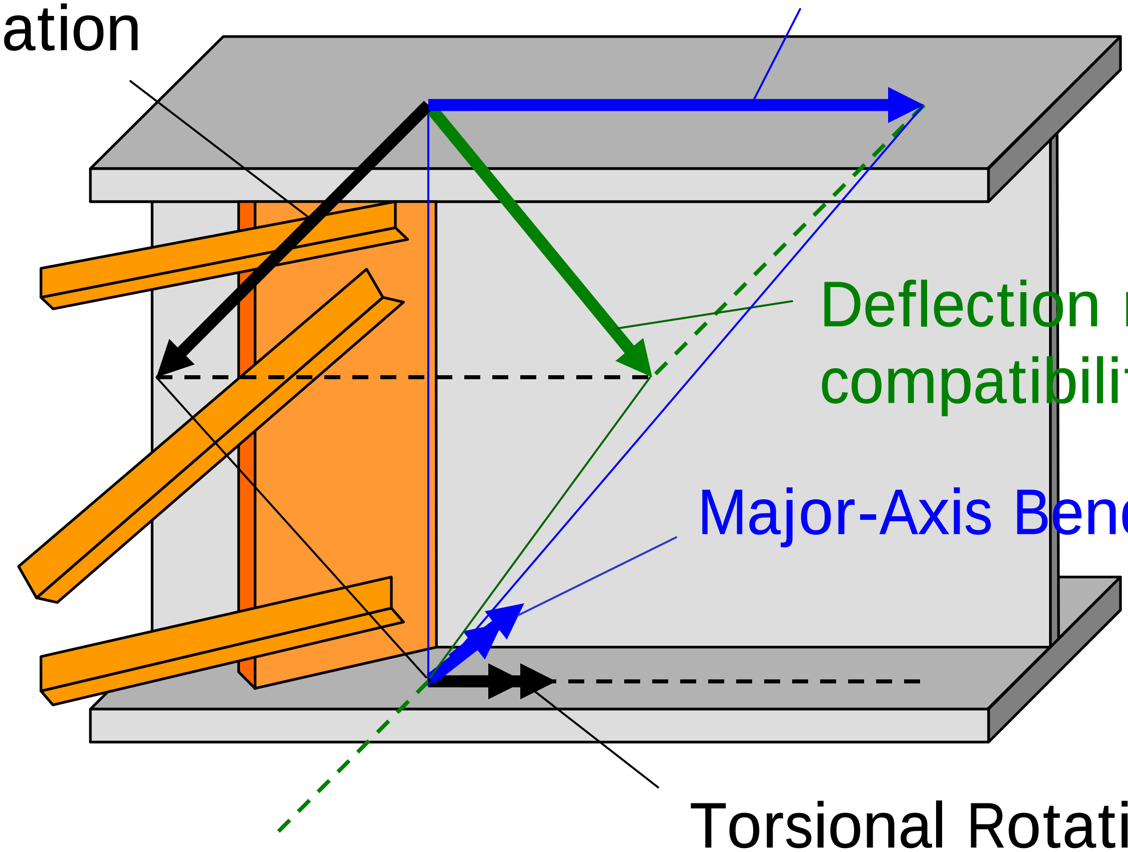
Plan View



- Single-span simply-supported
- Significant skew angles at the bearing lines
- Staggered cross-frames
- L_{as} = 162.5 ft (G1), 159.9 ft (G6)

- L_b / R = 0.01 to 0.03
- L_b / b_f = 5.0 to 17.2
- D = 72 in
- 7.5 in thick concrete deck

