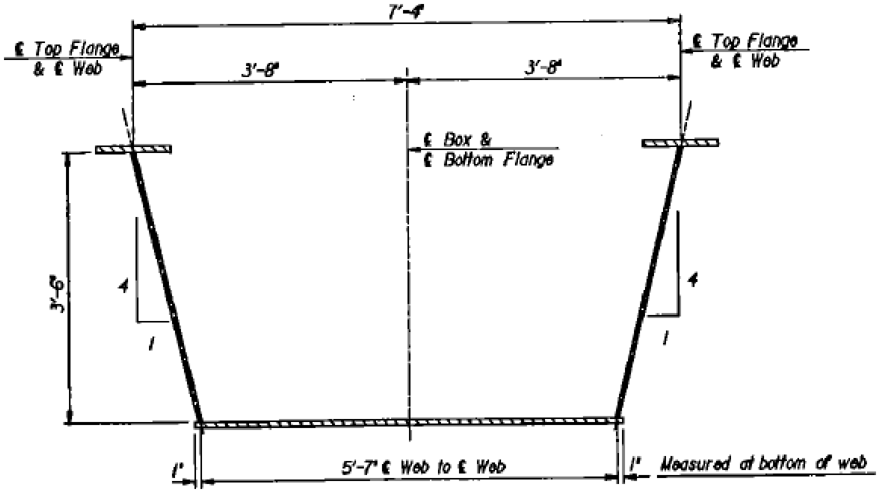
HDR

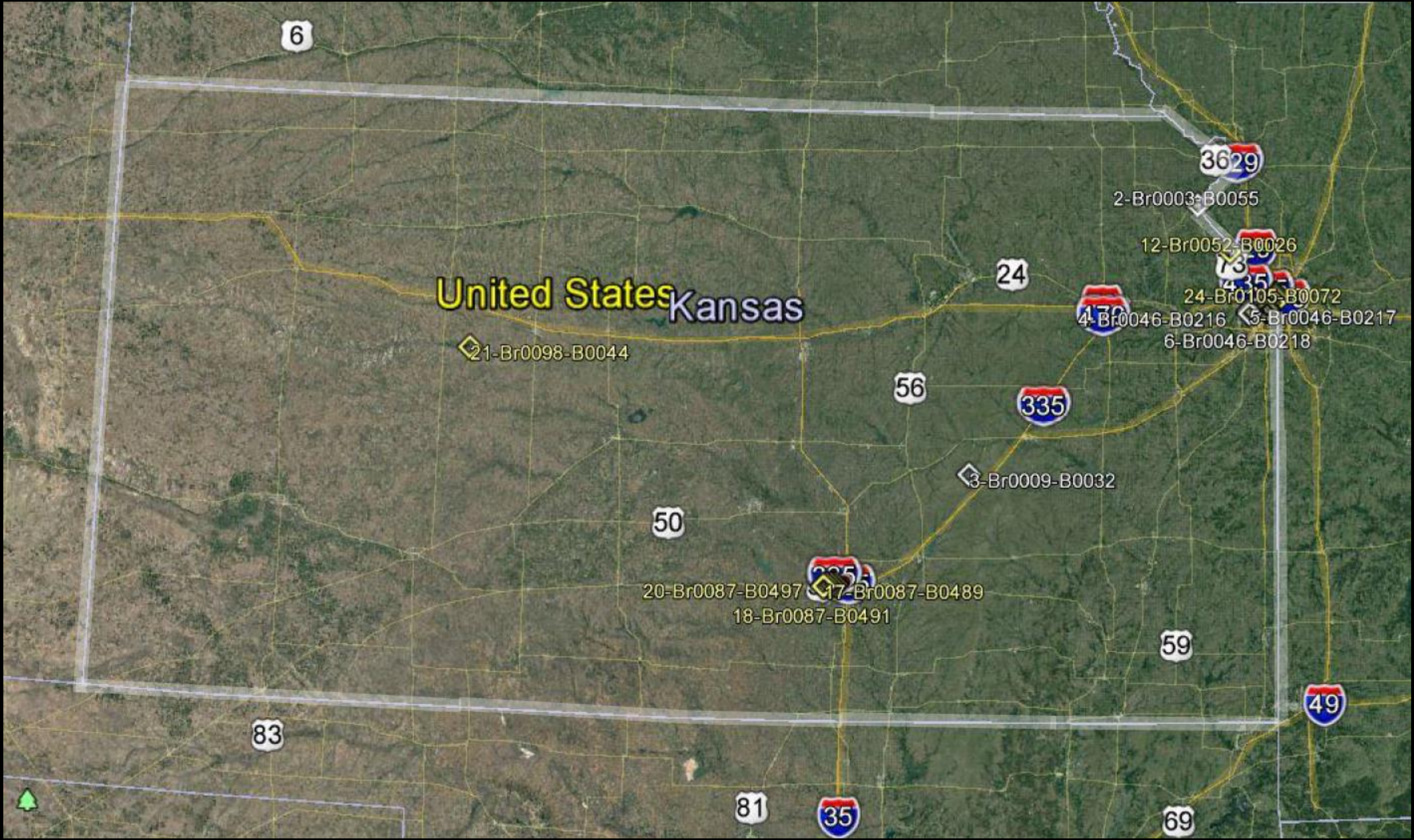
KDOT STEEL LOAD RATING PROJECT

LFD Rating of Composite Steel Tub Girders in AASHTOWare BrR

Kevin Gribble, P.E., and Brian Zeiger, P.E.



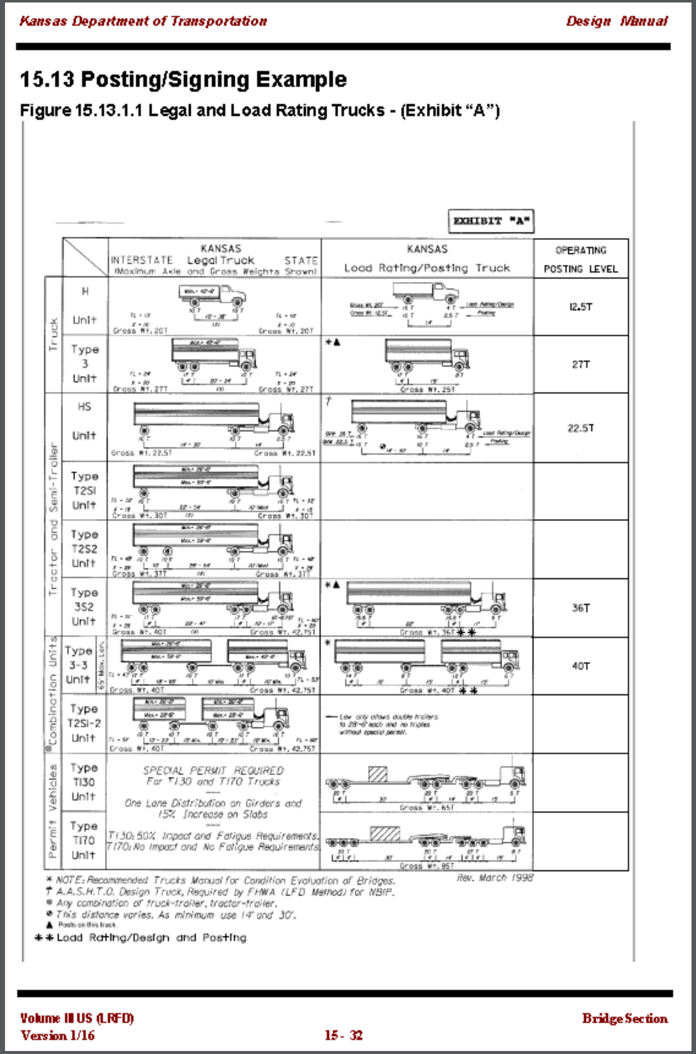
TYPICAL BOX GIRDER SECTION



United States
Kansas
2-Br0003-B0055
12-Br0052-B0026
24-Br0105-B0072
4-Br0046-B0216
5-Br0046-B0217
6-Br0046-B0218
21-Br0098-B0044
3-Br0009-B0032
20-Br0087-B0497
17-Br0087-B0489
18-Br0087-B0491
6
36
29
24
56
335
50
59
49
83
81
35
69

KDOT STEEL LOAD RATING PROJECT

- Deliverable – AASHTOWare Model of Every Bridge or Unit – 46 total steel units of varying superstructure type and complexity
- To be used in KDOT's **K-TRIPS**:
  - Kansas Truck Routing and Intelligent Permitting System


Kansas Department of Transportation — Design Manual

15.13 Posting/Signing Example

Figure 15.13.1.1 Legal and Load Rating Trucks - (Exhibit "A")

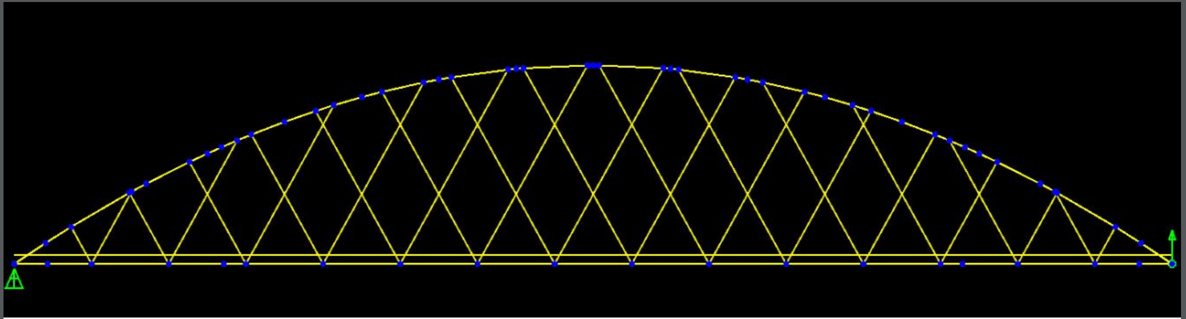
Volume III US (LRFD) — Bridge Section
Version 1/16 — 15 - 32

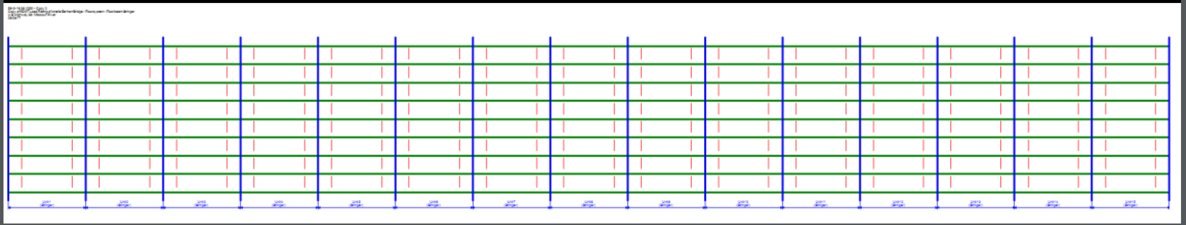
KDOT STEEL LOAD RATING PROJECT

- Curved I-Girder Bridges (SFGC, SFCC)
  - Heavy Skew Curved Multi-Girder Systems with Hinges, AASHTOWare 3D FEM
  - Curved Two-Girder Systems with Hinges, AASHTOWare 3D FEM
- **Straight and Curved Steel Tub Girder Bridges (SBCC)**
  - **Equivalent I-Girder Method in AASHTOWare (presented today)**

KDOT STEEL LOAD RATING PROJECT

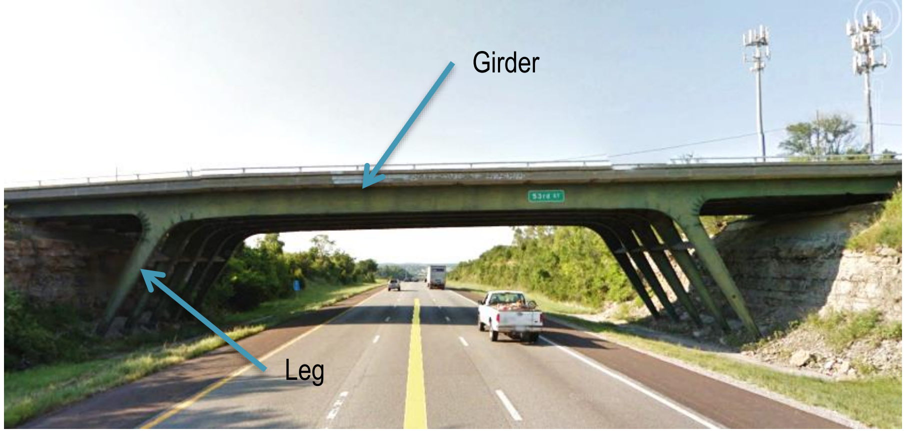
- Tied Arch Bridges (STAT)
  - Floor System in AASHTOWare with external verification to ensure arch ribs, hangers, and ties did not control





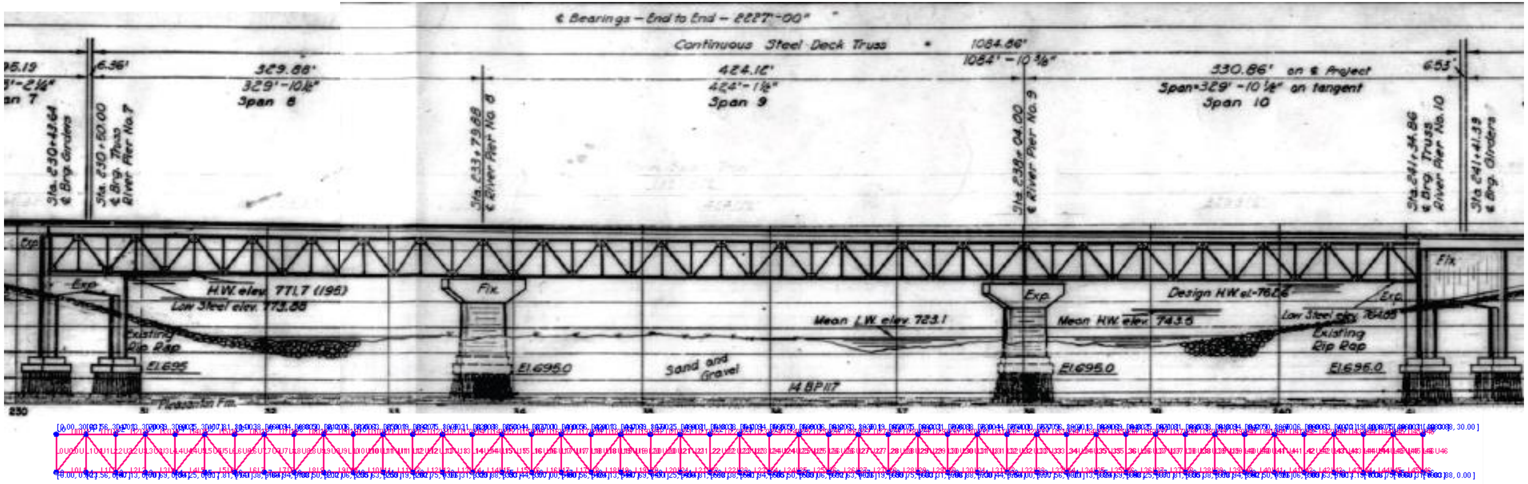
KDOT STEEL LOAD RATING PROJECT

- K-Frame Grasshopper Bridges (SRFC, WRFC)
  - Simplified AASHTOWare Spring Constant Method with external verification to ensure frame legs did not control
  - Once legs shown not to control, simplified AASHTOWare method was used for girders inside AASHTOWare BrR



KDOT STEEL LOAD RATING PROJECT

- Deck Truss Bridges (SDTS, SDTH, SDTC)
  - AASHTOWare 2D Truss Module
  - Floor System performed in AASHTOWare using:
    - Floor Line (isolated members)
    - Floor System



BOX GIRDER LOAD RATING

- Box Girders as Line Girders
  - Goal to get rating factors for shear and moment into one equivalent girder.

