FORTE & TABLADA

AASHTOWare™ BRIDGE DESIGN AND RATING

Railcar Load Rating

Integrating BrR and Mathcad

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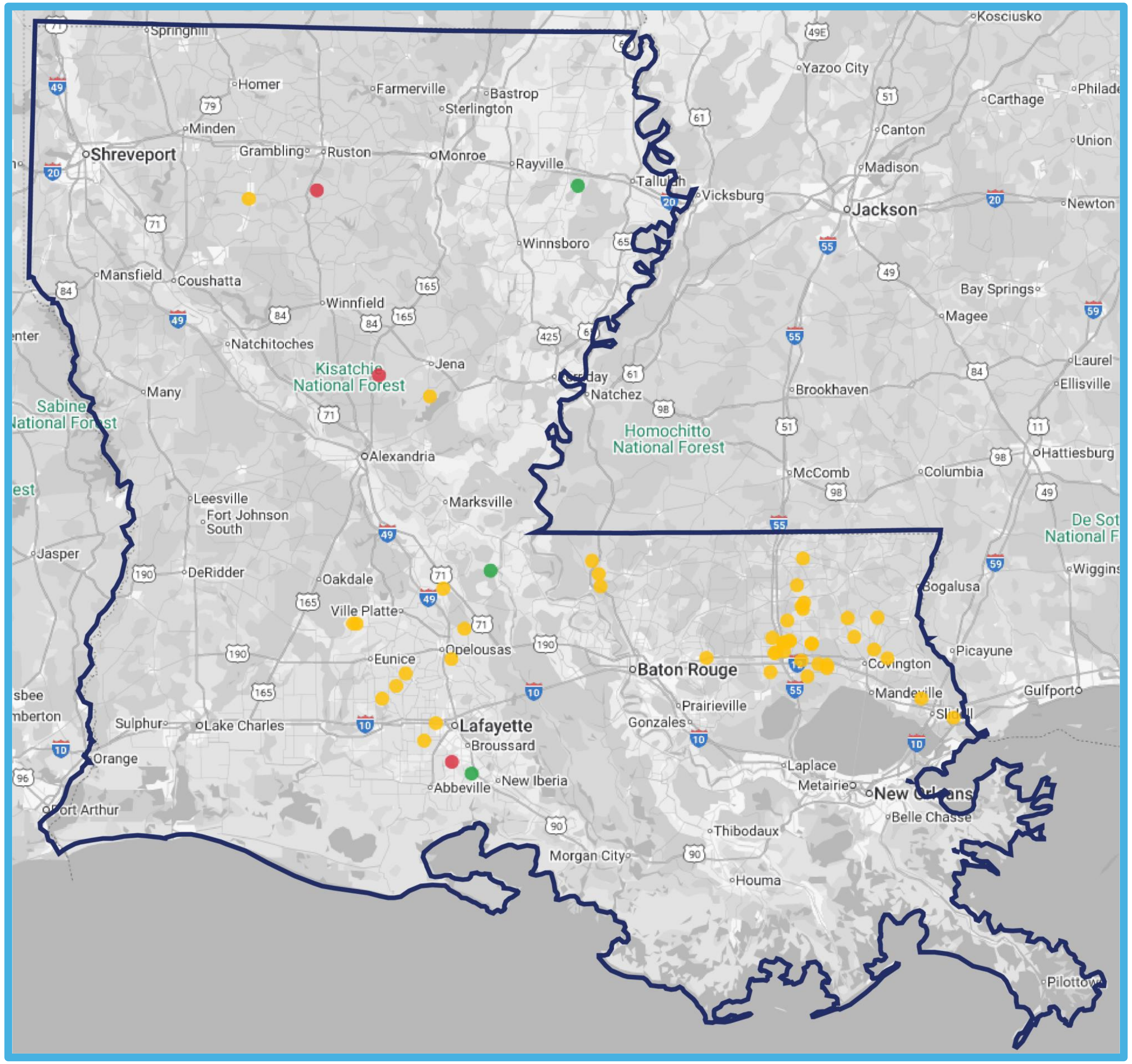
2025 Rating and Design User Group Meeting
Boise, ID | August 12-13, 2025

Railcar (RRFLCR) Bridge Inventory in Louisiana



- 51 bridge sites across the State
  - All but 1 on Off-System routes
- Most located in South Louisiana
- 33 Load Posted
- Approx. ½ have a Condition Rating ≤ 5 (Fair)
- Many constructed without engineering drawings
- Railcar span details rarely available
- Unique and analytically complex
- Existing conditions may differ from as-built state
  - Lack of bearing at abutments
  - Deterioration
- Parishes have limited budget for load rating
  - Little appetite for sophisticated modeling techniques or load testing

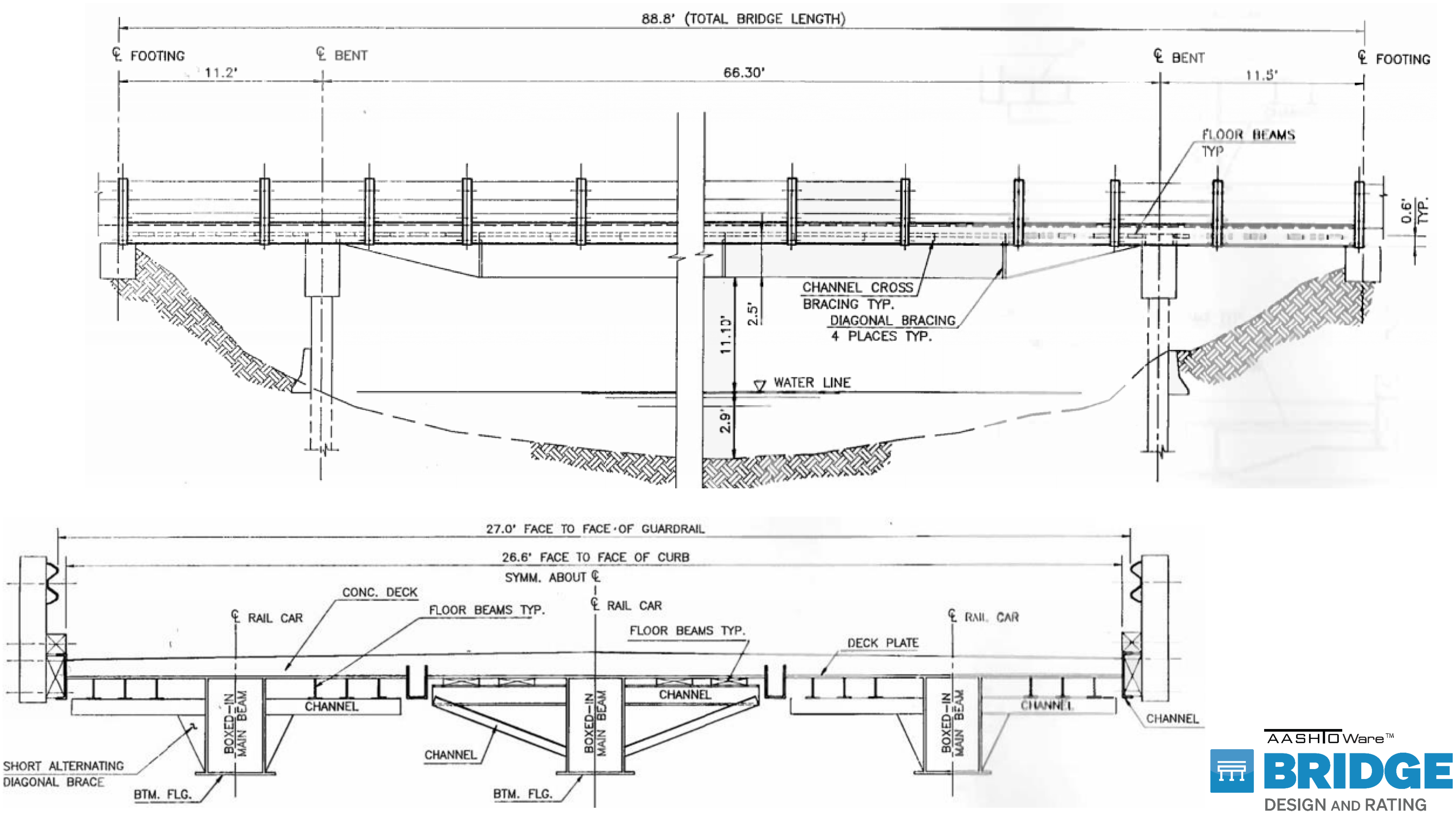
AASHTOWare™ BRIDGE DESIGN AND RATING

Example Installation 1

- Box Beam Main Girders
- Each Car is Unique
- 3-Span Continuous Unit
  - Propped Ends

