Comments for the RADBUG 2019 *Truss Analysis LFR & LRFR* presentation

Slide 8:
LFR and LRFR LL forces are the same. Force effects are the same because impact, distribution factor and scale factors are applied later in the analysis before specification checking.

Slide 15:
DL factor is not applied to preload for counter analysis. This behavior is correct to avoid a case where dead load increases the member capacity when live load causes opposite stress. Method of Solution needs updated (BSSD-1105).

Slide 20:
LRFR also does not need to apply impact since the counter analysis with and without impact do not change the actions. BSSD-1103 will cover this fix.

Slide 23:
This is enhancement request BSSD-1581 for treating net area differently between LFR and LRFR.

Slide 25:
This is also covered in BSSD-1581 to use effective area as per Std 10.18.4.

Slide 31:
Enhancement request: Consider combined tension and flexure for LFR.

Slide 33:
Enhancement request: Truss LRFR with adjacent vehicle.

Slide 37:
BrR includes effect of flexure when calculating rating as per MBE 6A.6.8 Combined Axial Compression and Flexure. Including flexure in rating is based on non-zero My or Mz which can be seen from the second load case (second row) shown on the slide. Both My and Mz moments for the first load case (first row) shown on the slide are zero, hence the note appears below the table for the “Note” column.

Truss Analysis
LFR and LRFR

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July 30, 2019

Discussion Points

Truss LFR/LRFR

- Force Effect
- Capacity
- Rating
- Conclusion

Purpose of the Presentation

Purpose:

- Show users what is available in BrR
- Discrepancies
- Deviation
- Creating Dialogue for discussion to come up with solution.

BrR / BrDR Version

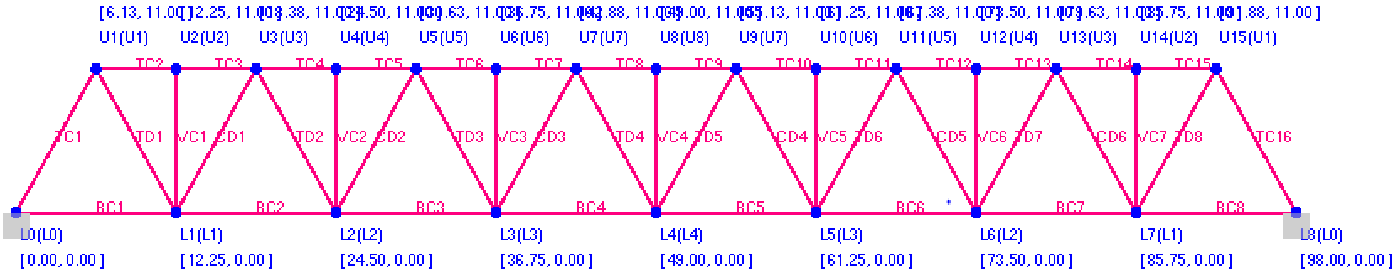
BrR/BrDR

- Version 6.8.4 Beta 4
- Version 7.0 Beta 3

Force Effect IL

Influence line: Truss without counters

- Sample Truss 8 Panels @ 12.25 ft
- Type 3 vehicle
- BC1
- Unit load will be applied at each panel point



Sample Truss-Linear analysis

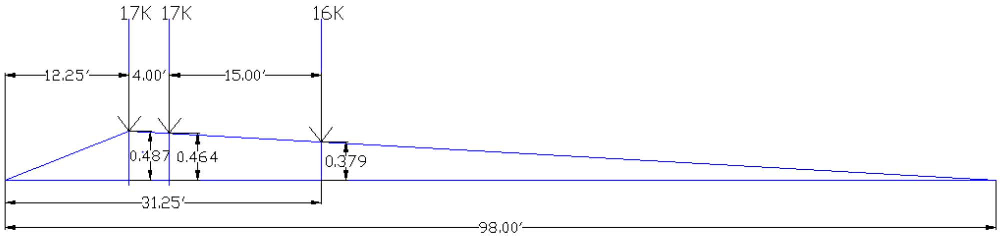
Influence Line: Linear Analysis LFR & LRFR

Method of Loading on Influence line

- Positioning the axle over the peaks.
- Placing the CG of the vehicle at the peak.
- Vehicle moves from right to left and vice versa.

Force Effect IL

Load at the peak, First Axle at 31.25 ft



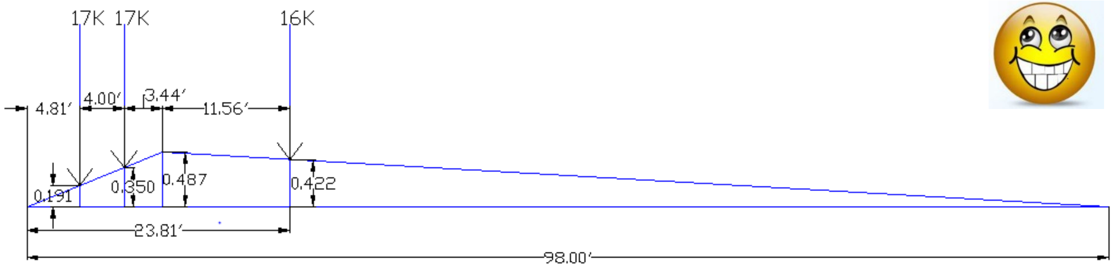
First axle at 31.25 ft
Axial Force=17*0.487+17*0.464+16*0.379=22.23k

```
--- Position 3 -- Axle 3 at peak [ 12.250 ft,   0.487 kip]
   31.250       0.379       0.3793     16.0000       1.000       6.0682       6.0682
   16.250       0.464       0.4645     17.0000       1.000       7.8963       7.8963
   12.250       0.487       0.4872     17.0000       1.000       8.2827       8.2827

  Total Action: Max    22.2472 kip  Min    22.2472 kip
  Vehicle moving left to right.  Position of first axle =   31.250 ft
```

Sample Truss-Linear analysis

Force Effect IL

CG of axles @ Peak



Force effect for both LFR & LRFR method are the same.

C.G @ peak 11.56 ft

Axial Force=17*0.191+17*0.35+16*0.422=15.95k

```
---  Position 4 -- CG [ 11.560 ft] at peak --
  23.810       0.422        0.4215    16.0000      1.000       6.7445       6.7445
   8.810       0.350        0.3504    17.0000      1.000       5.9568       5.9568
   4.810       0.191        0.1913    17.0000      1.000    |  3.2522       3.2522

 Total Action: Max    15.9535 kip  Min    15.9535 kip
 Vehicle moving left to right.  Position of first axle =   23.810 ft
```

Sample Truss-Linear analysis

Force Effect with Counter

Method of Solution

1.4 LIVE LOAD ANALYSIS OF A LONGITUDINAL TRUSS WITH COUNTERS

LFR

1.4.1.1 Truck Loading

1. All dead load cases are summed up and multiplied by dead load factor as one pre-load load case.

2. Multiple live load cases are generated by placing truck axle loads at locations on the truss. Each live load case is multiplied by live load factor and distribution factor. Pre-load dead load case is added to each live load case. When adjacent vehicle is included in the analysis, the primary truck axles will be superimposed with the adjacent truck axles at the center of gravity location.