6-80

6B.4—RATING EQUATION

6B.4.1—General

The following general expression should be used in determining the load rating of the structure:

$$RF = \frac{C - A_1 D}{A_2 L (1 + I)} \qquad (6B.4.1\text{-}1)$$

where:

RF = The rating factor for the live load carrying capacity. The rating factor multiplied by the rating vehicle in tons gives the rating of the structure (see Eq. 6B.4.1-2)

In the equation above "load effect" is the effect of the applied loads on the member. Typical "load effects" used by engineers are axial force, vertical shear force, bending moment, axial stress, shear stress, and bending stresses. Once the "load effect" to be evaluated is selected by the Engineer, the "capacity" of a member to resist such a load effect may be determined (see Article 6B.5).

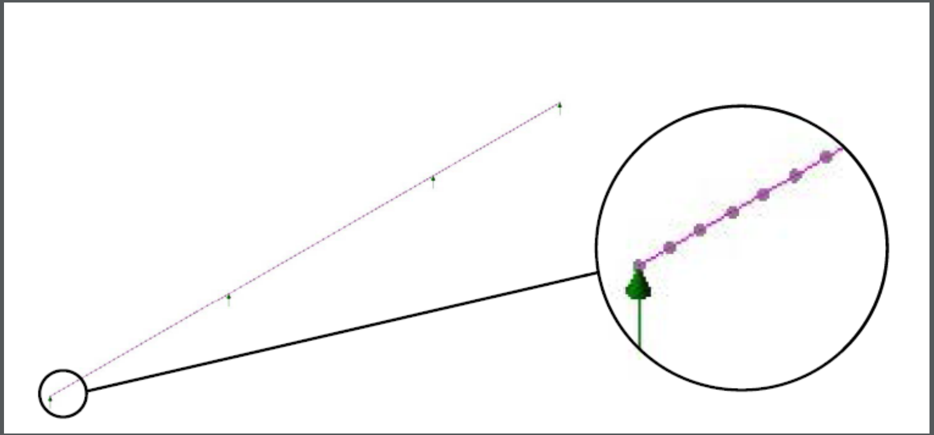
$$RT = (RF)W \qquad (6B.4.1\text{-}2)$$

where:

RT = Bridge member rating (tons)

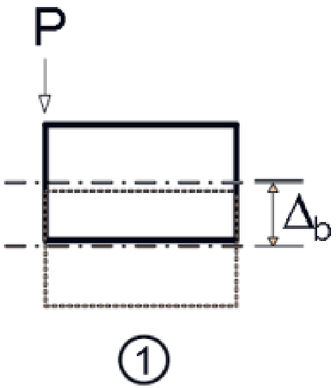
W = Weight of nominal truck used in determining the live load effect, L (tons)

The rating of a bridge is controlled by the member with the lowest rating in tons.



BOX GIRDER VS. EQUIVALENT I-GIRDER

- Box Girder (Fully Composite)
  - Web Shear
  - Web-Bend Buckling
  - Flange Yield (Top and Bottom Flange)
  - Local Flange Buckling (Bottom Flange)
  - No lateral torsional buckling
    - Boxes are 100 to 1000 times torsionally stiff than I-Girders.



VS.

- Equivalent I-Girder (Fully Composite)
  - Web Shear
  - Web-Bend Buckling
  - Flange Yield (Top and Bottom Flange)
  - Local Flange Buckling (Bottom Flange)
  - Lateral Torsional Buckling (Do not want in equivalent model)
    - "Dummy" bracing added at every 5 ft to simulate box girder torsional rigidity and ensure lateral torsional buckling in the equivalent I-Girder does not control

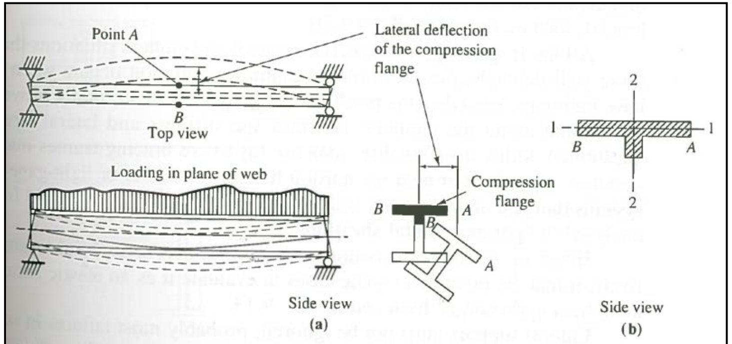
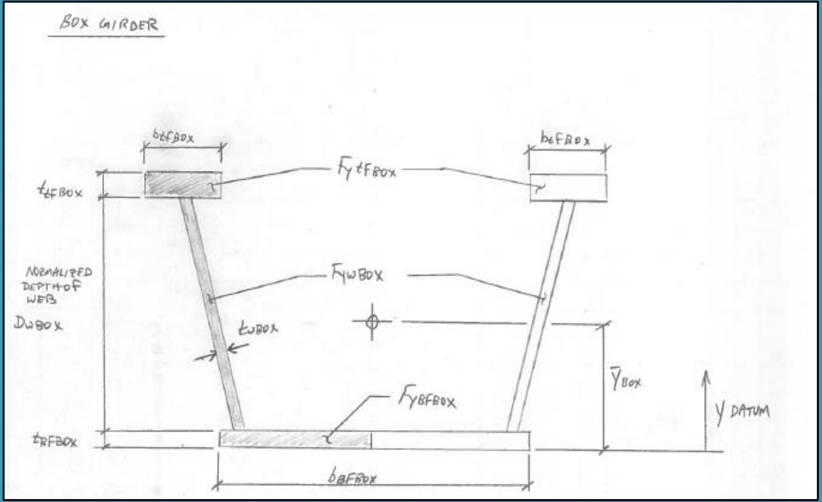


Figure 9.1.1 Beam laterally supported only at its ends.

ACTUAL BOX GIRDER



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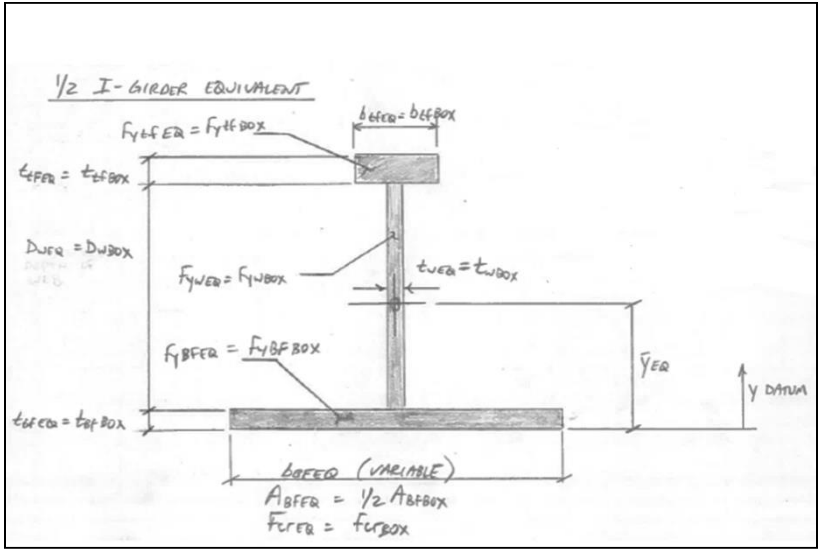
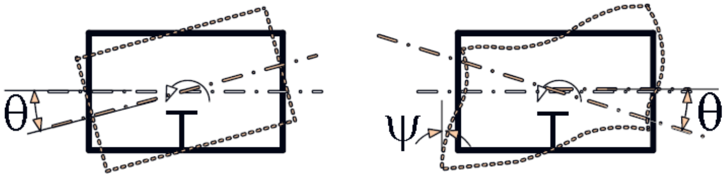
½ I-GIRDER EQUIVALENT



- Set S_{EQ} = ½ S_{BOX}
- Set DF_{LLEQ} = ½ DF_{LLBOX}
- Set F_{crEQ} = F_{crBOX} for bottom flange local buckling
- Set $Effwidth_{EQ}$ = ½ $Effwidth_{BOX}$
- f_{EQ} = f_{BOX} (f = Mc/I = M/S)

BOX/TUB GIRDER OBJECTIVES

- Captured:
  - Load Rating for Major Axis Bending – Positive and Negative Flexure, Top and Bottom Flanges
  - Load Rating for Major Axis Shear - Webs
- Not Captured:
  - St. Venant's Torsional Stresses
  - Cross-Sectional Distortion Stresses
  - System Effects (Line Girder Only)
  - Skew Effects (Bridges had minor skew or were square)
  - Curvature Effects (Bridges had minor curvature >5000' radius or were straight)



② ③

- AASHTO Std. Spec. 17th Ed. 2002

10.39.3.2 Secondary Bending Stresses

10.39.3.2.1 Web plates may be plumb (90° to bottom of flange) or inclined. If the inclination of the web plates to a plane normal to the bottom flange is no greater than 1 to 4, and the width of the bottom flange is no greater than 20% of the span, then the transverse bending stresses resulting from distortion of the span, and the transverse bending stresses resulting from distortion of the girder cross section and from vibrations of the bottom plate need not be considered. For structures in this category transverse bending stresses due to supplementary loadings, such as utilities, shall not exceed 5,000 psi.

10.39.3.2.2 For structures exceeding these limits, a detailed evaluation of the transverse bending stresses due to all causes shall be made. These stresses shall be limited to a maximum stress or range of stress of 20,000 psi.

- AASHTO LRFD 2014

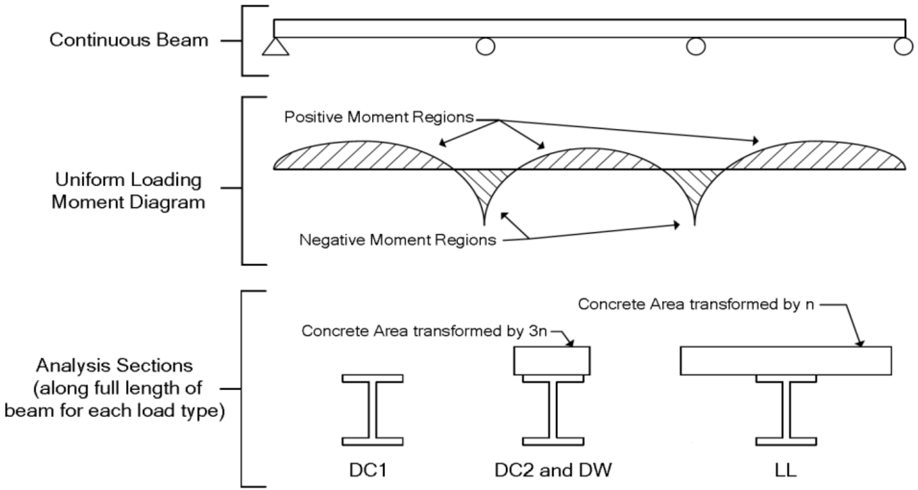
6.11.1.1—Stress Determinations

Box flanges in multiple and single box sections shall be considered fully effective in resisting flexure if the width of the flange does not exceed one-fifth of the effective span. For simple spans, the effective span shall be taken as the span length. For continuous spans, the effective span shall be taken equal to the distance between points of permanent load contraflexure, or between a simple support and a point of permanent load contraflexure, as applicable. If the flange width exceeds one-fifth of the effective span, only a width equal to one-fifth of the effective span shall be considered effective in resisting flexure.

For multiple box sections in straight bridges satisfying the requirements of Article 6.11.2.3, the live-load flexural moment in each box may be determined in accordance with the applicable provisions of Article 4.6.2.2.2b. Shear due to St. Venant torsion and transverse bending and longitudinal warping stresses due to cross-section distortion may also be neglected for sections within these bridges that have fully effective box flanges. The section of an exterior member assumed to resist horizontal factored wind loading within these bridges may be taken as the bottom box flange acting as a web and 12 times the thickness of the web acting as flanges.

EQUIVALENT STRESSES: BOX GIRDER VS. EQUIVALENT I-GIRDER

- ½ Girder Steel = ½ Steel Dead Load
- ½ Effective Deck Width = ½ Effective Deck Section for n and 3n
- ½ Tributary Deck Width = ½ Concrete Dead Load
- ½ Live Load Distribution Factor = ½ Live Load (Moment, Shear)



BOX GIRDER

$$\sigma = \frac{Mc}{I}$$

EQUIVALENT I-GIRDER

$$\sigma = \frac{\frac{1}{2} Mc}{\frac{1}{2} I}$$

$$\sigma = \frac{\frac{M}{2} c}{\frac{1}{2} \Sigma \left(\frac{1}{12} b h^3 + A d^2 \right)}$$

$$\sigma = \frac{\frac{M}{2} c}{\Sigma \frac{1}{12} \frac{b}{2} h^3 + \frac{b}{2} h d^2}$$

$$\therefore \quad \frac{Mc}{I} = \frac{\boxed{\frac{M}{2}}\, c}{\Sigma \frac{1}{12} \boxed{\frac{b}{2}} h^3 + \boxed{\frac{b}{2}} h d^2}$$

$$\boxed{\sigma_{BOX} = \sigma_{EQUIV\,I}}$$

EQUIVALENT SHEAR FORCE: BOX GIRDER VS. EQUIVALENT I-GIRDER

- With C factor included in calculation, ~2% error or less in most cases with d_0 normalized over the difference in D of the web
  - AASHTO Std. Spec. 17th Ed. 2002

10.48.8 Shear

10.48.8.1 The shear capacity of webs of rolled or fabricated flexural members shall be computed as follows:

For unstiffened webs, the shear capacity shall be limited to the plastic or buckling shear force as follows:

$$V_u = CV_p \qquad (10\text{-}113)$$

For stiffened web panels complying with the provisions of Article 10.48.8.3, the shear capacity shall be determined by including post-buckling resistance due to tension-field action as follows:

$$V_u = V_p\left[C + \frac{0.87(1-C)}{\sqrt{1+(d_o/D)^2}}\right] \qquad (10\text{-}114)$$

V_p is equal to the plastic shear force and is determined as follows:

$$V_p = 0.58F_y D t_w \qquad (10\text{-}115)$$

The constant C is equal to the buckling shear stress divided by the shear yield stress, and is determined as follows:

for $\frac{D}{t_w} < \frac{6{,}000\sqrt{k}}{\sqrt{F_y}}$

$$C = 1.0$$

for $\frac{6{,}000\sqrt{k}}{\sqrt{F_y}} \le \frac{D}{t_w} \le \frac{7{,}500\sqrt{k}}{\sqrt{F_y}}$

$$C = \frac{6{,}000\sqrt{k}}{\left(\frac{D}{t_w}\right)\sqrt{F_y}} \qquad (10\text{-}116)$$

for $\frac{D}{t_w} > \frac{7{,}500\sqrt{k}}{\sqrt{F_y}}$

$$C = \frac{4.5\times10^7 k}{\left(\frac{D}{t_w}\right)^2 F_y} \qquad (10\text{-}117)$$

where the buckling coefficient, $k = 5 + [5 \div (d_o/D)^2]$, except k shall be taken as 5 for unstiffened beams and girders.

