Load rating of a curved, simple-span plate girder bridge

www.mbrace3d.com

Purpose

Evaluate the **critical rating factor** of a curved, simple-span plate girder bridge using mBrace3D, under the following assumptions:

1. Consider the default **HL-93 notional live load** model

2. Check two limit states only: **principal moment at mid-span and vertical shear at the abutments**

3. Consider the AASHTO **Strength I load combination** only

Note: The above assumptions are used for simplicity – in particular, any truck load can be modelled in mBrace3D.

References

Steel Bridge Design Handbook

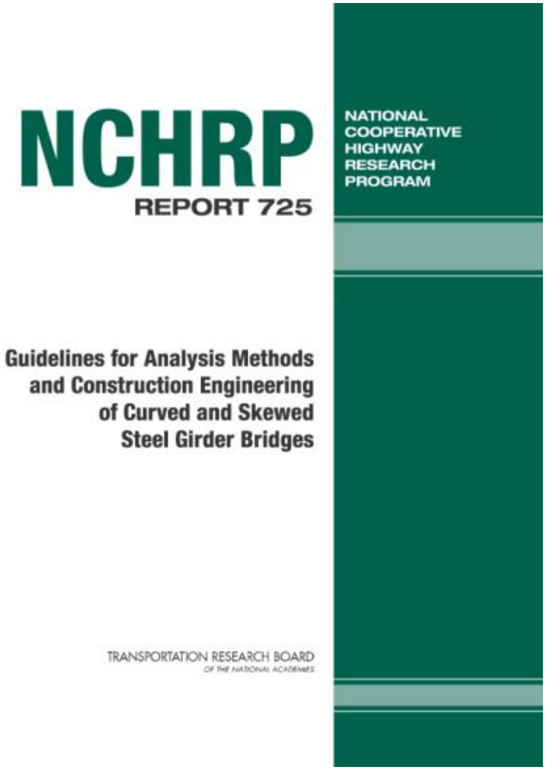
CHAPTER 18

Load Rating of Steel Bridges

February 2022

Smarter.
Stronger.
Steel.

Steel Bridge Design Handbook – Load Rating of Steel Bridges, D. Mertz and K. Oliver, 2022



NCHRP

REPORT 725

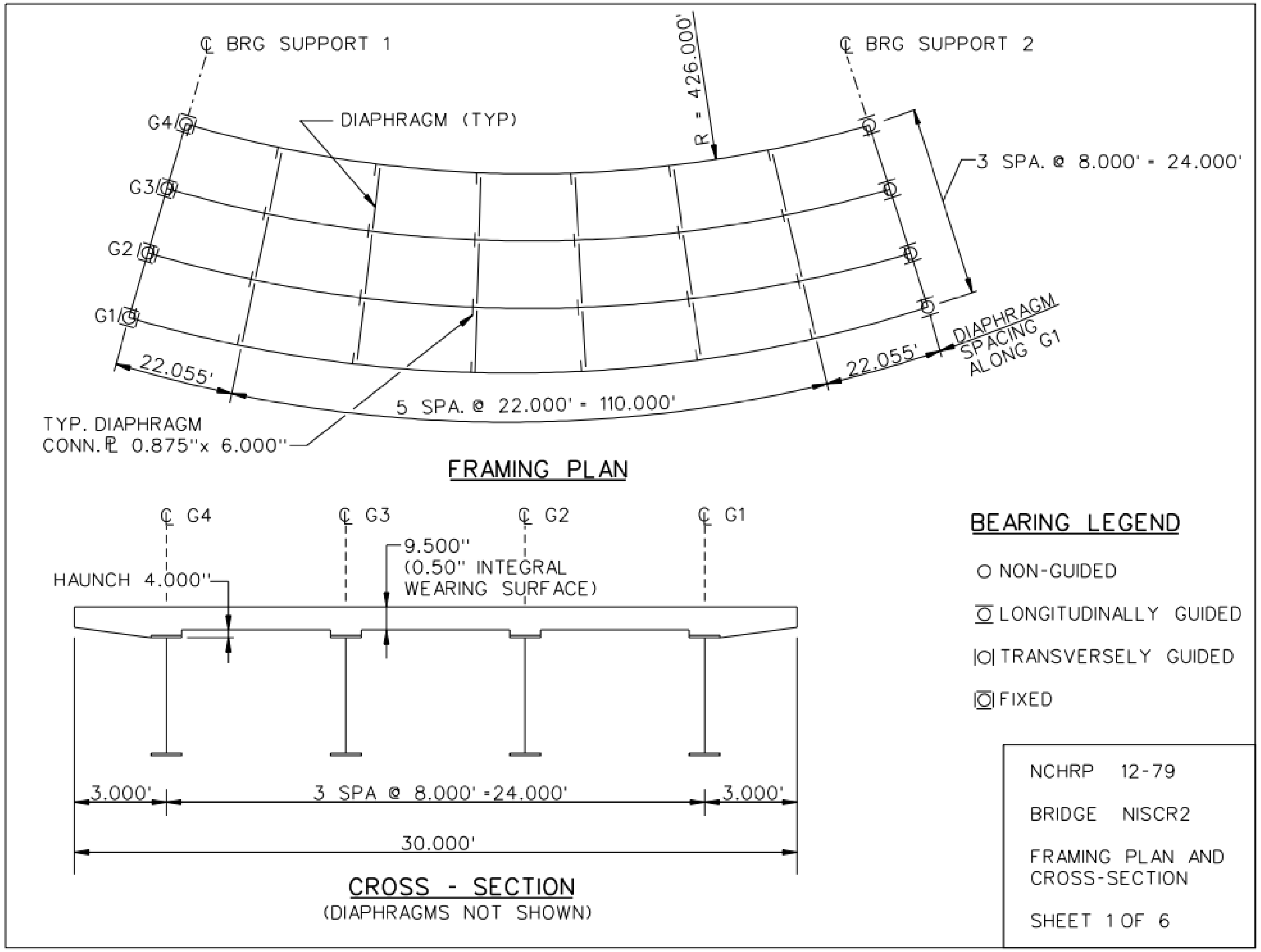
NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Guidelines for Analysis Methods
and Construction Engineering
of Curved and Skewed
Steel Girder Bridges

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

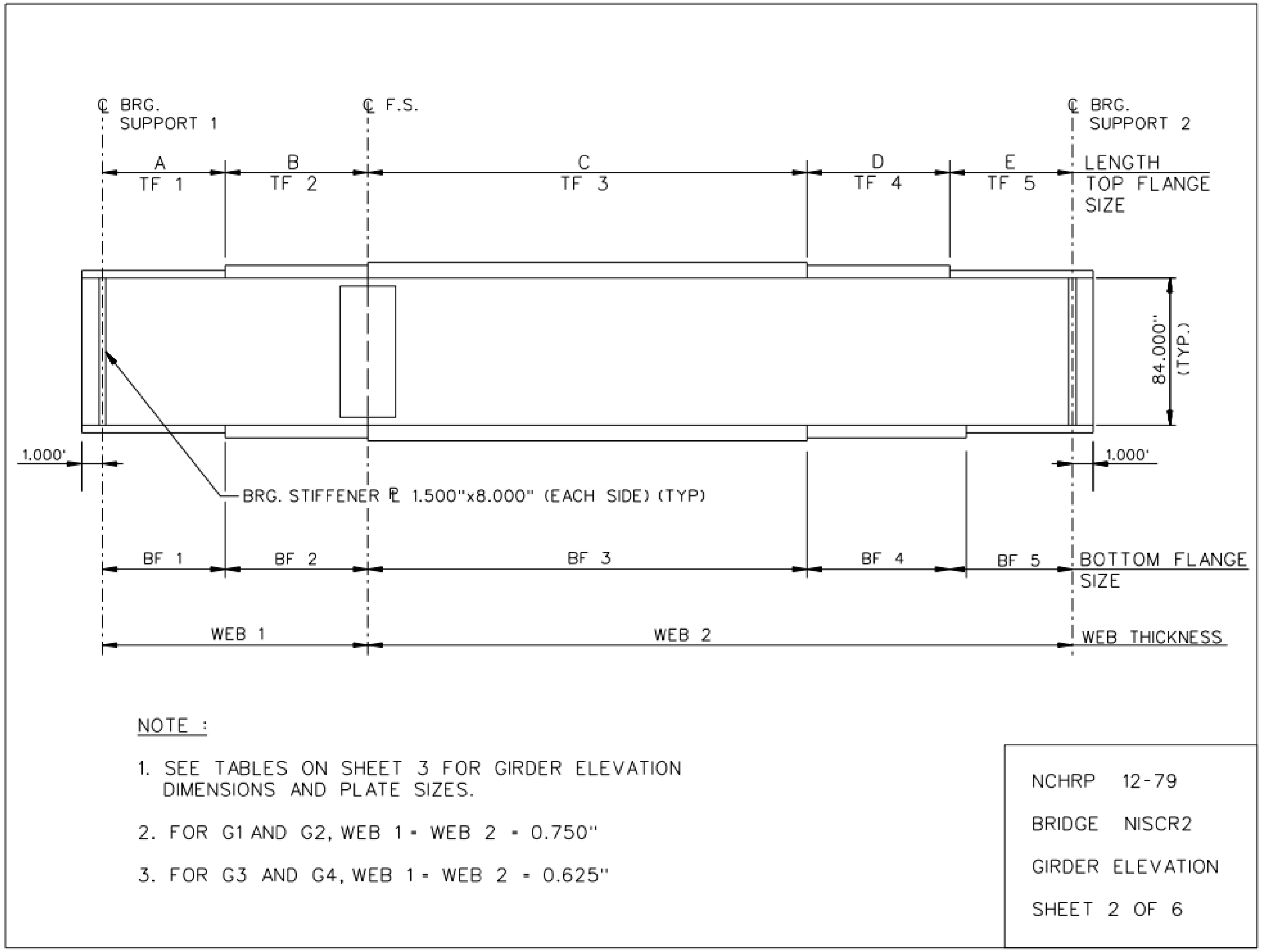
NCHRP Report 725 – Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges, D. White, D. Coletti et al., 2012

Case study: NISCR2



Source: NCHRP Report 725, Appendix J (Bridge Drawings), available at: https://www.trb.org/Publications/Blurbs/167646.aspx

