Analysis of a Curved Steel Plate Girder Bridge with BrR

2015 AASHTOWare
Bridge Design and Rating Software
User Group Meeting
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Introduction

Introduction

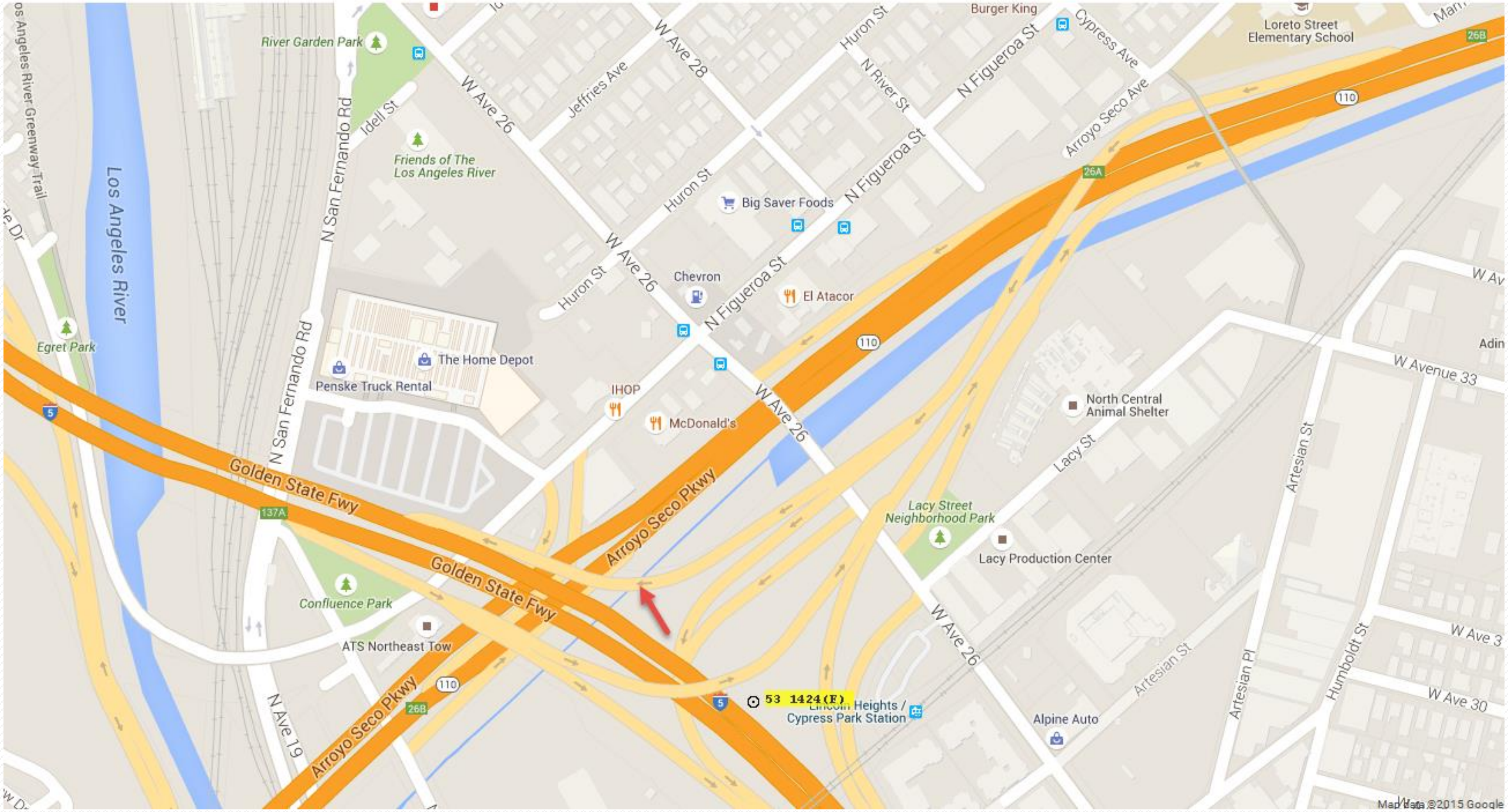
- The function of the curved steel plate girder rating analysis was introduced in V6.5 including diaphragms.
- Lateral bracing members were added in V6.6.
- Many issues in LFR analysis engine have been resolved since then.
- Only main girders are rated.

Structure Description

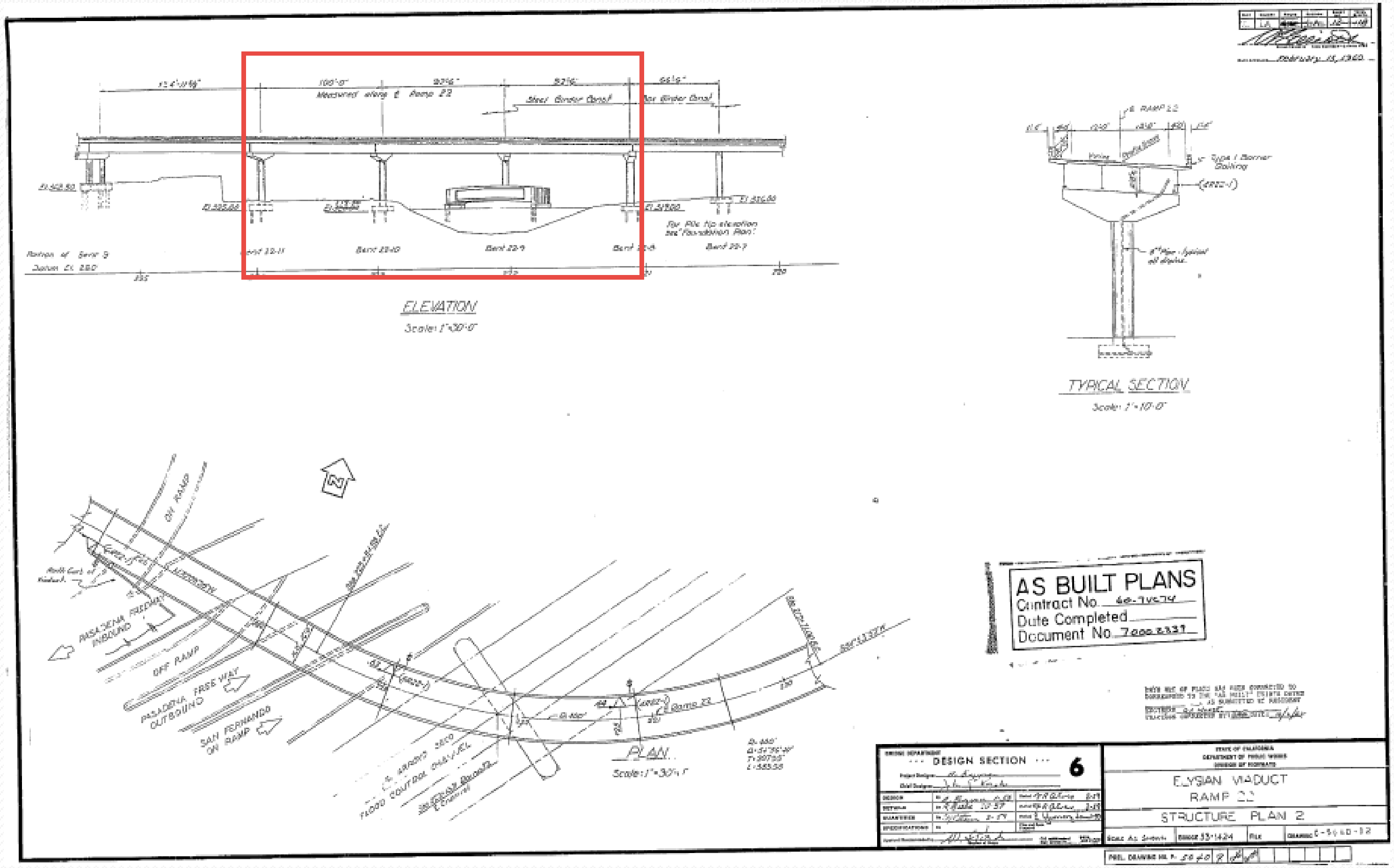
Structure Description

- Built in1962, connecting highway 110 to I-5.
- Curved Steel Plate Girders for Span 8 – 10
- Spans 8 - 9 are 2-span (92.5’-92.5’) continuous structure with curved alignment
- Span 10 is a simple span (97.5’) with curved and tangent alignment
- The RC deck with four steel girders spacing at 9’-3”.
- 400 ft radius is used for the curved alignment line.
- Maximum super elevation is 12%