AASHTOWare™ BRIDGE DESIGN AND RATING

Elevation & Typical Section Based on Field Measurements



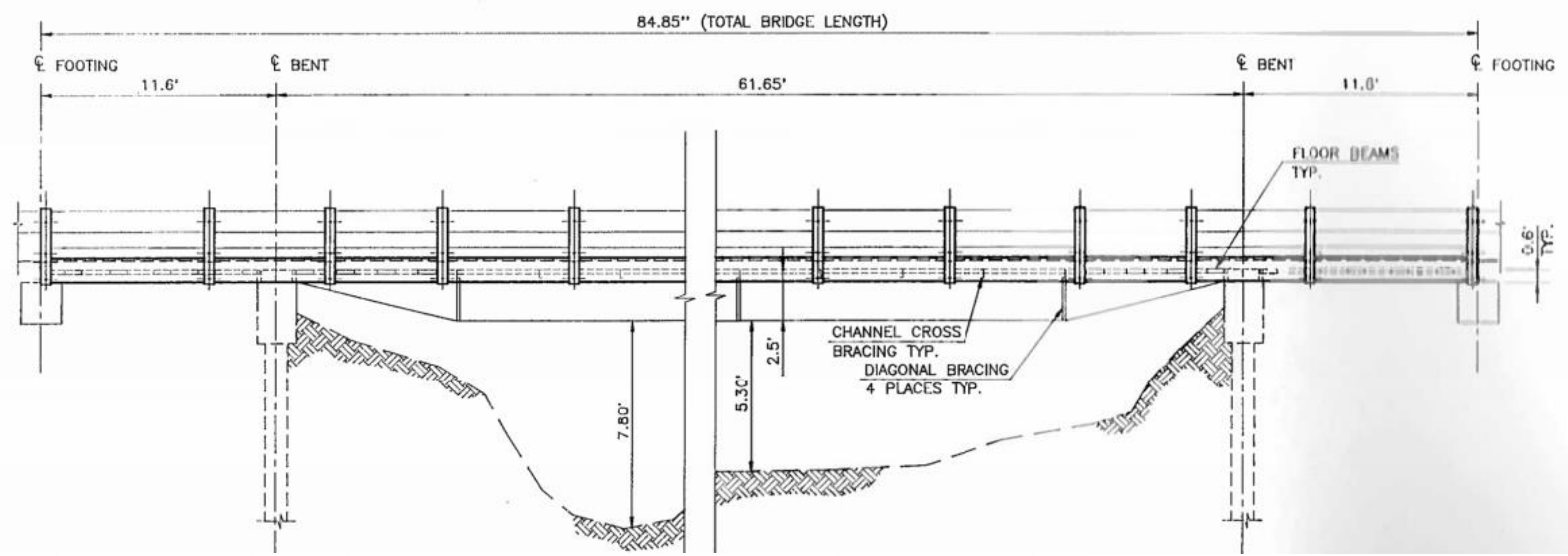
AASHTOWare™ BRIDGE DESIGN AND RATING

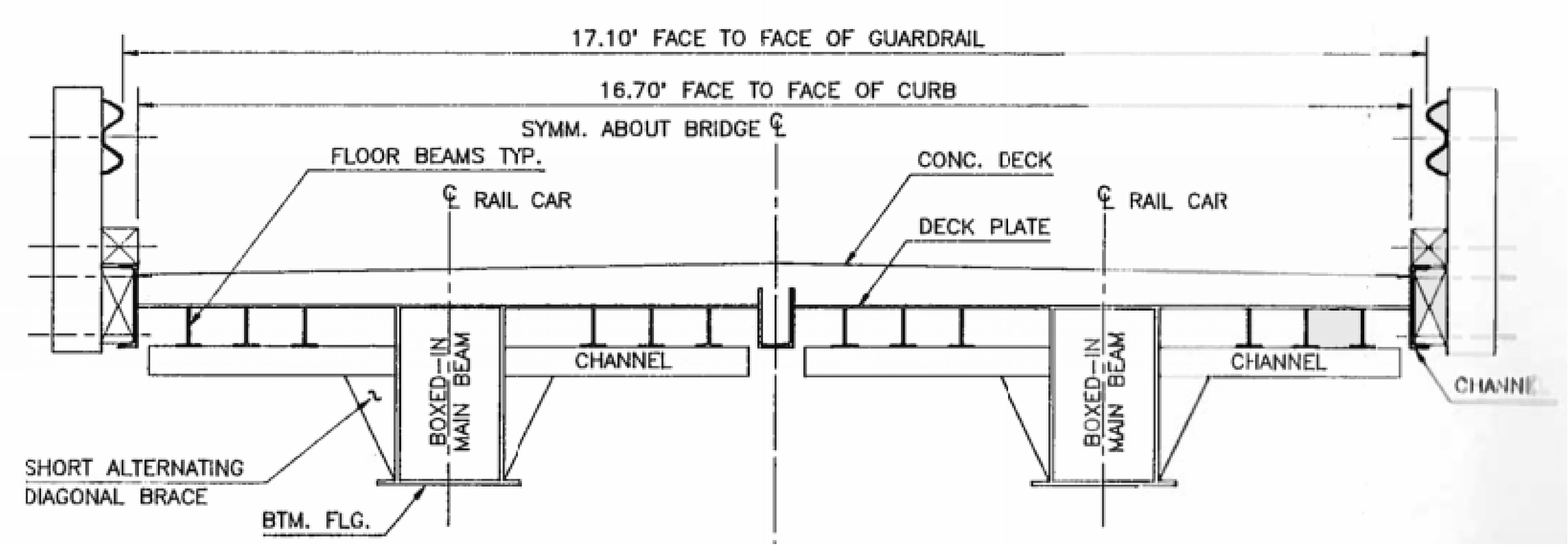
Example Installation 2

- Box Beam Main Girders
- 3-Span Continuous Unit
  - Propped Ends

AASHTOWare™ BRIDGE DESIGN AND RATING

Sketches Based on Field Measurements

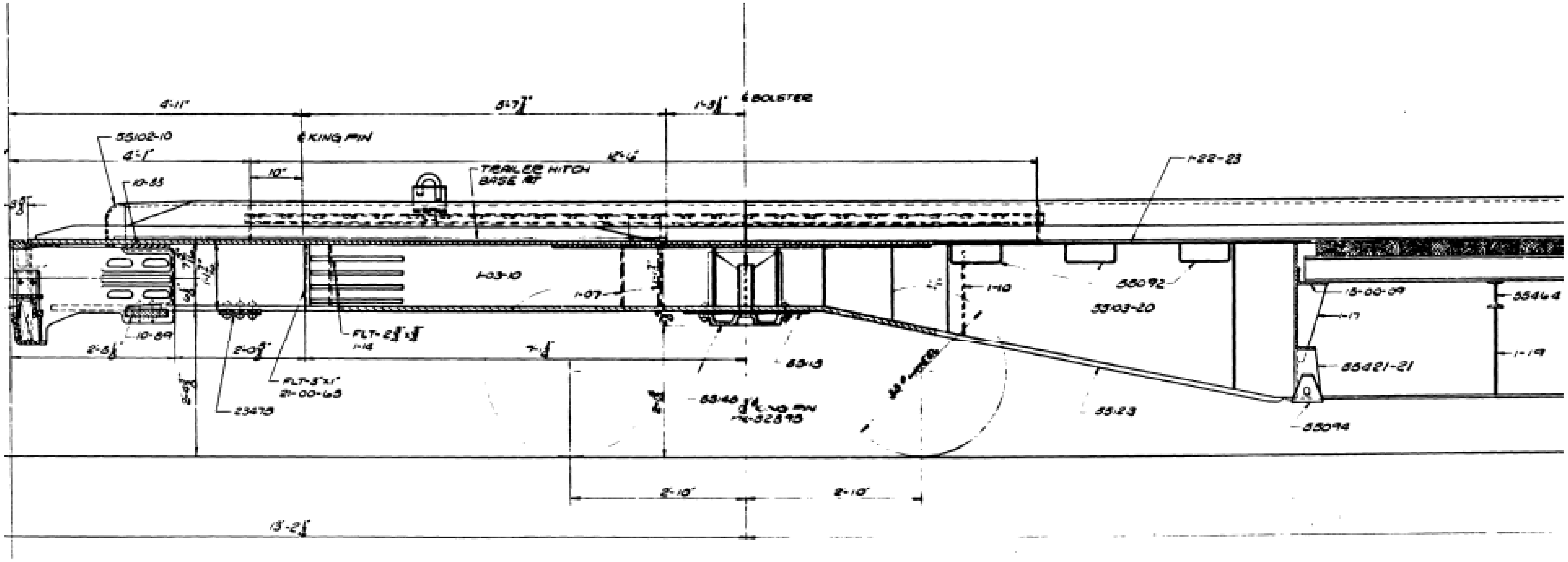


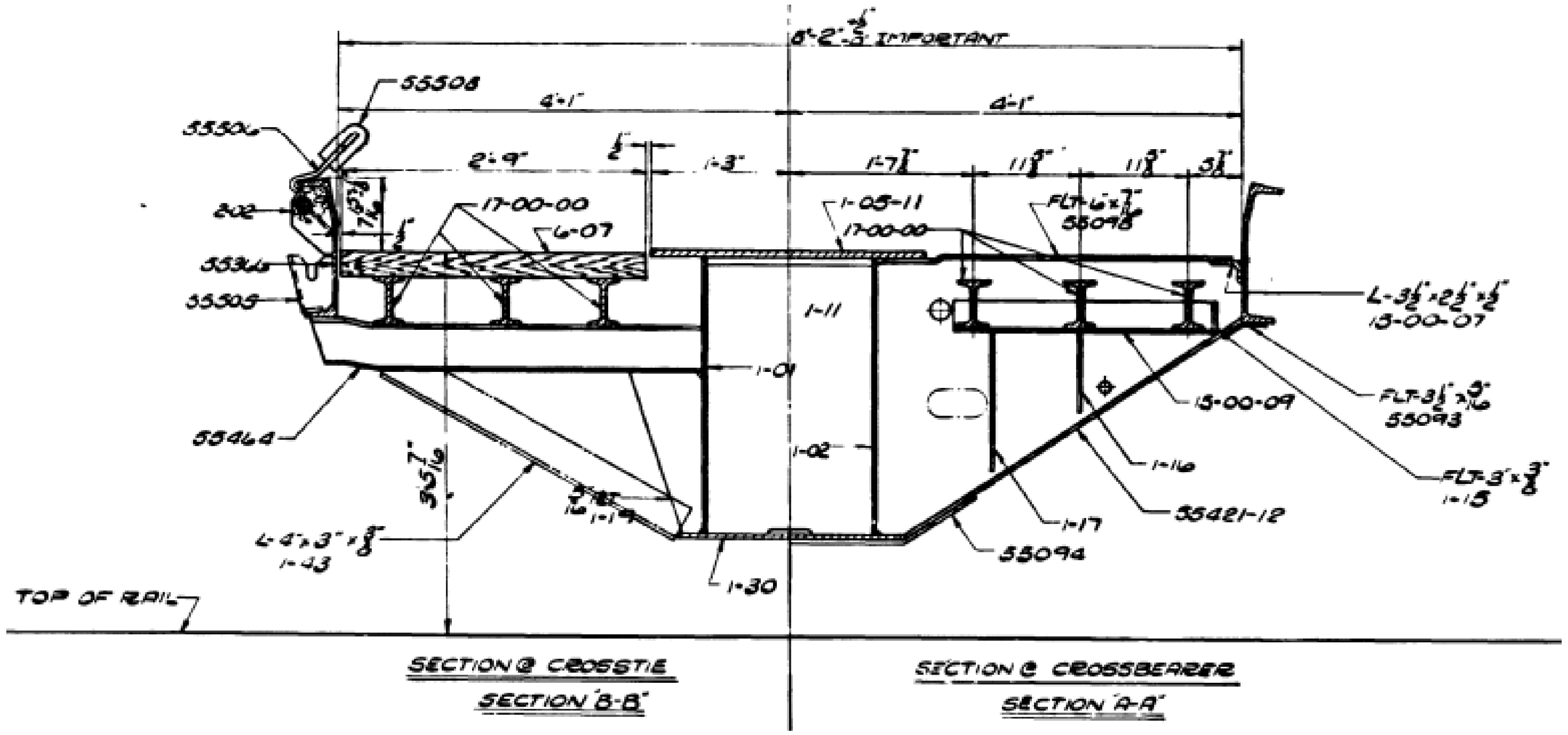


AASHTOWare™ BRIDGE DESIGN AND RATING

Railcar Details from Railroad

- May be able to get drawings with railcar number



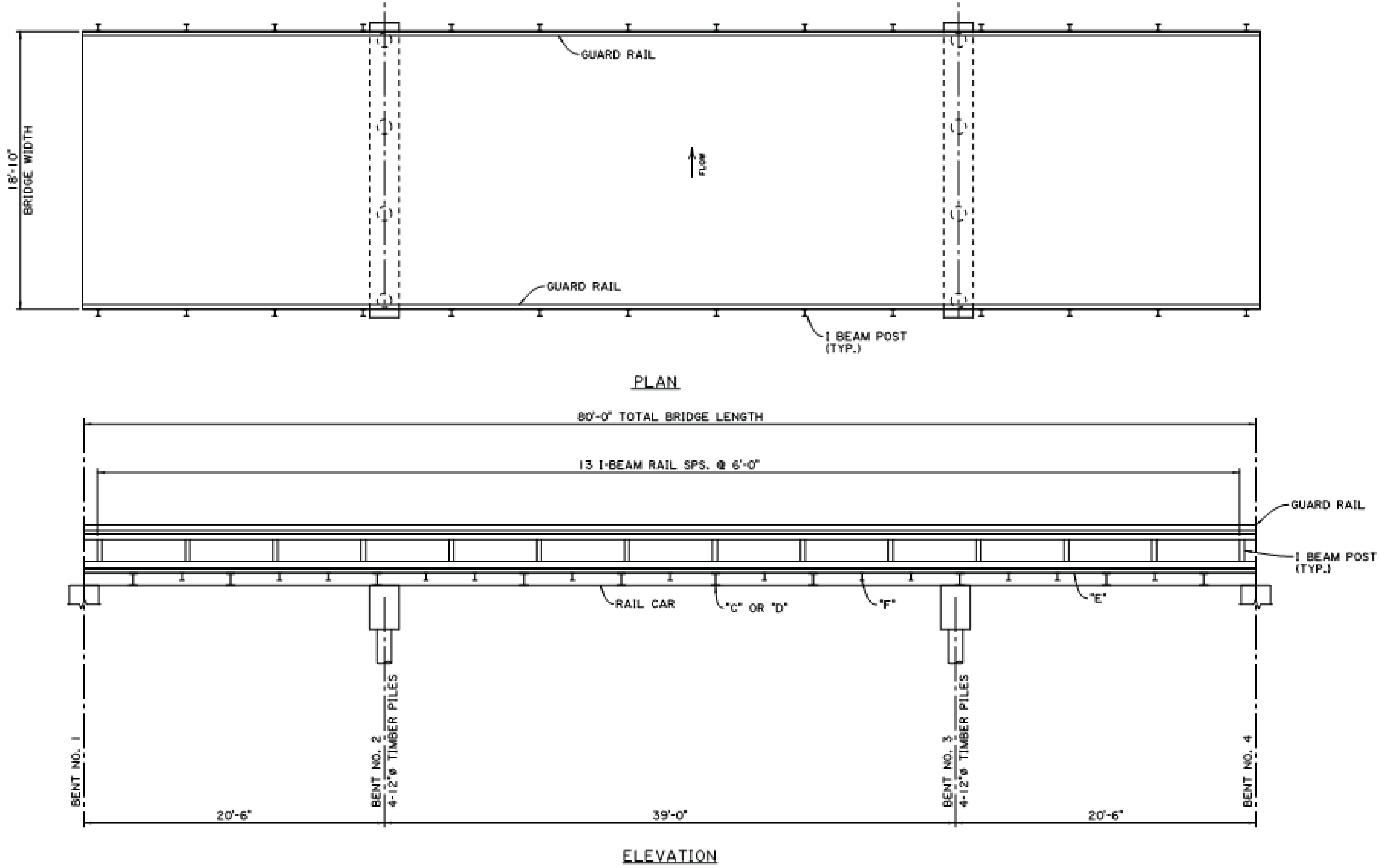