LRFR

1.4.1.1 Truck Loading

1. Dead load (DC) cases are summed up and multiplied by dead load factor (DC) as the first load case.

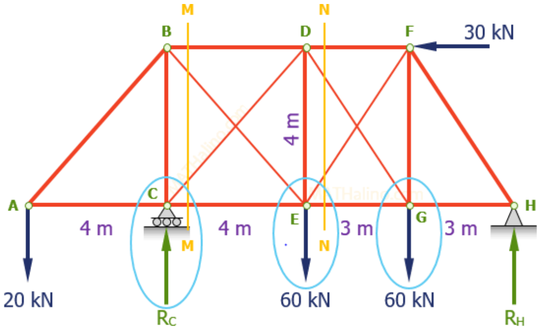
2. Dead load (DW) cases are summed up and multiplied by dead load factor (DW) and then summed up with factored DC load case above as one pre-load load case.

3. Multiple live load cases are generated by placing truck axle loads at locations on the truss. Each live load case is multiplied by live load factor, scale factor, dynamic load allowance and distribution factor. Pre-load dead load case is added to each live load case. Perform non-linear analyses for pre-load load case and all live load cases.

Force Effect with counter

Non-Linear Analysis: Background

- Background
- BrR

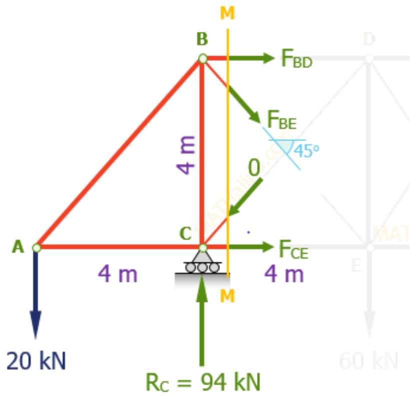


$\Sigma M_H = 0$

$10R_H = 4(30) + 3(60) + 6(60) + 14(20)$

$R_H = 94 \text{ kN}$

From FBD of Section Through M-M



$\Sigma F_V = 0$

$F_{BE} \sin 45° + 20 = 94$

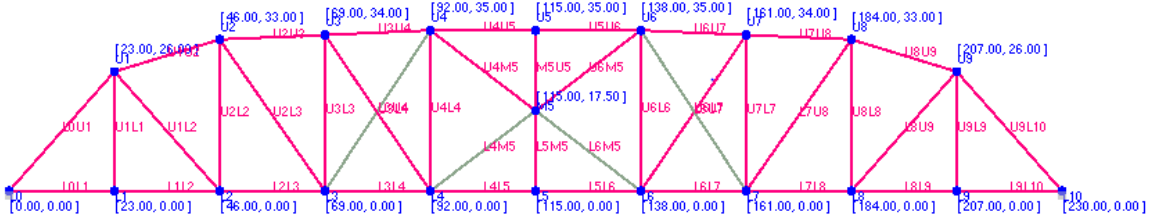
$F_{BE} = 74\sqrt{2} \text{ kN} = 104.65 \text{ kN tension}$

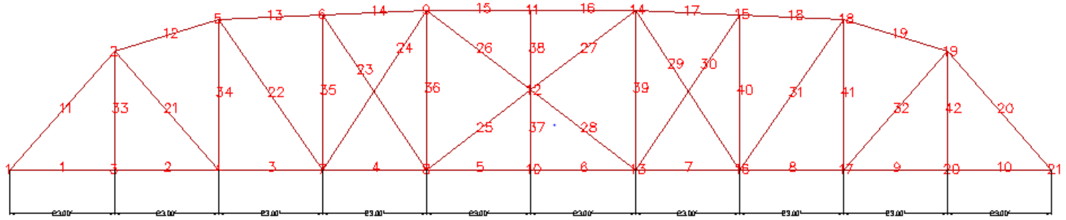
Force Effect With counter

Non-Linear Analysis: BrR/BrDR

Sample Truss 10 @ 23ft

- Type 3 vehicle
- Type 3-Inventory Level
- Member 1 & Member 11





Sample Truss-Non-Linear analysis

Force Effect-Parameters

Live Load Distribution Factor

LFR

- **Lever Rule**
- **MPF**

Standard LL Reduction Factor (RDF)

(AASHTO Standard 3.12.1)	
# of Lane	RDF
1&2	1
3	0.9
>3	0.75

LRFR

- **Lever Rule**
- **MPF**

LRFD Multiple Presence Factor (MPF)

(AASHTO 3.6.1.1.2-1)	
# of Lane	MPF
1	1.2
2	1
3	0.85
>3	0.65

Force Effect-Parameters

Impact Factor

LFR

- AASHTO Standard 3.8.2. for the loaded length L.

3.8.2 Impact Formula

3.8.2.1 The amount of the impact allowance or increment is expressed as a fraction of the live load stress, and shall be determined by the formula:

$$I = \frac{50}{L + 125} \qquad (3\text{-}1)$$

in which,

I = impact fraction (maximum 30 percent);

L = length in feet of the portion of the span that is loaded to produce the maximum stress in the member.

LRFR

- AASHTO LRFD Table 3.6.2.1-1

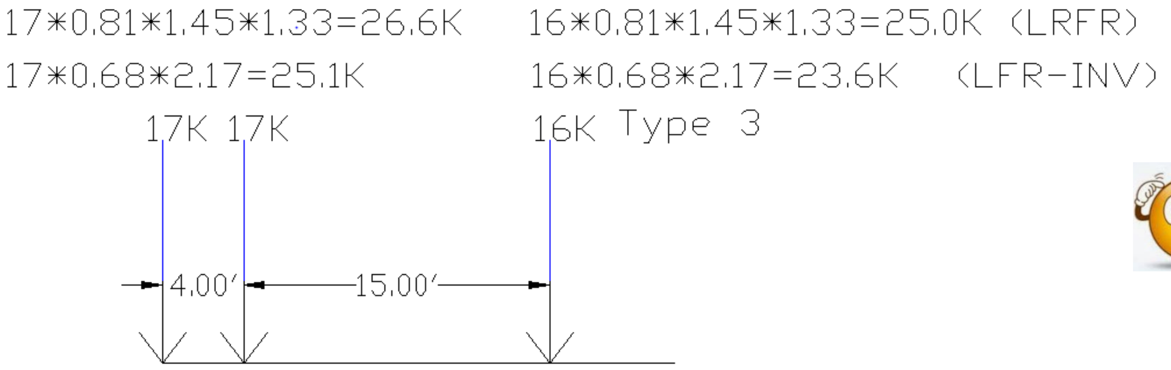
Table 3.6.2.1-1—Dynamic Load Allowance, *IM*

Component	IM
Deck Joints—All Limit States	75%
All Other Components:	
• Fatigue and Fracture Limit State	15%
• All Other Limit States	33%

Force Effect with Counter

Type 3

- LFR=Axle*LF*LLDF
- LRFR=Axle*LF*LLDF*I



- LFR Axle load does not include Impact.