Case study: NISCR2



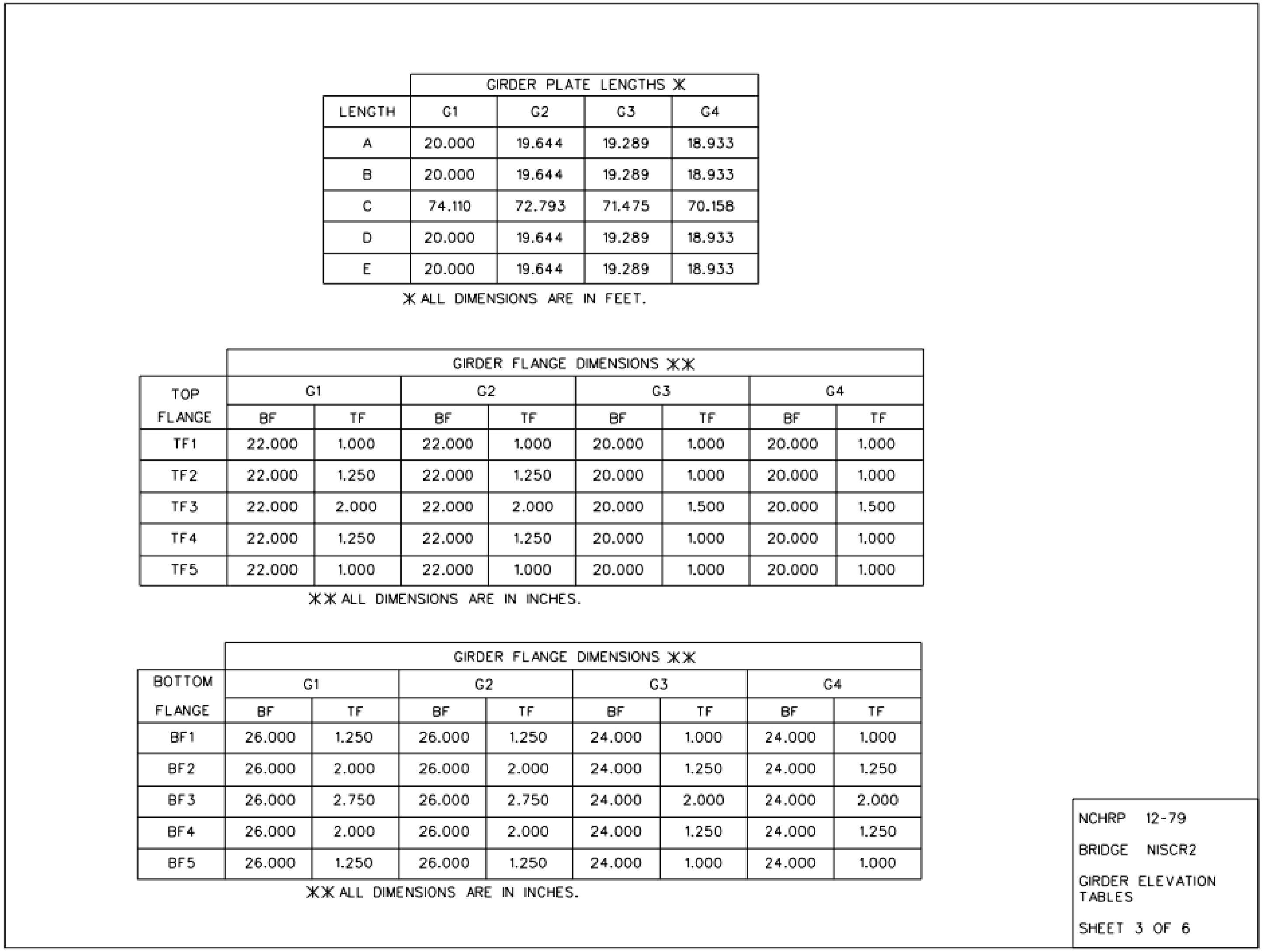
NOTE :

1. SEE TABLES ON SHEET 3 FOR GIRDER ELEVATION DIMENSIONS AND PLATE SIZES.
2. FOR G1 AND G2, WEB 1 = WEB 2 = 0.750"
3. FOR G3 AND G4, WEB 1 = WEB 2 = 0.625"

NCHRP 12-79
BRIDGE NISCR2
GIRDER ELEVATION
SHEET 2 OF 6

Source: NCHRP Report 725, Appendix J (Bridge Drawings), available at: https://www.trb.org/Publications/Blurbs/167646.aspx

Case study: NISCR2



	GIRDER PLATE LENGTHS *			
LENGTH	G1	G2	G3	G4
A	20.000	19.644	19.289	18.933
B	20.000	19.644	19.289	18.933
C	74.110	72.793	71.475	70.158
D	20.000	19.644	19.289	18.933
E	20.000	19.644	19.289	18.933

* ALL DIMENSIONS ARE IN FEET.

	GIRDER FLANGE DIMENSIONS **							
TOP FLANGE	G1		G2		G3		G4	
	BF	TF	BF	TF	BF	TF	BF	TF
TF1	22.000	1.000	22.000	1.000	20.000	1.000	20.000	1.000
TF2	22.000	1.250	22.000	1.250	20.000	1.000	20.000	1.000
TF3	22.000	2.000	22.000	2.000	20.000	1.500	20.000	1.500
TF4	22.000	1.250	22.000	1.250	20.000	1.000	20.000	1.000
TF5	22.000	1.000	22.000	1.000	20.000	1.000	20.000	1.000

** ALL DIMENSIONS ARE IN INCHES.

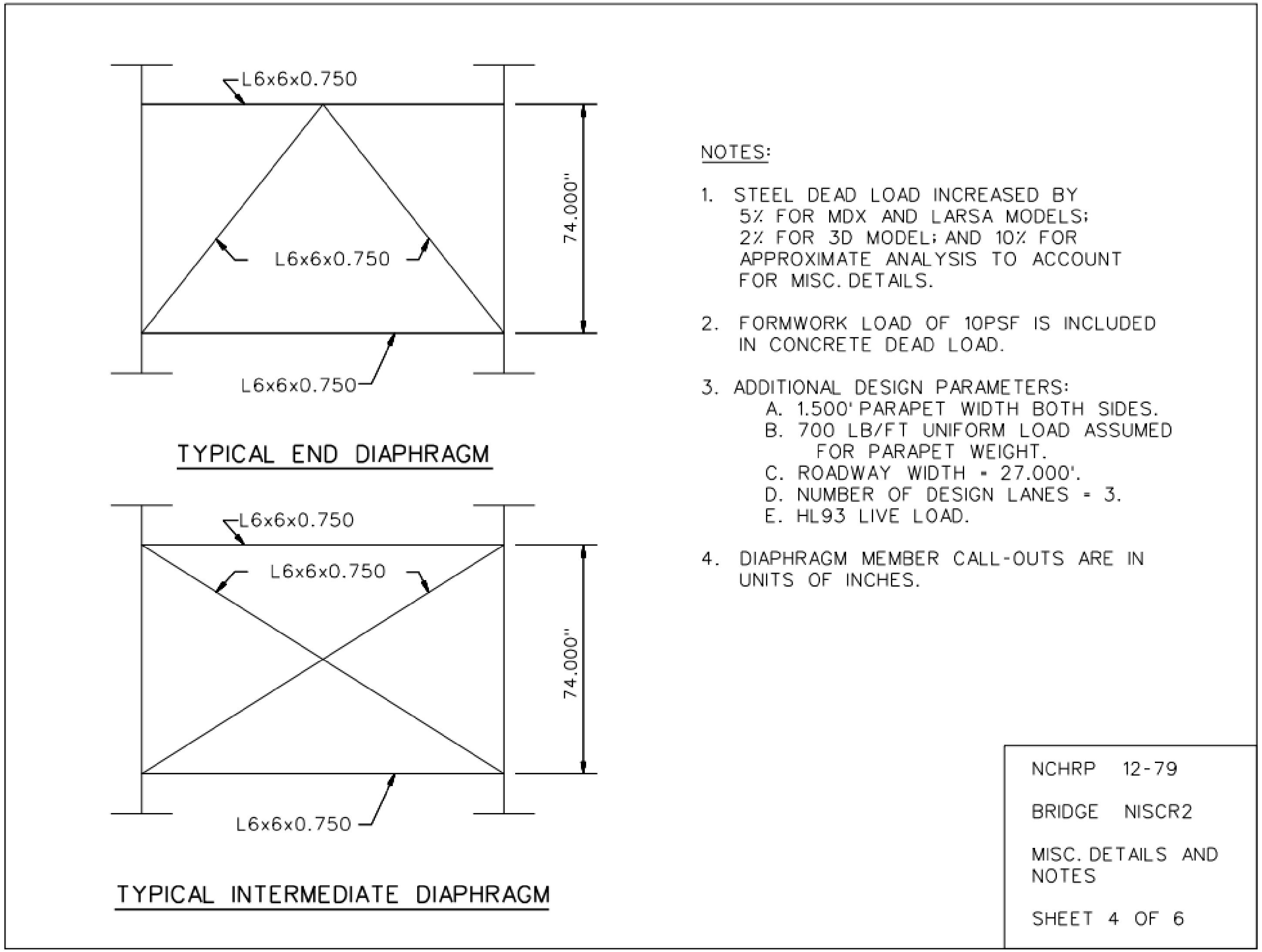
	GIRDER FLANGE DIMENSIONS **							
BOTTOM FLANGE	G1		G2		G3		G4	
	BF	TF	BF	TF	BF	TF	BF	TF
BF1	26.000	1.250	26.000	1.250	24.000	1.000	24.000	1.000
BF2	26.000	2.000	26.000	2.000	24.000	1.250	24.000	1.250
BF3	26.000	2.750	26.000	2.750	24.000	2.000	24.000	2.000
BF4	26.000	2.000	26.000	2.000	24.000	1.250	24.000	1.250
BF5	26.000	1.250	26.000	1.250	24.000	1.000	24.000	1.000

** ALL DIMENSIONS ARE IN INCHES.

NCHRP 12-79
BRIDGE NISCR2
GIRDER ELEVATION TABLES
SHEET 3 OF 6

Source: NCHRP Report 725, Appendix J (Bridge Drawings), available at: https://www.trb.org/Publications/Blurbs/167646.aspx

Case study: NISCR2



NOTES:

1. STEEL DEAD LOAD INCREASED BY 5% FOR MDX AND LARSA MODELS; 2% FOR 3D MODEL; AND 10% FOR APPROXIMATE ANALYSIS TO ACCOUNT FOR MISC. DETAILS.
2. FORMWORK LOAD OF 10PSF IS INCLUDED IN CONCRETE DEAD LOAD.
3. ADDITIONAL DESIGN PARAMETERS:
   - A. 1.500' PARAPET WIDTH BOTH SIDES.
   - B. 700 LB/FT UNIFORM LOAD ASSUMED FOR PARAPET WEIGHT.
   - C. ROADWAY WIDTH = 27.000'.
   - D. NUMBER OF DESIGN LANES = 3.
   - E. HL93 LIVE LOAD.
4. DIAPHRAGM MEMBER CALL-OUTS ARE IN UNITS OF INCHES.