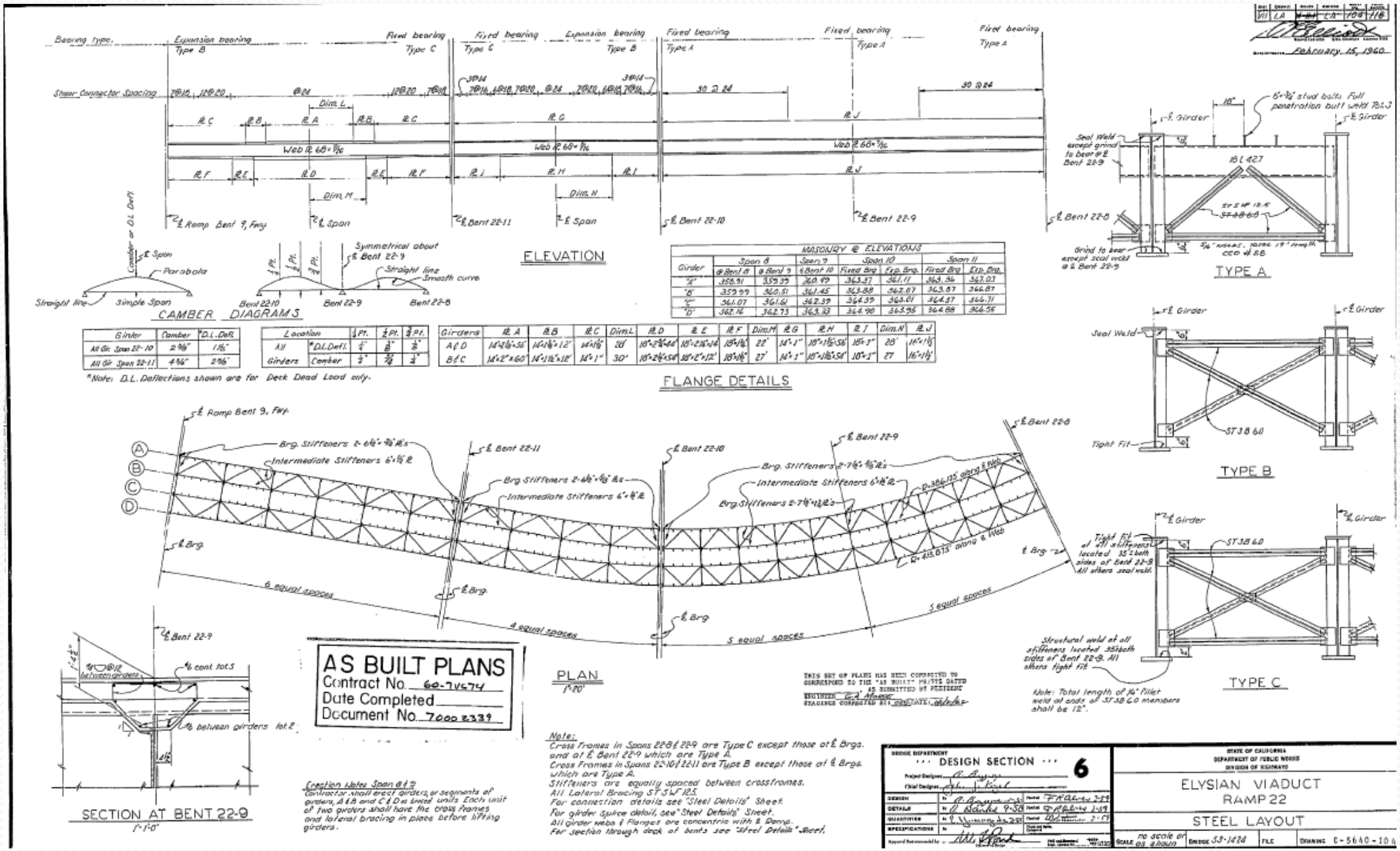
Bridge Location



Structure Plan



Steel Layout

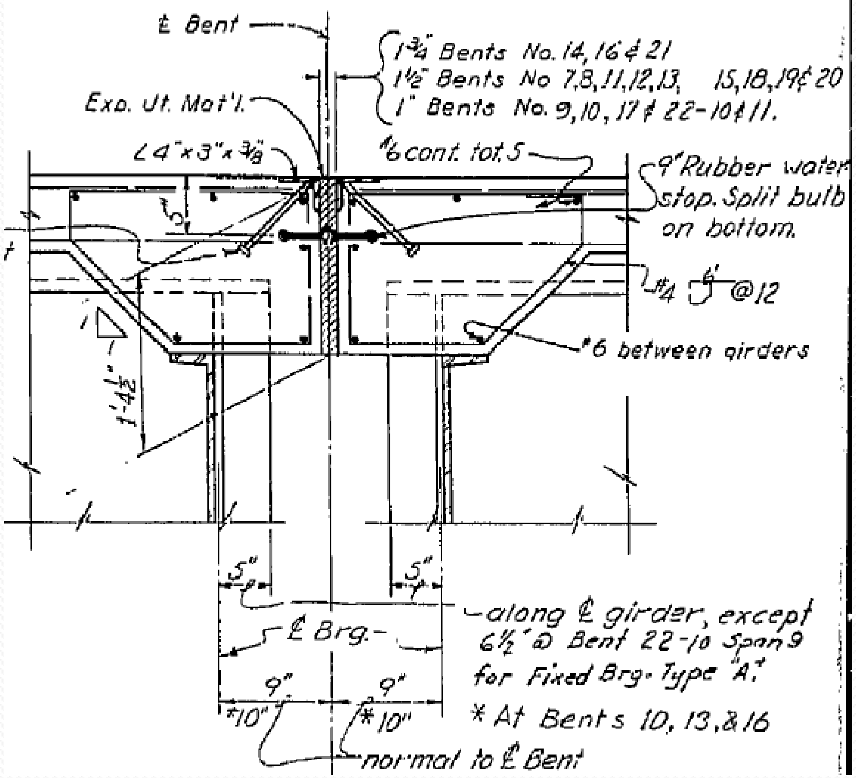


Top View

Side View

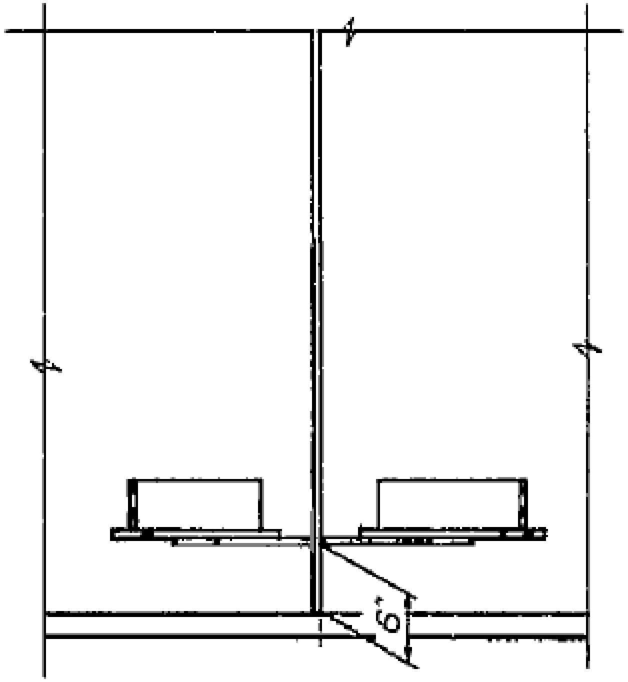
Bottom View

Girder End Details



Lateral Bracing Connection

(6" above bottom flange)



Girder Details

- Span 8-9: Web: 68” x 7/16”; Flanges: 16” x 1-1/2”
  Equal shear stiffener spacing: 53.1” to 56.9”
  Non-composite section near Bent 9
  Fixed bearings at all supports

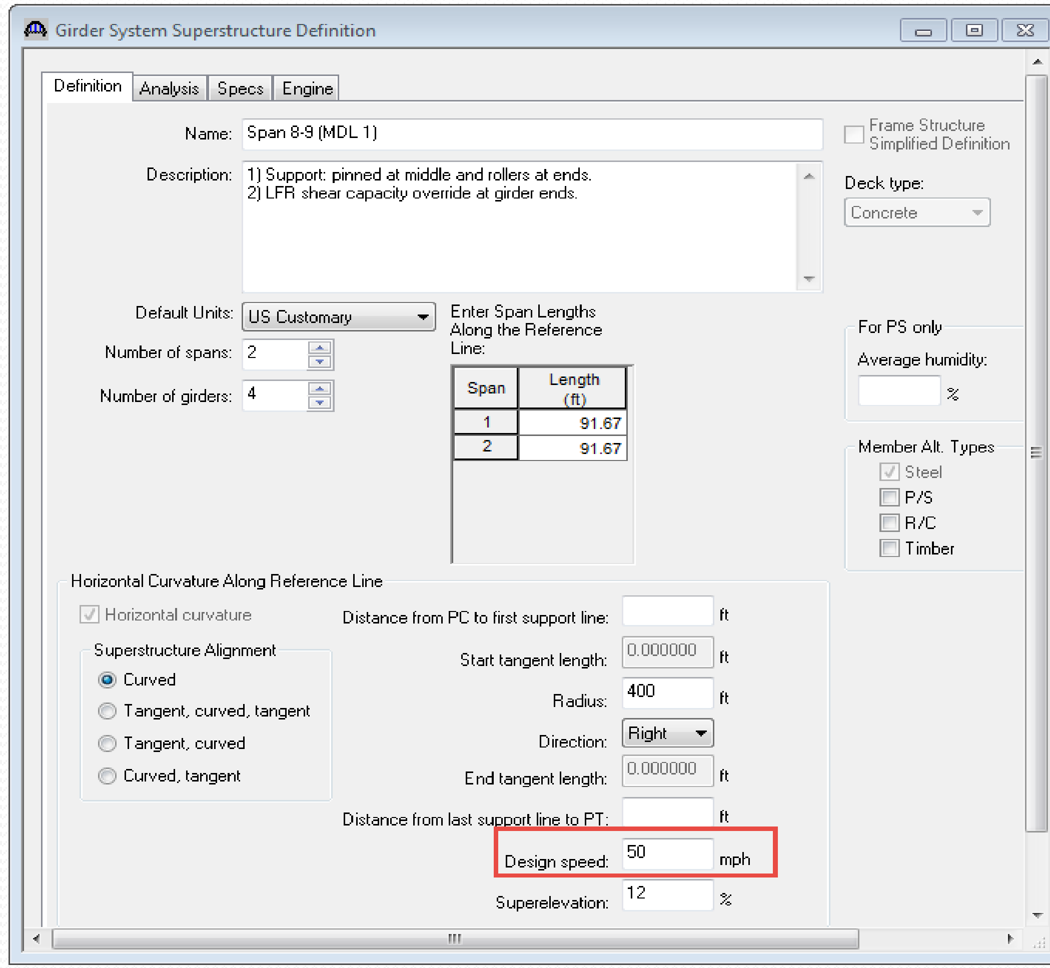
- Span 10: Web: 68 x 7/16, Stiffener Space: 47.5” to 51”
  Top Flange: 14 x 1
  Bottom Flange: 18 x 1-1/2 and 18 x 1
  Composite Section
  Expansion and fixed bearings used