Sample Truss-Non-Linear analysis

Force Effect with Counter

Force effect: Preload Dead load

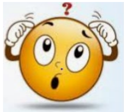
LFR

DC

Node	X	Y
1	0.00	0.00
3	23.00	0.00
4	46.00	0.00
7	69.00	0.00
8	92.00	0.00
10	115.00	0.00
13	138.00	0.00
16	161.00	0.00
17	184.00	0.00
20	207.00	0.00
21	230.00	0.00

Adding Preload load case as LC 1...

Node = 1 Load = -18.90
Node = 2 Load = -5.67
Node = 3 Load = -32.77
Node = 4 Load = -34.03
Node = 5 Load = -5.56
Node = 6 Load = -5.59
Node = 7 Load = -35.20
Node = 8 Load = -35.27
Node = 9 Load = -6.01
Node = 10 Load = -34.04
Node = 11 Load = -4.84
Node = 12 Load = -2.41
Node = 13 Load = -35.27
Node = 14 Load = -6.01
Node = 15 Load = -5.59
Node = 16 Load = -35.20
Node = 17 Load = -34.03
Node = 18 Load = -5.56
Node = 19 Load = -5.67
Node = 20 Load = -32.77
Node = 21 Load = -18.90



- DL values are not factored by DL factor as opposed to method of solution.

LRFR

DC1

Spec LL factor = 1.93=1.45*1.33
LL distribution factor = 0.81

Adding Preload load case as LC 1...

Node = 1 Load = -16.55
Node = 2 Load = -5.67
Node = 3 Load = -28.08
Node = 4 Load = -29.34
Node = 5 Load = -5.56
Node = 6 Load = -5.59
Node = 7 Load = -30.51
Node = 8 Load = -30.58
Node = 9 Load = -6.01
Node = 10 Load = -29.35
Node = 11 Load = -4.84
Node = 12 Load = -2.41
Node = 13 Load = -30.58
Node = 14 Load = -6.01
Node = 15 Load = -5.59
Node = 16 Load = -30.51
Node = 17 Load = -29.34
Node = 18 Load = -5.56
Node = 19 Load = -5.67
Node = 20 Load = -28.08
Node = 21 Load = -16.55

DC1+DC2

Adding Preload load case as LC 2...

Node = 1 Load = -18.90
Node = 2 Load = -5.67
Node = 3 Load = -32.77
Node = 4 Load = -34.03
Node = 5 Load = -5.56
Node = 6 Load = -5.59
Node = 7 Load = -35.20
Node = 8 Load = -35.27
Node = 9 Load = -6.01
Node = 10 Load = -34.04
Node = 11 Load = -4.84
Node = 12 Load = -2.41
Node = 13 Load = -35.27
Node = 14 Load = -6.01
Node = 15 Load = -5.59
Node = 16 Load = -35.20
Node = 17 Load = -34.03
Node = 18 Load = -5.56
Node = 19 Load = -5.67
Node = 20 Load = -32.77
Node = 21 Load = -18.90

Sample Truss-Non-Linear analysis

Force Effect with Counter

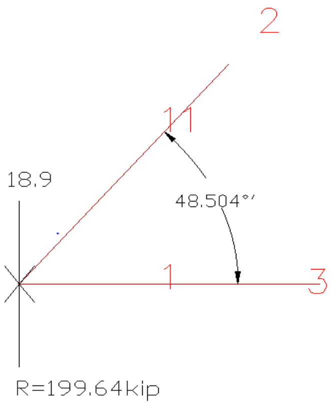
- **Force effect: Preload Dead Load-Mem 1 & 11**

LFR: DL

Load Case 1 Preload Load Case 1

Preload consists Dead Load acting (
the Live Load is applied.

Element	Axial Force
1	159.890
2	159.890
3	225.159
4	288.024
5	320.493
6	320.493
7	288.024
8	225.159
9	159.890
10	159.890
11	-241.316



Mem11sin48.504=R=199.64-18.9=180.74kip
Mem11=241.3kip

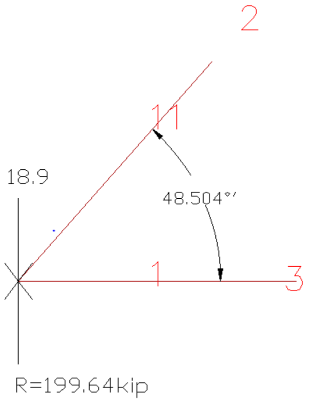
Mem11cos48.504=Mem1
Mem1=159.9kip

LRFR: DL

Load Case 2 Preload DC + DW

Preload consists Dead Load acti
the Live Load is applied.

Element	Axial Force
1	159.890
2	159.890
3	225.159
4	288.024
5	320.493
6	320.493
7	288.024
8	225.159
9	159.890
10	159.890
11	-241.316



Mem11sin48.504=R=199.64-18.9=180.74kip
Mem11=241.3kip

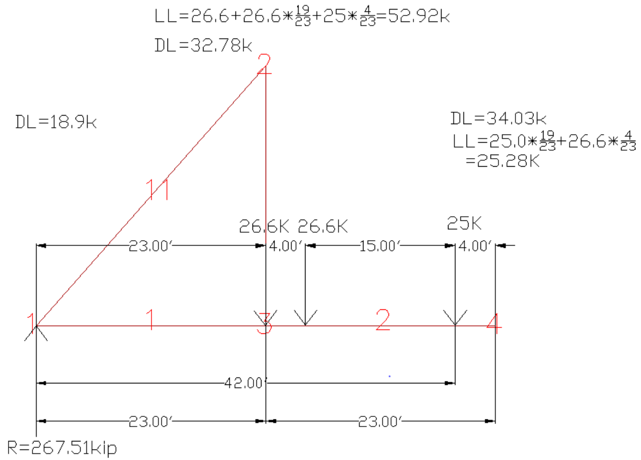
Mem11cos48.504=Mem1
Mem1=159.9kip

Sample Truss-Non-Linear analysis

Force Effect with Counter

- **Critical LL: First axle @ X=42 ft**

LRFR



Mem11sin48.504=R=267.51-18.9=248.61kip
Mem11=331.92kip
Mem11cos48.504=Mem1
Mem1=219.92kip