Example of Deflections at Skewed Bearing Lines



Layover due to Torsional Rotation

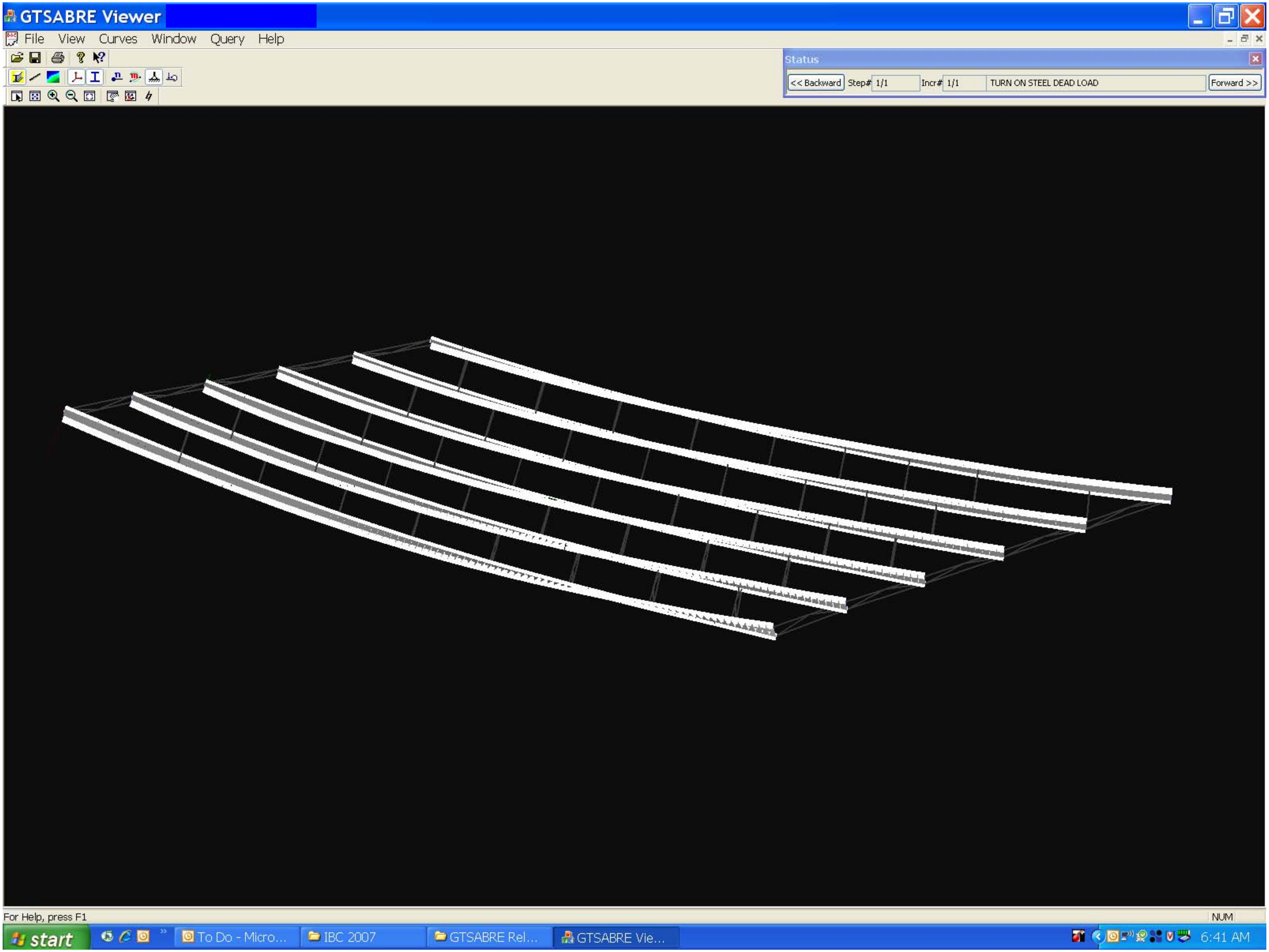
Top Flange Deflection due to Major-Axis Bending

Deflection required for compatibility with cross-frame

Major-Axis Bending Rotation (ϕ_x)

Torsional Rotation (ϕ_z)

Fixed Bearing (for illustration)