Bridge Modeling

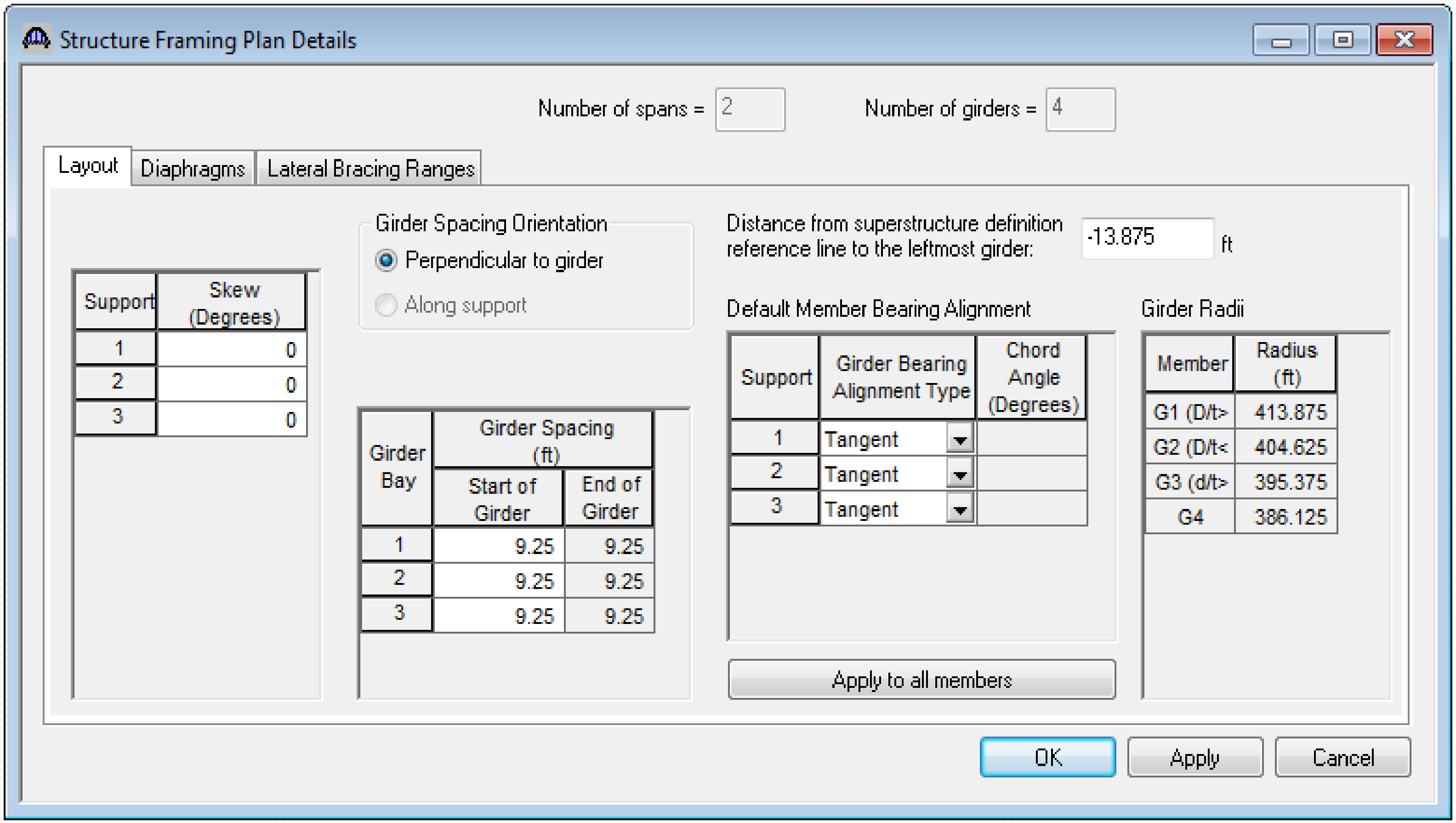
Superstructure Definition

- Curved alignment
- Radius
- Superelevation
- Design speed:

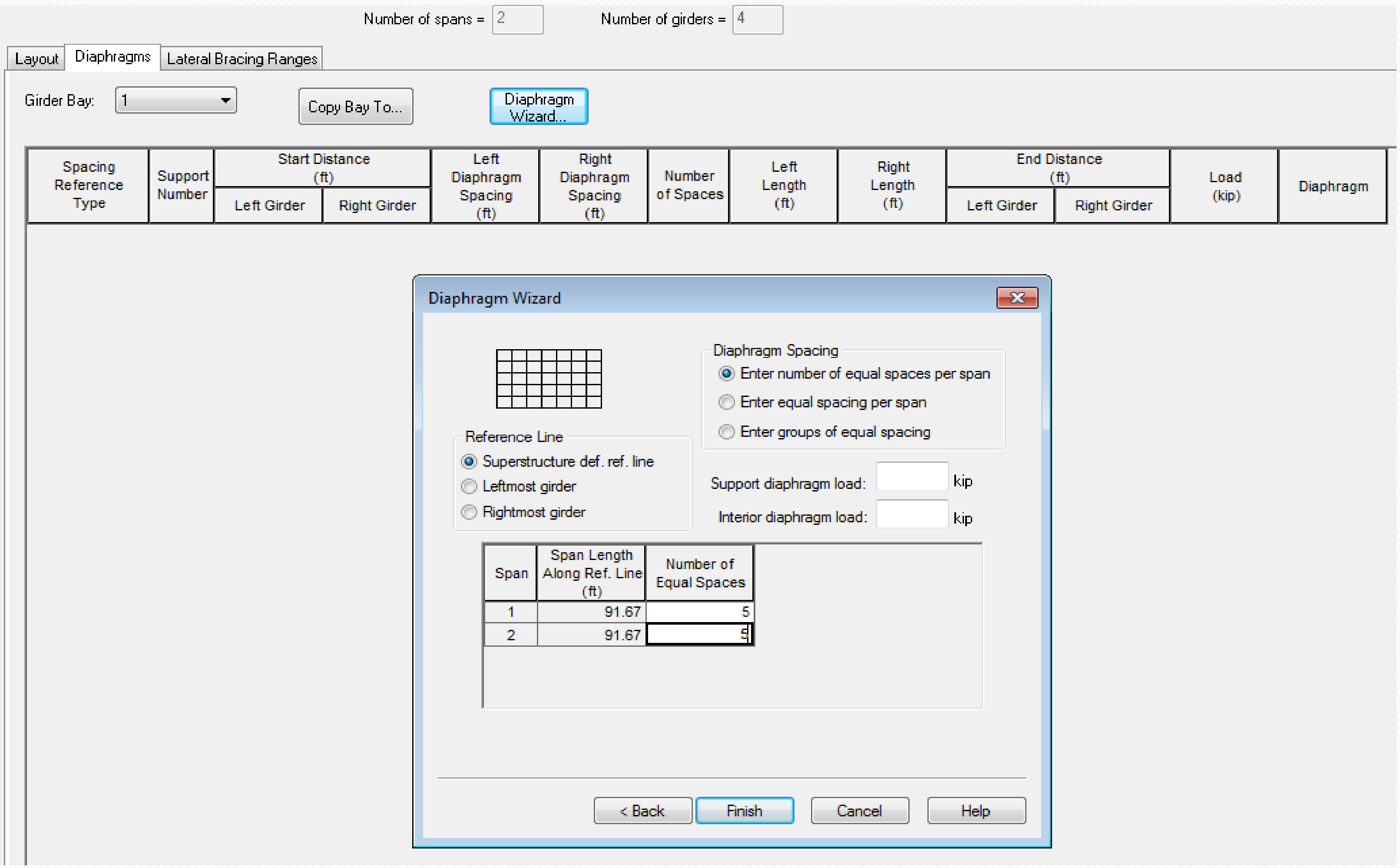
  50 mph



Structure Framing (Span 8-9)



Diaphragms (Span 8-9)



Diaphragms (cont.)

Number of spans = 2 Number of girders = 4

Layout | Diaphragms | Lateral Bracing Ranges

Girder Bay: 1 | Copy Bay To... | Diaphragm Wizard...

Spacing Reference Type	Support Number	Start Distance (ft)		Left Diaphragm Spacing (ft)	Right Diaphragm Spacing (ft)	Number of Spaces	Left Length (ft)	Right Length (ft)	End Distance (ft)		Load (kip)	Diaphragm
		Left Girder	Right Girder						Left Girder	Right Girder		
Both Gir	1	0	0	0	0	1	0	0	0	0		Type A
Both Gir	1	0	0	18.9699606	18.5459869	4	75.8798424	74.1839476	75.8798424	4.1839476		Type C
Both Gir	1	75.879842	74.183947	18.9699606	18.5459869	1	18.9699606	18.5459869	94.8498026	2.7299339		Type A
Both Gir	1	94.849803	92.729934	18.9699606	18.5459869	4	75.8798424	74.1839476	170.7296454	6.9138816		Type C
Both Gir	2	75.879842	74.183947	18.9699606	18.5459869	1	18.9699606	18.5459869	94.8498026	2.7299339		Type A

Layout | Diaphragms | Lateral Bracing Ranges

Girder Bay: 3 | Copy Bay To... | Diaphragm Wizard...