Live Load=Total-Preload

Mem1=219.92-159.9=60.02kip

Mem11=-331.92-(-241.3)=-90.62kip

```
Front axle of truck at 42.000
   First axle on model is   1 at 42
   Axle 1    25.05 at   42.00
      Apply   20.69 at node  4
      and    4.36 at node  3
   Axle 2    26.61 at   27.00
      Apply    4.63 at node  4
      and   21.99 at node  3
   Axle 3    26.61 at   23.00
      Apply   26.61 at node  3
   Adding LC       9...
      Node =  1    Load = -18.90
      Node =  2    Load =  -5.67
      Node =  3    Load = -85.72
      Node =  4    Load = -59.35
      Node =  5    Load =  -5.56
      Node =  6    Load =  -5.59
      Node =  7    Load = -35.20
      Node =  8    Load = -35.27
      Node =  9    Load =  -6.01
      Node = 10    Load = -34.04
      Node = 11    Load =  -4.84
      Node = 12    Load =  -2.41
      Node = 13    Load = -35.27
      Node = 14    Load =  -6.01
      Node = 15    Load =  -5.59
      Node = 16    Load = -35.20
      Node = 17    Load = -34.03
      Node = 18    Load =  -5.56
      Node = 19    Load =  -5.67
      Node = 20    Load = -32.77
      Node = 21    Load = -18.90
```

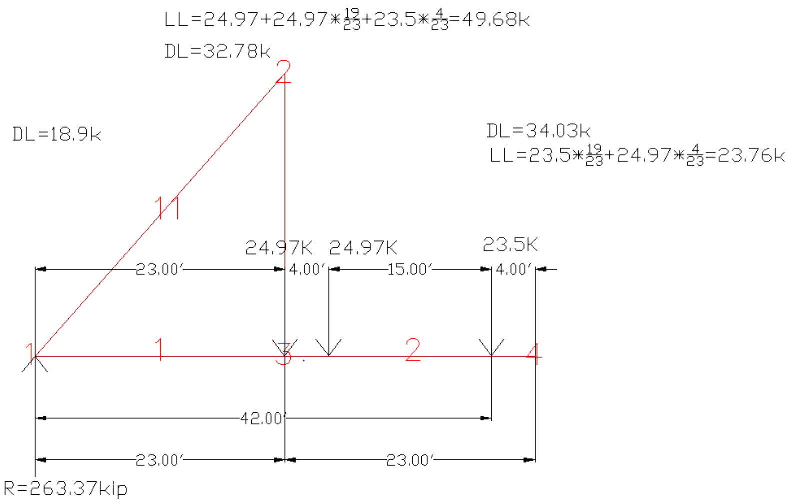
```
Load Case     9 Load Case 9

Using constant distribution factor of    0.81
Vehicle Loading Summary for element forces due to Type 3 - Legal Truck:

Truck positioned  42.00 ft from left
Direction of travel L to R

Element    Axial
           Force
  1       219.971
  2       219.971
  3       282.924
  4       337.081
  5       347.725
  6       347.725
  7       309.048
  8       239.600
  9       169.054
 10       169.054
 11      -331.995
```

Sample Truss-Non-Linear analysis

Force Effect with Counter

- **Critical LL: First axle @ X=42 ft**

LFR : No Impact



Mem11sin48.504=R=263.37-18.9=244.47kip
Mem11=326.39kip

Mem11cos48.504=Mem1
Mem1=216.26kip

Live Load=Total-Preload

Mem1=216.26-159.9=56.36kip

Mem11=-326.39-(-241.3)=-85.1kip

```
Front axle of truck at 42.000
   First axle on model is   1 at 42.000
   Axle 1    23.50 at   42.00
      Apply  19.41 at node   4
      and    4.09 at node   3
   Axle 2    24.97 at   27.00
      Apply   4.34 at node   4
      and   20.63 at node   3
   Axle 3    24.97 at   23.00
      Apply  24.97 at node   3
   Adding LC     8...
      Node = 1    Load = -18.90
      Node = 2    Load =  -5.67
      Node = 3    Load = -82.45
      Node = 4    Load = -57.79
      Node = 5    Load =  -5.56
      Node = 6    Load =  -5.59
      Node = 7    Load = -35.20
      Node = 8    Load = -35.27
      Node = 9    Load =  -6.01
      Node = 10    Load = -34.04
      Node = 11    Load =  -4.84
      Node = 12    Load =  -2.41
      Node = 13    Load = -35.27
      Node = 14    Load =  -6.01
      Node = 15    Load =  -5.59
      Node = 16    Load = -35.20
      Node = 17    Load = -34.03
      Node = 18    Load =  -5.56
      Node = 19    Load =  -5.67
      Node = 20    Load = -32.77
      Node = 21    Load = -18.90
```

```
Spec LL factor =   2.17
LL distribution factor =   0.68
```

```
Load Case     8 Load Case 8

Using constant distribution factor of    0.68
Vehicle Loading Summary for element forces due to Type 3 - Truck:

Truck positioned  42.00 ft from left
Direction of travel L to R
```

Element	Axial Force
1	216.253
2	216.253
3	279.349
4	334.045
5	346.040
6	346.040
7	307.747
8	238.707
9	168.487
10	168.487
11	-326.383