AASHTOWare™ BRIDGE DESIGN AND RATING

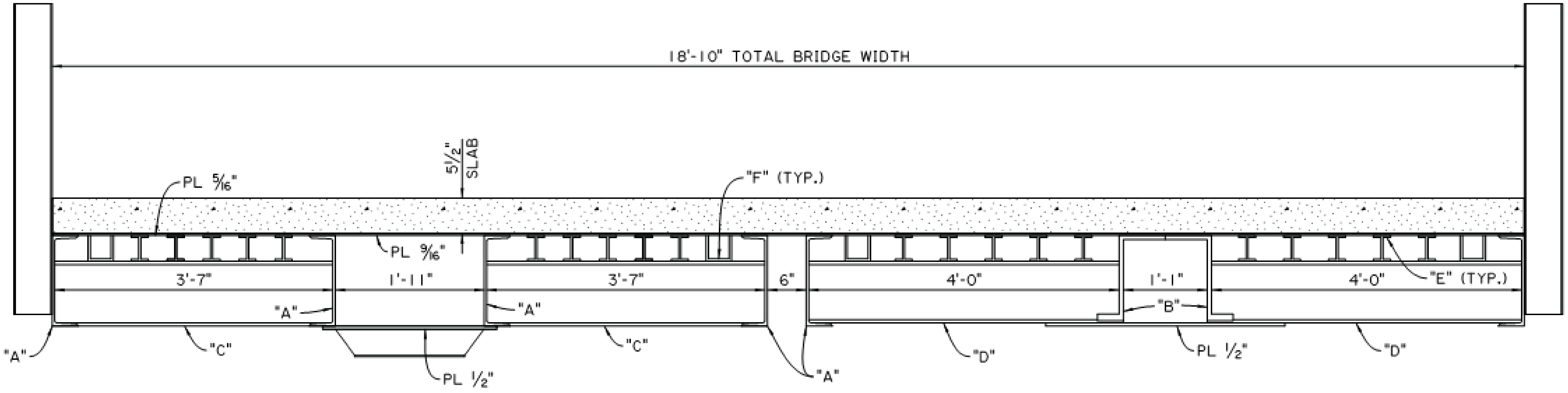
Load Rating a Railcar with Channels & Z-Shaped Main Beams

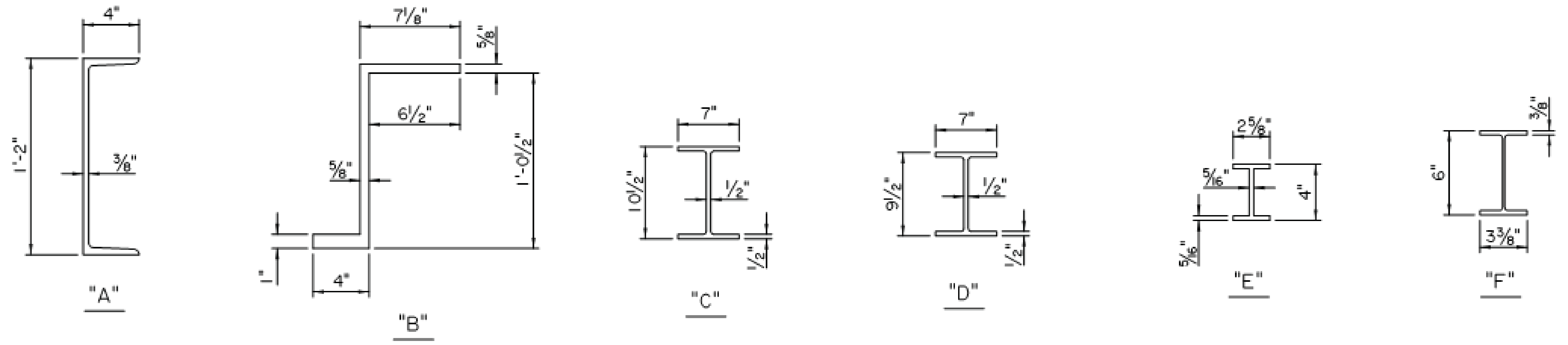
AASHTOWare™ BRIDGE DESIGN AND RATING

Load Rating a Railcar with Channels & Z-Shaped Main Beams



Load Rating a Railcar with Channels & Z-Shaped Main Beams





AASHTOWare™ BRIDGE DESIGN AND RATING

Previous Rating

- Last load rated in 2012
- Line Girder Analysis in BrR
- Channels and Z-Shapes modelled as "equivalent" I-shapes
- LLDF = 0.6 (single lane only)
- Recommended Posting Load
- **CLOSED** to Legal Trucks
  - School buses, garbage trucks, etc.)