Spacing Reference Type	Support Number	Start Distance (ft)		Left Diaphragm Spacing (ft)	Right Diaphragm Spacing (ft)	Number of Spaces	Left Length (ft)	Right Length (ft)	End Distance (ft)		Load (kip)	Diaphragm
		Left Girder	Right Girder						Left Girder	Right Girder		
Both Gir	1	0	0	0	0	1	0	0	0	0		Type A
Both Gir	1	0	0	18.1220131	17.6980394	4	72.4880524	70.7921576	72.4880524	0.7921576		Type C
Both Gir	1	72.488052	70.792157	18.1220131	17.6980394	1	18.1220131	17.6980394	90.6100651	8.4901964		Type A
Both Gir	2	0	0	18.1220131	17.6980394	4	72.4880524	70.7921576	72.4880524	0.7921576		Type C
Both Gir	2	72.488052	70.792157	18.1220131	17.6980394	1	18.1220131	17.6980394	90.6100651	8.4901964		Type A

Lateral Bracing (Span 8-9)

Layout | Diaphragms | Lateral Bracing Ranges

Girder Bay: 1

Copy Bay To...

Lateral Bracing Pattern	Support Number	Start Distance (ft)		Bracing Length (ft)		Number of Braces	Lateral Bracing	Length (ft)		End Distance (ft)	
		Left Girder	Right Girder	Along Left Girder	Along Right Girder			Left	Right	Left	Right
Alternating Λ	1		0		9.273	20	LB_ST	0	185.46	0	185.46

Layout | Diaphragms | Lateral Bracing Ranges

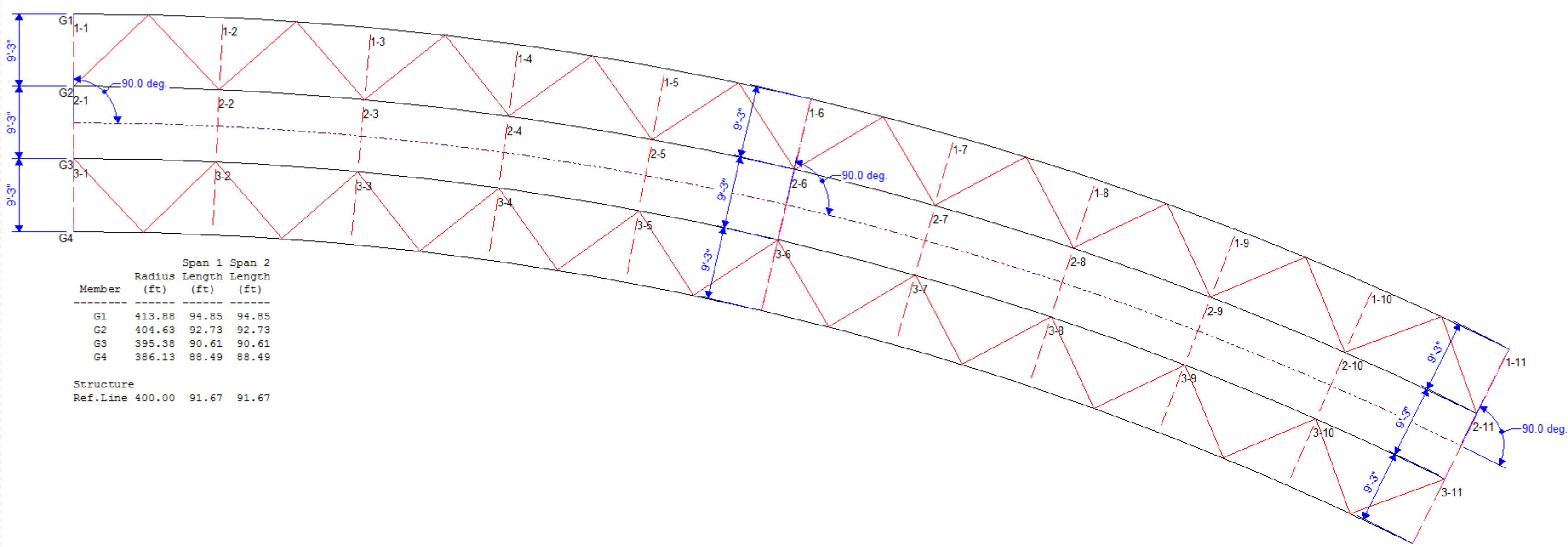
Girder Bay: 3

Copy Bay To...

Lateral Bracing Pattern	Support Number	Start Distance (ft)		Bracing Length (ft)		Number of Braces	Lateral Bracing	Length (ft)		End Distance (ft)	
		Left Girder	Right Girder	Along Left Girder	Along Right Girder			Left	Right	Left	Right
Alternating V	1	0		9.061		20	LB_ST	181.22	0	181.22	0

Framing Details: Span 8-9

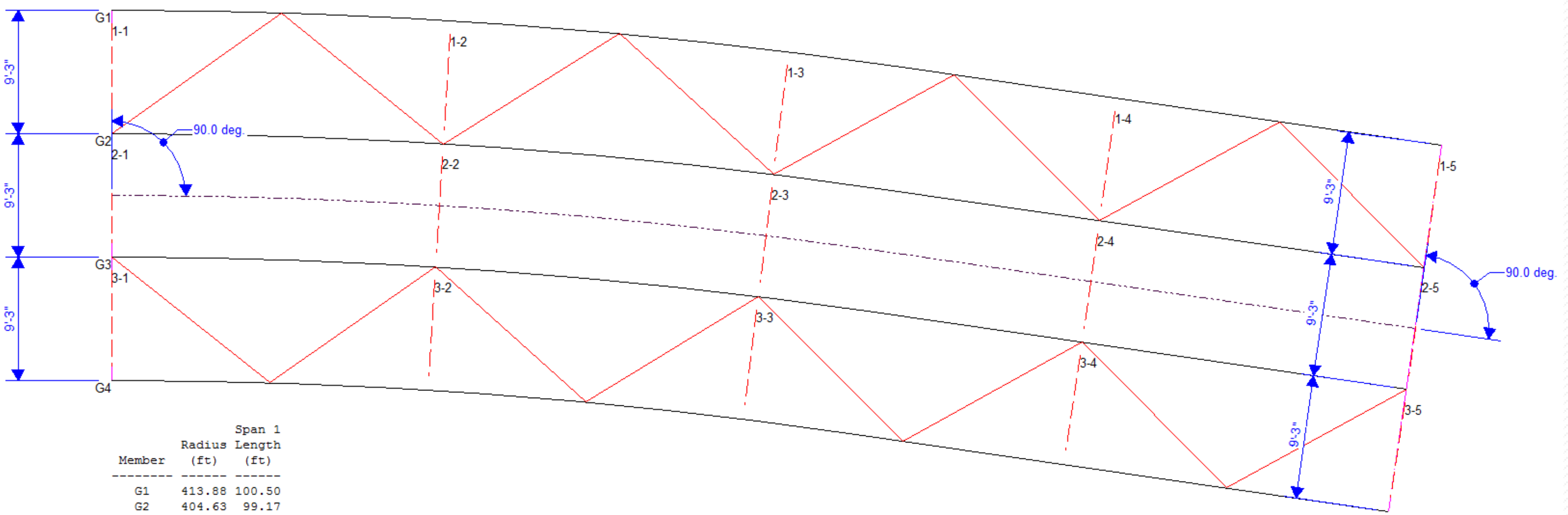
53 1424 RAMP 22
ELYSIAN VIADUCT RAMP 22 - Span 8-9 (MDL 1)
07/08/15



Member	Radius (ft)	Span 1 Length (ft)	Span 2 Length (ft)
G1	413.88	94.85	94.85
G2	404.63	92.73	92.73
G3	395.38	90.61	90.61
G4	386.13	88.49	88.49
Structure Ref.Line	400.00	91.67	91.67