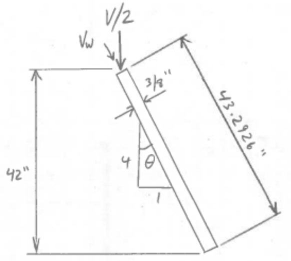
D = clear, unsupported distance between flange components;
d_o = distance between transverse stiffeners;
F_y = yield strength of the web plate.

BOX GIRDER

V

TWO WEBS

V/2



$V_w = \frac{V/2}{\cos\theta}$

θ = 14.03624°

(ASSUME C=1.0 FOR EXAMPLE)

$V_p = 0.58 F_y D t_w$

$= 0.58(50)(43.2926)(3/8)$

$= 470.81$ K

ASSUME V/2 = 400 K

$V_w = \frac{400}{\cos 14.03624°} = 412.31$ K

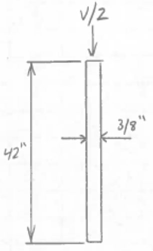
$PR = \frac{412.31 \text{ K}}{470.81 \text{ K}} = \boxed{0.876}$

EQUIVALENT I-GIRDER

$\frac{V}{2}$

ONE WEB

$\frac{V}{2}$



(ASSUME C=1.0 FOR EXAMPLE)

$V_p = 0.58 F_y D t_w$

$= 0.58(50)(42)(3/8)$

$= 456.75$

ASSUME V/2 = 400 K

$PR = \frac{400 \text{ K}}{456.75 \text{ K}} = \boxed{0.876}$

LIVE LOAD DISTRIBUTION

- AASHTO Std. Spec. 17th Ed. 2002

10.39.2 Lateral Distribution of Loads for Bending Moment

10.39.2.1 The live load bending moment for each box girder shall be determined by applying to the girder, the fraction W_L of a wheel load (both front and rear), determined by the following equation:

$$W_L = 0.1 + 1.7R + \frac{0.85}{N_w} \qquad (10\text{-}70)$$

where

$$R = \frac{N_w}{\text{Number of Box Girders}} \qquad (10\text{-}71)$$

N_w = $W_c/12$ reduced to the nearest whole number;
W_c = roadway width between curbs in feet, or barriers if curbs are not used. R shall not be less than 0.5 or greater than 1.5.

- Compute DF of actual box girder

LIVE LOAD DISTRIBUTION

Standard | LRFD

Distribution Factor Input Method

Use Simplified Method Use Advanced Method Use Advanced Method with 1994 Guide Specs

Allow distribution factors to be used to compute effects of permit loads with routine traffic

Lanes Loaded	Distribution Factor (Wheels)			
	Shear	Shear at Supports	Moment	Deflection
1 Lane	1.040	0.795	1.040	1.040
Multi-Lane	1.040	1.310	1.040	1.040

- DF Equivalent I-Girder = ½ DF Actual Box Girder

SETTING SECTION GEOMETRY – ACTUAL BOX

Longitudinal Location (Repeating Columns for Printing)				Actual Box Girder Steel Section Properties																				
Input	Iteration																							
				Top Flanges					Webs						Bottom Flange				Longitudinal Stiffeners					
Steel Section	Pier/Abut	Station	x location from CL Brg	Left t_{tf}	Left b_{tf}	Right t_{tf}	Right b_{tf}	Fy	Normalized Depth	Left t_{web}	Left D_{web}	Right t_{web}	Right D_{web}	Fy	t_{bf}	b_{bf}	b (btwn webs)	Fy	#	w (btwn stif	I	A	d	ȳ
			ft	in	in	in	in	psi	in	in	in	in	in	psi	in	in	in	psi		in	in^4	in^2	in	in
1	Abut 1	0	0	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1		1	35	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
2		0	35	0.75	12	0.75	12	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
2	Pier 1	1	45	0.75	12	0.75	12	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
2		0	55	0.75	12	0.75	12	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1		1	55	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1		0	62.5	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1	End Stiff.	1	62.5	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	0	N/A	N/A	N/A	N/A	N/A
1	Begin Stiff.	0	129.5	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	0	N/A	N/A	N/A	N/A	N/A
1		1	129.5	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1		0	137	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
2		1	137	0.75	12	0.75	12	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
2	Pier 2	0	147	0.75	12	0.75	12	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
2		1	147	0.75	12	0.75	12	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1		0	157	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54
1	Abut 2	1	192	0.75	9	0.75	9	50000	39	0.375	40.25	0.375	40.25	50000	0.438	66	64.5	50000	2	21.5	23.3	5.58	7.05	1.54

- For every longitudinal section
  - Steel Only Section – DC1 Load
  - n Section – Transient Short-Term Live Load
  - 3n Section – Long-Term Dead Load (DC2, DW)

SETTING SECTION GEOMETRY – ACTUAL BOX (CONT.)

Box Girder: Calculate Local Buckling Capacity of Bottom Flange of Actual Box girder at All Sections (AASHTO Std. Spec. 10.51.5)

w/t < 3,070√k/√Fy ?	6650√k/√F_y	3,070√k/√Fy < w/t < 6650√k/√Fy ?	c	w/t > 6650√k/√Fy ?	Critical Buckling Stress of Bottom Flange Fcr
					psi
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44342.6105
NO	67.70	YES	0.51	NO	44186.6532
NO	67.70	YES	0.51	NO	44186.6532
N/A	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A	N/A
NO	67.70	YES	0.51	NO	44186.6532
NO	67.70	YES	0.51	NO	44186.6532
NO	68.06	YES	0.52	NO	44342.6105
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44340.7464
NO	68.06	YES	0.52	NO	44340.7464

10.51.5.4 If longitudinal stiffeners are used, they shall be equally spaced across the flange width and shall be proportioned so that the moment of inertia of each stiffener about an axis parallel to the flange and at the base of the stiffener is at least equal to

$$I_s = \phi t^3 w \qquad (10\text{-}138)$$

where

ϕ = $0.07k^3n^4$ when n equals 2, 3, 4, or 5;
ϕ = $0.125k^3$ when n = 1;
w = width of flange between longitudinal stiffeners or distance from a web to the nearest longitudinal stiffener;
n = number of longitudinal stiffeners;
k = buckling coefficient which shall not exceed 4.

10.51.5.4.1

For a longitudinally stiffened flange designed for the yield stress F_y, the ratio w/t shall not exceed the value given by the formula

$$\frac{w}{t} = \frac{3{,}070\sqrt{k}}{\sqrt{F_y}} \qquad (10\text{-}139)$$

10.51.5.4.2 For greater values of w/t

$$\frac{3{,}070\sqrt{k}}{\sqrt{F_y}} < \frac{w}{t} \leq \frac{6{,}650\sqrt{k}}{\sqrt{F_y}} \qquad (10\text{-}140)$$

the buckling stress of the flange, including stiffeners, is given by Article 10.51.5.2 in which c shall be taken as

$$c = \frac{6{,}650\sqrt{k} - \frac{w}{t}\sqrt{F_y}}{3{,}580\sqrt{k}} \qquad (10\text{-}141)$$

10.51.5.4.3 For values of

$$\frac{w}{t} > \frac{6{,}650\sqrt{k}}{\sqrt{F_y}} \qquad (10\text{-}142)$$

the buckling stress of the flange, including stiffeners, is given by the formula

$$F_{cr} = 26.2k(t/w)^2 \times 10^6 \qquad (10\text{-}143)$$

- For every longitudinal section transition
  - Calculate Actual Bottom Flange Buckling Capacity

DOUBLE ITERATION OF BOTTOM FLANGE

Longitudinal Location (Repeating Columns for Printing)						Equivalent I-girder: Manipulate tbf and bbf of Bottom Flange to change Slenderness Ratio to meet Fcr and Sx										
Input	Iteration			Iteration												
				Bottom Flange		Slenderness Ratio of Bottom Flange			Critical Buckling Stress							
Steel Section	Pier/Abut	Station	x location from CL Brg	t_{bf}	b_{bf}	t/b?	Goal to match Box= t/b = (sqrt(Fcr)/4400)	% difference (Box/I-Girder)	Fcr Box (Goal)	Fcr I-Girder Equiv	% difference (Box/I-girder)	Instruct	1/2 *Abf Box	Abf I-Girder	% difference (Box/I-Girder)	Instruct
			ft	in	in			%	psi	psi	%		in^2	in^2	%	
1	Abut 1	0	0	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
1		1	35	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
2		0	35	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
2	Pier 1	1	45	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
2		0	55	0.83	17.39	0.047729	0.04786	0.272	44342.611	44102.415	0.545	make less slender	14.4375	14.4337	0.026	Add Area
1		1	55	0.83	17.39	0.047729	0.04777	0.095	44186.653	44102.415	0.191	make less slender	14.4375	14.4337	0.026	Add Area
1		0	62.5	0.83	17.39	0.047729	0.04777	0.095	44186.653	44102.415	0.191	make less slender	14.4375	14.4337	0.026	Add Area
1	End Stiff.	1	62.5	0.48	30.3	0.015842	0.01580	-0.285	4830.877	4858.504	-0.569	make more slender	14.4375	14.544	-0.732	Subtract A
1	Begin Stiff.	0	129.5	0.48	30.3	0.015842	0.01580	-0.285	4830.877	4858.504	-0.569	make more slender	14.4375	14.544	-0.732	Subtract A
1		1	129.5	0.83	17.39	0.047729	0.04777	0.095	44186.653	44102.415	0.191	make less slender	14.4375	14.4337	0.026	Add Area
1		0	137	0.83	17.39	0.047729	0.04777	0.095	44186.653	44102.415	0.191	make less slender	14.4375	14.4337	0.026	Add Area
2		1	137	0.83	17.39	0.047729	0.04786	0.272	44342.611	44102.415	0.545	make less slender	14.4375	14.4337	0.026	Add Area
2	Pier 2	0	147	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
2		1	147	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
1		0	157	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area
1	Abut 2	1	192	0.83	17.39	0.047729	0.04786	0.270	44340.746	44102.415	0.540	make less slender	14.4375	14.4337	0.026	Add Area

10.48.2 Braced Noncompact Sections

For sections of rolled or fabricated flexural members not meeting the requirements of Article 10.48.1.1 but meeting the requirements of Article 10.48.2.1 below, the maximum strength shall be computed as the lesser of

$$M_u = F_y S_{xt} \qquad (10\text{-}98)$$

or

$$M_u = F_{cr} S_{xc} R_b \qquad (10\text{-}99)$$

subject to the requirement of Article 10.48.2.1(c) where

$$F_{cr} = \left(4{,}400\frac{t}{b}\right)^2 \le F_y$$

b = compression flange width

t = compression flange thickness

S_{xt} = section modulus with respect to tension flange (in.^{3})

S_{xc} = section modulus with respect to compression flange (in.^{3})

R_b = flange-stress reduction factor determined from the provisions of Article 10.48.4.1, with f_b substituted for the term M_r/S_{xc} when Equation (10-103b) applies

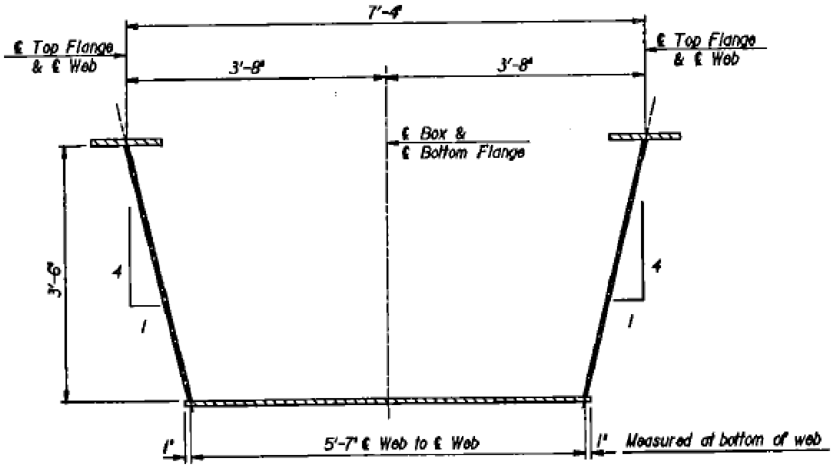
- All critical buckling stresses Box vs. Equivalent I-Girder within 1% or less
- All bottom flange areas ½ Box vs. Equivalent I-Girder within 1% or less
  - Contributes to section property comparison of section moduli (S, in^3)

SECTION PROPERTY COMPARISON: ACTUAL BOX VS. EQUIVALENT I-GIRDER

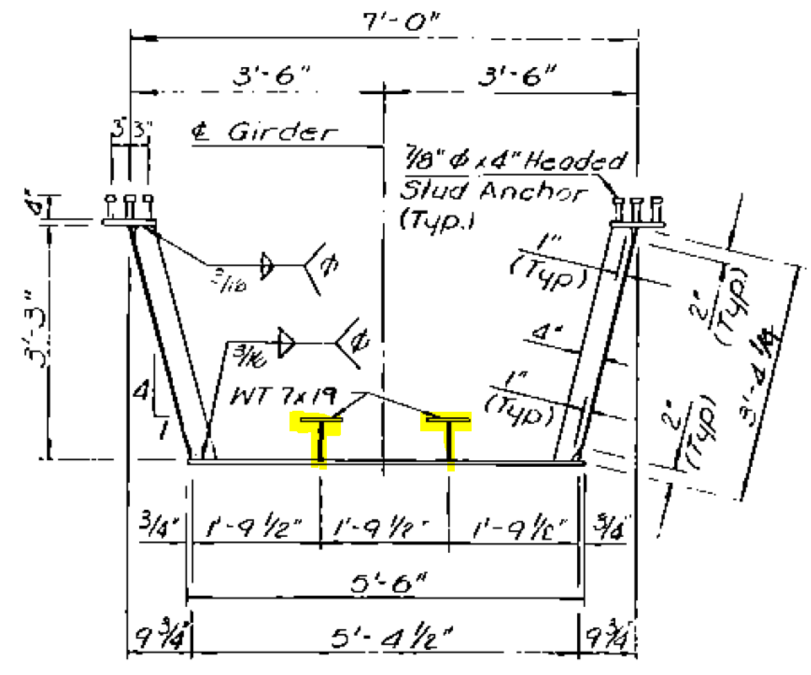
Longitudinal Location (Repeating Columns for Printing)				Final Comparison for Setting I-Equivalent vs. Actual Box							
Input	Iteration										
				W/O Deck and Fillet		W/ Deck and Fillet (n transform)		W/ Deck and Fillet (3n transform)		W/ Rebar Only Cracked Section	
Steel Section	Pier/Abut	Station	x location from CL Brg	S_{top} % Difference	S_{bottom} % Difference	S_{top} % Difference	S_{bottom} % Difference	S_{top} % Difference	S_{bottom} % Difference	S_{top} % Difference	S_{bottom} % Difference
			ft	IF 100 < %, Conservative	IF 100 < %, Conservative	IF 100 < %, Conservative	IF 100 < %, Conservative	IF 100 < %, Conservative	IF 100 < %, Conservative	IF 100 < %, Conservative	IF 100 < %, Conservative
1	Abut 1	0	0	100.69	101.50	98.84	101.03	99.62	101.05	101.95	101.54
1		1	35	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54
2		0	35	100.44	101.36	97.68	101.03	99.60	101.04	101.68	101.46
2	Pier 1	1	45	100.44	101.36	97.68	101.03	99.60	101.04	101.68	101.46
2		0	55	100.44	101.36	97.68	101.03	99.60	101.04	101.68	101.46
1		1	55	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54
1		0	62.5	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54
1	End Stiff.	1	62.5	100.68	99.51	98.55	100.16	99.94	100.04	102.87	100.37
1	Begin Stiff.	0	129.5	100.68	99.51	98.55	100.16	99.94	100.04	102.87	100.37
1		1	129.5	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54
1		0	137	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54
2		1	137	100.44	101.36	97.68	101.03	99.60	101.04	101.68	101.46
2	Pier 2	0	147	100.44	101.36	97.68	101.03	99.60	101.04	101.68	101.46
2		1	147	100.44	101.36	97.68	101.03	99.60	101.04	101.68	101.46
1		0	157	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54
1	Abut 2	1	192	100.69	101.50	97.68	101.03	99.62	101.05	101.95	101.54