NCHRP 12-79

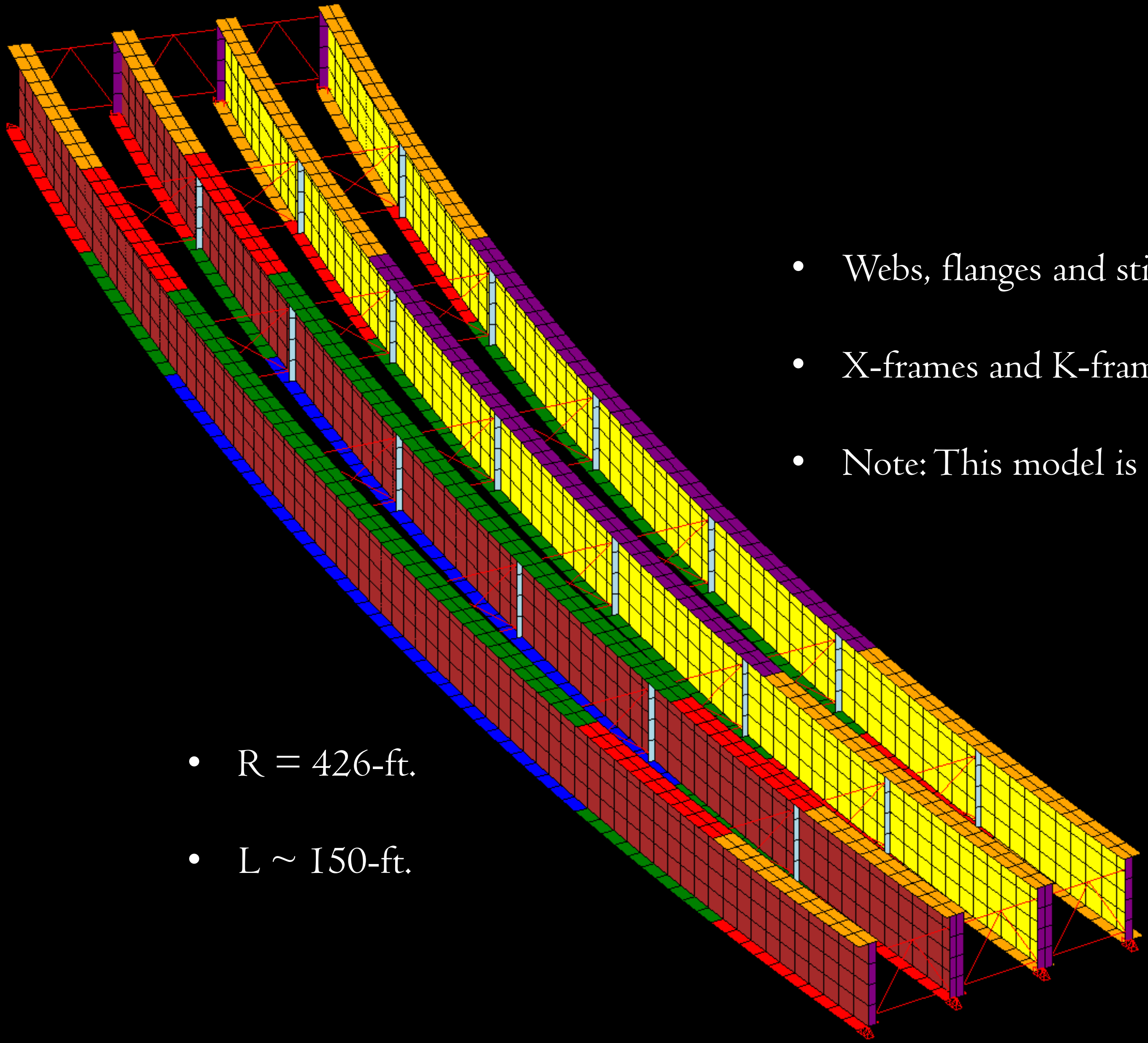
BRIDGE NISCR2

MISC. DETAILS AND NOTES

SHEET 4 OF 6

Source: NCHRP Report 725, Appendix J (Bridge Drawings), available at: https://www.trb.org/Publications/Blurbs/167646.aspx

mBrace3D model



- Webs, flanges and stiffeners modelled with **<u>shell elements</u>**

- X-frames and K-frames modelled with **<u>bar elements</u>**

- Note: This model is generated **<u>parametrically</u>** (no drawing involved)

- R = 426-ft.

- L ~ 150-ft.

Rating factor

Rating factor

Capacity

Dead load effect due to structural components and attachments

Dead load effect due to wearing load and utilities

$$RF = \frac{C - \gamma_{DC}(DC) - \gamma_{DW}(DW)}{\gamma_{L}(LL + IM)}$$

Live load effect, including dynamic allowance

-> Create 3 models: 1 for DC (non-composite), 1 for DW (composite, 3n), 1 for LL+IM (composite, n)

Source: Steel Bridge Design Handbook – Load Rating of Steel Bridges, D. Mertz and K. Oliver, 2022, available at:
https://www.aisc.org/globalassets/nsba/design-resources/steel-bridge-design-handbook/b918_sbdh_chapter18.pdf

Limit states

1. **Moment at mid-span**:

AASHTO Article 6.10.6.2.2:

Composite sections in all horizontally **curved** girder systems are to be treated as **non-compact sections** at the strength limit state

-> Check stresses in the top flange (compression, f_{bu}) and the bottom flange (tension, $f_{bu} + 1/3f_l$)

-> f_{bu} obtained from M/S, where S is the elastic section modulus; f_l obtained directly from the shell model[1]

2. **Shear at the abutment**

V obtained by integration of the vertical shear stresses directly within mBrace3D

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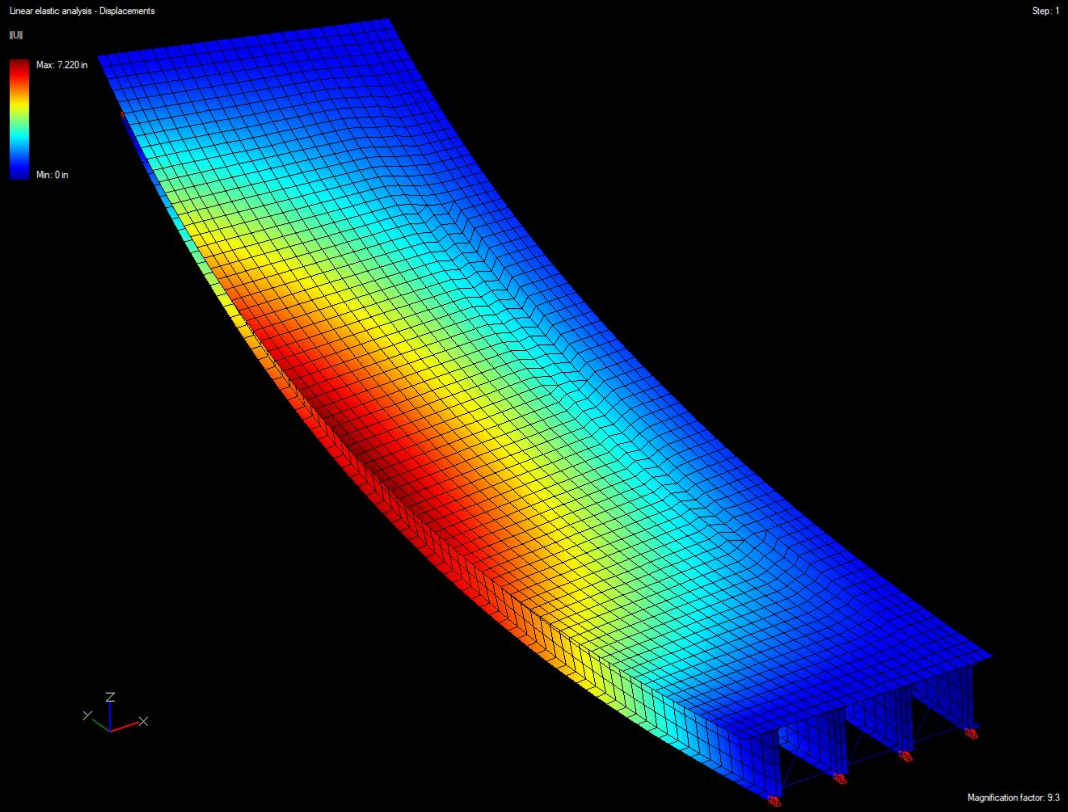
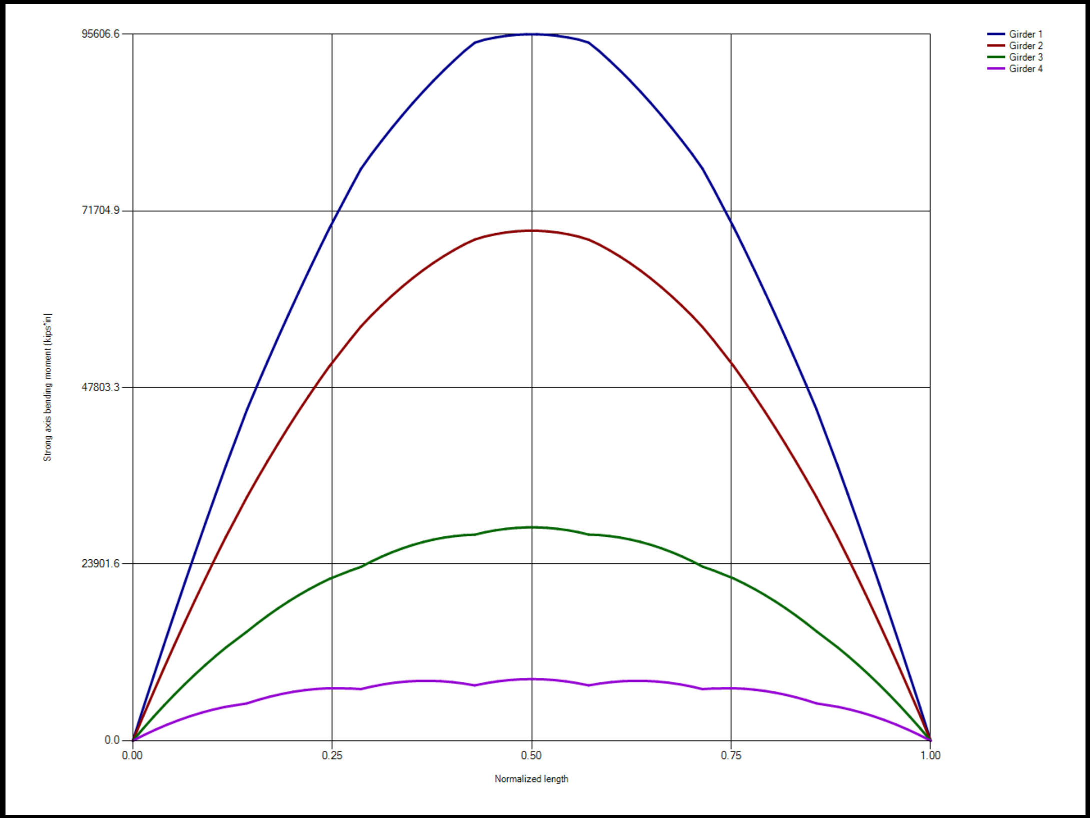
[1]: *f_{bu} could also be obtained directly from the shell model, but the more conventional M/S method is followed here*

Non-composite model (DC)

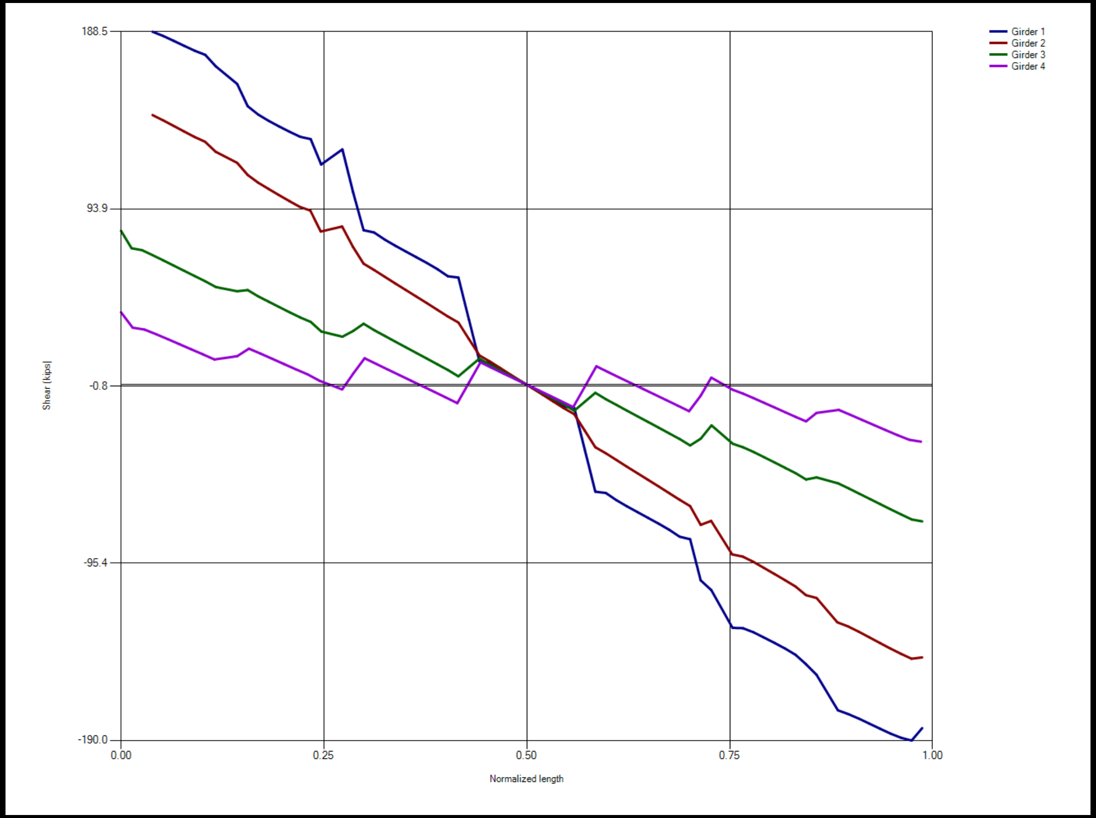


Linear elastic deflections
(Concrete deck modelled explicitly)