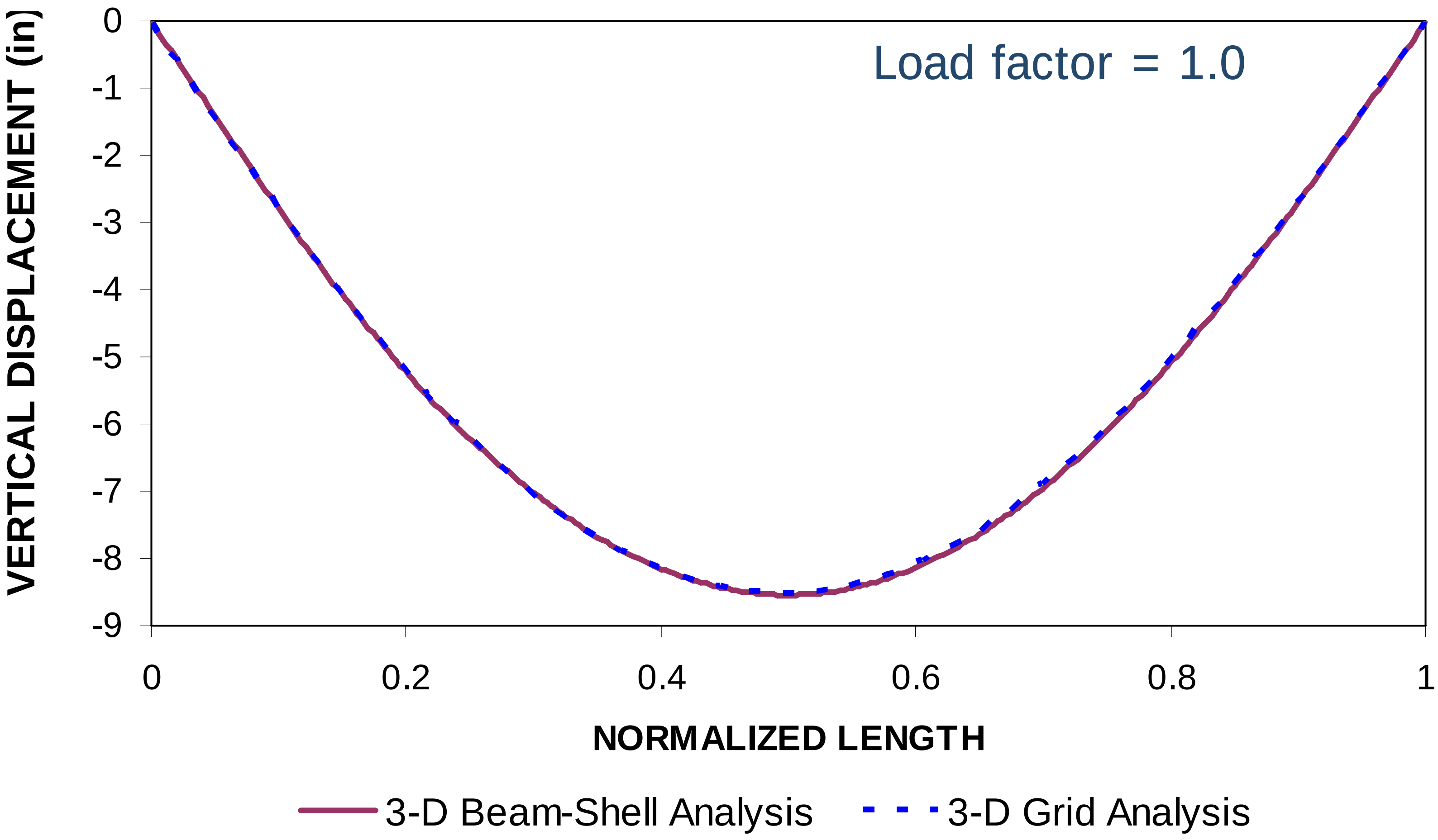
Step# 1/1

Incr# 1/1

TURN ON STEEL DEAD LOAD