		Superstructure/Deck				
Vehicle Type	GVW (kips)	Rating Factor	Controlling Member	Controlling Load Effect	IM	Live Load Distribution Factor (Single/Multiple)
HL-93 (INV)	N/A	0.14	Interior Girder	Flexure	33%	0.600 / 0.600
HL-93 (OPR)	N/A	0.19	Interior Girder	Flexure	33%	0.600 / 0.600
LADV-11(INV)	N/A	0.11	Interior Girder	Flexure	33%	0.600 / 0.600
LA Type 3S2	73.0	0.19	Interior Girder	Flexure	33%	0.600 / 0.600
LA Type 3	50.0	0.26	Interior Girder	Flexure	33%	0.600 / 0.600
Type 3-3	80.0	0.27	Interior Girder	Flexure	33%	0.600 / 0.600
LA Type 6	80.0	0.21	Interior Girder	Flexure	33%	0.600 / 0.600
LA Type 8	88.0	0.19	Interior Girder	Flexure	33%	0.600 / 0.600
NRL	80.0	0.17	Interior Girder	Flexure	33%	0.600 / 0.600
SU4	54.0	0.22	Interior Girder	Flexure	33%	0.600 / 0.600
SU5	62.0	0.21	Interior Girder	Flexure	33%	0.600 / 0.600
SU6	69.5	0.19	Interior Girder	Flexure	33%	0.600 / 0.600
SU7	77.5	0.18	Interior Girder	Flexure	33%	0.600 / 0.600
Lane-Type I	N/A	N/A				/
Lane Type II	N/A	0.31	Interior Girder			/
OFRD1	132.6	0.15	Interior Girder	Flexure	33%	0.600 / 0.600
OFRD2	142.5	0.12	Interior Girder	Flexure	33%	0.600 / 0.600
OFRD3	209.0	0.12	Interior Girder	Flexure	33%	0.600 / 0.600

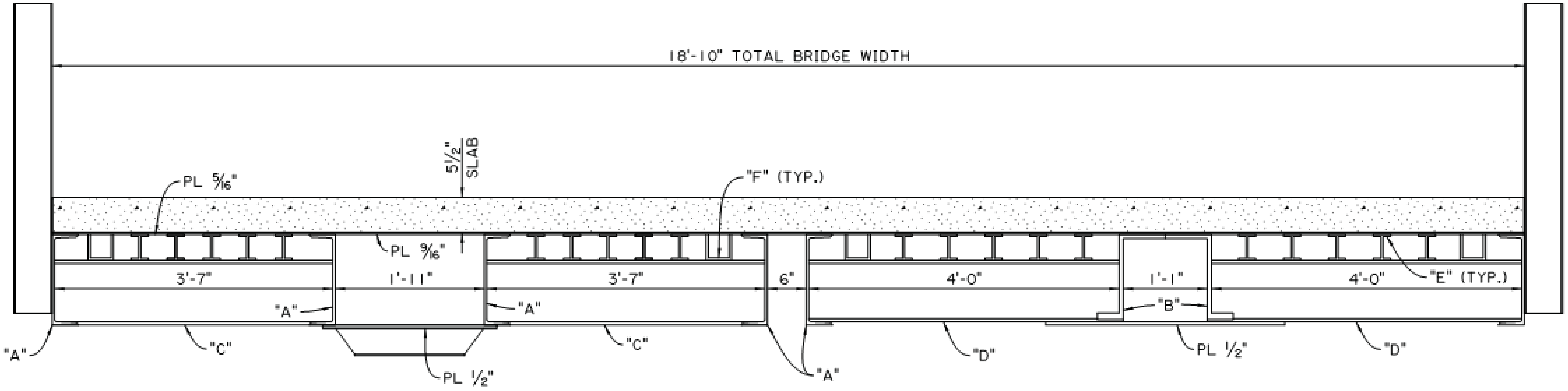
Posting Analysis Summary

Governing Rating Factor	0.19
Governing Load Model	LA Type 3-S2
Recommended Posting Load	Closed to Legal Trucks

AASHTOWare™ BRIDGE DESIGN AND RATING

BrR Limitations

- Not able to model Channels & Z-Shapes as Primary Members
  - There are certain situations where member bracing, support conditions, member properties (flange and web thickness, member depth, etc.) allow for certain member types to be modelled in BrR using equivalent sections, but making this determination requires time (and money).



AASHTOWare™ BRIDGE DESIGN AND RATING

Parish-Requested Rerating

- Looking to be able to allow school buses to cross the bridge.
- Load Rating Concepts:
  - Section Properties per AASHTO LRFD 6.12.2.2.5
  - Utilize 3D FEM analysis in BrR
- Primary Members
  - Channels & Z-Shapes (Main Beams)
  - Deck Plate
  - Diaphragms
- Secondary Members
  - Longitudinal Stringers (DL only)
- Concrete Deck modelled as non-composite
- Goal
  - 15T-25T Posting

AASHTOWare™ BRIDGE DESIGN AND RATING

Load Rating Process

Mathcad

- Determine Section Properties of Primary Members
- Determine Area & Weight of Secondary Members

BrR

- Input Section Properties of Primary Members
- Input DL of Secondary Members
- Run 3D FEM Analysis
- Pull DL and LL Moments and Shears at Controlling Locations

Mathcad

- Input Controlling Loads from BrR
- Determine Capacities of Primary Members
- Determine Load Rating Factors

AASHTOWare™ BRIDGE DESIGN AND RATING

Section Properties of Primary Members

Channels (X-X Axis)

- Calcs for Z-Shapes and Diaphragms similar
- Calcs for Y-Y axis performed, but not included
  - More complex due to varying orientation with deck plate

Cross section area of the channel sections:

$$A := (b_{f1} \cdot t_{f1} + t_w \cdot (d - t_{f1} - t_{f2}) + b_{f2} \cdot t_{f2}) + b_{deck\_plate} \cdot t_{deck\_plate1} = 15.625 \ in^2$$

Neutral axis of the channel sections about the X-X Axis:

$$c_{xx} := \frac{b_{f1} \cdot t_{f1} \cdot 0.5 \cdot t_{f1} + t_w \cdot (d - t_{f1} - t_{f2}) \cdot \left(t_{f1} + \frac{(d - t_{f1} - t_{f2})}{2}\right) + b_{f2} \cdot t_{f2} \cdot \left(t_{f1} + (d - t_{f1} - t_{f2}) + \frac{t_{f2}}{2}\right) + b_{deck\_plate} \cdot t_{deck\_plate1} \cdot (d + 0.5 \ t_{deck\_plate1})}{b_{f1} \cdot t_{f1} + t_w \cdot (d - t_{f1} - t_{f2}) + b_{f2} \cdot t_{f2} + b_{deck\_plate} \cdot t_{deck\_plate1}} = 10.507 \ in$$

Centroidal moment of inertia of the channel section about the X-X Axis:

$$I_{xx} := \frac{b_{f1} \cdot t_{f1}^3}{12} + \frac{t_w \cdot (d - t_{f1} - t_{f2})^3}{12} + \frac{b_{f2} \cdot t_{f2}^3}{12} + \frac{b_{deck\_plate} \cdot t_{deck\_plate1}^3}{12} + b_{f1} \cdot t_{f1} \cdot \left(c_{xx} - \frac{t_{f1}}{2}\right)^2 + t_w \cdot (d - t_{f1} - t_{f2}) \cdot \left(c_{xx} - \left(t_{f1} + \frac{(d - t_{f1} - t_{f2})}{2}\right)\right)^2 + b_{f2} \cdot t_{f2} \cdot \left(\left(t_{f1} + (d - t_{f1} - t_{f2}) + \frac{t_{f2}}{2}\right) - c_{xx}\right)^2 + b_{deck\_plate} \cdot t_{deck\_plate1} \cdot (d + 0.5 \cdot t_{deck\_plate1} - c_{xx})^2 = 411.988 \ in^4$$

Section Modulus of the channel section about the X-X Axis:

$$S_{xx} := \frac{I_{xx}}{c_{xx}} = 39.212 \ in^3$$

Radius of Gyration of the channel section about the X-X Axis:

$$r_{xx} := \sqrt{\frac{I_{xx}}{A}} = 5.135 \ in$$

AASHTOWare™ BRIDGE DESIGN AND RATING

DL from Secondary Members

Stringers E & F

- DL applied to Primary Members based on Tributary Width

Stringer "E" Section Dimensions

$$b_{f\_E} := 2.625\ in$$

$$t_{f\_E} := 0.3125\ in$$

$$t_{w\_E} := 0.3125\ in$$

$$d_E := 4\ in$$

$$A_{stringer\_E} := 2 \cdot \left(b_{f\_E} \cdot t_{f\_E}\right) + \left(t_{w\_E} \cdot \left(d_E - 2 \cdot t_{f\_E}\right)\right) = 2.695\ in^2$$

$$w_{stringer\_E} := \gamma_{steel} \cdot A_{stringer\_E} = 9.172\ \frac{lbf}{ft}$$

Stringer "F" Section Dimensions

$$b_{f\_F} := 3.75\ in$$

$$t_{f\_F} := 0.375\ in$$

$$t_{w\_F} := 0.3125\ in$$ (Assumed)

$$d_F := 6\ in$$

$$A_{stringer\_F} := 2 \cdot \left(b_{f\_F} \cdot t_{f\_F}\right) + \left(t_{w\_F} \cdot \left(d_F - 2 \cdot t_{f\_F}\right)\right) = 4.453\ in^2$$