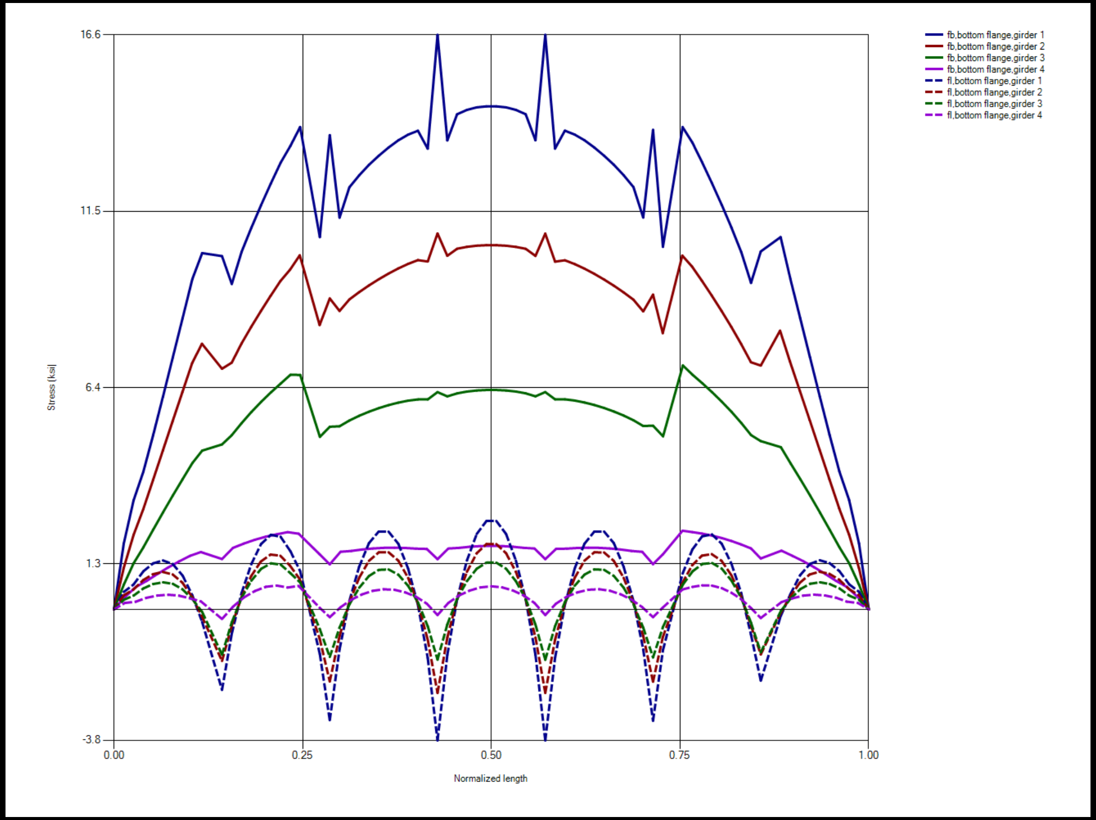


Moment diagram
(Stresses are integrated automatically within mBrace3D)

Non-composite model (DC)



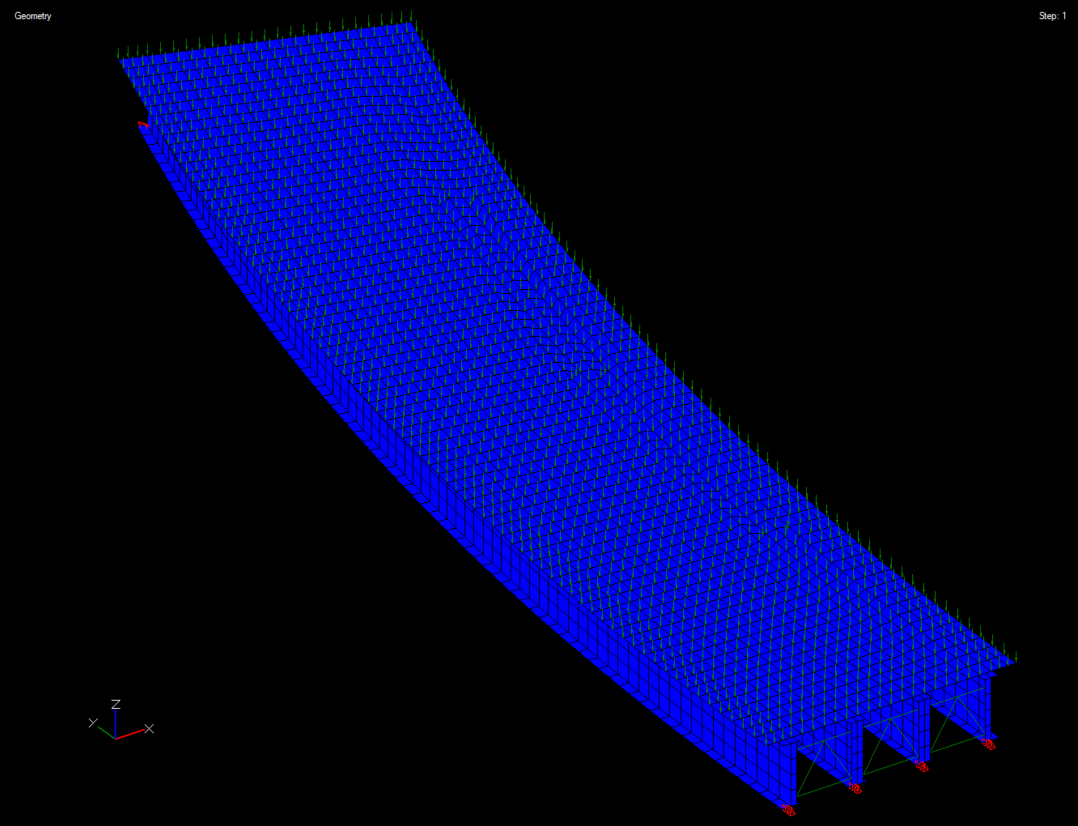
Shear diagram
(Stresses are integrated automatically within mBrace3D)



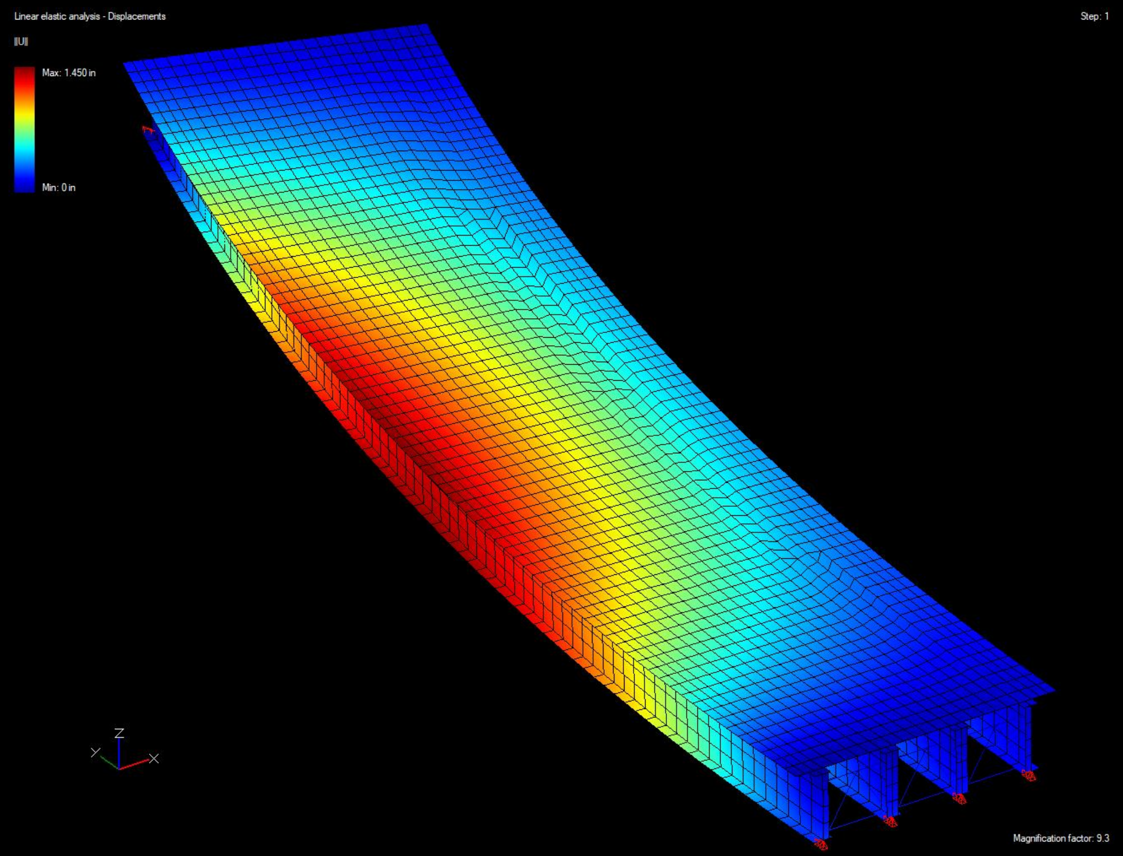
Principal vs. lateral bending stress diagram

Composite model (DW)

Assume $f'_c = 5$ ksi, $E_c = 1{,}417$ ksi (3n)



Applied loads
(Assume 30 psf wearing surface and 0.5 kip/ft barrier line load)



Linear elastic deflections
(Shear and moment derived automatically, as for DC)

Composite model (LL+IM) – Parameters

Assume $f'_c = 5$ ksi, $E_c = 4{,}250$ ksi (n)