For Help, press F1

G1 Displacements at End of Slab Casting



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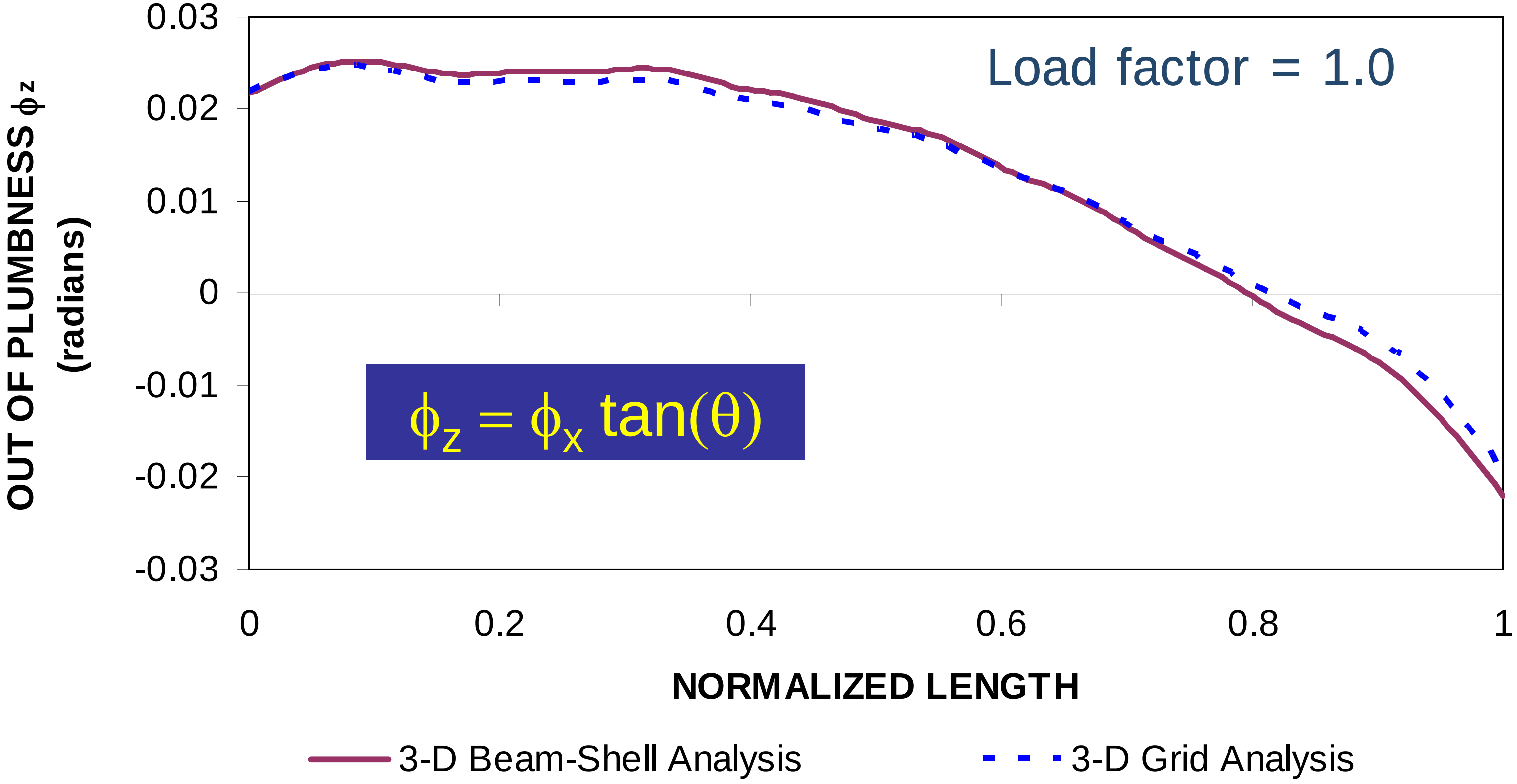
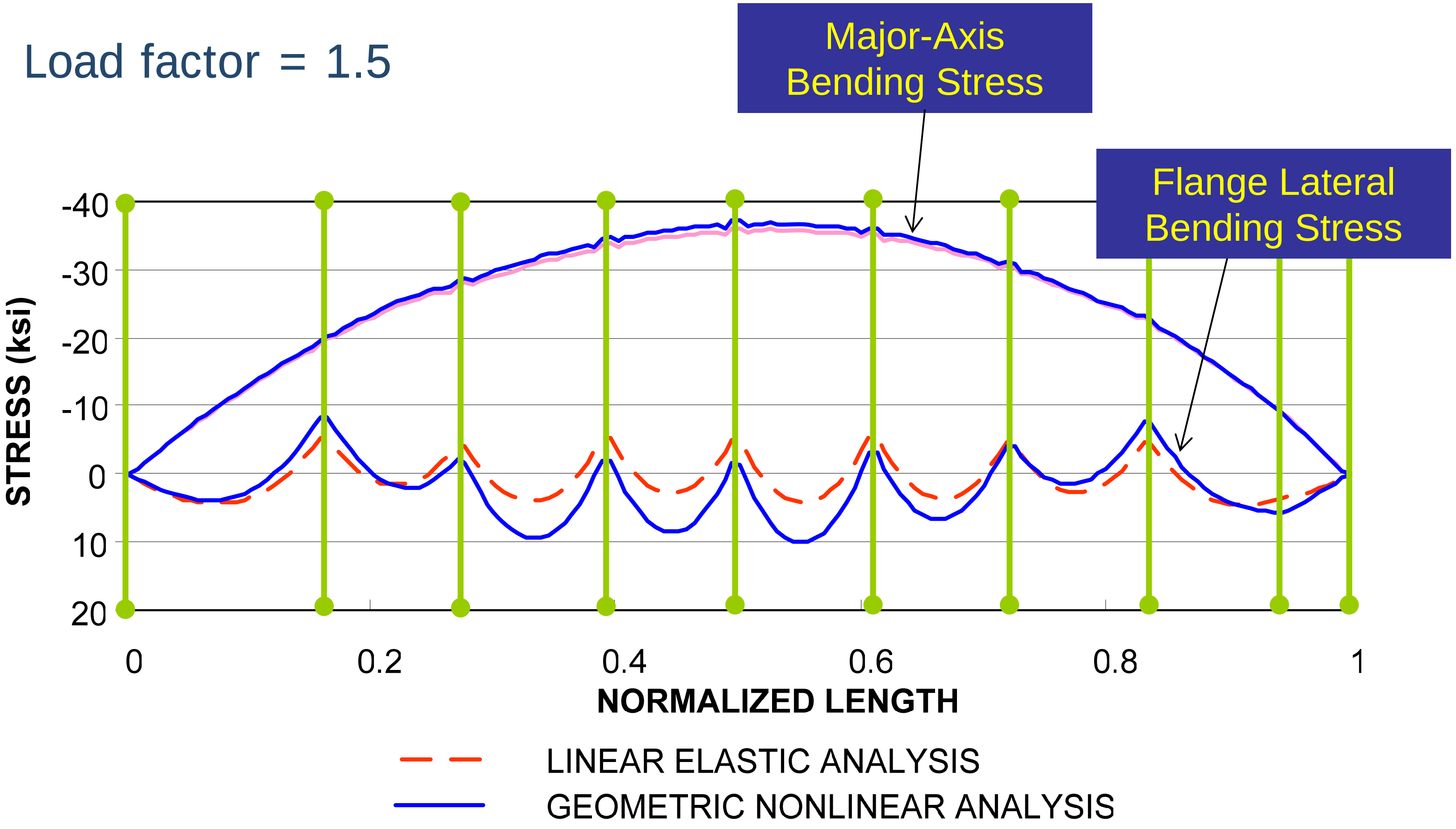