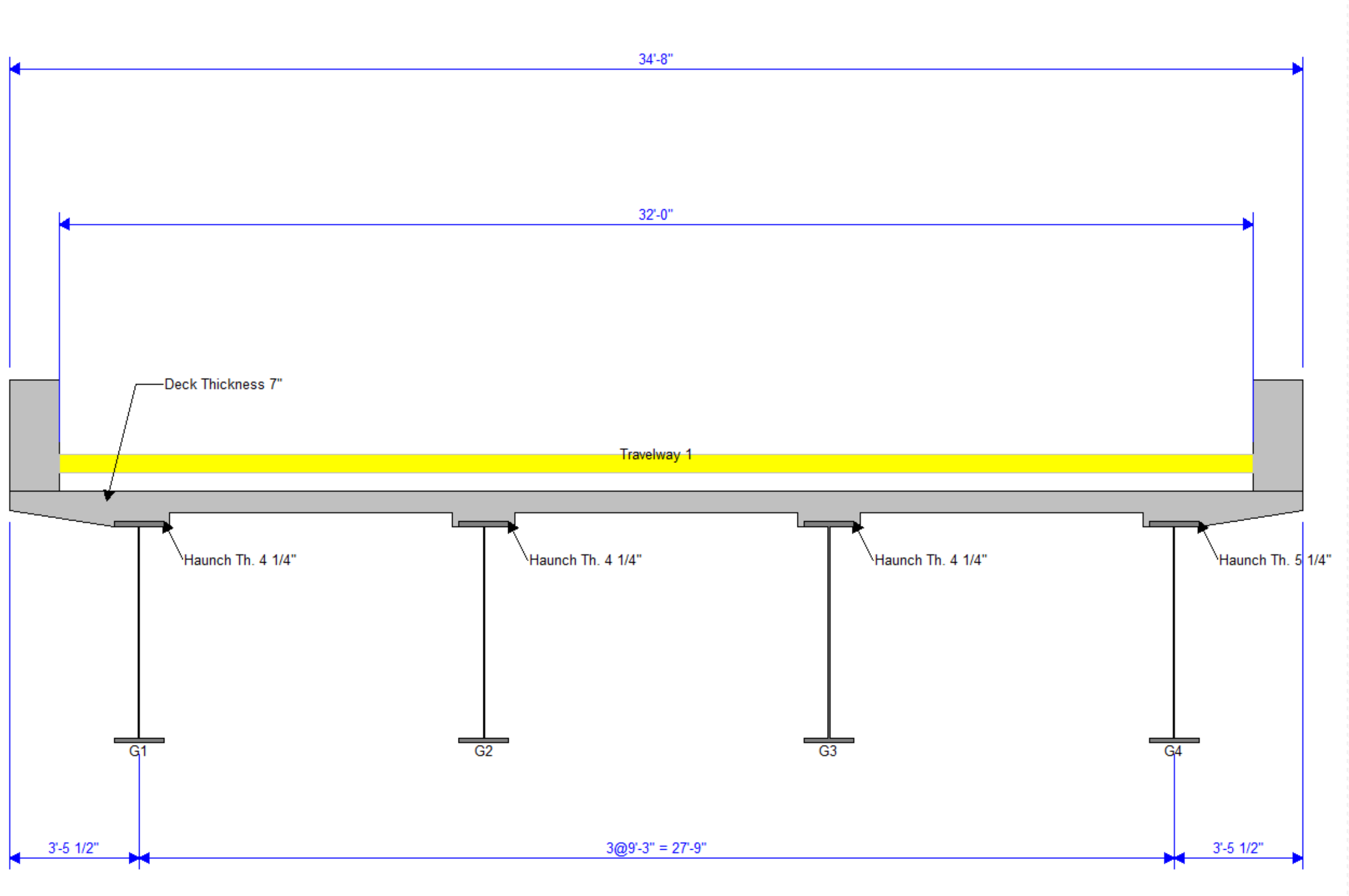
Framing Details: Span 10

53 1424 RAMP 22
ELYSIAN VIADUCT RAMP 22 - Span 10 (MDL 1)
07/08/15



Member	Radius (ft)	Span 1 Length (ft)
G1	413.88	100.50
G2	404.63	99.17
G3	395.38	97.83
G4	386.13	96.50
Structure Ref.Line	400.00	98.50

Typical Section



Shear Capacity

Shear Capacity

LFD (2003 Guide Spec)

- At simple support (end panel)

  $d_0 \le 0.5D$

- At interior panel:

  $d_0 \le D$

- Shear capacity at all location:

$$V_{cr} = CV_p$$

where:

V_p = $0.58F_yDt_w$

C = ratio of the elastic-shear-buckling strength to the shear-yield strength

LRFD (7th Ed. 2014)

- At end panel:

  $d_0 \le 1.5D$

  $V_n = V_{cr} = CV_p$

- At interior panel:

  $d_0 \le 3D$ (no LS)

$$V_n = V_p \left[C + \frac{0.87(1-C)}{\left(\sqrt{1+\left(\frac{d_o}{D}\right)^2} + \frac{d_o}{D} \right)} \right]$$

Shear Capacity in BrR (LFR)

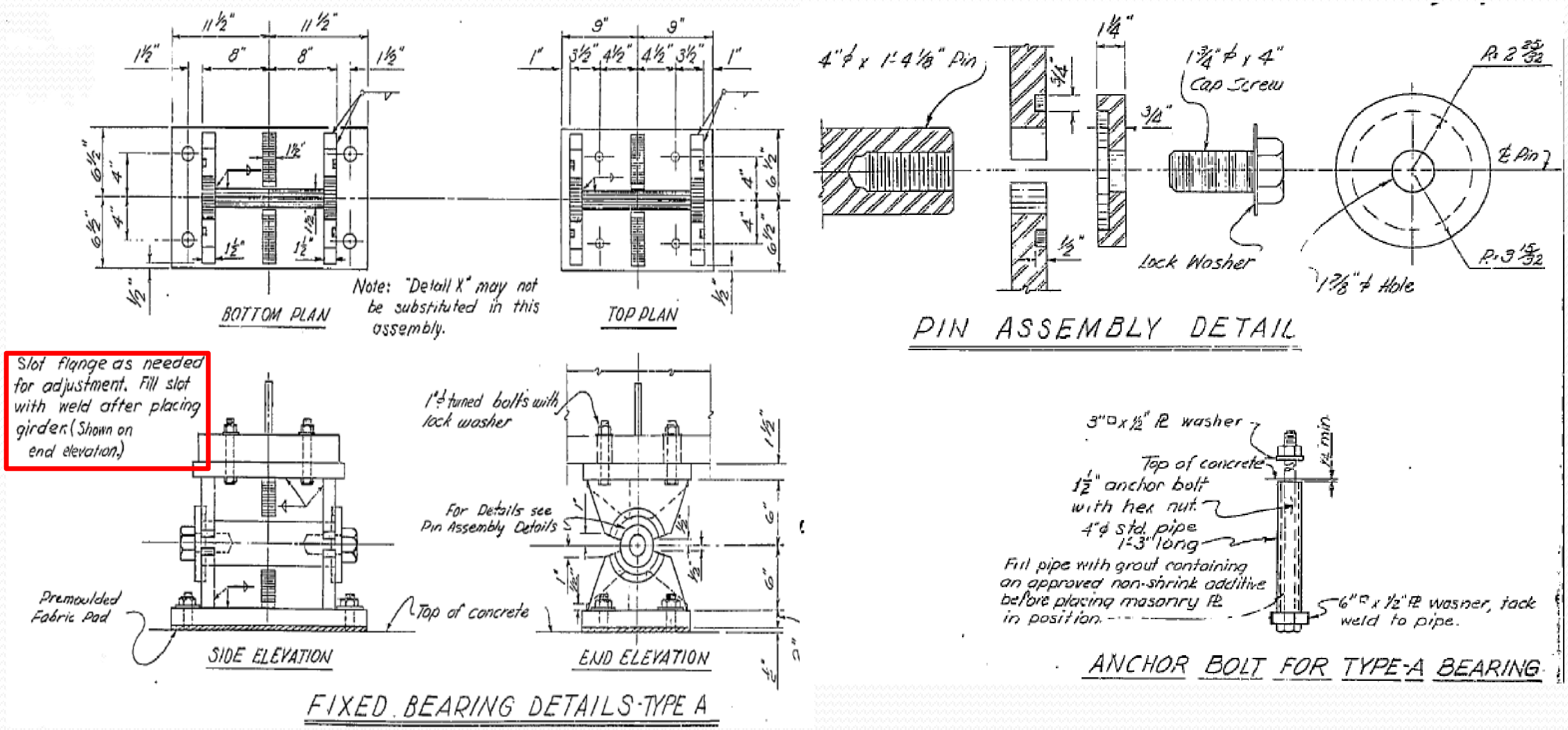
- With LFR, shear stiffener is ignored in BrR when d_0>0.5D at end support.
- For this bridge, d_o is constant along the girder and the ranges from 0.7D to 0.84D.
- For this analysis, the shear capacity override is used at span ends.
- The override capacity is calculated ignoring 0.5D limit, or the capacity at internal panel.

Shear Capacity Comparison

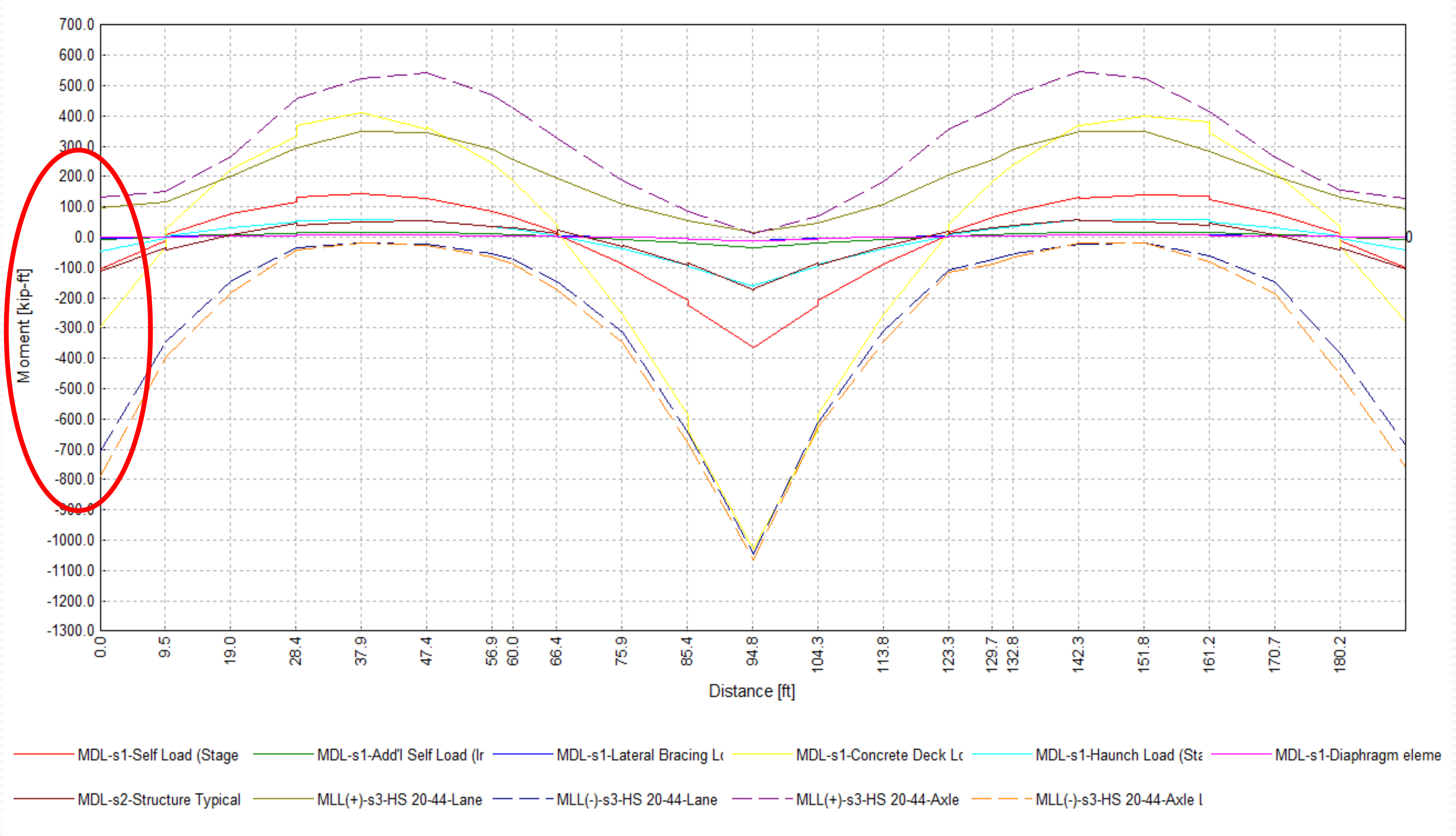
Unit: Kips	LFR	LFR	LRFR
Span 8-9	BrR	Override	BrR
G1 (Exterior D)	157.42	382.18	394.75
G2 (Interior C)	157.42	392.57	405.48
G3 (Interior B)	157.42	403.70	416.98
G4 (Exterior A)	157.42	415.64	429.31