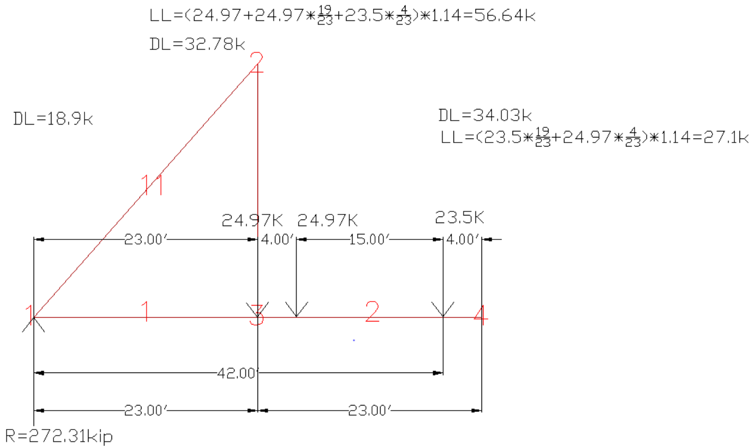
Sample Truss-Non-Linear analysis

Force Effect with Counter

- **Critical LL: First axle @ X=42 ft**

LFR : With Impact I=1.14

Spec LL factor = 2.17
LL distribution factor = 0.68



Mem11sin48.504=R=272.31-18.9=253.41kip
Mem11=338.33kip

Mem11cos48.504=Mem1
Mem1=224.18kip

Node	Load (L)	Distance (D)	L*D
	kip	ft	
1	-18.90	230	-4347.00
2	-5.67	207	-1173.07
3	-89.42	207	-18509.94
4	-61.13	184	-11247.92
5	-5.56	184	-1022.86
6	-5.59	161	-899.35
7	-35.20	161	-5667.20
8	-35.27	138	-4867.54
9	-6.01	138	-829.66
10	-34.04	115	-3914.49
11	-4.84	115	-556.95
12	-2.42	115	-277.73
13	-35.27	92	-3245.02
14	-6.01	92	-553.10
15	-5.59	69	-385.43
16	-35.20	69	-2428.80
17	-34.03	46	-1565.47
18	-5.56	46	-255.71
19	-5.67	23	-130.34
20	-32.77	23	-753.66
21	-18.90	0	0.00
			-62631.231
			230
		R=	-272.31

Live Load=Total-Preload

Mem1=224.18-159.9=64.28kip

Mem11=-338.33-(-241.3)=-97.03kip

Sample Truss-Non-Linear analysis

Force Effect with Counter

- **LL LFD Preload without Impact**

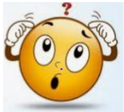
Live Load=Total-Preload
Mem1=216.26-159.9=56.36kip
Mem11=-326.39-(-241.3)=-85.1kip

LFR LL Impact with preload

Impact I=1.14

Live Load=Total-Preload
Mem1=224.18-159.9=64.28kip
Mem11=-338.33-(-241.3)=-97.03kip

Mem1=LL(1+I)/(1+I)=64.28/1.14=56.39kip
Mem11=LL(1+I)/(1+I)=-97.03/1.14=85.1kip



- **Including impact values with preload or during rating analysis does not make a difference.**
- **Why include impact for LRFR?**

Sample Truss-Non-Linear analysis

Capacity

Section Property

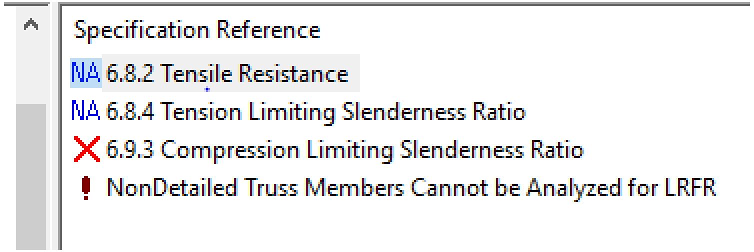
LFR

- Non-Detail
- Standard Section

LRFR

- Standard Section

If Non-Detail no rating or specification check.



Net and Effective Area

LFR

- According to AASHTO Standard Article 10.18.4
- Section 1.7 AASHTO 1985

10.18.4 Tension Members

$$A_e = A_n + \beta A_g \le A_g \qquad (10\text{-}4w)$$

where:

A_n = net section of the member computed as specified in Article 10.16.14

β = 0.0 for AASHTO M 270 Grade 100/100W (ASTM A 709 Grade 100/100W) steels, or when holes exceed 1¼ inch in diameter

= 0.15 for all other steels and when holes are less than or equal to 1¼ inch in diameter.

A_g = gross area of the member

1.7 NET SECTION OF TENSION MEMBERS

Subcommand	Connection <member_connection_type><effective_area_deduction>

LRFR

- According to AASHTO LRFD Article 6.8.3.

6.8.3—Net Area

The net area, A_n, of an element is the product of the thickness of the element and its smallest net width. The width of each standard bolt hole shall be taken as the nominal diameter of the hole. The width of oversize and slotted holes, where permitted for use in Article 6.13.2.4.1, shall be taken as the nominal diameter or width of the hole, as applicable, specified in Article 6.13.2.4.2. The net width shall be determined for each chain of holes extending across the member or element along any transverse, diagonal, or zigzag line.

AI Engineers, Inc.

Capacity

Tension Capacity

LFR

- **Method of solution 1.6.1**

1.6.1 Tension Capacity

Tension capacity is calculated using the following equation.

Max. Axial Tension Capacity $= A_{NET} F_Y$

Where,

A_{NET} = Net Area of the member cross section

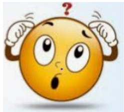
F_Y = Yield stress of the steel

LRFR

- **According to Article 6.8.3.**

Tensile Resistance, P_r
6.8.2

$$P_r = \min \begin{bmatrix} \phi_y P_{ny} = \phi_y F_y A_g & (6.8.2.1\text{-}1) \\ \phi_u P_{nu} = \phi_u F_u A_n R_p U & (6.8.2.1\text{-}2) \\ R_r & (6.13.4\text{-}1) \end{bmatrix}$$



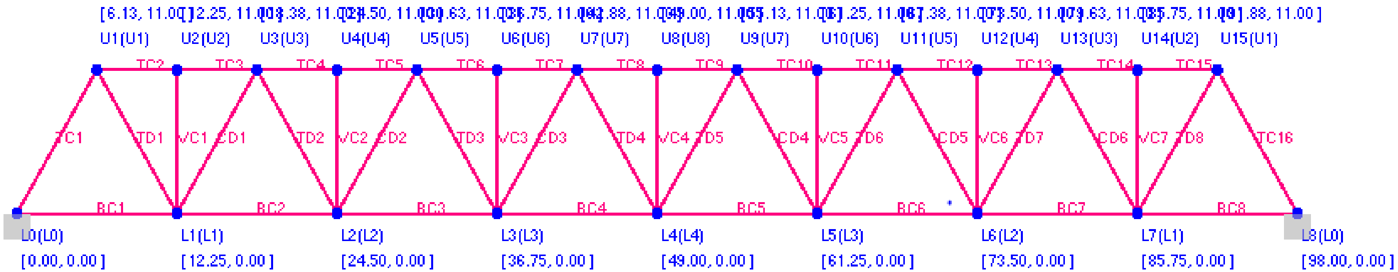
- BrR uses the same area for both LFR & LRFR method.
- Future Enhancement?