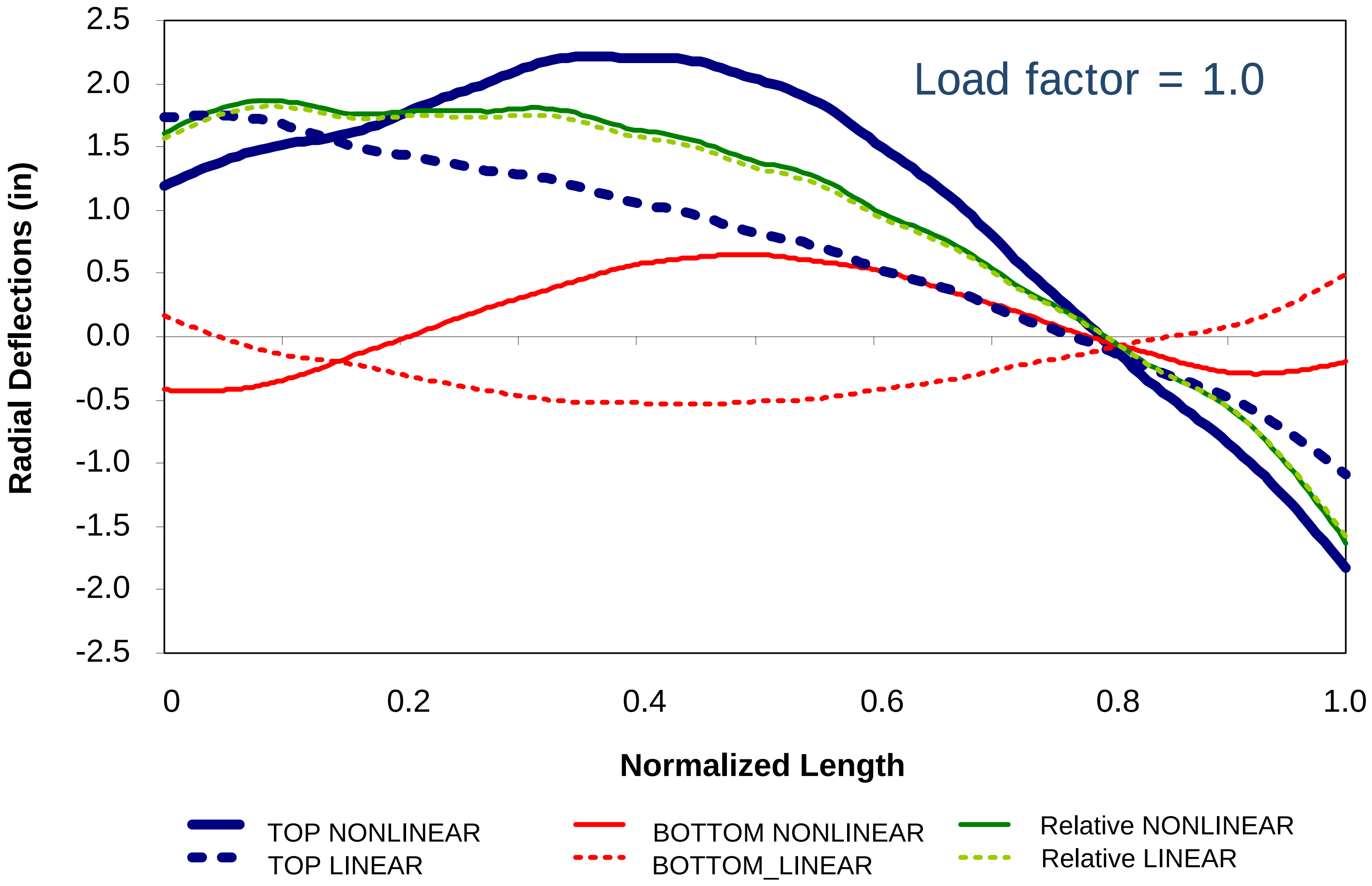
	Skew angle	ϕ_x	$\phi_{z(Approx.)}$	$\phi_{z(FEA)}$	% Diff.
Left Bearing	54.7	0.01543	0.0218	0.0217	0.4
Right Bearing	58.2	-0.01496	-0.0241	-0.0213	13.1