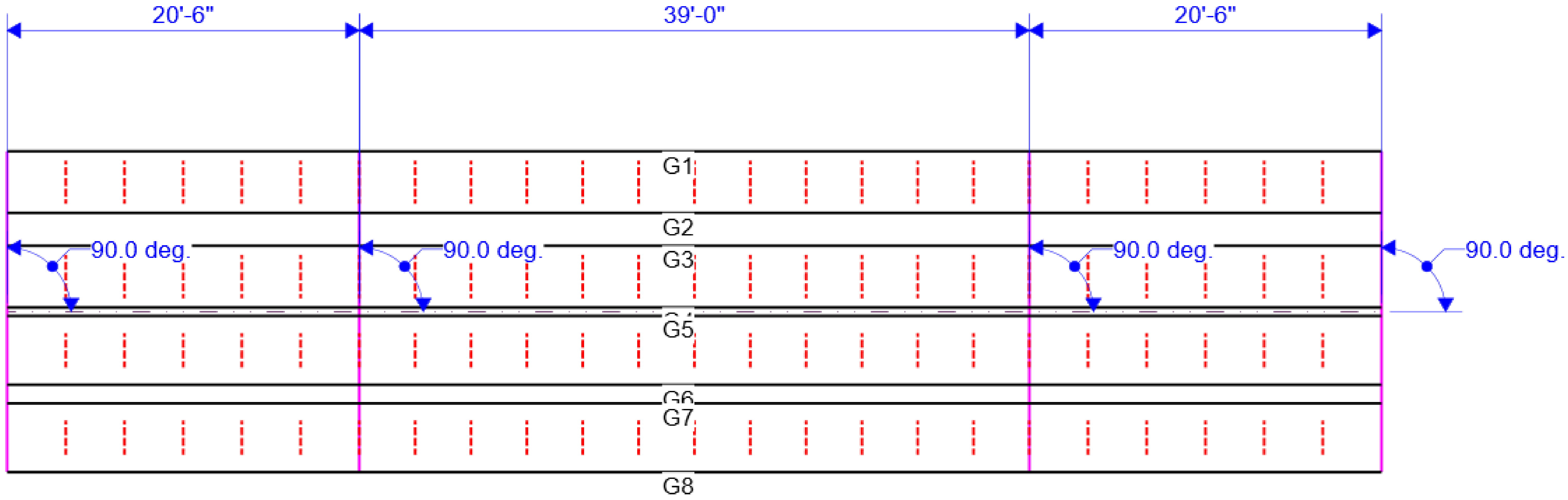
$$w_{stringer\_F} := \gamma_{steel} \cdot A_{stringer\_F} = 15.153\ \frac{lbf}{ft}$$

AASHTOWare™ BRIDGE DESIGN AND RATING

Framing Plan in BrR

Mathcad | **BrR** | Mathcad

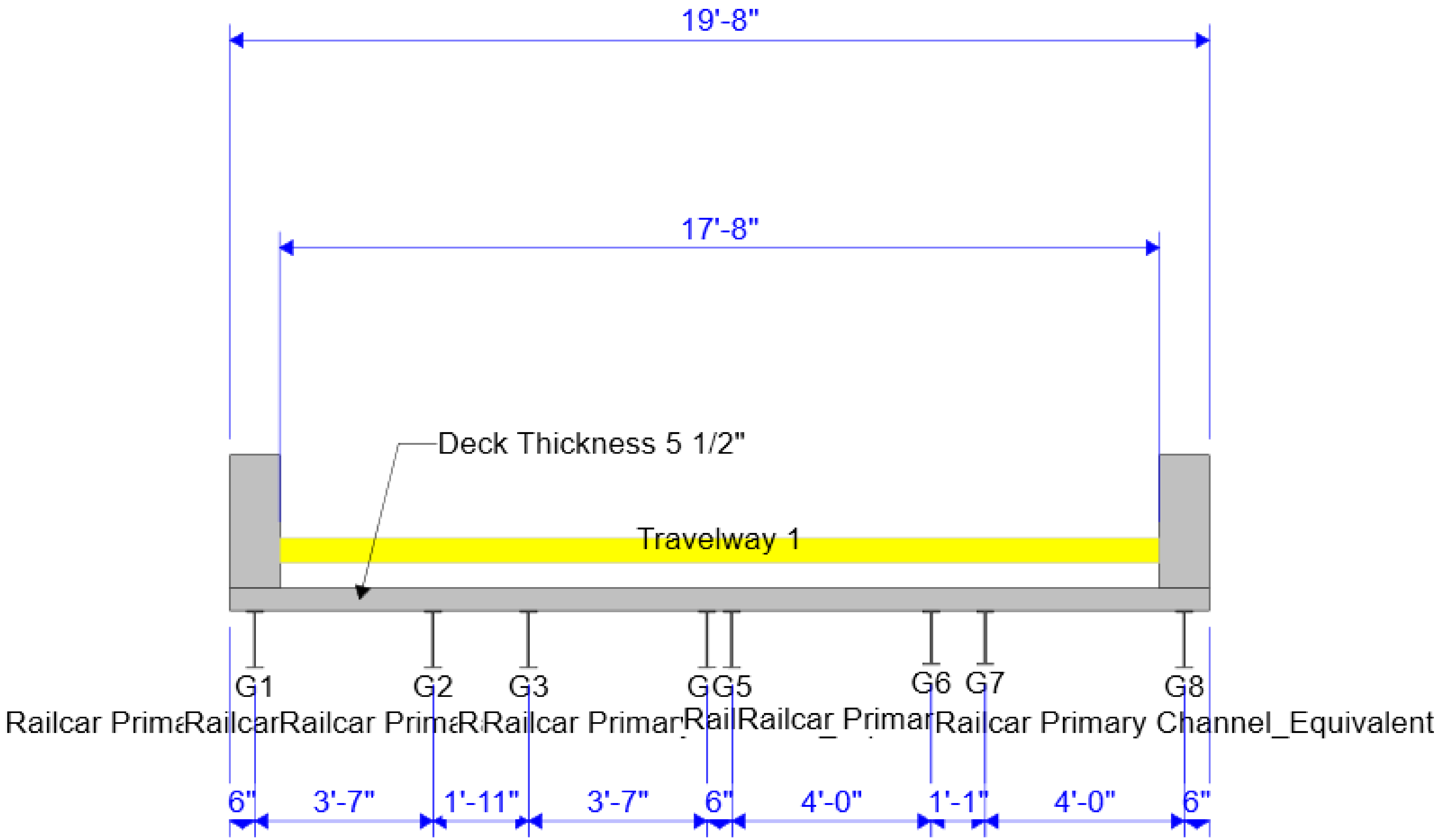
- Each Channel / Z-Shape and Diaphragm entered Individually



AASHTOWare™ BRIDGE DESIGN AND RATING

Typical Section in BrR

Mathcad BrR Mathcad



AASHTOWare™ BRIDGE DESIGN AND RATING

Primary Member Properties in BrR

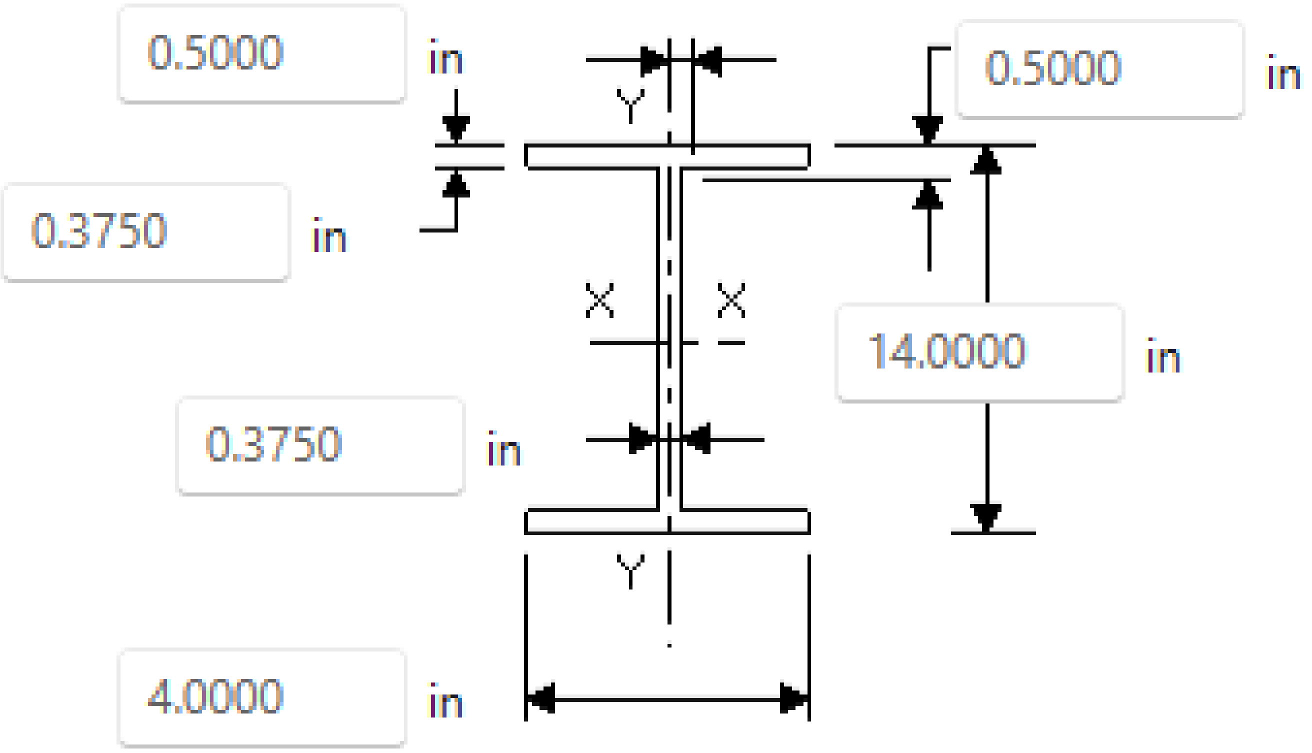
Channels

- Z-Shapes and Diaphragms similar

Name: Railcar Primary Channel_Equivalent

Description:

Dimensions | Properties



Name: Railcar Primary Channel_Equivalent

Description:

Dimensions | Properties

Area:	8.156	in^2
Nominal load:	27.750	lb/ft
Ix:	411.988	in^4
Iy:	393.231	in^4
Zx:	56.971	in^3
Zy:		in^3
Nominal depth:	14.0000	in

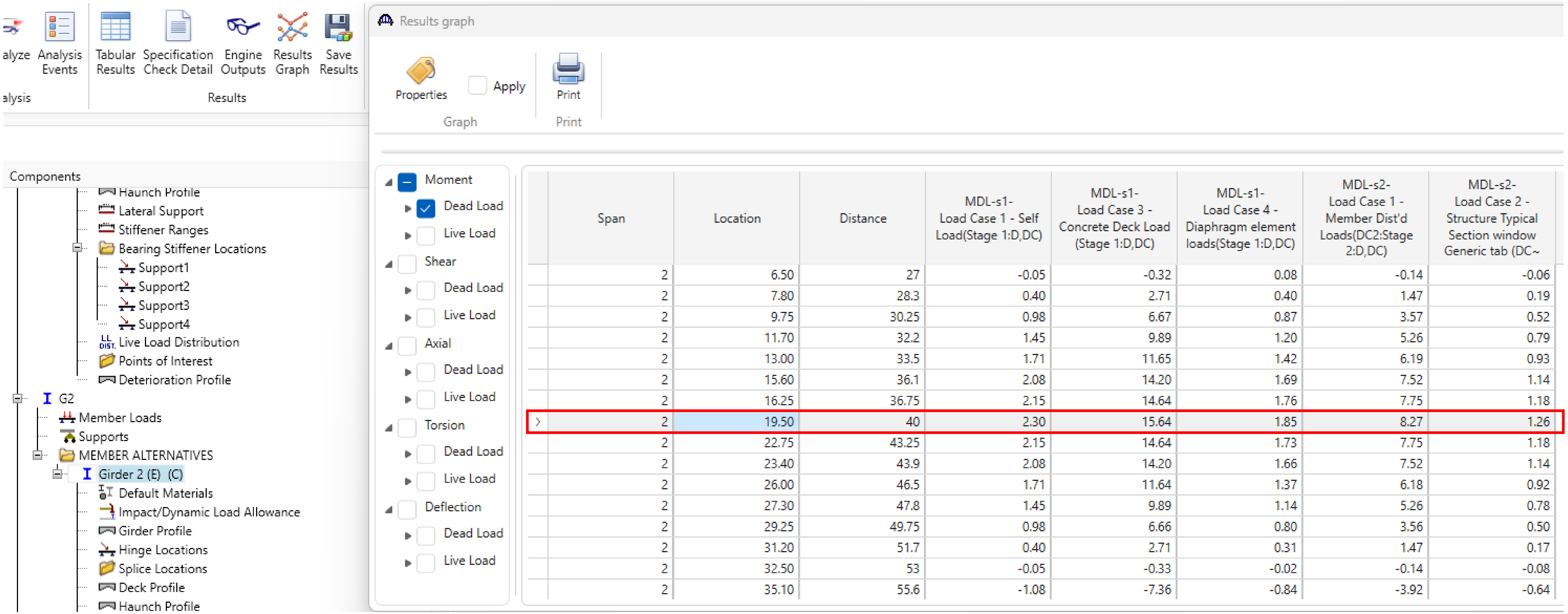
AASHTOWare™ BRIDGE DESIGN AND RATING

Pulling Loads from BrR

Mathcad → ***BrR*** → Mathcad

Dead Load to G2

- @ center of Main Span (+M controlling location)



Span	Location	Distance	MDL-s1-Load Case 1 - Self Load(Stage 1:D,DC)	MDL-s1-Load Case 3 - Concrete Deck Load (Stage 1:D,DC)	MDL-s1-Load Case 4 - Diaphragm element loads(Stage 1:D,DC)	MDL-s2-Load Case 1 - Member Dist'd Loads(DC2:Stage 2:D,DC)	MDL-s2-Load Case 2 - Structure Typical Section window Generic tab (DC~
2	6.50	27	-0.05	-0.32	0.08	-0.14	-0.06
2	7.80	28.3	0.40	2.71	0.40	1.47	0.19
2	9.75	30.25	0.98	6.67	0.87	3.57	0.52
2	11.70	32.2	1.45	9.89	1.20	5.26	0.79
2	13.00	33.5	1.71	11.65	1.42	6.19	0.93
2	15.60	36.1	2.08	14.20	1.69	7.52	1.14
2	16.25	36.75	2.15	14.64	1.76	7.75	1.18
2	19.50	40	2.30	15.64	1.85	8.27	1.26
2	22.75	43.25	2.15	14.64	1.73	7.75	1.18
2	23.40	43.9	2.08	14.20	1.66	7.52	1.14
2	26.00	46.5	1.71	11.64	1.37	6.18	0.92
2	27.30	47.8	1.45	9.89	1.14	5.26	0.78
2	29.25	49.75	0.98	6.66	0.80	3.56	0.50
2	31.20	51.7	0.40	2.71	0.31	1.47	0.17
2	32.50	53	-0.05	-0.33	-0.02	-0.14	-0.08
2	35.10	55.6	-1.08	-7.36	-0.84	-3.92	-0.64

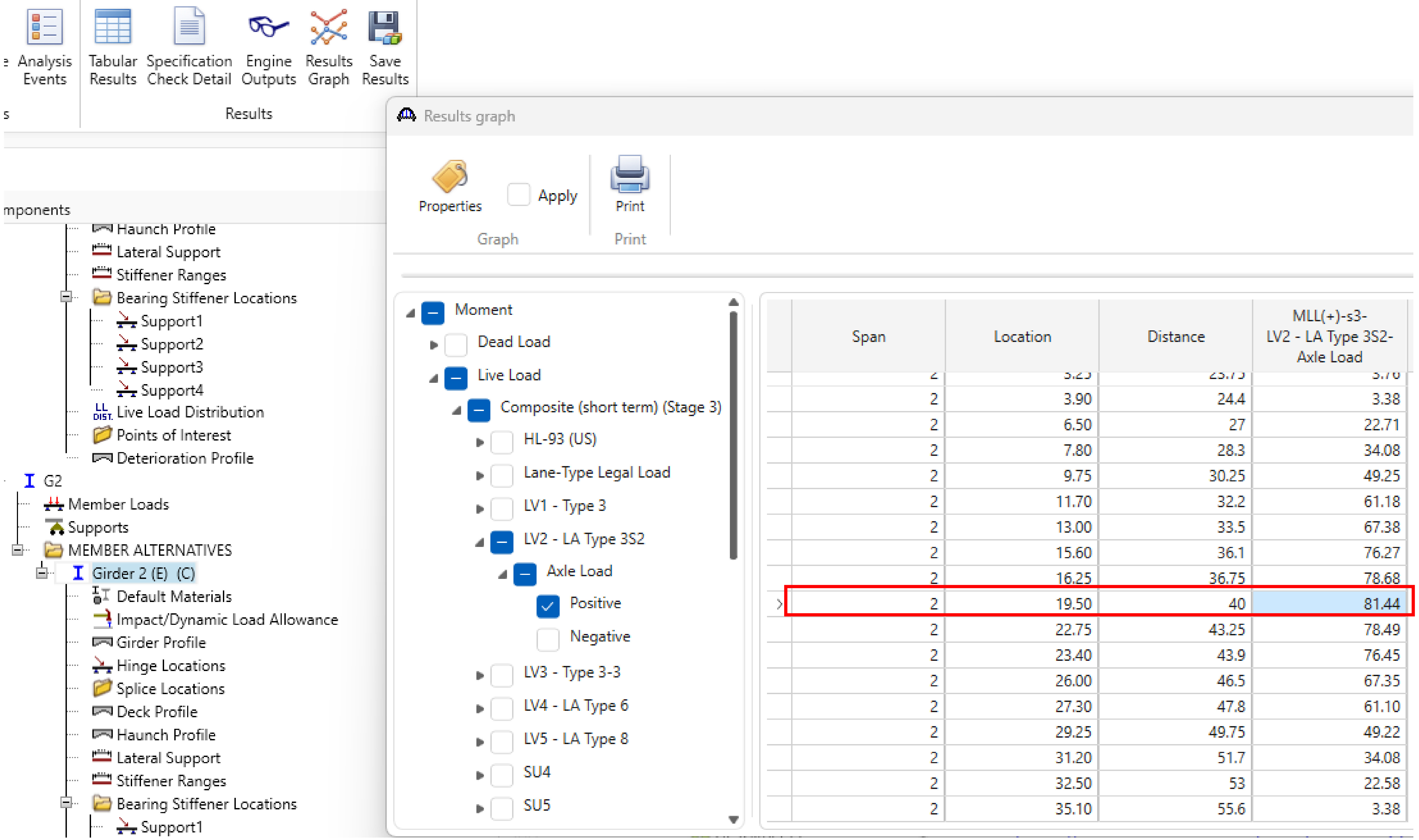
AASHTOWare™ BRIDGE DESIGN AND RATING

Pulling Loads from BrR

Mathcad → **BrR** → Mathcad

Live Load to G2

- @ center of Main Span (+M controlling location)