LFD Rating Comparison BrR Versus AASHTO

LFR

- **Sample bridge Truss without counter**

```
MemberCrossSection
ChannelBox = BC  //Bottom Chord
Channels  "C 15x50"  Inward  12.1875  A588
Connection  Bolted  4.565  //6 - 1-1/16" Bolt Holes in web
```



Capacity

LFD Rating Comparison BrR Versus AASHTO

LFR

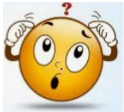
- **BrR Rating calculation**

```
Steel Channel Box - Truss Member BC1 - Start

Effective Area Deduction, Aeff =     4.5650 (in^2)
SUMMARY:

Net Area, Anet = Agross-Aeff     =    24.8350 (in^2)
Allowable Tension, Pu = Fy*Anet =  1241.7500 (kip)

PDL (Axial Dead Load) =    74.7362 (kip)

Rating                         Load Factors
 Level          Vehicle      A1        A2        PLL(1+I)
                                                  (kip)
-------------------------------------------------------------------
Inventory          1        1.300     2.171       8.17
Inventory          1        1.300     2.171       0.00

      RF        Capacity            Note
                 (Ton)
 -----------------------------------------------
  64.526     1613.16    AXIAL-TENSION
  99.000     2475.00    No Member Force
```

- According to AASHTO Standard Article 10.18.4

Ag=	29.4 in2	β=	0.15
An=	24.8 in2	Fy=	50
Ae=	29.2 in2	I=	1.224
Pu=	1462.25kip		
PLL=	22.23kip		
DF=	0.3		
PLL(1+I)=	8.16kip	(Including LLDF)	
C=	1462.25kip		
DL=	74.74kip		
A1=	1.3		
A2=	2.17		
R=	77.07		

```
AXIAL RATING FACTOR CALCUI

          C - (A1*PDL)
RF = -----------------
          A2*PLL(1+I)
```



- BrR is very conservative
- Future Enhancement ?

Compression Capacity

LFR

- Method of solution 1.6.2
- AASHTO 10.54.1

$$P_u = 0.85 A_s F_{cr} \qquad (10\text{-}150)$$

where A_s is the gross effective area of the column cross section and F_{cr} is determined by one of the following two formulas*:

$$F_{cr} = F_y\left[1 - \frac{F_y}{4\pi^2 E}\left(\frac{KL_c}{r}\right)^2\right] \qquad (10\text{-}151)$$

$$\text{for} \quad \frac{KL_c}{r} \le \sqrt{\frac{2\pi^2 E}{F_y}} \qquad (10\text{-}152)$$

$$F_{cr} = \frac{\pi^2 E}{\left(\frac{KL_c}{r}\right)^2} \qquad (10\text{-}153)$$

$$\text{for} \quad \frac{KL_c}{r} > \sqrt{\frac{2\pi^2 E}{F_y}} \qquad (10\text{-}154)$$

LRFR

- According to Article 6.9.4.1

- If $\frac{P_e}{P_o} \ge 0.44$, then:

$$P_n = \left[0.658^{\left(\frac{P_o}{P_e}\right)}\right] P_o \qquad (6.9.4.1.1\text{-}1)$$

- If $\frac{P_e}{P_o} < 0.44$, then:

$$P_n = 0.877 P_e \qquad (6.9.4.1.1\text{-}2)$$

- No deviation from the code or discrepancies.

Capacity

Flexural Capacity

LFR

- Method of solution 1.6.3
- AASHTO 10.54.1

1.6.3 Moment Capacity

Moment capacity is calculated using the following equation.

$$Mu = F_Y S$$

Where,

Mu = Moment Capacity

F_Y = Yield stress of the steel

S = The elastic section modulus corresponding to the bending axis

LRFR

- According to Article 6.12.1.2
- Method of solution page A-12
- Capacity varies by section type
- W section
- Weak & Strong axis

- BrR does not identify capacity based on section type as opposed to current AASHTO and AASHTO 1995.

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Capacity

Flexural Capacity

LFR

10.48.1 Compact Sections

Sections of properly braced constant-depth flexural members without longitudinal web stiffeners, without holes in the tension flange and with high resistance to local buckling qualify as compact sections.

Sections of rolled or fabricated flexural members meeting the requirements of Article 10.48.1.1 below shall be considered compact sections and the maximum strength shall be computed as

$$M_u = F_y Z \quad (10\text{-}92)$$

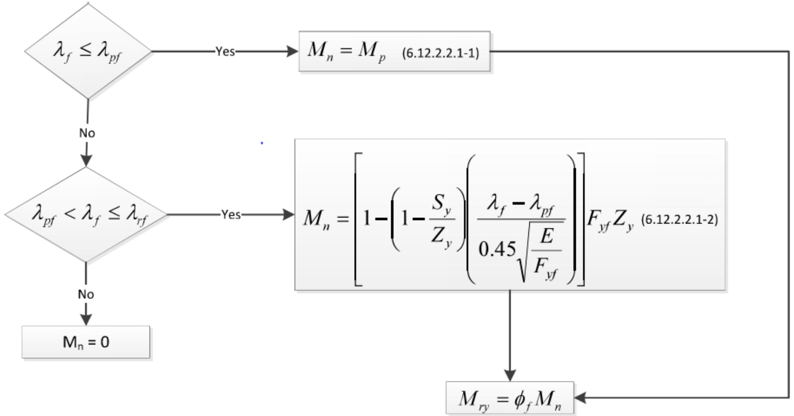
LRFR

Weak axis

$$\lambda_f = \frac{b_f}{2t_f} \quad (6.12.2.2.1\text{-}3)$$

$$\lambda_{pf} = 0.38\sqrt{\frac{E}{F_{yf}}} \quad (6.12.2.2.1\text{-}4)$$

$$\lambda_{rf} = 0.83\sqrt{\frac{E}{F_{yf}}} \quad (6.12.2.2.1\text{-}5)$$



Capacity

Flexural Capacity

LFR

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

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

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

LRFR

- Strong axis

Strong Axis Bending

For flexure about the strong axis, the following articles are evaluated to determine Fnc and Fnt:
6.10.8.1.1 Discretely Braced Flange in Compression
6.10.8.1.2 Discretely Braced Flange in Tension
6.10.8.2.2 Compression Flange – Local Buckling Resistance
6.10.8.2.3 Compression Flange – Lateral Torsional Buckling Resistance
6.10.8.3 Tension Flange Flexural Resistance

$$M_{rx} = \min(\phi_f F_{nc} S_{xc}, \phi_f F_{nt} S_{xt}) \qquad (C6.8.2.3\text{-}1)$$

Flexural Capacity

LFR

AASHTO 1995

where:

A_{ge} = Gross Effective Area
F_{cr} = Critical Load per AASHTO, Article 10.54.1.1 with a Suitable Effective Length Factor, K
C = Equivalent Moment Factor Taken as 0.85 or 1.00 as Appropriate
F_e = $(.85)(\pi^2)(E)/(KL/r)^2$ in Plane of Bending
M_y = $(F_y)(f)(S_{ge})$
S_{ge} = Section Modulus Reduced for Access Holes, if any
M_u = Maximum Bending Strength, Reduced for Lateral Buckling as Indicated Herein