G1 Top Flange Stresses at End of Slab Casting

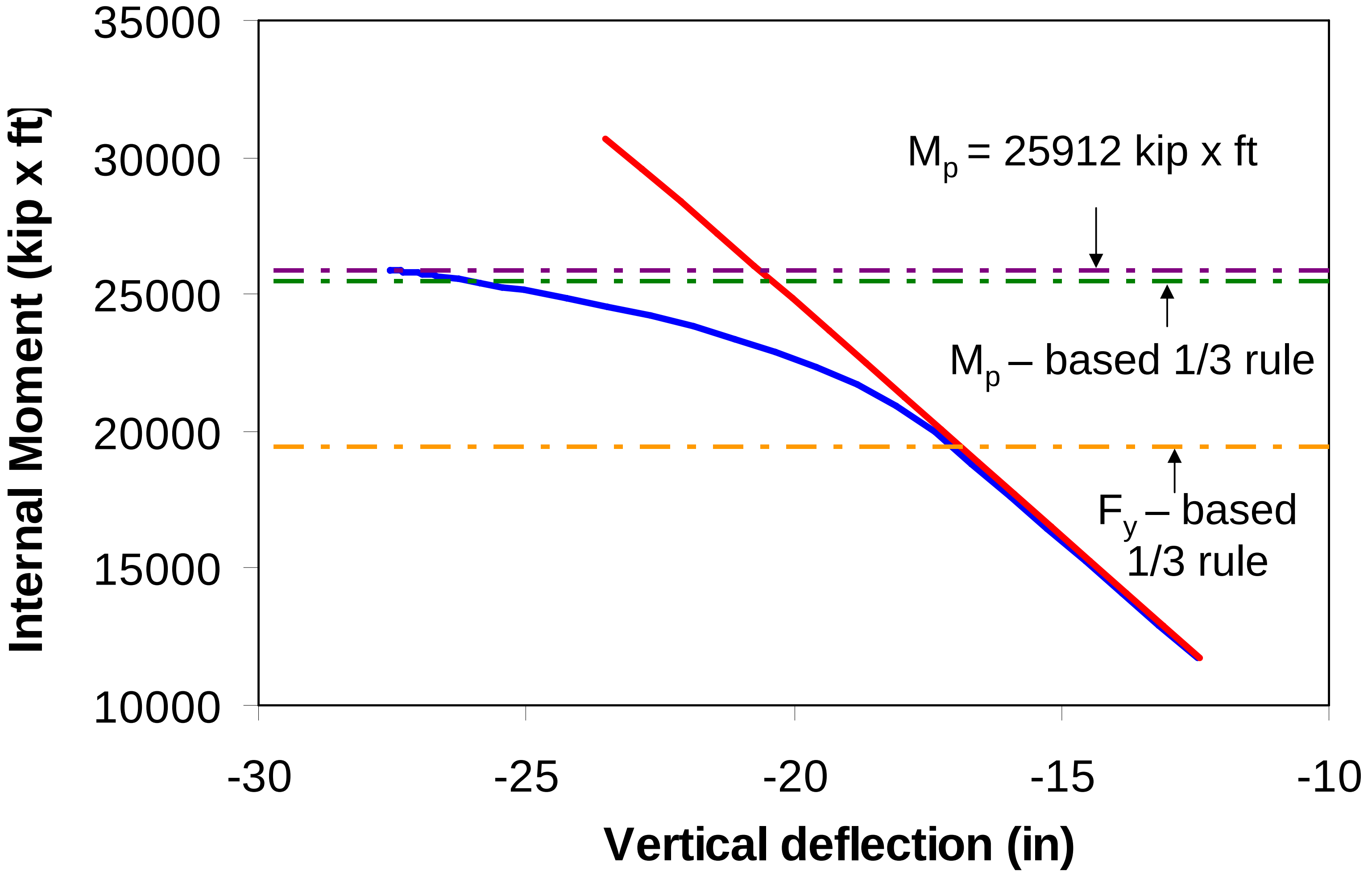
Load factor = 1.5



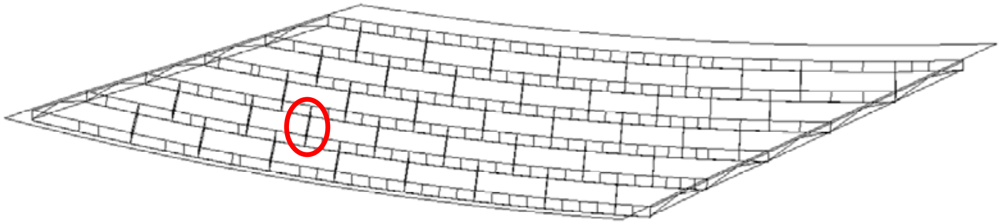
G1 Flange Radial Displacements at End of Slab Casting