Boundary Conditions

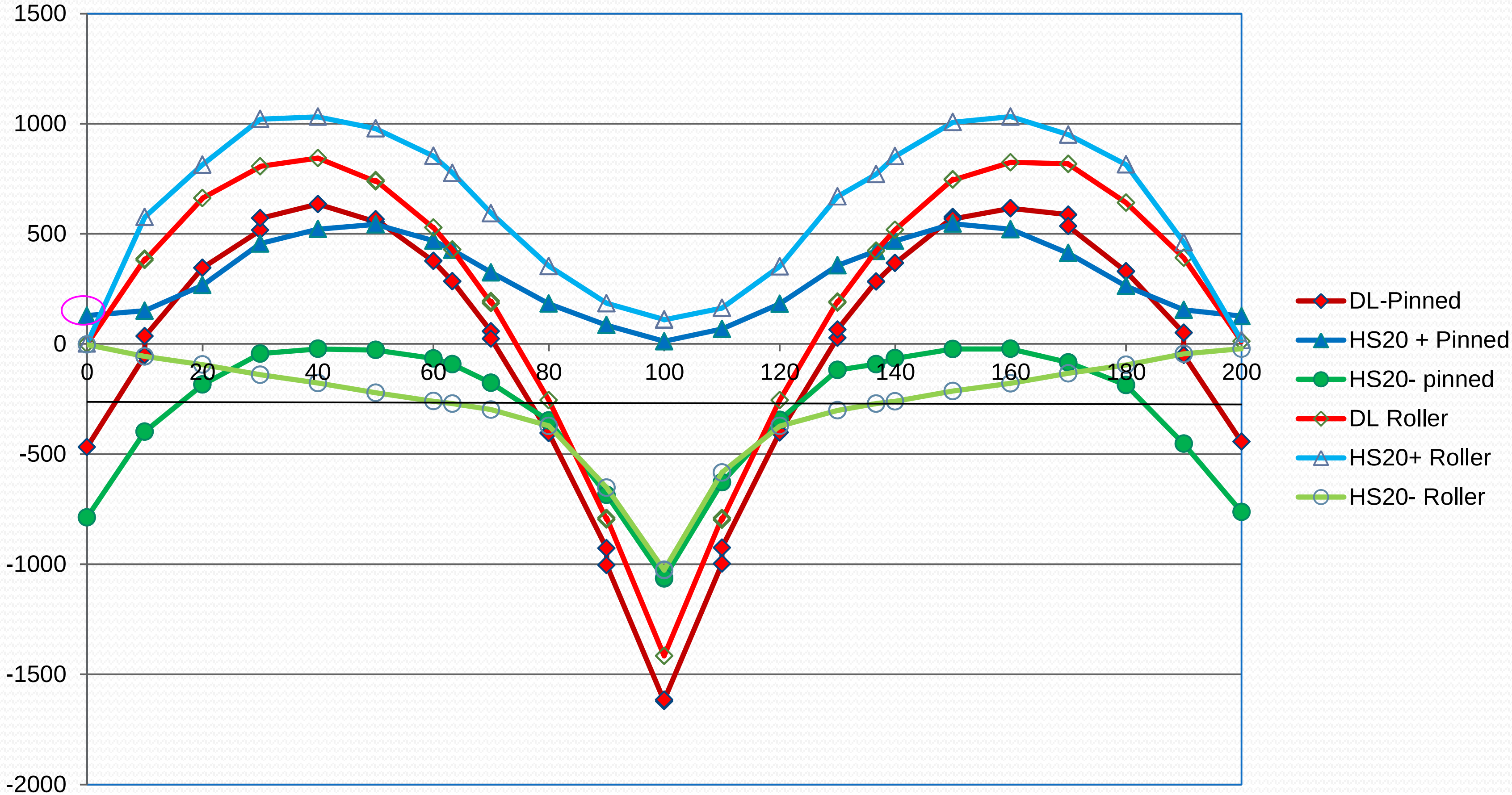
Fixed(Pinned) Bearing (Span 8-9)



Moments (Span 8-9, G1)



Moments with Different Supports (Span 8-9, G1)



Moments Comparison
(Span 8-9)

G1	M+ (max)			M- (max)		
	DL (S1)	ADL (S2)	HS20	DL (S1)	ADL (S2)	HS20
Roller	843.64	85.84	1031.45	-1416.66	-186.6	-1027.53
Pinned	634.92	48.6	521.48	-1622.21	-174.58	-1065.56
Ratio	1.33	1.77	1.98	0.87	1.07	0.96

G2	M+ (max)			M- (max)		
	DL (S1)	ADL (S2)	HS20	DL (S1)	ADL (S2)	HS20
Roller	744.25	55.01	965.35	-1311.66	-73.15	-913.61
Pinned	523.94	27.9	530.92	-1406.45	-67.72	-986.52
Ratio	1.42	1.97	1.82	0.93	1.08	0.93

G3	M+ (max)			M- (max)		
	DL (S1)	ADL (S2)	HS20	DL (S1)	ADL (S2)	HS20
Roller	646.28	45.97	879.96	-1166.97	-54.43	-811.05
Pinned	507.36	24.36	527.93	-1242.73	-56.4	-913.35
Ratio	1.27	1.89	1.67	0.94	0.97	0.89

G4	M+ (max)			M- (max)		
	DL (S1)	ADL (S2)	HS20	DL (S1)	ADL (S2)	HS20
Roller	523.72	72.88	811.6	-994.53	-139.38	-883.21
Pinned	342.24	45.89	431.94	-949.19	-140.15	-888.47
Ratio	1.53	1.59	1.88	1.05	0.99	0.99

Ratings: Pinned Supports (Span 8-9)

Analysis Results - Exterior Girder _ D

Report Type: Rating Results Summary

Lane/Impact Loading Type: (•) As Requested ( ) Detailed

Display Format: Single rating level per row

Live Load	Live Load Type	Rating Method	Rating Level	Load Rating (Ton)	Rating Factor	Location (ft)	Location Span-(%)	Limit State	Impact	Lane
HS 20-44	Lane	LFD	Inventory	45.69	1.269	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Lane	LFD	Operating	76.22	2.117	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Inventory	45.37	1.260	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Operating	75.41	2.095	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3	Axle Load	LFD	Operating	74.26	2.970	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3-3	Axle Load	LFD	Operating	88.81	2.220	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3S2	Axle Load	LFD	Operating	81.92	2.275	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 5 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	99.98	1.425	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 7 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	109.59	1.121	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 9 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	124.25	0.991	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P11 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	144.71	0.946	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P13 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	166.71	0.923	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested

AASHTO LFR 3D Engine Version 6.7.0.3001

Analysis Preference Setting: None

Close

Ratings: Rollers at Ends

(Span 8-9)

Analysis Results - Exterior Girder _ D

Report Type: Rating Results Summary

Lane/Impact Loading Type: (•) As Requested ( ) Detailed

Display Format: Single rating level per row

Live Load	Live Load Type	Rating Method	Rating Level	Load Rating (Ton)	Rating Factor	Location (ft)	Location Span-(%)	Limit State	Impact	Lane
HS 20-44	Lane	LFD	Inventory	51.65	1.435	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Lane	LFD	Operating	86.25	2.396	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Inventory	59.05	1.640	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Operating	98.61	2.739	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3	Axle Load	LFD	Operating	97.48	3.899	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3-3	Axle Load	LFD	Operating	114.26	2.856	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3S2	Axle Load	LFD	Operating	106.25	2.951	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 5 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	119.89	1.709	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 7 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	131.08	1.341	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 9 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	148.08	1.181	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P11 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	170.61	1.115	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P13 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	190.17	1.053	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested

AASHTO LFR 3D Engine Version 6.7.0.3001

Analysis Preference Setting: None

Close

End Support Choice

- With rollers at ends, there is some reduction for negative moments, but very large increase for positive moments (up to 53% for DL and 98% for LL).
- If slot holes are used in the flanges, there would be no horizontal force due to the steel weight.
- Considering actual pin location, 6” from bottom flange, will reduce horizontal force (up to 36% for DL) based on FEM analysis.
- Bearing anchor bolts may bend due to larger horizontal forces.

End Support Choice (Cont.)