The bending strength of truss members shall be computed using the equations given below:

(A) *For Box-Shaped Members:*

$$M_u = F_y S_{ge}\left[1 - 0.0641\frac{F_y S_{ge} L \sqrt{\Sigma(s/t)}}{E A \sqrt{I_y}}\right]$$

where:

A = Area Enclosed Within Centerlines of Plates of Box Members
s/t = Length of a Side Divided by its Thickness
I_y = Moment of Inertia About the Axis Perpendicular to the Bending Axis
L = Length of Member
S_{ge} = Gross Effective Section Modulus About Bending Axis

The capacity of *compression members* shall be evaluated using the two interaction equations given below:

$$\frac{P}{0.85 A_{ge} F_{cr}} + \frac{MC}{M_u\left[1 - \frac{P}{A_{ge} F_e}\right]} \le 1.0$$

$$\frac{P}{0.85 A_{ge} F_y} + \frac{M}{M_y} \le 1.0$$

(B) *For H-Shaped Members Bent About Their Minor Axis:*

$$M_u = 1.5 F_y S_{ge}$$

(C) *For H-Shaped Members, and Members with Channel Flanges and a Web Plate, Bent About Their Major Axis:*

$$\text{if } \sigma_{cr} \le 0.5 F_y,\ M_u = \sigma_{cr} S_{ge}$$

$$\text{if } \sigma_{cr} > 0.5 F_y,\ M_u = F_y S_{ge}\left[1 - \frac{F_y}{4\sigma_{cr}}\right]$$

$$\sigma_{cr} = \frac{1}{S_{ge}}\sqrt{\frac{\pi^2 E I_y G J}{(KL)^2} + \frac{\pi^4 h^2 I_y^2 E^2}{4(KL)^4}}$$

where:

S_{ge} = Gross Effective Section Modulus About Bending Axis

Capacity

Combined Tension and Flexure

LFR

- Method of solution 1.8.2

Tension members are only rated for concentric axial force.

1.8 COMPUTATION OF MEMBER CAPACITY

The capacity of *tension members* shall be evaluated using the two interaction equations given below:

$$\frac{P}{(F_y)(A_n)} + \frac{M}{(S_n)(F_y)(f)} \leq 1.0$$

$$\frac{P}{(F_u)(A_{\bar{n}})} + \frac{M}{(S_{\bar{n}})(F_u)(f)} \leq 1.0$$

where:

P = Factored Axial Load
F_y = Yield Point
A_n = Net Area—Per Section 1.7 Herein
M = Factored Dead Load Moment
S_n = Net Section Modulus—Per Section 1.7 Herein
f = Plastic Shape Factor Computed on the basis of Gross or Gross Effective Properties
F_u = Ultimate Strength of Steel
$A_{\bar{n}}$ = Net Area with All Holes Removed
$S_{\bar{n}}$ = Net Section Modulas wth All Holes Removed

LRFR

- Method of solution flow chart

6.8.2.3—Combined Tension and Flexure

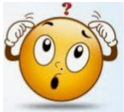
A component subjected to tension and flexure shall satisfy Eq. 6.8.2.3-1 or 6.8.2.3-2.

If $\frac{P_u}{P_r} < 0.2$, then

$$\frac{P_u}{2.0\,P_r} + \left(\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}}\right) \leq 1.0 \qquad (6.8.2.3\text{-}1)$$

If $\frac{P_u}{P_r} \geq 0.2$, then

$$\frac{P_u}{P_r} + \frac{8.0}{9.0}\left(\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}}\right) \leq 1.0 \qquad (6.8.2.3\text{-}2)$$



- AASHTO 1995 shows combined tension and Flexure.

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Capacity

Combined Compression and Flexure

LFR

- Method of solution 1.8.2
- AASHTO Article 10.54.2

10.54.2 Combined Axial Load and Bending

10.54.2.1 Maximum Capacity

The combined maximum axial force P and the maximum bending moment M acting on a beam-column subjected to eccentric loading shall satisfy the following equations:

$$\frac{P}{0.85 A_s F_{cr}} + \frac{MC}{M_u\left(1 - \frac{P}{A_s F_e}\right)} \leq 1.0 \qquad (10\text{-}155)$$

$$\frac{P}{0.85 A_s F_y} + \frac{M}{M_p} \leq 1.0 \qquad (10\text{-}156)$$

LRFR

- Method of solution flow chart.
- AASHTO Article 6.4.2

$$\frac{P_u}{P_r} + \frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1.0$$

- No deviation from the code or discrepancies.

Concentric Axial Rating

LFR

- Method of solution 1.8.1
- Rating without adjacent vehicle
- Rating with adjacent vehicle

$$RF = \frac{C - (A_1 D)}{A_2 L(1 + I)\alpha\beta}$$

$$RF = \frac{C - (A_1 D) - (A_3 L_2 (1 + I)\alpha_2)}{A_2 L_1 (1 + I)\alpha_1 \beta}$$

LRFR

- Method of solution flow chart.
- Rating without adjacent vehicle only.

$$RF = \frac{\varphi_c \varphi_s P_r - \gamma_{DC} P_{DC} - \gamma_{DW} P_{DW}}{\lambda_{LL} P_{LL+IM}}$$

Pr is the factored tensile resistance or the factored compression resistance. Angles are only rated for tension and compression regardless of their end connections. As per C6.12.2.2.6, flexure due to eccentric axial tension is addressec through the shear lag coefficient, U. Flexure due to eccentric axial compression is taken into account by 6.9.4.4.

- BrR does not include the effect of adjacent vehicle for LRFR.
- Future Enhancement?