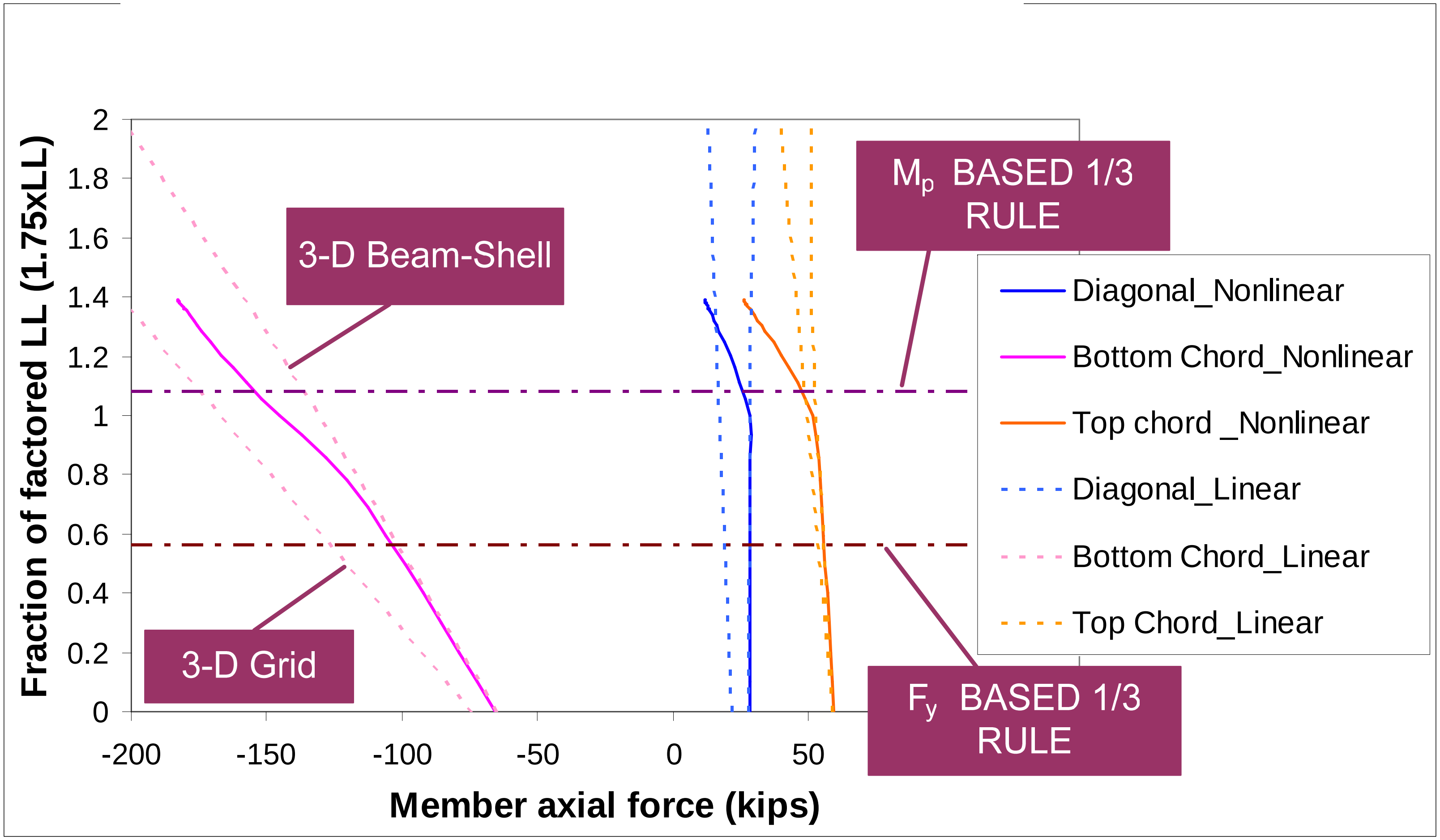


G1 Maximum Internal Moment vs. Vertical Deflection



Applied Load vs. Cross-Frame Forces





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Thank you for your attention

I’d be happy to address any comments or questions