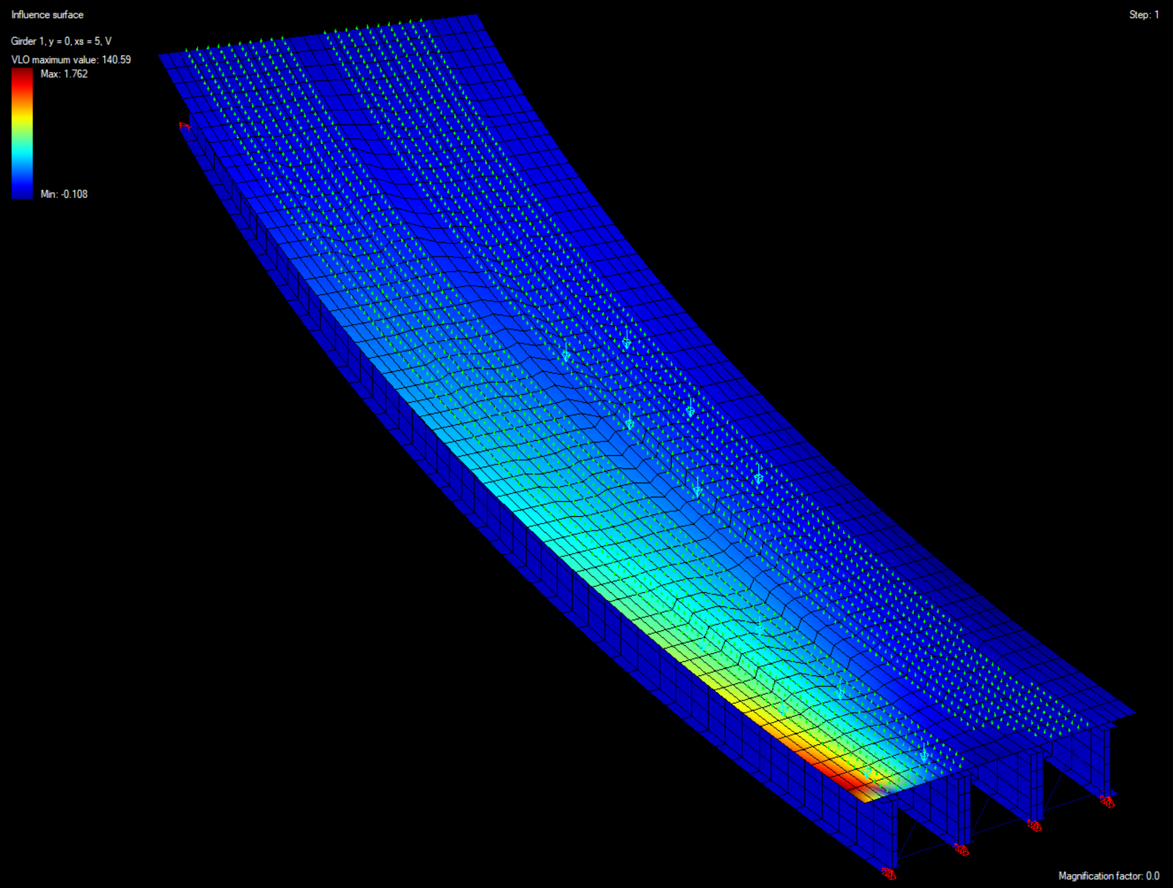
Request **8 influence surfaces** (2 for each girder):

1. **Shear** at the first abutment (4 influence surfaces)
2. **Composite moment** at mid-span (4 influence surfaces)

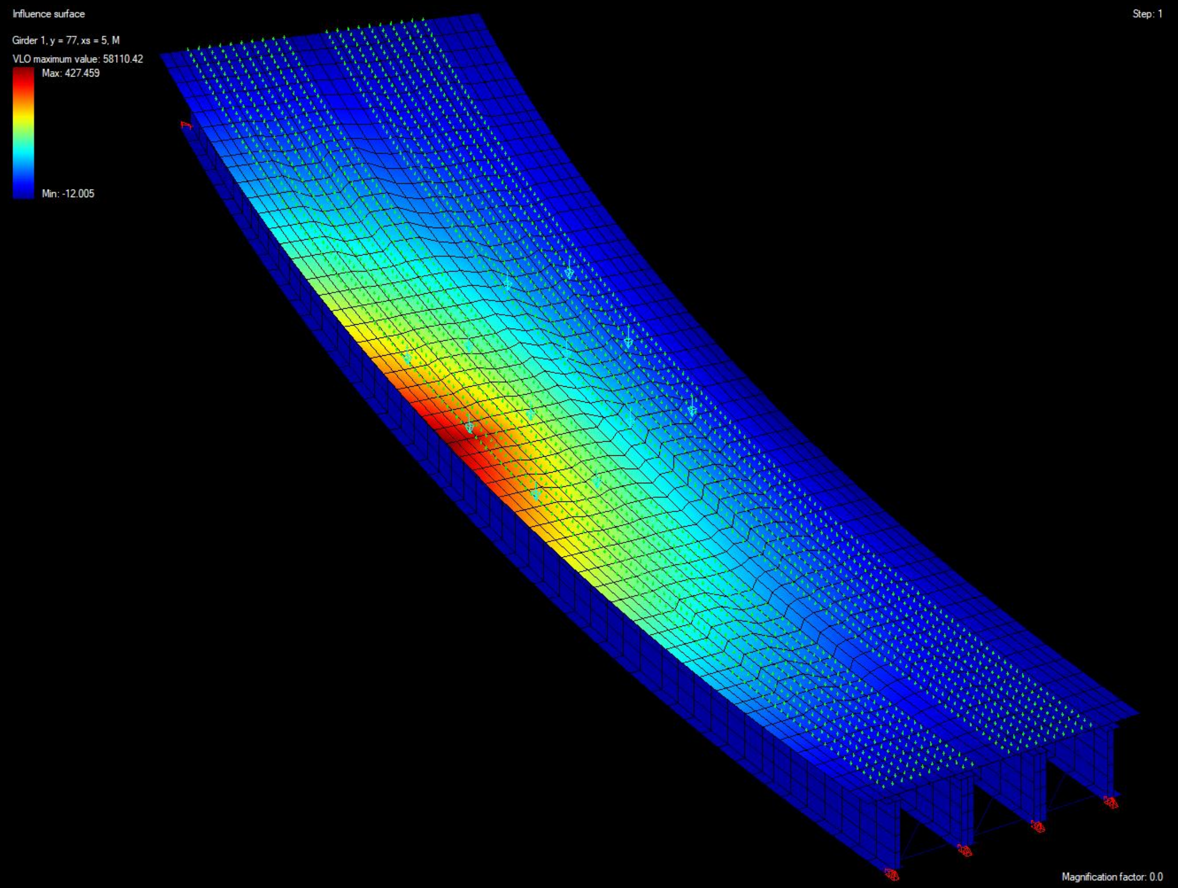
Run a VLO (**Vehicle Load Optimization**) analysis using the following parameters:

- Dynamic impact factor: 1.33
- Two design lanes (with the relevant multiple presence factors)
- One truck model (standard HL-93 notional live load model)
- 0.64 kip/ft design lane load
- 1-ft. live load increment in both the longitudinal and transverse directions

Composite model (LL+IM), Girder 1

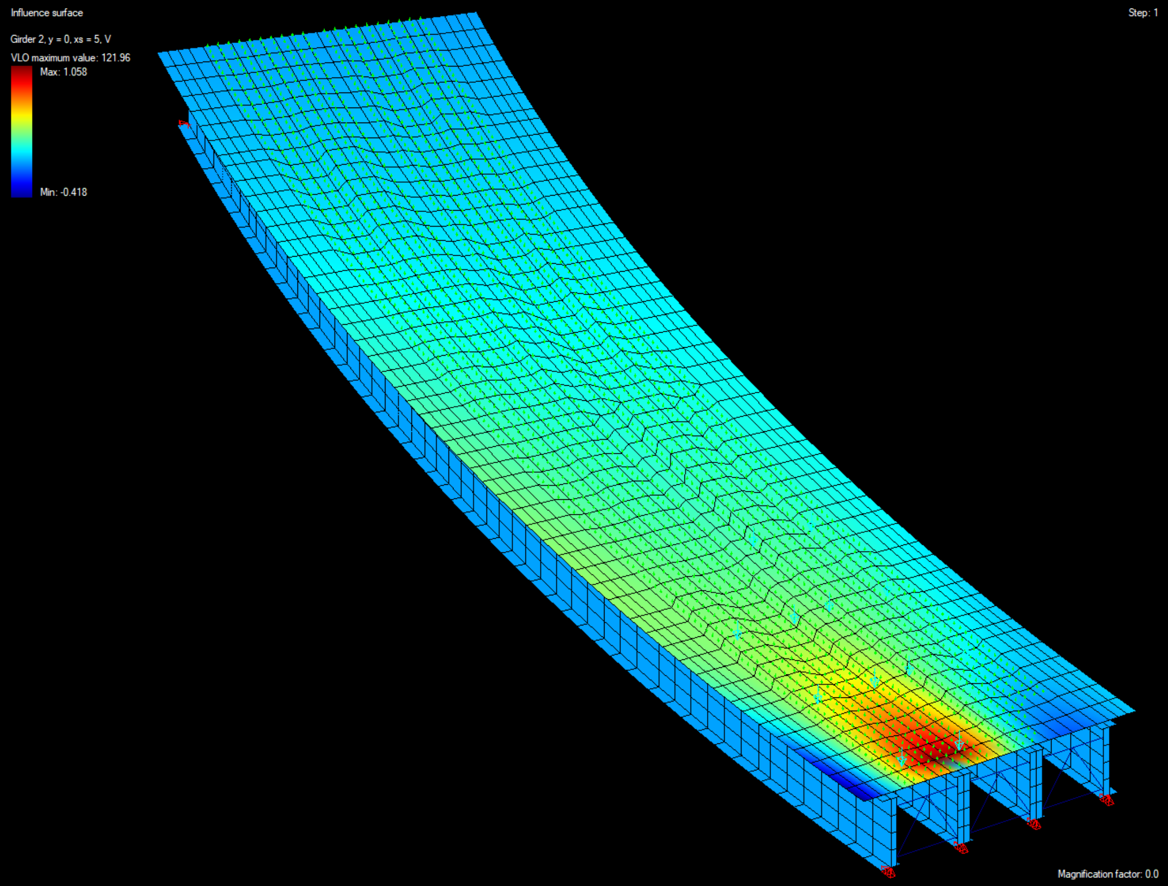


Influence surface for the shear at the first abutment, Girder 1
V_{max} = 141 kips

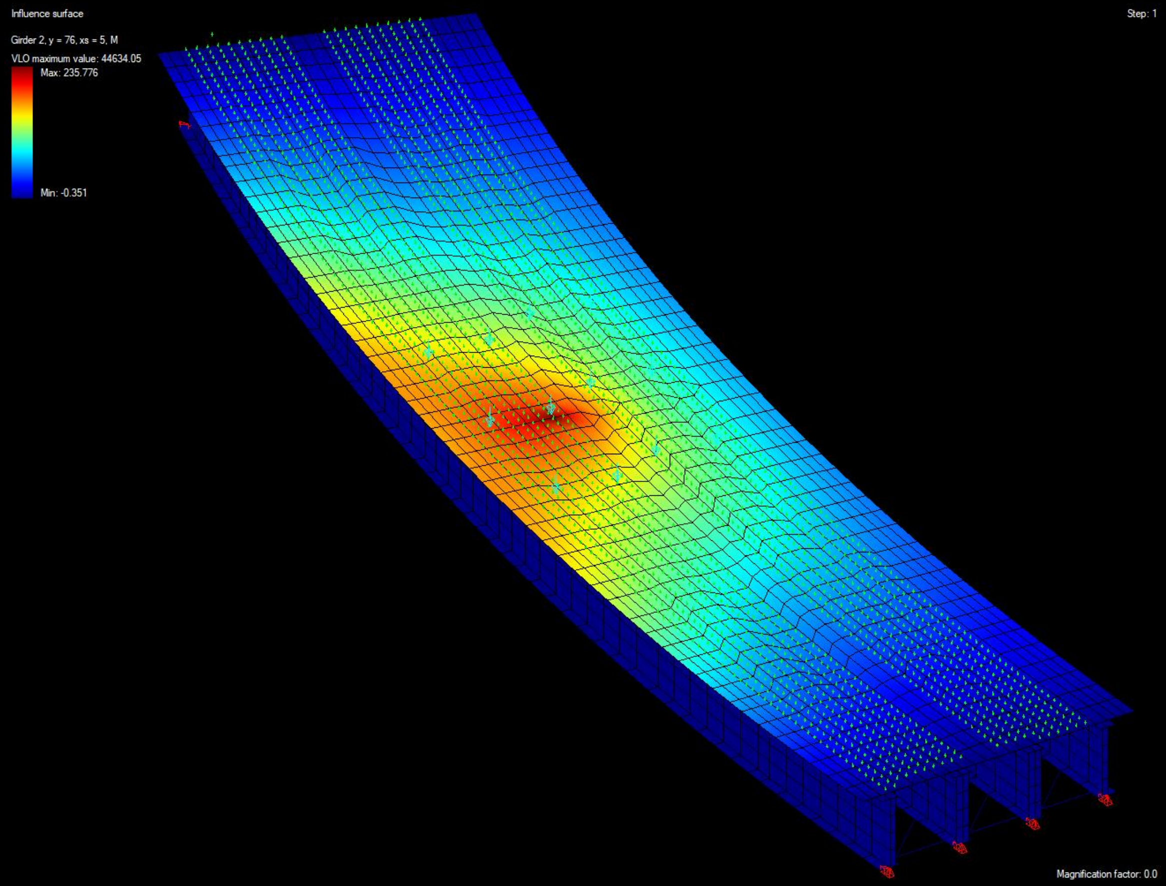


Influence surface for the composite moment at mid-span, Girder 1
M_{max} = 58,110 kips-in