- All Sections Section Moduli Within ~3% or less
- $S=I/c$

BOX GIRDERS WITH OR WITHOUT LONGITUDINAL STIFFENERS



TYPICAL BOX GIRDER SECTION



SECTION A-A

- b/t ratio of bottom flange of equivalent I-Girder can be iterated to match the local buckling capacity of the bottom flange of an actual box section with or without longitudinal stiffeners
- On KDOT Load Rating Project we had both scenarios

SECTION GEOMETRY IN AASHTOWARE BRR

Type: Plate Girder

Web | Top Flange | Bottom Flange

Begin Depth (in)	Depth Vary	End Depth (in)	Thickness (in)	Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Material	Weld at Right
39.0000	None	39.00	0.3750	1	0.00	192.00	192.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None --

Type: Plate Girder

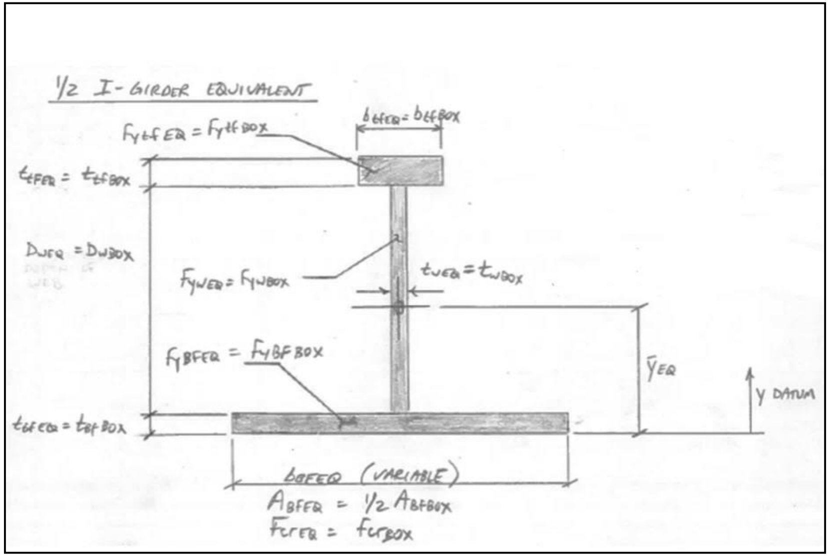
Web | Top Flange | Bottom Flange

Begin Width (in)	End Width (in)	Thickness (in)	Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Material	Weld	Weld at Right
9.0000	9.0000	0.7500	1	0.00	35.00	35.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None
12.0000	12.0000	0.7500	1	35.00	20.00	55.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None
9.0000	9.0000	0.7500	2	10.00	82.00	92.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None
12.0000	12.0000	0.7500	2	92.00	20.00	112.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None
9.0000	9.0000	0.7500	3	10.00	35.00	45.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None

Type: Plate Girder

Web | Top Flange | Bottom Flange

Begin Width (in)	End Width (in)	Thickness (in)	Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Material	Weld	Weld at Right
17.3900	17.3900	0.8300	1	0.00	62.50	62.50	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None
30.3000	30.3000	0.4800	2	17.50	67.00	84.50	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None
17.3900	17.3900	0.8300	2	84.50	62.50	147.00	ASTM A572 - <= 3/4", Fy = 50 ksi	-- None	-- None



TRANSVERSE STIFFENERS

- Transverse Stiffener Spacing and Geometry
  - Same as actual box girder web
- Fictional diaphragms every 5 to 6 ft – simulates box girder torsional rigidity, ensures lateral torsional buckling doesn't control rating

Diaphragms | Lateral Support Ranges | Lateral Support Locations

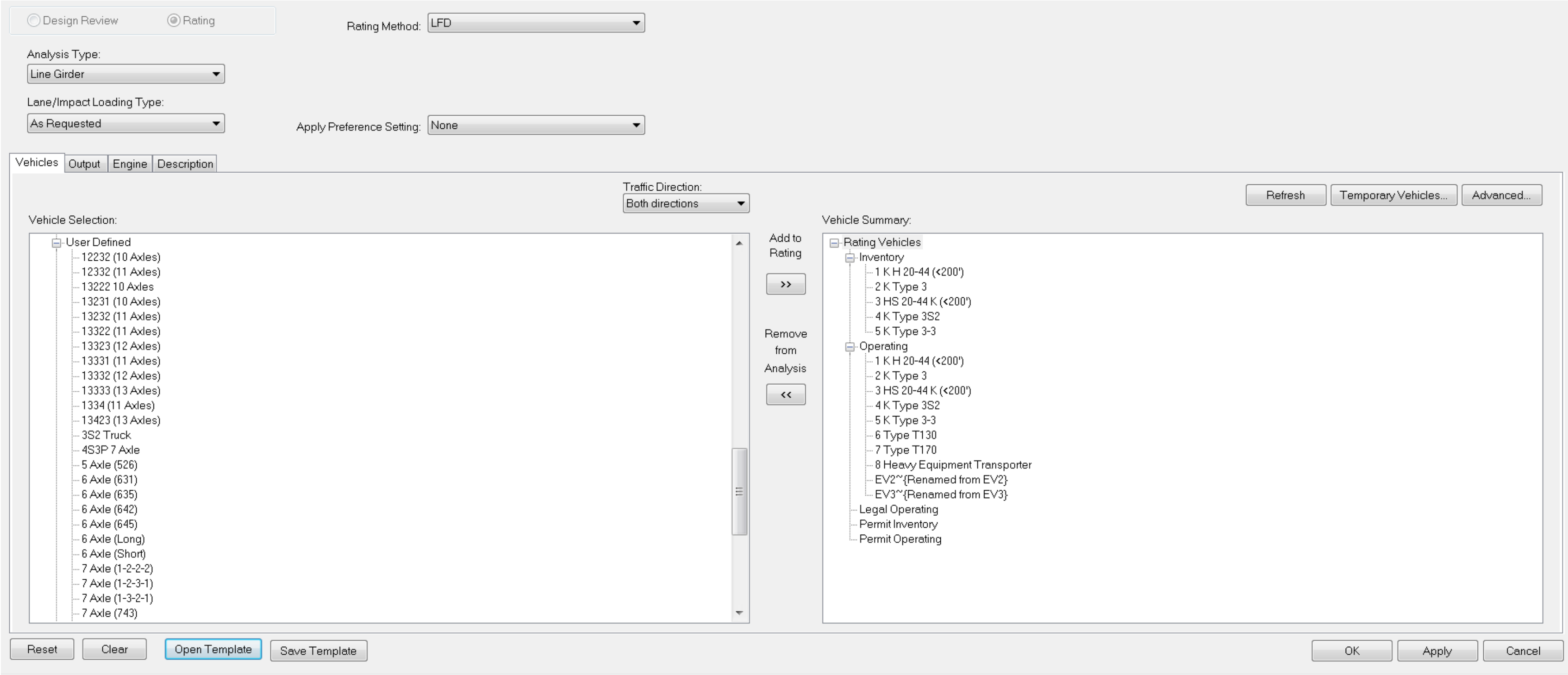
Support Number	Start Distance (ft)	Spacing (ft)	Number of Spaces	Length (ft)	End Distance (ft)	Load (kip)
1	0.00	0.00	1	0.00	0.00	
1	0.00	5.00	9	45.00	45.00	
2	0.00	6.00	1	6.00	6.00	
2	6.00	5.00	18	90.00	96.00	
2	96.00	6.00	1	6.00	102.00	
3	0.00	5.00	9	45.00	45.00	

Transverse Stiffener Ranges | Longitudinal Stiffener Ranges

Name	Support Number	Start Distance (ft)	Number of Spaces	Spacing (in)	Length (ft)	End Distance (ft)
Intermediate Stiffener	1	0.00	1	0.0000	0.00	0.00
Intermediate Stiffener	1	0.00	1	40.0000	3.33	3.33
Intermediate Stiffener	1	3.33	1	140.0000	11.67	15.00
Intermediate Stiffener	1	15.00	1	180.0000	15.00	30.00
Intermediate Stiffener	1	30.00	4	36.8125	12.27	42.27
Intermediate Stiffener	1	42.27	1	32.7500	2.73	45.00
Intermediate Stiffener	2	0.00	1	31.0000	2.58	2.58
Intermediate Stiffener	2	2.58	3	31.0000	7.75	10.33
Intermediate Stiffener	2	10.33	2	40.0000	6.67	17.00
Intermediate Stiffener	2	17.00	1	44.0000	3.67	20.67
Intermediate Stiffener	2	20.67	2	40.0000	6.67	27.33
Intermediate Stiffener	2	27.33	1	80.0000	6.67	34.00
Intermediate Stiffener	2	34.00	1	204.0000	17.00	51.00
Intermediate Stiffener	2	51.00	1	204.0000	17.00	68.00
Intermediate Stiffener	2	68.00	1	80.0000	6.67	74.67
Intermediate Stiffener	2	74.67	2	40.0000	6.67	81.33
Intermediate Stiffener	2	81.33	1	44.0000	3.67	85.00
Intermediate Stiffener	2	85.00	2	40.0000	6.67	91.67
Intermediate Stiffener	2	91.67	3	32.6250	8.16	99.82
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Apply at Diaphragms... | Stiffeners between Diaphragms...

KDOT LOAD RATING VEHICLES



SPECIFICATION CHECKS

- Span 1 - 27.00 ft.
- Span 1 - 27.50 ft.
- Span 1 - 30.00 ft.
- Span 1 - 31.50 ft.
- Span 1 - 32.50 ft.
- Span 1 - 35.00 ft.
- Span 1 - 36.00 ft.
- Span 1 - 37.50 ft.
- Span 1 - 40.00 ft.
- Span 1 - 40.50 ft.
- Span 1 - 42.50 ft.
- Span 1 - 45.00 ft.
- Span 2 - 3.00 ft.
- Span 2 - 6.00 ft.
- Span 2 - 8.50 ft.
- Span 2 - 10.00 ft.
- Span 2 - 10.20 ft.
- Span 2 - 11.00 ft.
- Span 2 - 13.50 ft.
- Span 2 - 16.00 ft.
- Span 2 - 17.50 ft.
- Span 2 - 18.50 ft.
- Span 2 - 20.40 ft.
- Span 2 - 21.00 ft.
- Span 2 - 23.50 ft.
- Span 2 - 26.00 ft.
- Span 2 - 26.33 ft.
- Span 2 - 28.50 ft.
- Span 2 - 30.60 ft.
- Span 2 - 31.00 ft.
- Span 2 - 33.50 ft.
- Span 2 - 36.00 ft.
- Span 2 - 38.50 ft.
- Span 2 - 40.80 ft.
- Span 2 - 41.00 ft.

Specification Reference	Limit State	Flex. Sense	Pass/Fail
NA 10.48.1 Noncomposite Compact Section		N/A	Not Required
10.48.1.1 Compact Section Requirements		N/A	General Com...
NA 10.48.2 Braced Noncompact Sections		N/A	Not Required
10.48.2.1 Cross-section requirements		N/A	General Com...
NA 10.48.3 Noncomposite Transition Section		N/A	Not Required
10.48.4 Noncomposite Noncompact Partially Braced Members		N/A	Failed
NA 10.48.4.1.Cb Noncomposite Cb Calculation		N/A	Not Required
10.48.4.1.Mr Noncomposite Mr Calculation		N/A	Failed
10.48.4.1.Rb Noncomposite Rb Calculation		N/A	General Com...
10.48.8 LFD Shear Calculations		N/A	Passed
NA 10.50.1.1.2 Composite Compact Positive Moment Section		N/A	Not Required
10.50.1.2 Noncompact Positive Moment Members		N/A	Passed
10.50.1.2.Rb Composite Rb Calculation		N/A	General Com...
NA 10.50.2.1 Composite Compact Negative Moment Section		N/A	Not Required
10.50.2.2 Noncompact Negative Moment Members		N/A	Failed
10.50.2.2 Composite Cb Calculation		N/A	General Com...
NA 10.53.1.2 Braced Noncompact Hybrid Sections		N/A	Not Required
6B.4 Steel Combined Moment and Shear		N/A	Passed
6B.4 Steel Flexure Moment		N/A	Passed
6B.4 Steel Flexure Overload		N/A	Passed
6B.4 Steel Flexure Stress		N/A	Passed
6B.4 Steel Shear Stress		N/A	Passed
Depth of web in compression in the Elastic Range (Dc)		N/A	General Com...
First Yield Moment (My) Calculations for All Sections		N/A	General Com...
LFD General Steel Flexural Results		N/A	Failed
LFD Steel Elastic Section Properties		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Negative Moment		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Positive Moment		N/A	General Com...
NA Plastic Moment (Mp) for Noncomposite Sections		N/A	Not Required
Steel Stresses for Sections in Positive Flexure		N/A	General Com...