AASHTOWare™ BRIDGE DESIGN AND RATING

BrR Loads into Mathcad

Mathcad → BrR → ***Mathcad***

DC Loads (Stringer 2)

+M @ center of main span

$$\gamma M_{DC\_positive} := \gamma_{DC} \cdot \begin{bmatrix} 2.30 \cdot kip \cdot ft + 13.03 \cdot kip \cdot ft + 1.85 \cdot kip \cdot ft + 8.75 \cdot kip \cdot ft + 2.24 \cdot kip \cdot ft \\ 2.30 \cdot kip \cdot ft + 15.64 \cdot kip \cdot ft + 1.85 \cdot kip \cdot ft + 8.27 \cdot kip \cdot ft + 1.26 \cdot kip \cdot ft \\ 2.30 \cdot kip \cdot ft + 15.64 \cdot kip \cdot ft + 1.85 \cdot kip \cdot ft + 7.97 \cdot kip \cdot ft + 0.84 \cdot kip \cdot ft \\ 2.30 \cdot kip \cdot ft + 11.61 \cdot kip \cdot ft + 1.85 \cdot kip \cdot ft + 7.20 \cdot kip \cdot ft + 0.49 \cdot kip \cdot ft \\ 2.30 \cdot kip \cdot ft + 12.80 \cdot kip \cdot ft + 2.07 \cdot kip \cdot ft + 7.15 \cdot kip \cdot ft + 0.49 \cdot kip \cdot ft \\ 4.40 \cdot kip \cdot ft + 14.45 \cdot kip \cdot ft + 2.07 \cdot kip \cdot ft + 7.79 \cdot kip \cdot ft + 1.00 \cdot kip \cdot ft \\ 4.40 \cdot kip \cdot ft + 14.45 \cdot kip \cdot ft + 2.07 \cdot kip \cdot ft + 7.71 \cdot kip \cdot ft + 1.28 \cdot kip \cdot ft \\ 2.30 \cdot kip \cdot ft + 14.22 \cdot kip \cdot ft + 2.07 \cdot kip \cdot ft + 6.74 \cdot kip \cdot ft + 2.19 \cdot kip \cdot ft \end{bmatrix} = \begin{bmatrix} 35.213 \\ 36.65 \\ 35.75 \\ 29.313 \\ 31.013 \\ 37.138 \\ 37.388 \\ 34.4 \end{bmatrix} kip \cdot ft$$

-M @ Interior Support

$$\gamma M_{DC\_negative} := \gamma_{DC} \cdot \begin{bmatrix} 2.98 \cdot kip \cdot ft + 16.91 \cdot kip \cdot ft + 2.40 \cdot kip \cdot ft + 11.13 \cdot kip \cdot ft + 3.76 \cdot kip \cdot ft \\ 2.98 \cdot kip \cdot ft + 20.29 \cdot kip \cdot ft + 2.40 \cdot kip \cdot ft + 11.08 \cdot kip \cdot ft + 1.58 \cdot kip \cdot ft \\ 2.98 \cdot kip \cdot ft + 20.29 \cdot kip \cdot ft + 2.40 \cdot kip \cdot ft + 10.65 \cdot kip \cdot ft + 0.80 \cdot kip \cdot ft \\ 2.98 \cdot kip \cdot ft + 15.07 \cdot kip \cdot ft + 2.40 \cdot kip \cdot ft + 9.30 \cdot kip \cdot ft + 0.31 \cdot kip \cdot ft \\ 2.98 \cdot kip \cdot ft + 16.60 \cdot kip \cdot ft + 2.67 \cdot kip \cdot ft + 9.18 \cdot kip \cdot ft + 0.30 \cdot kip \cdot ft \\ 5.72 \cdot kip \cdot ft + 18.67 \cdot kip \cdot ft + 2.68 \cdot kip \cdot ft + 9.95 \cdot kip \cdot ft + 0.97 \cdot kip \cdot ft \\ 5.72 \cdot kip \cdot ft + 18.76 \cdot kip \cdot ft + 2.68 \cdot kip \cdot ft + 9.90 \cdot kip \cdot ft + 1.55 \cdot kip \cdot ft \\ 2.98 \cdot kip \cdot ft + 18.45 \cdot kip \cdot ft + 2.67 \cdot kip \cdot ft + 8.67 \cdot kip \cdot ft + 3.76 \cdot kip \cdot ft \end{bmatrix} = \begin{bmatrix} 46.475 \\ 47.913 \\ 46.4 \\ 37.575 \\ 39.663 \\ 47.488 \\ 48.263 \\ 45.663 \end{bmatrix} kip \cdot ft$$

Shear @ Interior Support

$$\gamma V_{DC} := \gamma_{DC} \cdot \begin{bmatrix} 0.54 \cdot kip + 3.07 \cdot kip + 0.45 \cdot kip + 1.99 \cdot kip + 0.76 \cdot kip \\ 0.54 \cdot kip + 3.69 \cdot kip + 0.45 \cdot kip + 2.08 \cdot kip + 0.24 \cdot kip \\ 0.54 \cdot kip + 3.69 \cdot kip + 0.45 \cdot kip + 1.97 \cdot kip + 0.09 \cdot kip \\ 0.54 \cdot kip + 2.74 \cdot kip + 0.45 \cdot kip + 1.69 \cdot kip + 0.03 \cdot kip \\ 0.54 \cdot kip + 3.02 \cdot kip + 0.50 \cdot kip + 1.65 \cdot kip + 0.02 \cdot kip \\ 1.04 \cdot kip + 3.41 \cdot kip + 0.50 \cdot kip + 1.78 \cdot kip + 0.11 \cdot kip \\ 1.04 \cdot kip + 3.41 \cdot kip + 0.50 \cdot kip + 1.81 \cdot kip + 0.24 \cdot kip \\ 0.54 \cdot kip + 3.35 \cdot kip + 0.50 \cdot kip + 1.54 \cdot kip + 0.76 \cdot kip \end{bmatrix} = \begin{bmatrix} 8.513 \\ 8.75 \\ 8.425 \\ 6.813 \\ 7.163 \\ 8.55 \\ 8.75 \\ 8.363 \end{bmatrix} kip$$

AASHTOWare™ BRIDGE DESIGN AND RATING

BrR Loads into Mathcad

Mathcad › BrR › ***Mathcad***

Live Loads (Stringer 2)

+M @ center of main span

$\gamma M_{LL\_positive} :=$

"Vehicle"	"Stringer 2"
"HL93 Inv"	$1.75 \cdot 104.35 \cdot kip \cdot ft$
"HL93 Op"	$1.35 \cdot 104.35 \cdot kip \cdot ft$
"Type 3"	$\gamma_{Legal} \cdot 64.60 \cdot kip \cdot ft$
"LA Type 3S2"	$\gamma_{Legal} \cdot 81.44 \cdot kip \cdot ft$
"Type 3–3"	$\gamma_{Legal} \cdot 50.19 \cdot kip \cdot ft$
"LA Type 6"	$\gamma_{Legal} \cdot 64.87 \cdot kip \cdot ft$
"LAType 8"	$\gamma_{Legal} \cdot 71.33 \cdot kip \cdot ft$
"SU4"	$\gamma_{Legal} \cdot 75.15 \cdot kip \cdot ft$
"SU5"	$\gamma_{Legal} \cdot 78.92 \cdot kip \cdot ft$
"SU6"	$\gamma_{Legal} \cdot 85.46 \cdot kip \cdot ft$
"SU7"	$\gamma_{Legal} \cdot 89.00 \cdot kip \cdot ft$
"EV2"	$\gamma_{EV} \cdot 80.48 \cdot kip \cdot ft$
"EV3"	$\gamma_{EV} \cdot 116.65 \cdot kip \cdot ft$

-M @ Interior Support

$\gamma M_{LL\_negative} :=$

"Vehicle"	"Stringer 2"
"HL93 Inv"	$1.75 \cdot 93.55 \cdot kip \cdot ft$
"HL93 Op"	$1.35 \cdot 93.55 \cdot kip \cdot ft$
"Type 3"	$\gamma_{Legal} \cdot 52.92 \cdot kip \cdot ft$
"LA Type 3S2"	$\gamma_{Legal} \cdot 76.60 \cdot kip \cdot ft$
"Type 3–3"	$\gamma_{Legal} \cdot 54.49 \cdot kip \cdot ft$
"LA Type 6"	$\gamma_{Legal} \cdot 70.81 \cdot kip \cdot ft$
"LAType 8"	$\gamma_{Legal} \cdot 77.56 \cdot kip \cdot ft$
"SU4"	$\gamma_{Legal} \cdot 61.02 \cdot kip \cdot ft$
"SU5"	$\gamma_{Legal} \cdot 66.85 \cdot kip \cdot ft$
"SU6"	$\gamma_{Legal} \cdot 75.2 \cdot kip \cdot ft$
"SU7"	$\gamma_{Legal} \cdot 82.21 \cdot kip \cdot ft$
"EV2"	$\gamma_{EV} \cdot 62.17 \cdot kip \cdot ft$
"EV3"	$\gamma_{EV} \cdot 93.0 \cdot kip \cdot ft$