Composite model (LL+IM), Girder 2

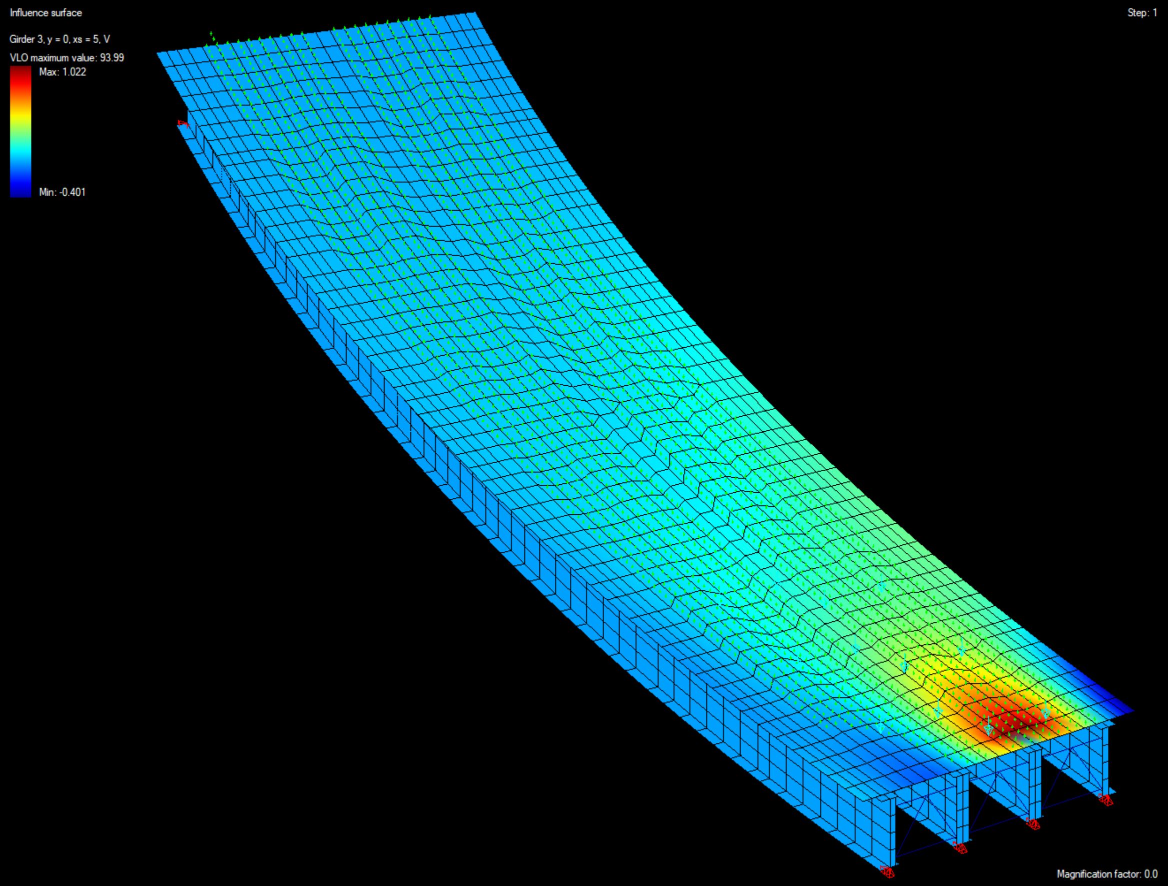


Influence surface for the shear at the first abutment, Girder 2
V_{max} = 122 kips

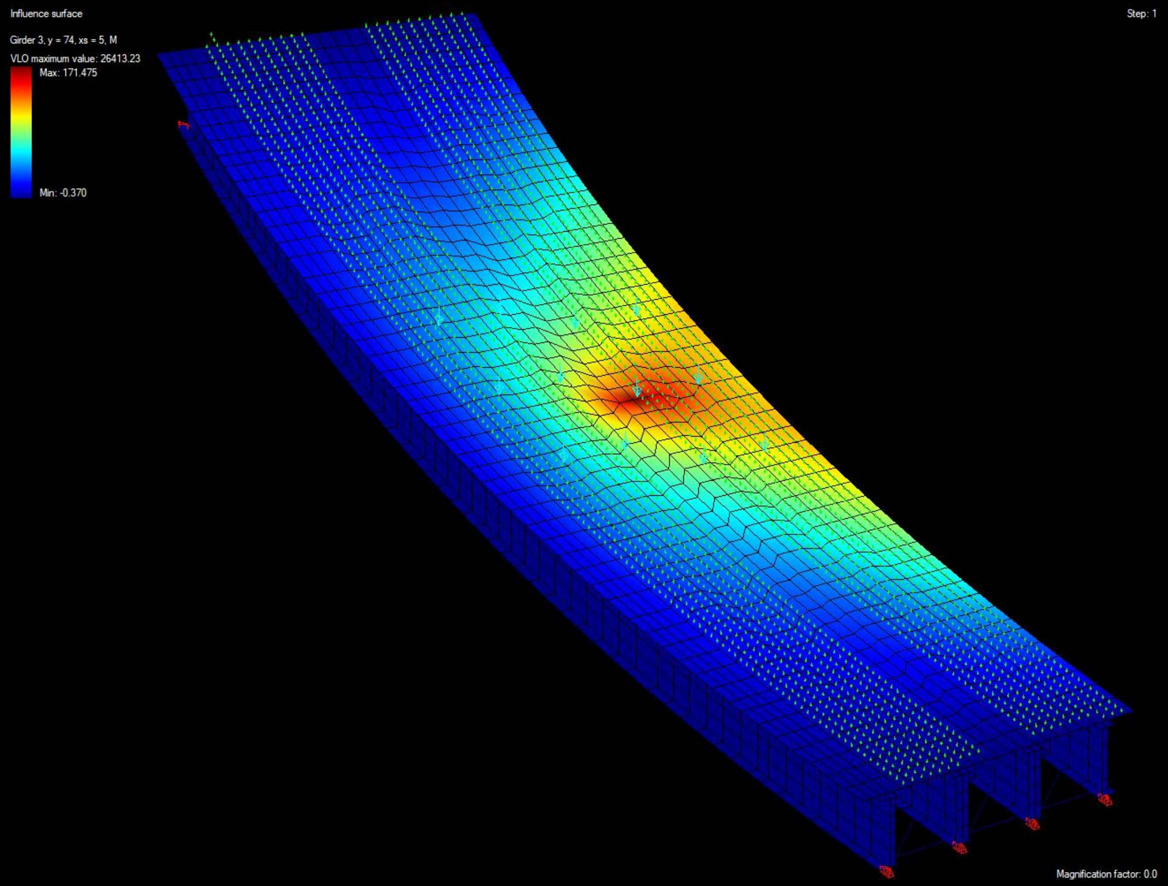


Influence surface for the composite moment at mid-span, Girder 2
M_{max} = 44,634 kips-in

Composite model (LL+IM), Girder 3

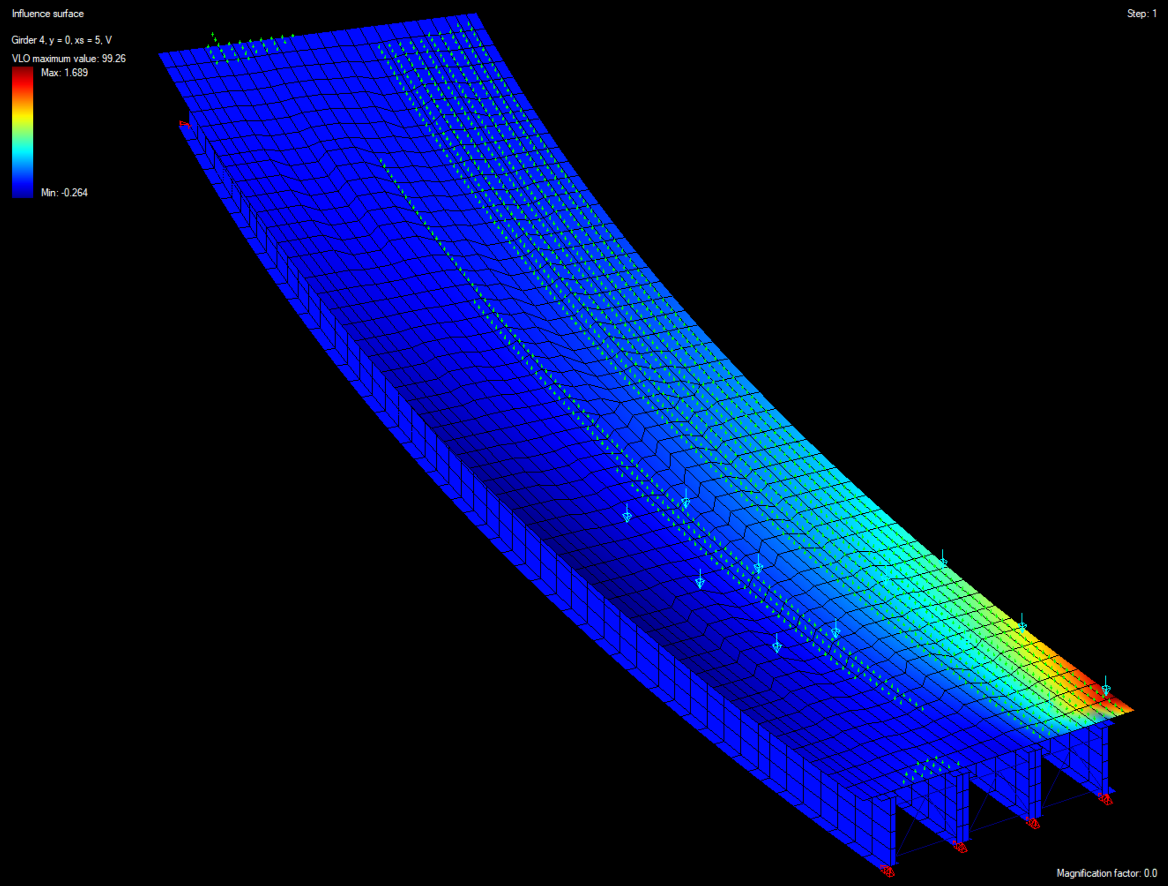


Influence surface for the shear at the first abutment, Girder 3
$V_{max} = 94$ kips