Span 2 – 17.50 ft

Longitudinal Stiffener Termination Location

SPECIFICATION CHECKS

- Even though Iyc/Iy falls outside of 0.1 and 0.9 limits, AASHTOWare still computes Mr

```
SUMMARY:

(a) Compression flange proportionality

              Iyc
     0.1 <= ----- <= 0.9
              Iy

Mu = Mr*Rb*R        (10-103a)

   where, Mr = partially braced resistance moment, 10.48.4.1
          Rb = web slenderness ratio, 10.48.4.1
          R  = hybrid reduction factor, 10.53.1.2


RESULTS:

   Top flange Iyt/Iy = 0.039 (Fail)
   Bot flange Iyb/Iy = 0.961 (Fail)
```

Load Group	Load Comb	Flexure Type	(a)	Mr (kip-ft)	Rb	R	Mu (kip-ft)
Inventory	1, INV, MAX	Pos	Fail	3638.42	1.000	1.000	3638.42
Inventory	1, INV, MIN	Neg	Fail	2707.55	1.000	1.000	2707.55
Inventory	2, INV, MAX	Pos	Fail	3638.42	1.000	1.000	3638.42
Inventory	2, INV, MIN	Neg	Fail	2707.55	1.000	1.000	2707.55
Inventory	3, INV, MAX	Pos	Fail	3638.42	1.000	1.000	3638.42
Inventory	3, INV, MIN	Neg	Fail	2707.55	1.000	1.000	2707.55
Inventory	4, INV, MAX	Pos	Fail	3638.42	1.000	1.000	3638.42
Inventory	4, INV, MIN	Neg	Fail	2707.55	1.000	1.000	2707.55
Inventory	5, INV, MAX	Pos	Fail	3638.42	1.000	1.000	3638.42
Inventory	5, INV, MIN	Neg	Fail	2707.55	1.000	1.000	2707.55
Operating	1, OPG, MAX	Pos	Fail	3638.42	1.000	1.000	3638.42
Operating	1, OPG, MIN	Neg	Fail	2707.55	1.000	1.000	2707.55

SPECIFICATION CHECKS

- Span 1 - 27.00 ft.
- Span 1 - 27.50 ft.
- Span 1 - 30.00 ft.
- Span 1 - 31.50 ft.
- Span 1 - 32.50 ft.
- Span 1 - 35.00 ft.
- Span 1 - 36.00 ft.
- Span 1 - 37.50 ft.
- Span 1 - 40.00 ft.
- Span 1 - 40.50 ft.
- Span 1 - 42.50 ft.
- Span 1 - 45.00 ft.
- Span 2 - 3.00 ft.
- Span 2 - 6.00 ft.
- Span 2 - 8.50 ft.
- Span 2 - 10.00 ft.
- Span 2 - 10.20 ft.
- Span 2 - 11.00 ft.
- Span 2 - 13.50 ft.
- Span 2 - 16.00 ft.
- Span 2 - 17.50 ft.
- Span 2 - 18.50 ft.
- Span 2 - 20.40 ft.
- Span 2 - 21.00 ft.
- Span 2 - 23.50 ft.
- Span 2 - 26.00 ft.
- Span 2 - 26.33 ft.
- Span 2 - 28.50 ft.
- Span 2 - 30.60 ft.
- Span 2 - 31.00 ft.
- Span 2 - 33.50 ft.
- Span 2 - 36.00 ft.
- Span 2 - 38.50 ft.
- Span 2 - 40.80 ft.
- Span 2 - 41.00 ft.
- Span 2 - 43.50 ft.

Specification Reference	Limit State	Flex. Sense	Pass/Fail
NA 10.48.1 Noncomposite Compact Section		N/A	Not Required
10.48.1.1 Compact Section Requirements		N/A	General Com...
NA 10.48.2 Braced Noncompact Sections		N/A	Not Required
10.48.2.1 Cross-section requirements		N/A	General Com...
NA 10.48.3 Noncomposite Transition Section		N/A	Not Required
10.48.4 Noncomposite Noncompact Partially Braced Members		N/A	Failed
NA 10.48.4.1.Cb Noncomposite Cb Calculation		N/A	Not Required
10.48.4.1.Mr Noncomposite Mr Calculation		N/A	Failed
10.48.4.1.Rb Noncomposite Rb Calculation		N/A	General Com...
10.48.8 LFD Shear Calculations		N/A	Passed
NA 10.50.1.1.2 Composite Compact Positive Moment Section		N/A	Not Required
10.50.1.2 Noncompact Positive Moment Members		N/A	Passed
10.50.1.2.Rb Composite Rb Calculation		N/A	General Com...
NA 10.50.2.1 Composite Compact Negative Moment Section		N/A	Not Required
10.50.2.2 Noncompact Negative Moment Members		N/A	Failed
10.50.2.2 Composite Cb Calculation		N/A	General Com...
NA 10.53.1.2 Braced Noncompact Hybrid Sections		N/A	Not Required
6B.4 Steel Combined Moment and Shear		N/A	Passed
6B.4 Steel Flexure Moment		N/A	Passed
6B.4 Steel Flexure Overload		N/A	Passed
6B.4 Steel Flexure Stress		N/A	Passed
6B.4 Steel Shear Stress		N/A	Passed
Depth of web in compression in the Elastic Range (Dc)		N/A	General Com...
First Yield Moment (My) Calculations for All Sections		N/A	General Com...
LFD General Steel Flexural Results		N/A	Failed
LFD Steel Elastic Section Properties		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Negative Moment		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Positive Moment		N/A	General Com...
NA Plastic Moment (Mp) for Noncomposite Sections		N/A	Not Required
Steel Stresses for Sections in Positive Flexure		N/A	General Com...

SPECIFICATION CHECKS

RESULTS:

Note - Bottom flange b/t is too large. Minimum capacity between 10.48.2 and 10.48.4.1 will be used.

Load Group	Load Comb	Flexure Type	Cb	Dc (in)	My (kip-ft)	r' (in)	Lp (in)	Lr (in)	EQ	Mr (kip-ft)
Inventory	1, INV, MAX	Pos	1.4455	1.3178	3638.42				103c	3638.42
Inventory	1, INV, MIN	Neg	2.0605	19.2691	2707.55				103c	2707.55
Inventory	2, INV, MAX	Pos	1.4741	1.2799	3638.42				103c	3638.42
Inventory	2, INV, MIN	Neg	1.9428	19.2691	2707.55				103c	2707.55
Inventory	3, INV, MAX	Pos	1.4340	1.6165	3638.42				103c	3638.42
Inventory	3, INV, MIN	Neg	1.7223	19.2691	2707.55				103c	2707.55
Inventory	4, INV, MAX	Pos	1.5727	0.9832	3638.42				103c	3638.42
Inventory	4, INV, MIN	Neg	2.0026	19.2691	2707.55				103c	2707.55
Inventory	5, INV, MAX	Pos	1.6764	0.4183	3638.42				103c	3638.42
Inventory	5, INV, MIN	Neg	2.0294	19.2691	2707.55				103c	2707.55
Operating	1, OPG, MAX	Pos	1.5814	0.2702	3638.42				103c	3638.42
Operating	1, OPG, MIN	Neg	2.3000	19.2691	2707.55				103c	2707.55
Operating	10, OPG, MAX	Pos	1.4555	1.3760	3638.42				103c	3638.42
Operating	10, OPG, MIN	Neg	1.9092	19.2691	2707.55				103c	2707.55
Operating	2, OPG, MAX	Pos	1.6056	0.2015	3638.42				103c	3638.42
Operating	2, OPG, MIN	Neg	2.3000	19.2691	2707.55				103c	2707.55
Operating	3, OPG, MAX	Pos	1.5479	0.8048	3638.42				103c	3638.42
Operating	3, OPG, MIN	Neg	2.1088	19.2691	2707.55				103c	2707.55
Operating	4, OPG, MAX	Pos	1.6956	0.0000	3638.42				103c	3638.42
Operating	4, OPG, MIN	Neg	2.3000	19.2691	2707.55				103c	2707.55
Operating	5, OPG, MAX	Pos	1.7954	0.0000	3638.42				103c	3638.42
Operating	5, OPG, MIN	Neg	2.3000	19.2691	2707.55				103c	2707.55
Operating	6, OPG, MAX	Pos	1.6929	0.0165	3638.42				103c	3638.42

10.48.4 Partially Braced Members

Members not meeting the lateral bracing requirement of Article 10.48.2.1(c) shall be braced at discrete locations spaced at a distance, L_b, such that the maximum strength of the section under consideration satisfies the requirements of Article 10.48.4.1. Bracing shall be provided such that lateral deflection of the compression flange is restrained and the entire section is restrained against twisting.

10.48.4.1 If the lateral bracing requirement of Article 10.48.2.1(c) is not satisfied and the ratio of the moment of inertia of the compression flange to the moment of inertia of the member about the vertical axis of the web, I_{yc}/I_y, is within the limits of $0.1 \le I_{yc}/I_y \le 0.9$, the maximum strength for the limit state of lateral-torsional buckling shall be computed as

$$M_u = M_r R_b \qquad (10\text{-}103a)$$

10.48.2 Braced Noncompact Sections

For sections of rolled or fabricated flexural members not meeting the requirements of Article 10.48.1.1 but meeting the requirements of Article 10.48.2.1 below, the maximum strength shall be computed as the lesser of

$$M_u = F_y S_{xt} \qquad (10\text{-}98)$$

or

$$M_u = F_{cr} S_{xc} R_b \qquad (10\text{-}99)$$

subject to the requirement of Article 10.48.2.1(c) where

$$F_{cr} = \left(4{,}400\frac{t}{b}\right)^2 \le F_y$$

SPECIFICATION CHECKS

- Span 1 - 35.00 ft.
- Span 1 - 36.00 ft.
- Span 1 - 37.50 ft.
- Span 1 - 40.00 ft.
- Span 1 - 40.50 ft.
- Span 1 - 42.50 ft.
- Span 1 - 45.00 ft.
- Span 2 - 3.00 ft.
- Span 2 - 6.00 ft.
- Span 2 - 8.50 ft.
- Span 2 - 10.00 ft.
- Span 2 - 10.20 ft.
- Span 2 - 11.00 ft.
- Span 2 - 13.50 ft.
- Span 2 - 16.00 ft.
- Span 2 - 17.50 ft.
- Span 2 - 18.50 ft.
- Span 2 - 20.40 ft.
- Span 2 - 21.00 ft.
- Span 2 - 23.50 ft.
- Span 2 - 26.00 ft.
- Span 2 - 26.33 ft.
- Span 2 - 28.50 ft.
- Span 2 - 30.60 ft.
- Span 2 - 31.00 ft.
- Span 2 - 33.50 ft.
- Span 2 - 36.00 ft.
- Span 2 - 38.50 ft.
- Span 2 - 40.80 ft.
- Span 2 - 41.00 ft.
- Span 2 - 43.50 ft.
- Span 2 - 46.00 ft.
- Span 2 - 48.50 ft.
- Span 2 - 51.00 ft.
- Span 2 - 53.50 ft.

Specification Reference	Limit State	Flex. Sense	Pass/Fail
NA 10.48.1 Noncomposite Compact Section		N/A	Not Required
10.48.1.1 Compact Section Requirements		N/A	General Com...
NA 10.48.2 Braced Noncompact Sections		N/A	Not Required
10.48.2.1 Cross-section requirements		N/A	General Com...
NA 10.48.3 Noncomposite Transition Section		N/A	Not Required
10.48.4 Noncomposite Noncompact Partially Braced Members		N/A	Failed
NA 10.48.4.1.Cb Noncomposite Cb Calculation		N/A	Not Required
10.48.4.1.Mr Noncomposite Mr Calculation		N/A	Failed
10.48.4.1.Rb Noncomposite Rb Calculation		N/A	General Com...
10.48.8 LFD Shear Calculations		N/A	Passed
NA 10.50.1.1.2 Composite Compact Positive Moment Section		N/A	Not Required
10.50.1.2 Noncompact Positive Moment Members		N/A	Passed
10.50.1.2.Rb Composite Rb Calculation		N/A	General Com...
NA 10.50.2.1 Composite Compact Negative Moment Section		N/A	Not Required
10.50.2.2 Noncompact Negative Moment Members		N/A	Failed
10.50.2.2 Composite Cb Calculation		N/A	General Com...
NA 10.53.1.2 Braced Noncompact Hybrid Sections		N/A	Not Required
6B.4 Steel Combined Moment and Shear		N/A	Passed
6B.4 Steel Flexure Moment		N/A	Passed
6B.4 Steel Flexure Overload		N/A	Passed
6B.4 Steel Flexure Stress		N/A	Passed
6B.4 Steel Shear Stress		N/A	Passed
Depth of web in compression in the Elastic Range (Dc)		N/A	General Com...
First Yield Moment (My) Calculations for All Sections		N/A	General Com...
LFD General Steel Flexural Results		N/A	Failed
LFD Steel Elastic Section Properties		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Negative Moment		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Positive Moment		N/A	General Com...
NA Plastic Moment (Mp) for Noncomposite Sections		N/A	Not Required
Steel Stresses for Sections in Positive Flexure		N/A	General Com...

SPECIFICATION CHECKS

Longitudinal Location (Repeating Columns for Printing)				Actual Box Girder		Equivalent I-girder: Manipulate tbf and bbf of Bottom Flange to change Slenderness Ratio to meet Fcr and Sx										
Input	Iteration															
						Slenderness Ratio of Bottom Flange			Critical Buckling Stress							
Steel Section	Pier/Abut	Station	x location from CL Brg	Left t_{tf}	Left b_f	t/b?	Goal to match Box= t/b = (sqrt(Fcr)/4400)	% difference (Box/I-Girder)	Fcr Box (Goal)	Fcr I-Girder Equiv	% difference (Box/I-girder)	Instruct	1/2 *Abf Box	Abf I-Girder	% difference (Box/I-Girder)	Instruct
			ft	in	in			%	psi	psi	%					
1	Abut 1	0	0	0.75	9	0.047729	0.04786	0.270	44340.746	44102.415						
1		1	35	0.75	9	0.047729	0.04786	0.270	44340.746	44102.415						
2		0	35	0.75	12	0.047729	0.04786	0.270	44340.746	44102.415						
2	Pier 1	1	45	0.75	12	0.047729	0.04786	0.270	44340.746	44102.415						
2		0	55	0.75	12	0.047729	0.04786	0.272	44342.611	44102.415						
1		1	55	0.75	9	0.047729	0.04777	0.095	44186.653	44102.415						
1		0	62.5	0.75	9	0.047729	0.04777	0.095	44186.653	44102.415						
1	End Stiff.	1	62.5	0.75	9	0.015842	0.01580	-0.285	4830.877	4858.504						
1	Begin Stiff.	0	129.5	0.75	9	0.015842	0.01580	-0.285	4830.877	4858.504						
1		1	129.5	0.75	9	0.047729	0.04777	0.095	44186.653	44102.415						
1		0	137	0.75	9	0.047729	0.04777	0.095	44186.653	44102.415						
2		1	137	0.75	12	0.047729	0.04786	0.272	44342.611	44102.415						
2	Pier 2	0	147	0.75	12	0.047729	0.04786	0.270	44340.746	44102.415						
2		1	147	0.75	12	0.047729	0.04786	0.270	44340.746	44102.415						
1		0	157	0.75	9	0.047729	0.04786	0.270	44340.746	44102.415						
1	Abut 2	1	192	0.75	9	0.047729	0.04786	0.270	44340.746	44102.415						

```
IF 10.48.2.1(c) fails, then
   Mu = min(Mu from 10.48.2, Mu from 10.48.4.1)
```

Spec Check Detail for 10.50.2.2 Noncompact Negative Moment Members

***** Compression Flange *****

Limit State	Load Comb	Flexure Type	Component	(a)	(b)	Rb	R	Fcr 10.48.2 (ksi)	(c)	Mu/Sxc 10.48.2 (ksi)	Mu Comp (kip-ft)	Status
Inventory	1, INV, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Inventory	1, INV, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Inventory	2, INV, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Inventory	2, INV, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Inventory	3, INV, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Inventory	3, INV, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Inventory	4, INV, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Inventory	4, INV, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Inventory	5, INV, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Inventory	5, INV, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	1, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	1, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	10, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	10, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	2, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	2, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	3, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	3, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	4, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	4, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	5, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	5, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	6, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	6, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	7, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	7, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	8, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	8, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail
Operating	9, OPG, MAX	Pos	-	-	-	-	-	-	-	-	-	N/A*
Operating	9, OPG, MIN	Neg	Bot Flange	Fail	Pass	1.000	1.000	4.86	Pass		280.06	Fail

* Article does not apply to composite sections in positive flexure.