Shear @ Interior Support

$\gamma V_{LL} :=$ … $=$

"Vehicle"	"Stringer 2"	"Vehicle"	"Stringer 2"
"HL93 Inv"	$1.75 \cdot 33.68 \cdot kip$	"HL93 Inv"	$58940\ lbf$
"HL93 Op"	$1.35 \cdot 33.68 \cdot kip$	"HL93 Op"	$45468\ lbf$
"Type 3"	$\gamma_{Legal} \cdot 20.75 \cdot kip$	"Type 3"	$26975\ lbf$
"LA Type 3S2"	$\gamma_{Legal} \cdot 25.24 \cdot kip$	"LA Type 3S2"	$32812\ lbf$
"Type 3–3"	$\gamma_{Legal} \cdot 17.52 \cdot kip$	"Type 3–3"	$22776\ lbf$
"LA Type 6"	$\gamma_{Legal} \cdot 22.71 \cdot kip$	"LA Type 6"	$29523\ lbf$
"LAType 8"	$\gamma_{Legal} \cdot 25.09 \cdot kip$	"LAType 8"	$32617\ lbf$
"SU4"	$\gamma_{Legal} \cdot 22.63 \cdot kip$	"SU4"	$29419\ lbf$
"SU5"	$\gamma_{Legal} \cdot 24.10 \cdot kip$	"SU5"	$31330\ lbf$
"SU6"	$\gamma_{Legal} \cdot 24.41 \cdot kip$	"SU6"	$31733\ lbf$
"SU7"	$\gamma_{Legal} \cdot 24.73 \cdot kip$	"SU7"	$32149\ lbf$
"EV2"	$\gamma_{EV} \cdot 26.86 \cdot kip$	"EV2"	$29546\ lbf$
"EV3"	$\gamma_{EV} \cdot 36.96 \cdot kip$	"EV3"	$40656\ lbf$

AASHTOWare™ BRIDGE DESIGN AND RATING

Calculating Capacity in Mathcad

Stringer 2 +M Capacity (@ center of span)

Capacity of Channels (AASHTO LRFD)

6.12.2.2.5—Channels

For channels in flexure about their strong or *x*-axis, the nominal flexural resistance shall be taken as the smaller value based on yielding or LTB, as applicable.

For yielding, the nominal flexural resistance shall be taken as:

$$M_n = M_p = F_y Z_x \qquad (6.12.2.2.5\text{-}1)$$

where:

F_y = specified minimum yield strength (ksi)
M_p = plastic moment (kip-in.)
Z_x = plastic section modulus about the *x*-axis (in.[3])

Stringer 2:

$$y_{pna\_2} := 13.960875\ in$$

$$A_{stringer2\_above} := b_{deck\_plate} \cdot t_{deck\_plate1} + b_{f2} \cdot (d - y_{pna\_2}) = 7.81\ in^2$$

$$A_{stringer2\_below} := b_{f1} \cdot t_{f1} + t_w \cdot (d - t_{f1} - t_{f2}) + b_{f2} \cdot (y_{pna\_2} - t_{f1} - (d - t_{f1} - t_{f2})) = 7.81\ in^2$$

LOTS of calcs between what is shown above & below

$$Z_{x\_prime\_channel\_pos\_moment} := \begin{Vmatrix} \text{for } i \in 0..n-1 \\ \quad \| Z_{x\_prime\_channel\_pos\_moment_{i,0}} \leftarrow A_{c_{i,0}} \cdot y_{c_{i,0}} + A_{t_{i,0}} \cdot y_{t_{i,0}} \\ Z_{x\_prime\_channel\_pos\_moment} \end{Vmatrix}$$

$$M_{p\_prime\_channel\_pos\_moment} := F_y \cdot Z_{x\_prime\_channel\_pos\_moment} = \begin{bmatrix} 170.914 \\ 170.914 \\ 170.914 \\ 170.914 \\ 170.914 \\ 290.619 \\ 290.619 \\ 170.914 \end{bmatrix} kip \cdot ft$$

AASHTOWare™ BRIDGE DESIGN AND RATING

Calculating Capacity in Mathcad

Mathcad → BrR → ***Mathcad***

Stringer 2 LTB Check (@ Interior Support)

AASHTO LRFD LTB Check (6.12.2.2.5)

Where the unbraced length L_b exceeds L_p, LTB shall be checked. For LTB, the nominal flexural resistance shall be taken as:

- If $L_b \leq L_r$, then:

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_yS_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] \leq M_p \qquad (6.12.2.2.5\text{-}2)$$

- If $L_b > L_r$, then:

$$M_n = F_{cr}S_x \leq M_p \qquad (6.12.2.2.5\text{-}3)$$

From AASHTO LRFD 6.12.2.2.5 Commentary:

- Where Lb ≤ Lp, LTB does not control and need not be checked.

$$E := 29000\ ksi$$

$$L_b := 3.4167\ ft$$

$$L_p := 1.76 \cdot r_{yy} \cdot \sqrt{\frac{E}{F_y}} = \begin{bmatrix} 23.694 \\ 20.883 \\ 20.883 \\ 27.086 \\ 27.086 \\ 22.331 \\ 22.331 \\ 23.694 \end{bmatrix} ft$$

AASHTOWare™ BRIDGE DESIGN AND RATING

Calculating Capacity in Mathcad

Stringer 2 Shear Capacity (@ Interior Support)

AASHTO LRFD 6.10.9.3.2

- Ratio of shear-buckling resistance to the shear yield strength

$k_1 := 5$

$$C := \begin{cases} 1.0 & \text{if } \dfrac{d}{t_w} \le 1.12 \cdot \sqrt{\dfrac{E \cdot k_1}{F_y}} \\ \dfrac{1.12}{\dfrac{d}{t_w}} \cdot \sqrt{\dfrac{E \cdot k_1}{F_y}} & \text{if } 1.12 \cdot \sqrt{\dfrac{E \cdot k_1}{F_y}} < \dfrac{d}{t_w} \le 1.40 \cdot \sqrt{\dfrac{E \cdot k_1}{F_y}} \\ \dfrac{1.57}{\left(\dfrac{d}{t_w}\right)^2} \cdot \left(\dfrac{E \cdot k_1}{F_y}\right) & \text{if } \dfrac{d}{t_w} > 1.40 \cdot \sqrt{\dfrac{E \cdot k_1}{F_y}} \end{cases} = 1$$

$V_p := 0.58 \cdot F_y \cdot d \cdot t_w = 109.62 \ \mathbf{kip}$ Plastic shear force (AASHTO 6.10.9.2)

$V_{cr} := C \cdot V_p = 109.62 \ \mathbf{kip}$ Shear-yielding or shear-buckling resistance (AASHTO 6.10.9.2)

$V_n := V_{cr} = 109.62 \ \mathbf{kip}$ Nominal shear resistance (AASHTO 6.10.9.2)

$\phi_v := 1.0$

$\phi V_n := \phi_v \cdot V_n = 109.62 \ \mathbf{kip}$

AASHTOWare™ BRIDGE DESIGN AND RATING

Load Rating Equation

AASHTO MBE

6A.4.2—General Load-Rating Equation

6A.4.2.1—General

The following general expression shall be used in determining the load rating of each component and connection subjected to a single force effect (i.e., axial force, flexure, or shear):

$$RF = \frac{C-(\gamma_{DC})(DC)-(\gamma_{DW})(DW)\pm(\gamma_P)(P)}{(\gamma_{LL})(LL+IM)} \quad (6A.4.2.1\text{-}1)$$

For the strength limit states:

$$C = \varphi_c \varphi_s \varphi R_n \quad (6A.4.2.1\text{-}2)$$

Where the following lower limit shall apply:

$$\varphi_c \varphi_s \geq 0.85 \quad (6A.4.2.1\text{-}3)$$

$RF_{Moment\_positive} =$

"Vehicle"	"Stringer 2"
"HL93 Inv"	0.553
"HL93 Op"	0.717
"Type 3"	1.202
"LA Type 3S2"	0.954
"Type 3–3"	1.547
"LA Type 6"	1.197
"LA Type 8"	1.089
"SU4"	1.033
"SU5"	0.984
"SU6"	0.909
"SU7"	0.873
"EV2"	1.14
"EV3"	0.787

Posting Analysis

$$\text{LRFR Posting Load} = \frac{W}{0.7}[(RF) - 0.3]$$ MBE Eq. (6A.8.3-1)

Recommended Legal Posting Load: **15-25**

AASHTOWare™ BRIDGE DESIGN AND RATING

Re-rating Summary

- 3D FEM analysis in BrR
- Primary Members
  - Channels & Z-Shapes (Main Beams)
  - Deck Plate
  - Diaphragms
- Section Properties per AASHTO LRFD 6.12.2.2.5
- Secondary Members
  - Longitudinal Stringers (DL only)
- Concrete Deck modelled as non-composite
- 15T-25T Posting (conservative)

		Superstructure/Deck/Culvert			
Vehicle Type	GVW (kips)	Rating Factor	Posting Weight (tons)	Controlling Member	Controlling Load Effect
HL-93 (INV)	N/A	0.55		Stringer 2	Flexure
HL-93 (OPR)	N/A	0.72		Stringer 2	Flexure
LADV-11(INV)	N/A				
Type 3	50.0	1.20	44.0	Stringer 2	Flexure
LA Type 3S2	**73.0**	0.93	**32.7**	**Stringer 2**	**Flexure**
Type 3-3	**80.0**	1.31	**52.2**	**Stringer 2**	**Flexure**
LA Type 6	**80.0**	1.01	**44.0**	**Stringer 2**	**Flexure**
LA Type 8	**88.0**	0.92	**38.7**	**Stringer 2**	**Flexure**
SU4	54.0	1.03	44.0	Stringer 2	Flexure
SU5	62.0	0.98	30.2	Stringer 2	Flexure
SU6	69.5	0.91	30.2	Stringer 2	Flexure
SU7	77.5	0.87	31.2	Stringer 2	Flexure
Lane-Type I	N/A				
Lane Type II	N/A				
EV2	57.5	1.14	44.0*	Stringer 2	Flexure
EV3	86.0	0.79	29.9*	Stringer 2	Flexure

* Informational purposes only

Posting Analysis Summary

	PV-Single	PV-Comb	
Superstructure	30	32	As-Design Rating: ☐
Substructure			
Recommended Legal Posting Load:		15-25	

AASHTOWare™ BRIDGE DESIGN AND RATING

Thank You!

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