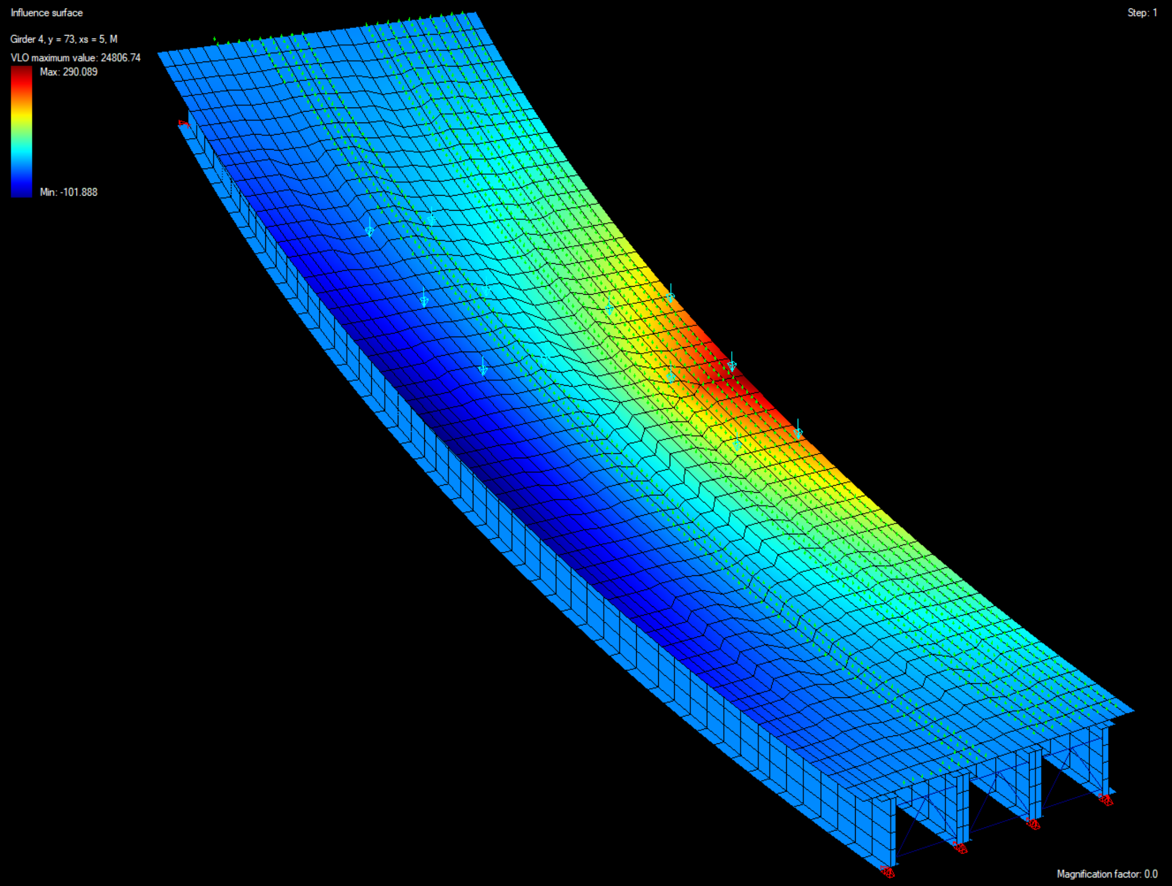


Influence surface for the composite moment at mid-span, Girder 3
$M_{max} = 26{,}413$ kips-in

Composite model (LL+IM), Girder 4



Influence surface for the shear at the first abutment, Girder 4
$V_{max} = 99$ kips

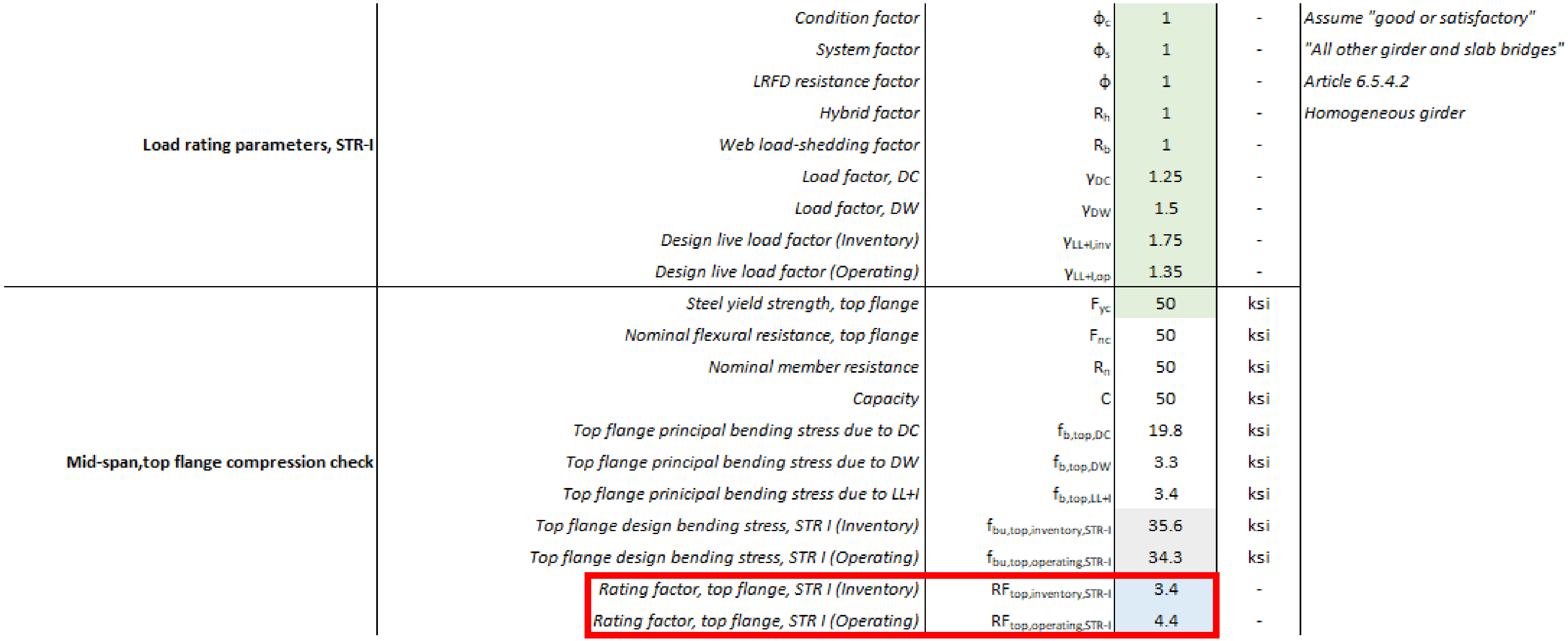


Influence surface for the composite moment at mid-span, Girder 4
$M_{max} = 24{,}807$ kips-in

Rating factor calculation, Girder I (1/4)

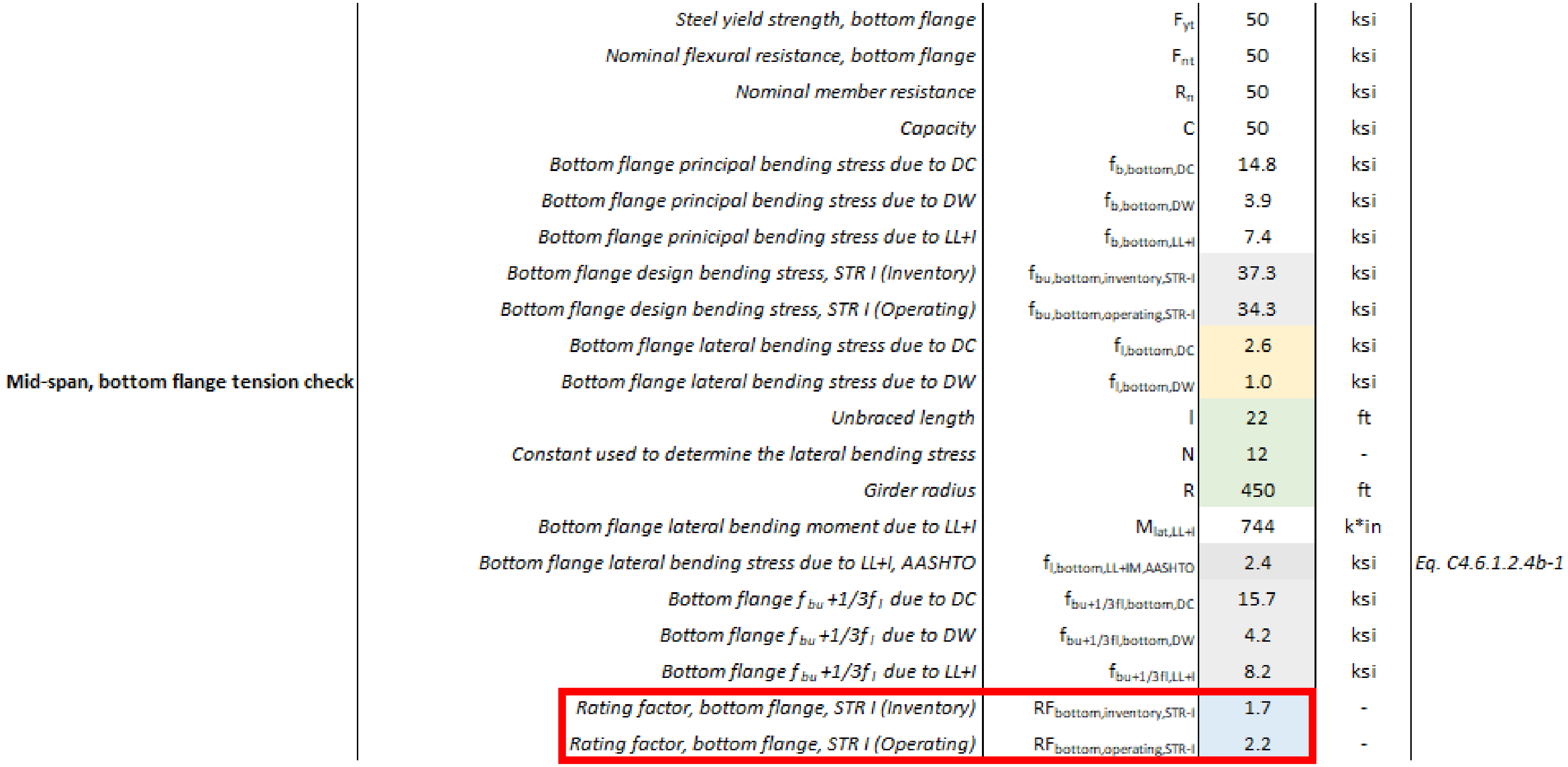
Concrete properties	*Concrete strength*	f'_c	5	ksi	
	Concrete modulus of elasticity (short term)	E_n	4250	ksi	*AASHTO LRFD 2017 Eq. C5.4.2.4-1*
	Concrete modulus of elasticity (long term)	E_{3n}	1417	ksi	
DC	*Moment at mid-span due to steel superstructure and concrete deck self-weight*	$M_{max,DC}$	95606	k*in	
DW	*Concrete parapet line load*	$w_{parapet}$	0.5	k/ft	
	Wearing surface load	$w_{wearing\ surface}$	30	psf	
	Moment at mid-span due to concrete parapet line load and wearing surface load	$M_{max,DW}$	28266	k*in	
LL+I	*Moment at mid-span due to live load*	$M_{max,LL+I}$	58110	k*in	
Section properties	*Deck centerline elevation (from bottom of section)*	$d_{concrete}$	95.5	in	
	Concrete deck thickness	t_s	9.5	in	
	Haunch (from top of top flange to bottom of concrete deck)	h_0	2	in	
	Girder spacing	sp	8	ft	
	Overhance width	$b_{overhang}$	3	ft	
	Effective width	b_{eff}	7	ft	
	Top flange width (at mid-span)	b_{tf}	22	in	
	Top flange thickness (at mid-span)	t_{tf}	2	in	
	Web depth (at mid-span)	D	84	in	
	Web thickness (at mid-span)	t_w	0.75	in	
	Bottom flange width (at mid-span)	b_{bf}	26	in	
	Bottom flange thickness (at mid-span)	t_{bf}	2.75	in	
	Overall section depth	h	88.75	in	
Non-composite section properties	*Elastic section modulus (from NA to top of steel section)*	$S_{top\ of\ steel}$	4821	in3	
	Elastic section modulus (from NA to bottom of steel section)	$S_{bottom\ of\ steel}$	6446	in3	
Long-term composite section properties (3n)	*Elastic section modulus (from NA to top of steel section)*	$S_{top\ of\ steel}$	8673	in3	
	Elastic section modulus (from NA to bottom of steel section)	$S_{bottom\ of\ steel}$	7268	in3	
Short-term composite section properties (n)	*Elastic section modulus (from NA to top of steel section)*	$S_{top\ of\ steel}$	17121	in3	
	Elastic section modulus (from NA to bottom of steel section)	$S_{bottom\ of\ steel}$	7893	in3	