OK

SPECIFICATION CHECKS

- Span 1 - 35.00 ft.
- Span 1 - 36.00 ft.
- Span 1 - 37.50 ft.
- Span 1 - 40.00 ft.
- Span 1 - 40.50 ft.
- Span 1 - 42.50 ft.
- Span 1 - 45.00 ft.
- Span 2 - 3.00 ft.
- Span 2 - 6.00 ft.
- Span 2 - 8.50 ft.
- Span 2 - 10.00 ft.
- Span 2 - 10.20 ft.
- Span 2 - 11.00 ft.
- Span 2 - 13.50 ft.
- Span 2 - 16.00 ft.
- Span 2 - 17.50 ft.
- Span 2 - 18.50 ft.
- Span 2 - 20.40 ft.
- Span 2 - 21.00 ft.
- Span 2 - 23.50 ft.
- Span 2 - 26.00 ft.
- Span 2 - 26.33 ft.
- Span 2 - 28.50 ft.
- Span 2 - 30.60 ft.
- Span 2 - 31.00 ft.
- Span 2 - 33.50 ft.
- Span 2 - 36.00 ft.
- Span 2 - 38.50 ft.
- Span 2 - 40.80 ft.
- Span 2 - 41.00 ft.
- Span 2 - 43.50 ft.
- Span 2 - 46.00 ft.
- Span 2 - 48.50 ft.
- Span 2 - 51.00 ft.
- Span 2 - 53.50 ft.

Specification Reference	Limit State	Flex. Sense	Pass/Fail
10.48.1 Noncomposite Compact Section		N/A	Not Required
10.48.1.1 Compact Section Requirements		N/A	General Com...
10.48.2 Braced Noncompact Sections		N/A	Not Required
10.48.2.1 Cross-section requirements		N/A	General Com...
10.48.3 Noncomposite Transition Section		N/A	Not Required
10.48.4 Noncomposite Noncompact Partially Braced Members		N/A	Failed
10.48.4.1.Cb Noncomposite Cb Calculation		N/A	Not Required
10.48.4.1.Mr Noncomposite Mr Calculation		N/A	Failed
10.48.4.1.Rb Noncomposite Rb Calculation		N/A	General Com...
10.48.8 LFD Shear Calculations		N/A	Passed
10.50.1.1.2 Composite Compact Positive Moment Section		N/A	Not Required
10.50.1.2 Noncompact Positive Moment Members		N/A	Passed
10.50.1.2.Rb Composite Rb Calculation		N/A	General Com...
10.50.2.1 Composite Compact Negative Moment Section		N/A	Not Required
10.50.2.2 Noncompact Negative Moment Members		N/A	Failed
10.50.2.2 Composite Cb Calculation		N/A	General Com...
10.53.1.2 Braced Noncompact Hybrid Sections		N/A	Not Required
6B.4 Steel Combined Moment and Shear		N/A	Passed
6B.4 Steel Flexure Moment		N/A	Passed
6B.4 Steel Flexure Overload		N/A	Passed
6B.4 Steel Flexure Stress		N/A	Passed
6B.4 Steel Shear Stress		N/A	Passed
Depth of web in compression in the Elastic Range (Dc)		N/A	General Com...
First Yield Moment (My) Calculations for All Sections		N/A	General Com...
LFD General Steel Flexural Results		N/A	Failed
LFD Steel Elastic Section Properties		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Negative Moment		N/A	General Com...
Plastic Moment (Mp) for Composite Sections in Positive Moment		N/A	General Com...
Plastic Moment (Mp) for Noncomposite Sections		N/A	Not Required
Steel Stresses for Sections in Positive Flexure		N/A	General Com...

SPECIFICATION CHECKS

10.50.2.2 Noncompact Sections

When the steel section does not satisfy the compactness requirements of Article 10.50.2.1 but does satisfy all the requirements of Article 10.48.2.1, the sum of the bending stresses due to the appropriate loadings acting on the re-

- The girder does not satisfy noncompact criteria for compressive strength so AASHTOWare takes the minimum of the partially braced compressive capacity or the local flange buckling capacity.
- Since the partially braced capacity is Fy due to the fictional bracing input at every 5’, local flange buckling controls
- Therefore, for the bottom flange, AASHTOWare checks capacity to Fy and Fcr only, mimicking the behavior of the actual box girder

- Fcr = 4.86 ksi
- S, negative moment = 691.73 in^3
- Mu=Fcr x S
- Mu=4.86 ksi x 691.73 in^3 x 1/12 in = 280 k-ft (verified)

Spec Check Detail for LFD General Steel Flexural Results

SUMMARY:

Limit State	Load Comb	Flexure Type	Capacity Type	Governing Resistance Article	Mu (kip-ft)	Code
Inventory	1, INV, MAX	Pos	Stress	10.50.1.2	--	Pass
Inventory	1, INV, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	1, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	1, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Inventory	2, INV, MAX	Pos	Stress	10.50.1.2	--	Pass
Inventory	2, INV, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	2, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	2, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Inventory	3, INV, MAX	Pos	Stress	10.50.1.2	--	Pass
Inventory	3, INV, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	3, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	3, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Inventory	4, INV, MAX	Pos	Stress	10.50.1.2	--	Pass
Inventory	4, INV, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	4, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	4, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Inventory	5, INV, MAX	Pos	Stress	10.50.1.2	--	Pass
Inventory	5, INV, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	5, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	5, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	6, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	6, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	7, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	7, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	8, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	8, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	9, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	9, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail
Operating	10, OPG, MAX	Pos	Stress	10.50.1.2	--	Pass
Operating	10, OPG, MIN	Neg	Moment	10.50.2.2	-280.06	Fail

FINAL BOX GIRDER RATING SUMMARY

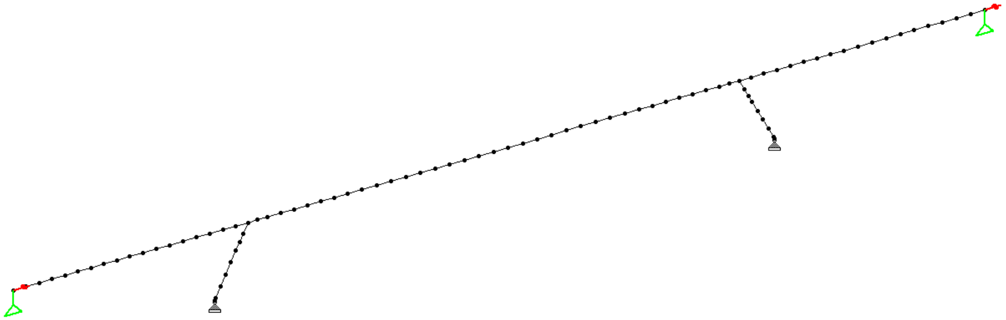
- N.B. I-635 over E.B I-35

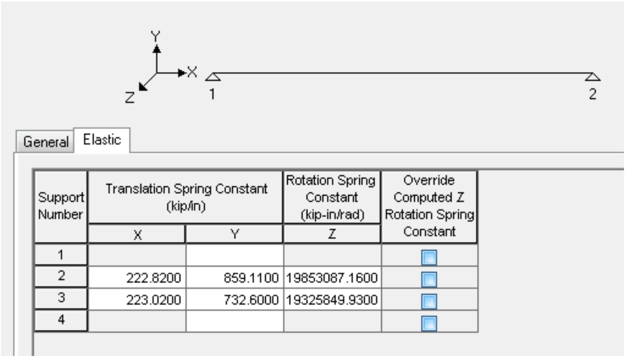
Live Load	Live Load Type	Rating Method	Inventory Load Rating (Ton)	Operating Load Rating (Ton)	Legal Operating Load Rating (Ton)	Permit Inventory Load Rating (Ton)	Permit Operating Load Rating (Ton)	Inventory Rating Factor	Operating Rating Factor	nventory -ocation (ft)	Inventory Location Span-(%)	Operating Location (ft)	Operating Location Span-(%)	Inventory Limit State	Operating Limit State
1 K H 20-44 (<200')	Axle Load	LFD	45.22	75.51				2.261	3.776	129.50	2 - (82.8)	129.50	2 - (82.8)	Design Flexure - Steel	Design Flexure - Steel
2 K Type 3	Axle Load	LFD	48.91	81.68				1.956	3.267	129.50	2 - (82.8)	129.50	2 - (82.8)	Design Flexure - Steel	Design Flexure - Steel
3 HS 20-44 K (<200')	Axle Load	LFD	49.94	83.40				1.387	2.317	147.00	2 - (100.0)	147.00	2 - (100.0)	Design Flexure - Steel	Design Flexure - Steel
4 K Type 3S2	Axle Load	LFD	54.17	90.47				1.505	2.513	147.00	2 - (100.0)	147.00	2 - (100.0)	Design Flexure - Steel	Design Flexure - Steel
5 K Type 3-3	Axle Load	LFD	58.06	96.97				1.452	2.424	147.00	2 - (100.0)	147.00	2 - (100.0)	Design Flexure - Steel	Design Flexure - Steel
6 Type T130	Axle Load	LFD		118.46					1.823			147.00	2 - (100.0)		Design Flexure - Steel
7 Type T170	Axle Load	LFD		147.89					1.740			147.00	2 - (100.0)		Design Flexure - Steel
8 Heavy Equipment Transporter	Axle Load	LFD		97.68					0.888			147.00	2 - (100.0)		Design Flexure - Steel
EV2~{Renamed from EV2}	Axle Load	LFD		79.99					2.782			129.50	2 - (82.8)		Design Flexure - Steel
EV3~{Renamed from EV3}	Axle Load	LFD		80.54					1.873			129.50	2 - (82.8)		Design Flexure - Steel

- Results:
  - typically areas of high moment or areas with abrupt changes in capacities i.e. flange transitions or longitudinal stiffener termination locations controlled the rating
  - Shear controlled rating for areas of high shear, heavy axles on various trucks, panel length changes due to changes in transverse stiffener spacing

OTHER NOTABLE STEEL RATING METHODS

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification

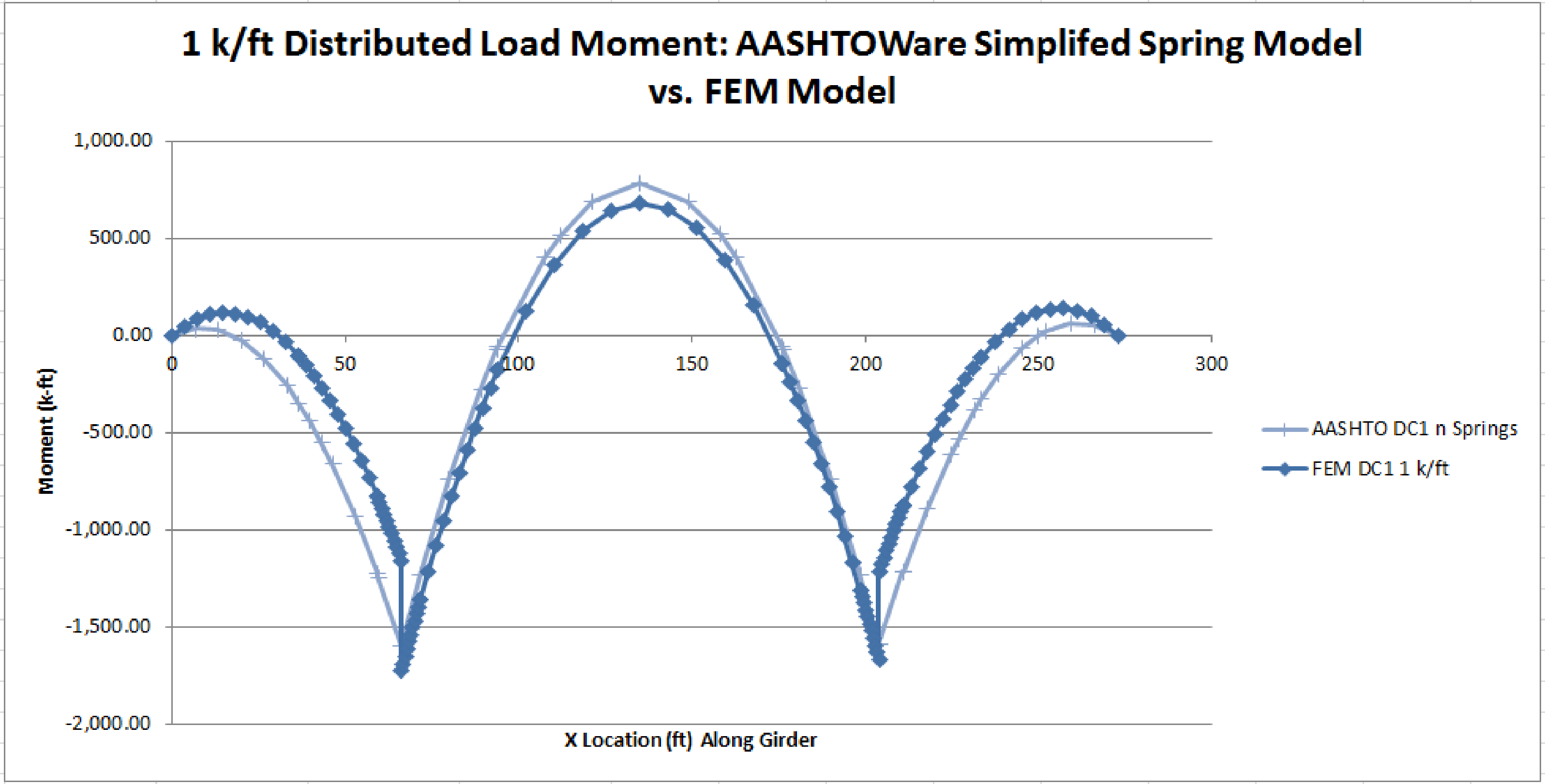




- I-435 over I-70

OTHER NOTABLE STEEL RATING METHODS

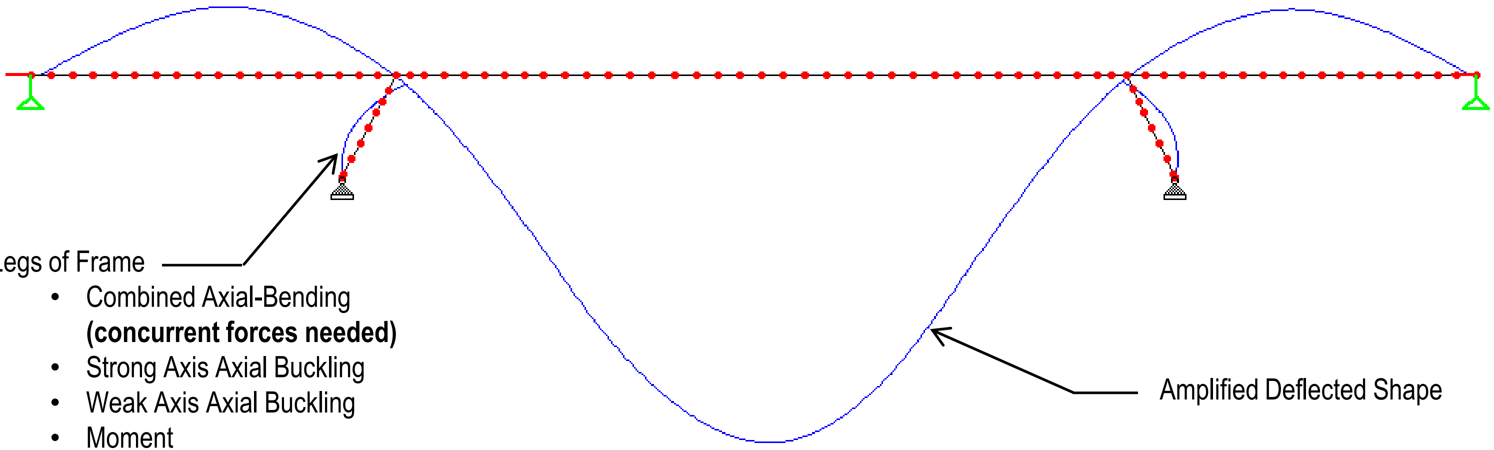
- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification



OTHER NOTABLE STEEL RATING METHODS

n_Br_No_0105-B0213_214.std - Whole Structure

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification



- Legs of Frame
  - Combined Axial-Bending **(concurrent forces needed)**
  - Strong Axis Axial Buckling
  - Weak Axis Axial Buckling
  - Moment
  - Shear

Amplified Deflected Shape

- (Deflections not to Scale)

OTHER NOTABLE STEEL RATING METHODS

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification

			User Input							
Live Load Code	Live Load									
1	H 20									
2	Type 3									
3	HS 20									
4	Type 3S2		Girders							
5	Type 3-3									
6	Type T130		AASHTO Std. Spec. 3.12:							
7	Type T170									
8	HET		Load Reduction:	One Lane =	1.00					
9	EV2			Two Lanes =	1.00					
10	EV3			Three Lanes =	0.90					
11	KDOT Specified			Four Lanes or More =	0.75					
			AASHTO Std. Spec. Table 3.23.1:							
								LFD Factors For Info only:		
			Distribution of Wheel Loads in Longitudinal Beams:					Oper	1.3	
				One Lane =	1.532	wheels		Inv	2.171	
				Multi-Lanes =	2.333	wheels				
			Interior Frame						LFD	LFD
			Live Load Code	# Lanes Loaded (5 max)	Distribution Factor (wheels)	Reduce Intensity (wheels)	Reduced DF (lanes)	Impact (1 = Yes, 2 = No)	LL Factor	DL Factor
			1	2	2.333	1.00	1.1665	1	2.171	1.3
			Girders							
			Flexure							
			Top Flange			Bottom Flange				
			Min RF	xlocation	truck location	Min RF	xlocation	truck location		
			3.12	66.00	134.00	2.07	135.00	136.00		
			Shear							
			Min RF	xlocation	truck location					
			3.42	261.50	264.00					

OTHER NOTABLE STEEL RATING METHODS

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification

Leg 1					
Flexure					
Top Flange			Bottom Flange		
Min RF	xlocation (along leg)	truck location	Min RF	xlocation	truck location
3.36	0.00	164.00	4.24	0.00	164.00
Shear					
Min RF	xlocation (along leg)	truck location			
3.65	20.71	164.00			
Axial (weak)					
Min RF	xlocation (along leg)	truck location			
10.65	21.38	94.00			
Axial (strong)					
Min RF	xlocation (along leg)	truck location			
10.46	21.38	94.00			
Combined Axial (Strong Axis) and Flexure					
Min RF	xlocation (along leg)	truck location			
3.34	0.00	160.00			
Leg 2					
Flexure					
Top Flange			Bottom Flange		
Min RF	xlocation (along leg)	truck location	Min RF	xlocation	truck location
3.82	0.00	112.00	4.96	0.00	234.00
Shear					
Min RF	xlocation (along leg)	truck location			
4.19	20.97	112.00			
Axial (weak)					
Min RF	xlocation (along leg)	truck location			
10.67	21.64	182.00			
Axial (strong)					
Min RF	xlocation (along leg)	truck location			
10.48	21.64	182.00			
Combined Axial (Strong Axis) and Flexure					
Min RF	xlocation (along leg)	truck location			
3.74	0.00	116.00			

OTHER NOTABLE STEEL RATING METHODS

- Modeling of K-Frame Grasshopper Bridges using simplified spring method with external verification

- AASHTOWare BrR

Live Load	Inventory Rating Factor	Operating Rating Factor
1 K H 20-44 (<200')	2.025	3.382
2 K Type 3	1.774	2.963
4 K Type 3S2	1.508	2.519
5 K Type 3-3	1.511	2.523
6 Type T130		2.733
7 Type T170		2.618
8 Heavy Equipment Transporter		1.390
EV2		2.583
EV3		1.697

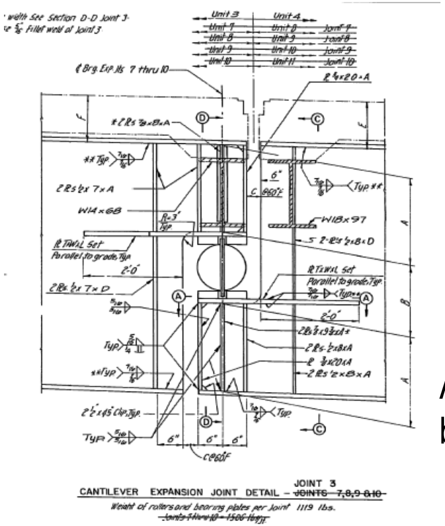
VS.

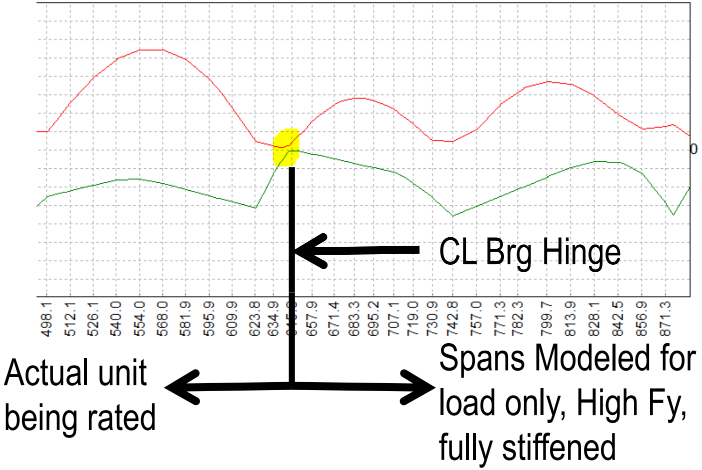
- STAAD FEM/Excel Post-Processing

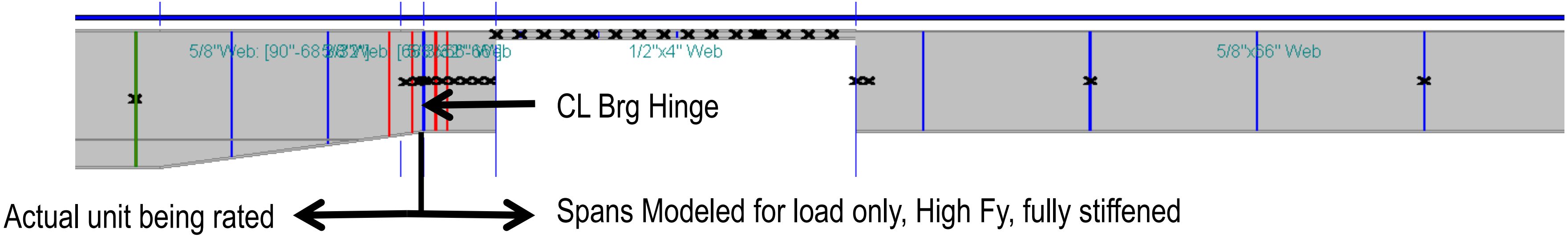
Live Load		Inventory Rating Factor	Operating Rating Factor
1	H 20	2.07	3.45
2	Type 3	1.79	2.99
4	Type 3S2	1.49	2.50
5	Type 3-3	1.48	2.48
6	Type T130		2.68
7	Type T170		2.54
8	HET		1.37
9	EV2		2.59
10	EV3		1.71

OTHER NOTABLE STEEL RATING METHODS

- Modeling of Hinges (Shelf Plate) in 3D FEM I-Girder Models
- Moment to “zero” at hinge, shear carried across hinge, hinges rated for local moment externally using shear force generated from AASHTOWare model