- The actual end support conditions are between rollers and pinned.
- For this bridge with constant girder section and same top and bottom flanges, it would be conservative to use pinned supports.
- Considering the 1.3 load factor used and the possible slower speed of heavy permit trucks, it would be reasonable to allow all permit trucks on this structure, or simply use the results with rollers at ends.

Rating w/o Shear Override (rollers at ends)

Analysis Results - Exterior Girder _ D

Report Type: Rating Results Summary

Lane/Impact Loading Type: (•) As Requested ( ) Detailed

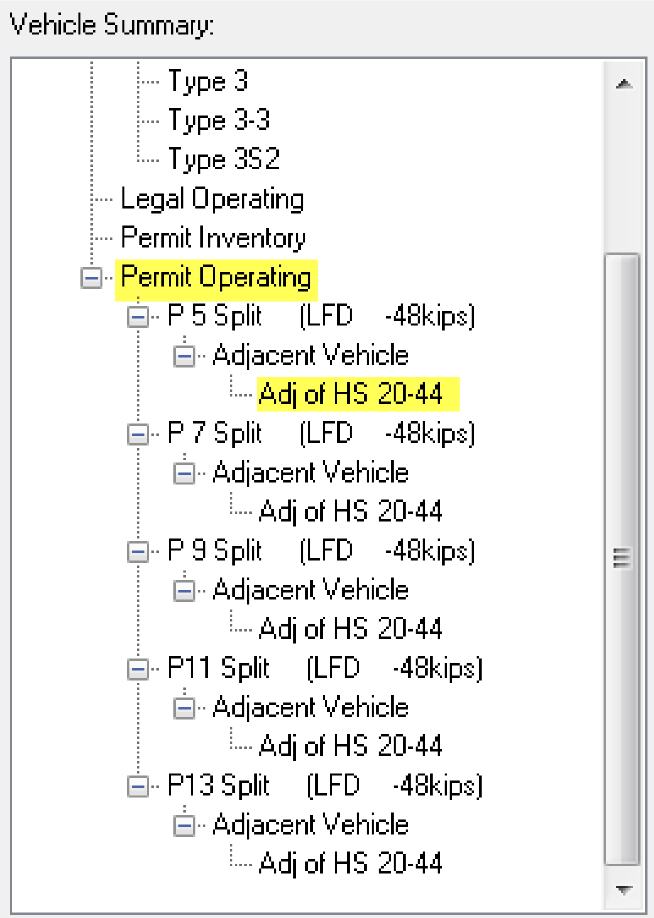
Display Format: Single rating level per row

Live Load	Live Load Type	Rating Method	Rating Level	Load Rating (Ton)	Rating Factor	Location (ft)	Location Span-(%)	Limit State	Impact	Lane
HS 20-44	Lane	LFD	Inventory	36.26	1.007	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
HS 20-44	Lane	LFD	Operating	60.56	1.682	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Inventory	20.59	0.572	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Operating	34.39	0.955	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
Type 3	Axle Load	LFD	Operating	33.16	1.326	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
Type 3-3	Axle Load	LFD	Operating	44.01	1.100	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
Type 3S2	Axle Load	LFD	Operating	39.95	1.110	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
P 5 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	40.41	0.576	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
P 7 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	47.90	0.490	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
P 9 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	57.54	0.459	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
P11 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	69.17	0.452	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested
P13 Split (LFD -48kips)	Axle Load	LFD	Permit Ope	81.65	0.452	189.70	2 - (100.0)	Design Shear - Steel	As Requested	As Requested

AASHTO LFR 3D Engine Version 6.7.0.3001

Analysis Preference Setting: None

Permit Load Setting



Vehicle Properties

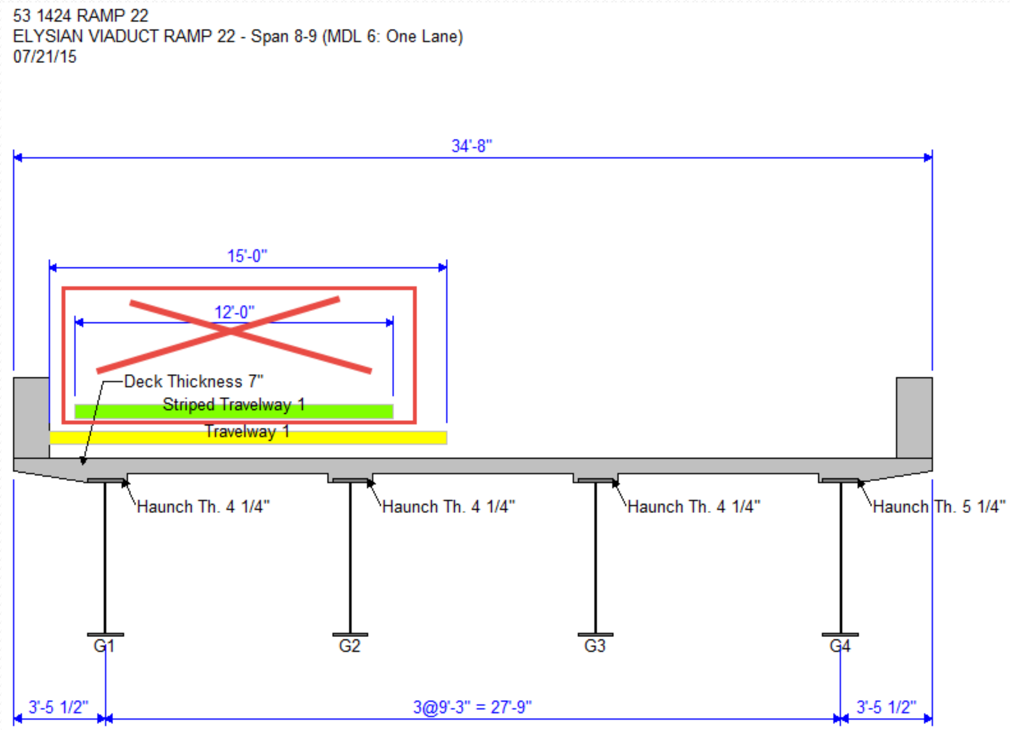
Vehicle	Tandem Train	Scale Factor	Impact	Single Lane Loaded
HS 20-44	☐	1		☐
Type 3	☐	1		☐
Type 3-3	☐	1		☐
Type 3S2	☐	1		☐
P 5 Split (LFD -48kips)	☐	1.15		☐
P 7 Split (LFD -48kips)	☐	1.15		☐
P 9 Split (LFD -48kips)	☐	1.15		☐
P11 Split (LFD -48kips)	☐	1.15		☐
P13 Split (LFD -48kips)	☐	1.15		☐

Adjacent vehicle live load factor: 1.3

Rating for Striped Lane

One Lane Striping

- Left ETW: 1 ft from the barrier
- Traffic lane width: 12 ft
- Used 15 ft travel way width
- Do not used striped travel way function when edge stripe is less than 2 ft from barrier.



Rating with Pinned Supports

Analysis Results - Exterior Girder _ D

Report Type: Rating Results Summary

Lane/Impact Loading Type: (•) As Requested ( ) Detailed

Display Format: Single rating level per row

Live Load	Live Load Type	Rating Method	Rating Level	Load Rating (Ton)	Rating Factor	Location (ft)	Location Span-(%)	Limit State	Impact	Lane
HS 20-44	Lane	LFD	Inventory	60.18	1.672	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Lane	LFD	Operating	100.39	2.789	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Inventory	60.11	1.670	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
HS 20-44	Axle Load	LFD	Operating	99.90	2.775	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3	Axle Load	LFD	Operating	98.44	3.937	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3-3	Axle Load	LFD	Operating	115.97	2.899	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
Type 3S2	Axle Load	LFD	Operating	107.71	2.992	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 5 Split (LFD -48kips)	Axle Load	LFD	Operating	105.88	1.509	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 7 Split (LFD -48kips)	Axle Load	LFD	Operating	116.23	1.189	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P 9 Split (LFD -48kips)	Axle Load	LFD	Operating	131.72	1.051	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P11 Split (LFD -48kips)	Axle Load	LFD	Operating	153.25	1.002	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested
P13 Split (LFD -48kips)	Axle Load	LFD	Operating	176.43	0.977	94.85	1 - (100.0)	Design Flexure - Steel	As Requested	As Requested