Rating factor calculation, Girder I (2/4)



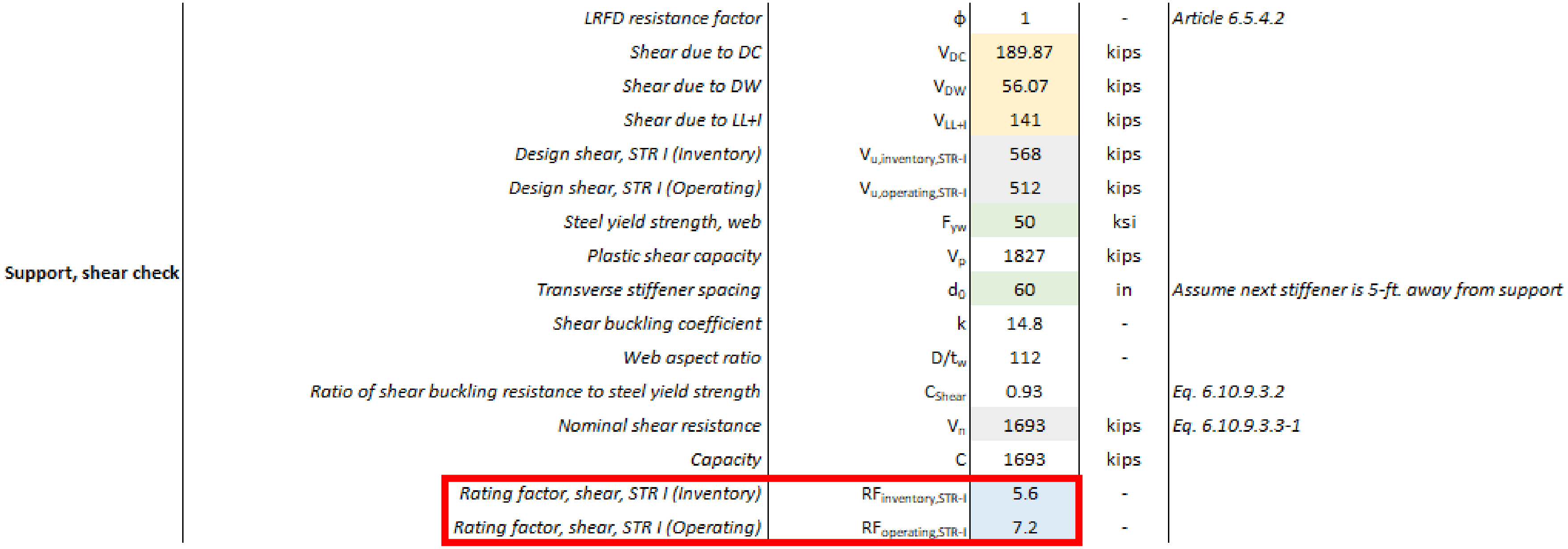
Load rating parameters, STR-I	*Condition factor*	ϕ_c	1	-	*Assume "good or satisfactory"*
	System factor	ϕ_s	1	-	*"All other girder and slab bridges"*
	LRFD resistance factor	ϕ	1	-	*Article 6.5.4.2*
	Hybrid factor	R_h	1	-	*Homogeneous girder*
	Web load-shedding factor	R_b	1	-	
	Load factor, DC	γ_{DC}	1.25	-	
	Load factor, DW	γ_{DW}	1.5	-	
	Design live load factor (Inventory)	$\gamma_{LL+I,inv}$	1.75	-	
	Design live load factor (Operating)	$\gamma_{LL+I,op}$	1.35	-	
Mid-span,top flange compression check	*Steel yield strength, top flange*	F_{yc}	50	ksi	
	Nominal flexural resistance, top flange	F_{nc}	50	ksi	
	Nominal member resistance	R_n	50	ksi	
	Capacity	C	50	ksi	
	Top flange principal bending stress due to DC	$f_{b,top,DC}$	19.8	ksi	
	Top flange principal bending stress due to DW	$f_{b,top,DW}$	3.3	ksi	
	Top flange prinicipal bending stress due to LL+I	$f_{b,top,LL+I}$	3.4	ksi	
	Top flange design bending stress, STR I (Inventory)	$f_{bu,top,inventory,STR\text{-}I}$	35.6	ksi	
	Top flange design bending stress, STR I (Operating)	$f_{bu,top,operating,STR\text{-}I}$	34.3	ksi	
	Rating factor, top flange, STR I (Inventory)	$RF_{top,inventory,STR\text{-}I}$	3.4	-	
	Rating factor, top flange, STR I (Operating)	$RF_{top,operating,STR\text{-}I}$	4.4	-	

Rating factor calculation, Girder I (3/4)



Mid-span, bottom flange tension check	*Steel yield strength, bottom flange*	F_{yt}	50	ksi	
	Nominal flexural resistance, bottom flange	F_{nt}	50	ksi	
	Nominal member resistance	R_n	50	ksi	
	Capacity	C	50	ksi	
	Bottom flange principal bending stress due to DC	$f_{b,bottom,DC}$	14.8	ksi	
	Bottom flange principal bending stress due to DW	$f_{b,bottom,DW}$	3.9	ksi	
	Bottom flange prinicipal bending stress due to LL+I	$f_{b,bottom,LL+I}$	7.4	ksi	
	Bottom flange design bending stress, STR I (Inventory)	$f_{bu,bottom,inventory,STR\text{-}I}$	37.3	ksi	
	Bottom flange design bending stress, STR I (Operating)	$f_{bu,bottom,operating,STR\text{-}I}$	34.3	ksi	
	Bottom flange lateral bending stress due to DC	$f_{l,bottom,DC}$	2.6	ksi	
	Bottom flange lateral bending stress due to DW	$f_{l,bottom,DW}$	1.0	ksi	
	Unbraced length	l	22	ft	
	Constant used to determine the lateral bending stress	N	12	-	
	Girder radius	R	450	ft	
	Bottom flange lateral bending moment due to LL+I	$M_{lat,LL+I}$	744	k*in	
	Bottom flange lateral bending stress due to LL+I, AASHTO	$f_{l,bottom,LL+IM,AASHTO}$	2.4	ksi	*Eq. C4.6.1.2.4b-1*
	Bottom flange f_{bu} +1/3f_l due to DC	$f_{bu+1/3fl,bottom,DC}$	15.7	ksi	
	Bottom flange f_{bu} +1/3f_l due to DW	$f_{bu+1/3fl,bottom,DW}$	4.2	ksi	
	Bottom flange f_{bu} +1/3f_l due to LL+I	$f_{bu+1/3fl,LL+I}$	8.2	ksi	
	Rating factor, bottom flange, STR I (Inventory)	$RF_{bottom,inventory,STR\text{-}I}$	1.7	-	
	Rating factor, bottom flange, STR I (Operating)	$RF_{bottom,operating,STR\text{-}I}$	2.2	-	

Rating factor calculation, Girder I (4/4)



Support, shear check	*LRFD resistance factor*	ϕ	1	-	*Article 6.5.4.2*
	Shear due to DC	V_{DC}	189.87	kips	
	Shear due to DW	V_{DW}	56.07	kips	
	Shear due to LL+I	V_{LL+I}	141	kips	
	Design shear, STR I (Inventory)	$V_{u,inventory,STR\text{-}I}$	568	kips	
	Design shear, STR I (Operating)	$V_{u,operating,STR\text{-}I}$	512	kips	
	Steel yield strength, web	F_{yw}	50	ksi	
	Plastic shear capacity	V_p	1827	kips	
	Transverse stiffener spacing	d_0	60	in	*Assume next stiffener is 5-ft. away from support*
	Shear buckling coefficient	k	14.8	-	
	Web aspect ratio	D/t_w	112	-	
	Ratio of shear buckling resistance to steel yield strength	C_{Shear}	0.93		*Eq. 6.10.9.3.2*
	Nominal shear resistance	V_n	1693	kips	*Eq. 6.10.9.3.3-1*
	Capacity	C	1693	kips	
	Rating factor, shear, STR I (Inventory)	$RF_{inventory,STR\text{-}I}$	5.6	-	
	Rating factor, shear, STR I (Operating)	$RF_{operating,STR\text{-}I}$	7.2	-	

Results summary, all girders

RF	**Strength I - Inventory**		
	Top flange, compression	*Bottom flange, tension*	*Shear*
Girder 1	3.4	1.7	5.6
Girder 2	7.0	2.8	6.8
Girder 3	14.9	4.2	6.2
Girder 4	17.2	5.3	6.1

RF	**Strength I - Operating**		
	Top flange, compression	*Bottom flange, tension*	*Shear*
Girder 1	4.4	2.2	7.2
Girder 2	9.0	3.7	8.9
Girder 3	19.3	5.4	8.0
Girder 4	22.3	6.8	7.9

Controlling rating factor 1.7

Concluding remarks

1. mBrace3D allows for **parametric generation of 3D shell models**, which are the most **refined analysis method** for curved steel bridges, as stated in NCHRP Report 725 and other design guides.

2. For the purpose of load rating, **three models** shall be defined: one for the non-composite system (**DC**), one for the superimposed dead loads on the composite system (**DW , 3n**), and one for the live loads on the composite system (**LL+IM, n**).

3. mBrace3D can automatically calculate the **principal and lateral bending stresses**, as well as the **shear and composite moment**; these quantities are then used to compute the rating factors for specific truck models and load combinations.

4. A curved, simple-span plate girder bridge taken from the NCHRP Report 725 was modelled in mBrace3D (both for the DC, DW and LL+IM conditions); **influence surfaces** for the moment at mid-span and the shear at the abutments were presented, together with the calculation of the corresponding **load rating factors**.

5. The **complexity** of the influence surface calculations is $O(n^3)$ – where n is the number of nodes representing the concrete deck – and can therefore become quite time-consuming for large models, for which a **coarse mesh** is required to keep running times reasonable.