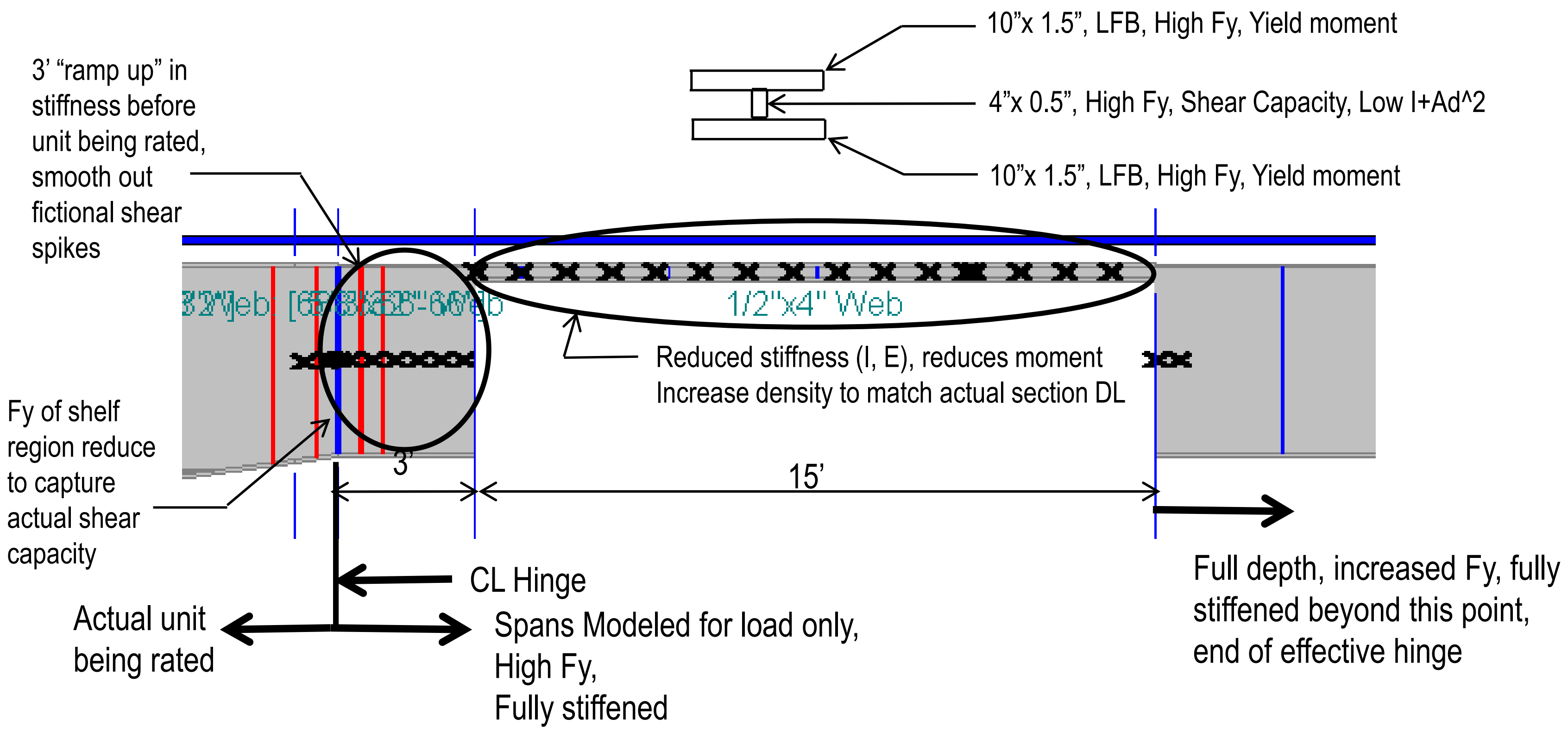






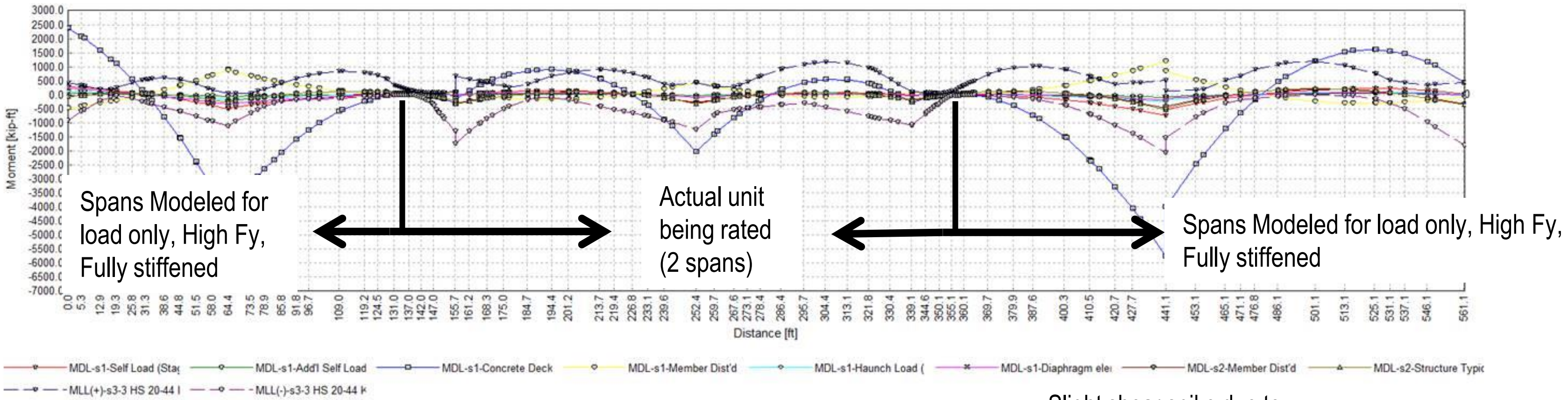
OTHER NOTABLE STEEL RATING METHODS

- Modeling of Hinges (Shelf Plate) in 3D FEM I-Girder Models

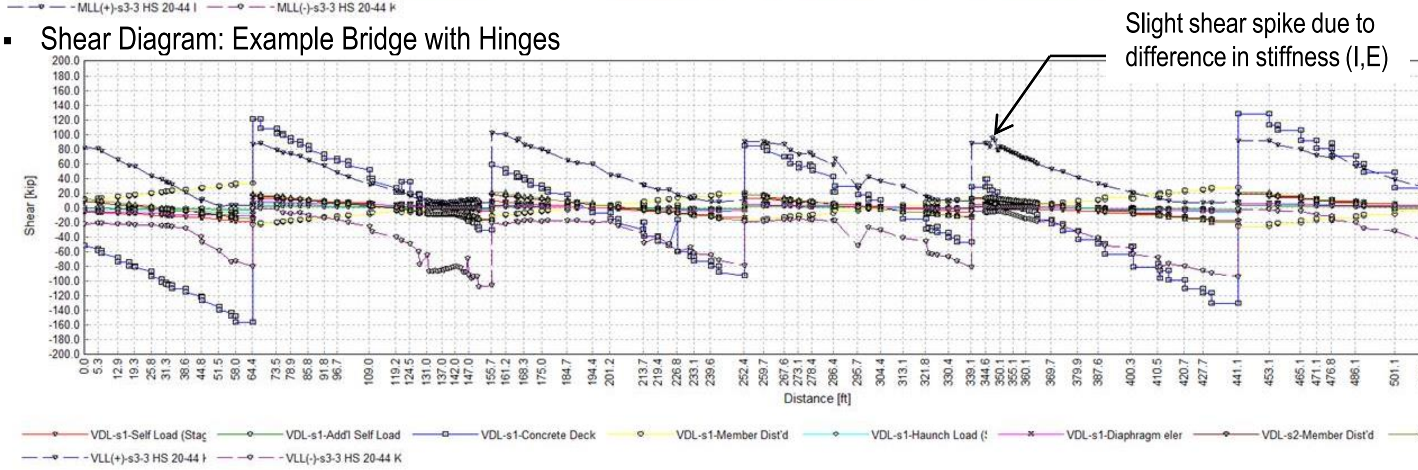


OTHER NOTABLE STEEL RATING METHODS

- Moment Diagram: Example Bridge with Hinges

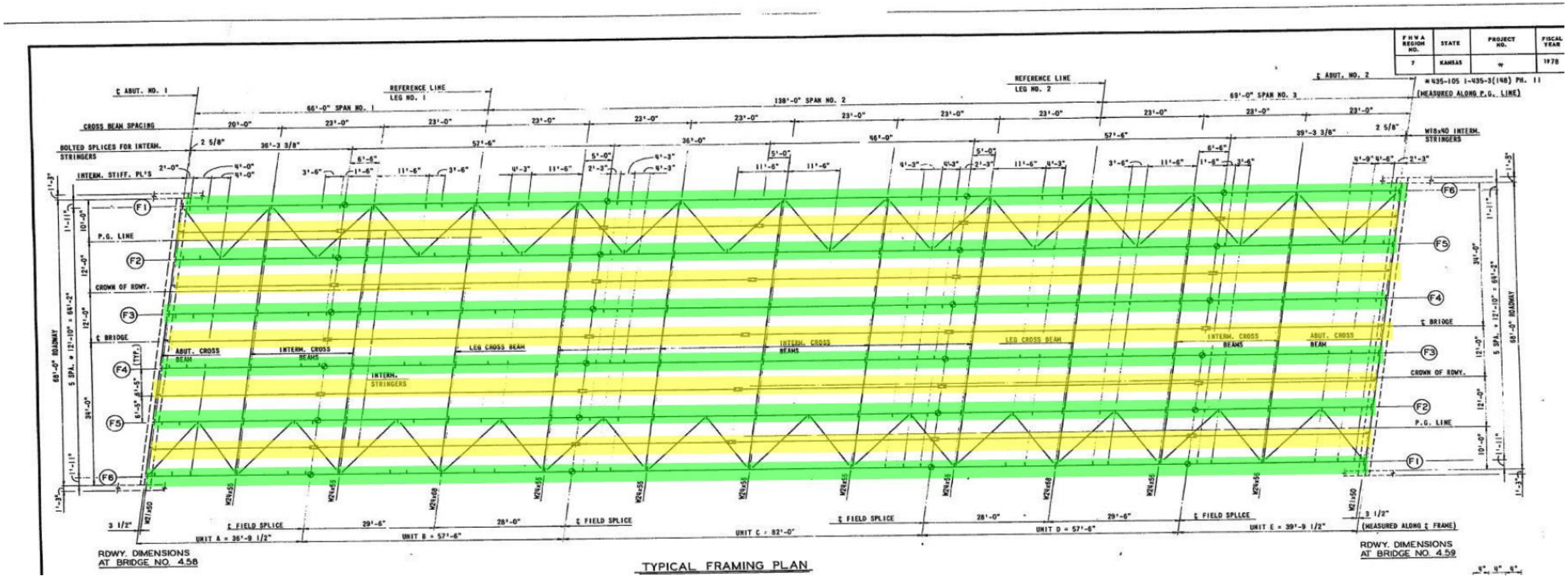


- Shear Diagram: Example Bridge with Hinges



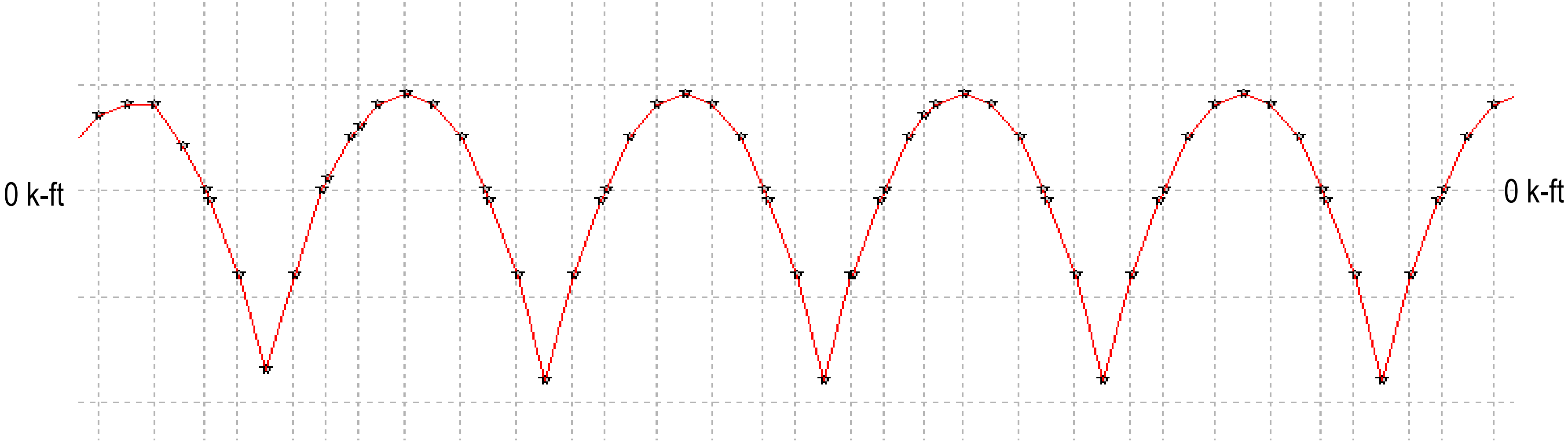
OTHER NOTABLE STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members



OTHER NOTABLE STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members



OTHER NOTABLE STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members
  - C_b factor modification

- 2014 AASHTO LRFD 7th Edition, 6.10.8.2.3 (LTB)

$$F_{nc} = C_b\left[1-\left(1-\frac{F_{yr}}{R_h F_{yc}}\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] R_b R_h F_{yc} \le R_b R_h F_{yc} \qquad (6.10.8.2.3\text{-}2)$$

- If $L_b > L_r$, then:

$$F_{nc} = F_{cr} \le R_b R_h F_{yc} \qquad (6.10.8.2.3\text{-}3)$$

- For unbraced cantilevers and for members where $f_{mid}/f_2 > 1$ or $f_2 = 0$

$$C_b = 1.0 \qquad (6.10.8.2.3\text{-}6)$$

- For all other cases:

$$C_b = 1.75 - 1.05\left(\frac{f_1}{f_2}\right) + 0.3\left(\frac{f_1}{f_2}\right)^2 \le 2.3 \qquad (6.10.8.2.3\text{-}7)$$

- 2014 AASHTO LRFD 7th Edition, C6.10.8.2.3

For unbraced lengths where the member consists of monosymmetric noncomposite I-sections and is subject to reverse curvature bending, the lateral torsional buckling resistance must be checked in general for both flanges, unless the top flange is considered to be continuously braced. Since the flanges are of different sizes in these types of sections, the lateral torsional buckling resistance may be governed by compression in the smaller flange, even though this compressive stress may be smaller than the maximum compression in the larger flange. The specified approach generally produces accurate to conservative values of C_b for these cases. For highly

OTHER NOTABLE STEEL RATING METHODS

- AISC Steel Manual, 14th Edition

Since 1961, the following equation has been used in AISC Specifications to adjust the lateral-torsional buckling equations for variations in the moment diagram within the unbraced length.

$$C_b = 1.75 + 1.05\left(\frac{M_1}{M_2}\right) + 0.3\left(\frac{M_1}{M_2}\right)^2 \qquad \text{(C-F1-1)}$$

where

M_1 = smaller moment at end of unbraced length, kip-in. (N-mm)
M_2 = larger moment at end of unbraced length, kip-in. (N-mm)
(M_1/M_2) is positive when moments cause reverse curvature and negative for single curvature

This equation is only applicable to moment diagrams that consist of straight lines between braced points—a condition that is rare in beam design. The equation provides a lower bound to the solutions developed in Salvadori (1956). Equation C-F1-1 can be easily misinterpreted and misapplied to moment diagrams that are not linear within the unbraced segment. Kirby and Nethercot (1979) present an equation that applies to various shapes of moment diagrams within the unbraced segment. Their original equation has been slightly adjusted to give Equation C-F1-2 (Equation F1-1 in the body of the Specification):

$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C} \qquad \text{(C-F1-2)}$$

This equation gives a more accurate solution for a fixed-end beam, and gives approximately the same answers as Equation C-F1-1 for moment diagrams with straight lines between points of bracing. C_b computed by Equation C-F1-2 for moment diagrams with other shapes shows good comparison with the more precise but also more complex equations (Ziemian, 2010). The absolute values of the three quarter-point moments and the maximum moment regardless of its location are used in Equation C-F1-2. The maximum moment in the unbraced segment is always used for comparison with the nominal moment, M_n. The length between braces, not the distance to inflection points is used. It is still satisfactory to use C_b from Equation C-F1-1 for straight-line moment diagrams within the unbraced length.

- Reverse Curvature Bending in longitudinal members
  - C_b factor modification

- 1961 AASHO

Compression in extreme fibers of rolled shapes, girders and built sections, subject to bending, gross section.

Thickness	Low alloy steel ¾ in. and under	Low-alloy steel over ¾ in. to 1½ in. incl.	Low-alloy steel over 1½ in. to 4 in. incl.
When compression flange is supported laterally its full length by embedment in concrete or by other means	27,000	24,000	22,000
*When compression flange is partially supported or is unsupported	$27{,}000 - 7.5\frac{L^2}{b^2}$	$24{,}000 - 6.67\frac{L^2}{b^2}$	$22{,}000 - 6.11\frac{L^2}{b^2}$

For values of L/b not to exceed 25, where

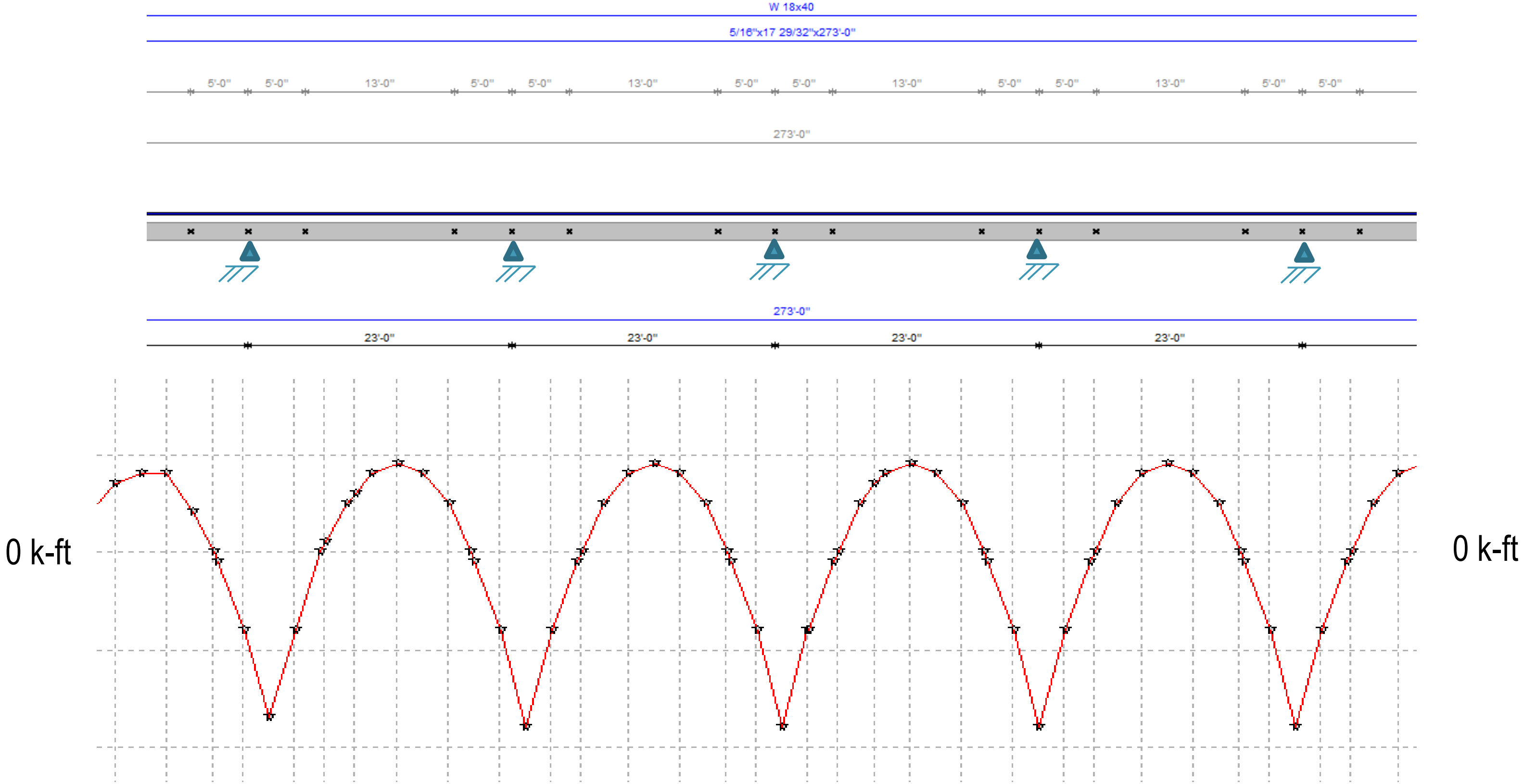
L = length, in inches, of unsupported flange between lateral connections, knee braces or other points of support. For continuous beams and girders, L may be taken as the distance from interior support to point of dead load contraflexure if this distance is less than that designated above.

b = flange width in inches.

* Note. Continuous or cantilever beams or girders may be proportioned for negative moment at interior supports for an allowable unit stress 20 per cent higher than permitted by above formula but in no case exceeding allowable unit stress for compression flange supported its full length. If cover plates are used, the allowable stress at the point of cut-off shall be as determined by the formula.

OTHER NOTABLE STEEL RATING METHODS

- Reverse Curvature Bending in longitudinal members
  - Braces at DL inflection points
  - Hand calculations to verify C_b with AISC Equations after braces are added



QUESTIONS?