AASHTO LFR 3D Engine Version 6.7.0.3001

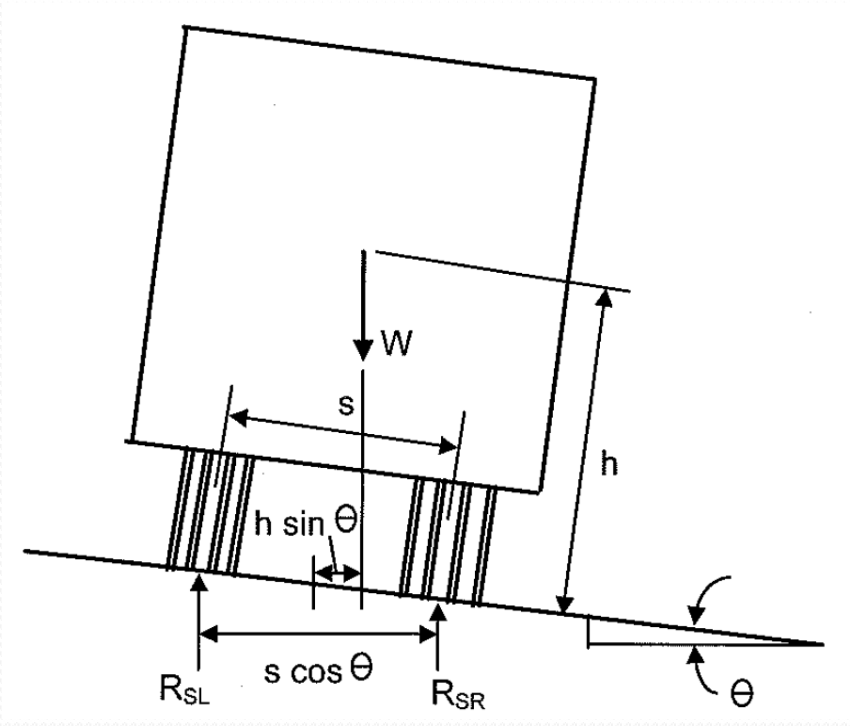
Analysis Preference Setting: None

Close

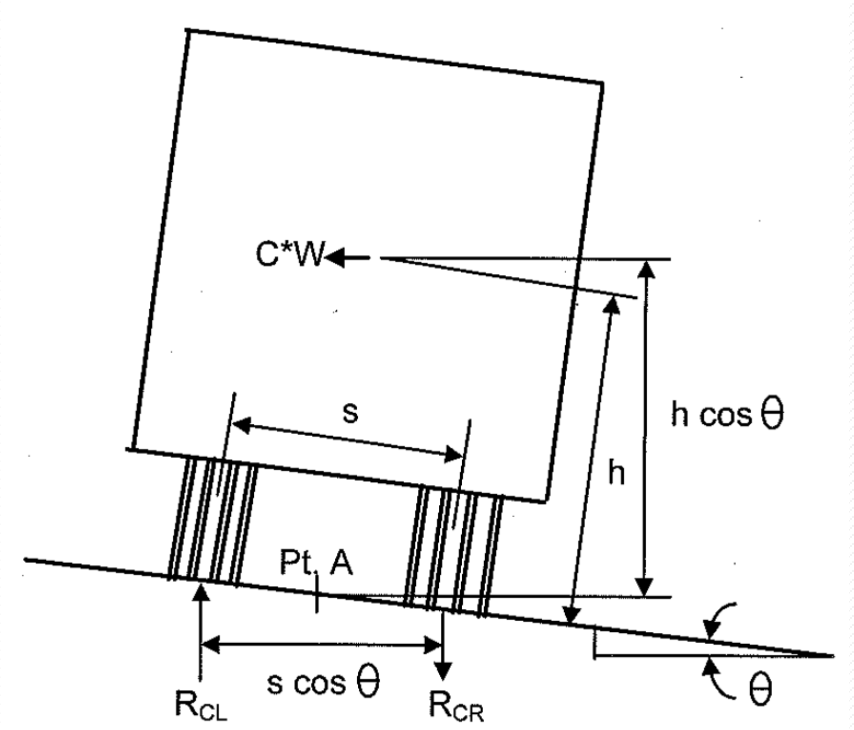
Design Speed and Centrifugal Force

Slope and Centrifugal Force

Vehicle Self Weight



Vehicle Centrifugal Force



Centrifugal Force

LFD

3.10 CENTRIFUGAL FORCES

3.10.1 Structures on curves shall be designed for a horizontal radial force equal to the following percentage of the live load, without impact, in all traffic lanes:

$$C = 0.00117S^2D = \frac{6.68S^2}{R} \qquad (3-2)$$

where,

C = the centrifugal force in percent of the live load, without impact;
S = the design speed in miles per hour;
D = the degree of curve;
R = the radius of the curve in feet.

LRFD

3.6.3—Centrifugal Forces: *CE*

For the purpose of computing the radial force or the overturning effect on wheel loads, the centrifugal effect on live load shall be taken as the product of the axle weights of the design truck or tandem and the factor C, taken as:

$$C = f\frac{v^2}{gR} \qquad (3.6.3\text{-}1)$$

where:

v = highway design speed (ft/s)
f = 4/3 for load combinations other than fatigue and 1.0 for fatigue
g = gravitational acceleration: 32.2 (ft/s^2)
R = radius of curvature of traffic lane (ft)

Centrifugal Force (cont.)

- Ratio of centrifugal forces with the same speed:

  $C_{LRFD}/C_{LFD}=1.33$

- Maximum design speed: $S_{max,LRFD}/S_{max,LFD}=0.867$

- This bridge: $S_{max,LRFD}= 52.5$ mph

  $S_{max,LFD} = 60.9$ mph

- A design speed that works with LFR, may not work with LRFR.

LRFR and Refined Analysis

Permit Checks

6A.4.5.4.2c—Permit Checks Using Refined Analysis

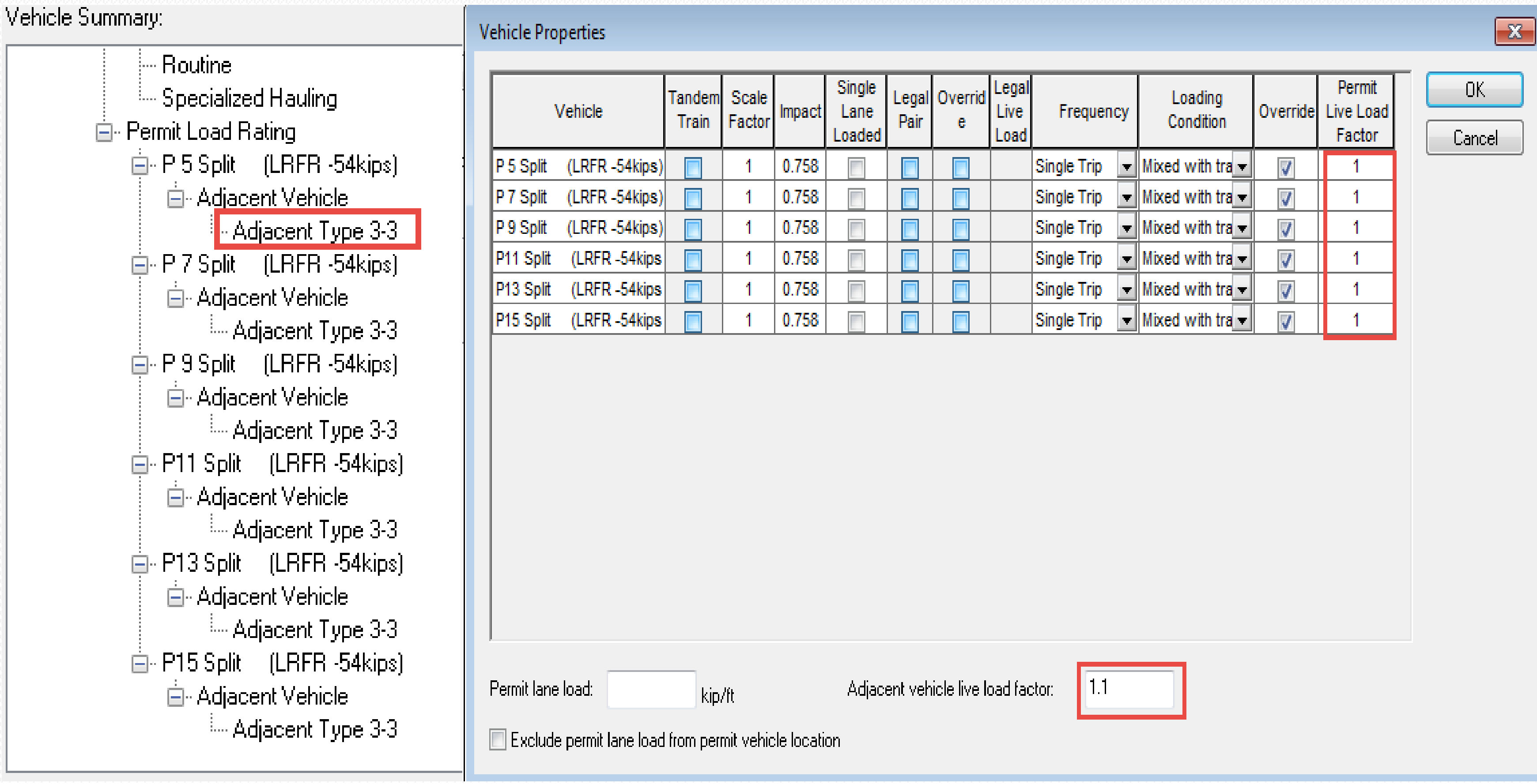
When routine permit checks are evaluated using a refined analysis, the load factors as given in Table 6A.4.5.4.2a-1 shall be increased (by adding) 0.10 and applied on the two permit trucks placed in adjacent lanes.

When escorted special permits with no other vehicles on the bridge are evaluated using a refined analysis, $\gamma_L = 1.1$ should be applied to the escorted vehicle.

Permit Checks (cont.)

When special permits mixed with traffic are evaluated using a refined analysis, a live load factor $\gamma_L = 1.0$ shall be applied on the permit truck while a $\gamma_L = 1.10$ shall be applied on the governing AASHTO legal truck placed in the adjacent lane.

LRFR 3D with Single Permit



Results Missing Vehicles

Analysis Results - Exterior Girder _ D

Report Type: Rating Results Summary

Lane/Impact Loading Type: (•) As Requested ( ) Detailed

Display Format: Single rating level per row

Live Load	Live Load Type	Rating Method	Rating Level	Load Rating (Ton)	Rating Factor	Location (ft)	Location Span-(%)	Limit State	Impact	Lane
P15 Split (LRFR -54kips)	Axle Load	LRFR	Permit	150.21	0.744	94.85	1 - (100.0)	SERVICE-II Steel Flexu	As Requested	As Requested

AASHTO LRFR 3D Engine Version 6.7.0.3001

Analysis Preference Setting: None

Conclusion

Conclusion

- LFR Engine produces all required rating results
- Ready to be used for rating production
- Will be more efficient after other issues resolved
- Would also be more efficient:

  (1) Extend d_0/D limit for shear capacity

  (2) Extend the 300 foot span length limit

  (3) Consider the bearing pin location

  (4) List lateral force at support
- LRFR Engine needs more testing

Questions?