Eccentric Axial Rating: Compression & Bending

LFR

- Method of solution flow chart
- Compression & Bending

Substituting P and M into 10-155 using $P = P_1 + RFP_2$, $M = M_1 + RFM_2$

$$aRF^2 + bRF + c = 0$$

Substituting P and M into 10-156 using $P = P_1 + RFP_2$, $M = M_1 + RFM_2$

$$RF = \frac{1 - \frac{P_1}{P_y} - \frac{M_1}{M_p}}{\frac{P_2}{P_y} + \frac{M_2}{M_p}}$$

LRFR

- Method of solution flow chart.
- Compression & Bending
- δ_b in both x and y direction

Column Rating: Is based on MBE Appendix H6A

If $\frac{P_u}{P_r} < 0.2$ then:

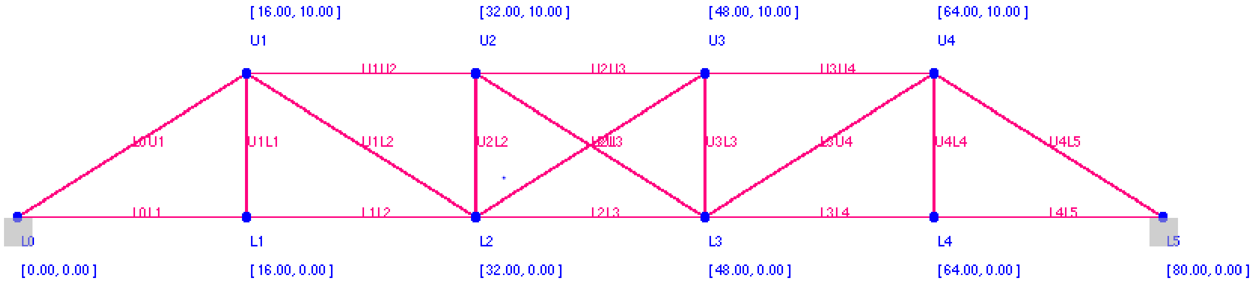
$$\gamma_D\left[\frac{1}{2}\frac{P_{DL}}{P_r} + \delta_b\left(\frac{M_{DL}}{M_r}\right)\right] + RF \times \gamma_L\left[\frac{P_{LL+IM}}{2P_r} + \delta_b\left(\frac{M_{LL+IM}}{M_r}\right)\right] = 1.0$$

If $\frac{P_u}{P_r} > 0.2$ and $M_{uy} = 0$ then:

$$\gamma_D\left[\frac{P_{DL}}{P_r} + \frac{8}{9}\delta_b\left(\frac{M_{DL}}{M_r}\right)\right] + RF \times \gamma_L\left[\frac{P_{LL+IM}}{P_r} + \frac{8}{9}\delta_b\left(\frac{M_{LL+IM}}{M_r}\right)\right] = 1.0$$

Eccentric Axial Rating: Compression & Bending

Sample Bridge:



Member	Eccen
L0U1	0.0656
U1U2	0.101
U2U3	0.101
U3U4	0.101
U4L5	0.0656

Eccentric Axial Rating: Compression & Bending

LFR:

Mem U1U2

6B.4 Combined Axial and Bending

Limit State: Stage: 3

Vehicle: Flex Sense: N/A

```
Part B - ALLOWABLE STRESS RATING AND LOAD FACTOR RATING
 6B.4 RATING EQUATION
 6B.4.1 Combined Axial and Bending
 (AASHTO Manual for Bridge Evaluation, Third Edition with 2019 Interims)

 Steel Angle Box - Truss Member U1U2 - Start     Stage 3


 COMBINED AXIAL AND BENDING RATING FACTOR CALCULATIONS

 Use the smaller rating factor from eq. 10-155 and 10-156

 From 10-155:

    P1 + RF1*P2       (M1 + RF1*M2)*C
    ---------- + --------------------  = 1.0
        Pcr           (     P1 + RF1*P2)
                  Mu*(1 - -----------)
                      (          Pe    )

    Solve above equation for RF1.
```

```
From 10-155:

   P1 + RF1*P2       (M1 + RF1*M2)*C
   ---------- + --------------------  = 1.0
       Pcr           (     P1 + RF1*P2)
                 Mu*(1 - -----------)
                     (          Pe    )

   Solve above equation for RF1.

From 10-156:

        1 - P1/Py - M1/Mp
RF2 = -----------------
          P2/Py + M2/Mp

RF = min(RF1, RF2)

where,

   C                    =  1.0
   Pcr = .85*As*Fcr =   355.3078 (kip)
   Pe  =  As*Fe      =  1548.3596 (kip)
   Py  = .85*As*Fy   =   383.2013 (kip)
   Mp                =    79.8094 (kip-ft)
   Mu                =    79.8094 (kip-ft)
   Eccentricity      =     0.0084 (ft)
   PDL               =   -42.9235 (kip)
   MDL               =    -0.3613 (kip-ft)
   P1                =  A1*PDL
   M1                =  A1*MDL
```

Rating Level	Vehicle	Load Case	Load Factors A1	Load Factors A2	PLL (kip)	MLL (kip-ft)	RF1	RF2	RF	Capacity (Ton)
Inventory	1	NegativeLiveLoad	1.300	2.171	-72.60	-0.61	1.797	1.983	1.797	44.93

Rating

Eccentric Axial Rating: Compression & Bending

LRFR

Mem U1U2

6A.6.8 Truss Combined Axial and Flexure Rating

Limit State: Stage: 3

Vehicle: Flex Sense: N/A

```
6A Load and Resistance Factor Rating
 6A.6 Steel Structures
 6A.6.8 Truss Combined Axial and Flexure Rating
 (AASHTO Manual for Bridge Evaluation, Third Edition with 2019 Interims)

 Steel Angle Box - Truss Member U1U2 - Start      Stage 3

 Input:

 Unsupported Length Y  =   192.000 (in)
 Unsupported Length Z  =   192.000 (in)

 Fixity Start Y        =     Fixed
 Fixity Start Z        =     Fixed
 Fixity End Y          =     Fixed
 Fixity End Z          =     Fixed

 Condition Factor      =     1.000
 System Factor         =     1.000
 Phi_F                 =     1.000
 Phi_K                 =     1.000

 DC Axial              =   -34.675 (kip)
 DW Axial              =    -8.248 (kip)
 DC Moment Y           =     0.000 (kip-ft)
 DW Moment Y           =     0.000 (kip-ft)
 DC Moment Z           =    -0.292 (kip-ft)
 DW Moment Z           =    -0.069 (kip-ft)
```

Load	Load Combo	Limit State	Pr (kip-ft)	Mrz (kip-ft)	Mry (kip-ft)	Capacity Override: PnPhi	PnOvr (kip-ft)	MznPhi	MznOvr (kip-ft)	MynPhi	MynOvr (kip-ft)	Note
LegalRout~	1	STR-I	--	--	--							*
LegalRout~	1	STR-I	-359.19	-78.82	117.16							

* Moments are zero, therefore, load case handled by axial only article.

Load	Load Combo	Limit State	Axial (kip)	Mz (kip-ft)	My (kip-ft)	DC	DW	LL	RF	Capacity (Ton)	Note
LegalRoutine	1	STR-I	0.00	0.00	0.00	1.25	1.50	1.45	--	--	*
LegalRoutine	1	STR-I	-93.15	-0.78	0.00	1.25	1.50	1.45	2.15	53.78	

* Moments are zero, therefore, load case handled by axial only article.

- BrR does not include the effect of flexure when calculating rating as opposed method of solution.
- Future Enhancement or Bug?

Eccentric Axial Rating: Tension & Bending

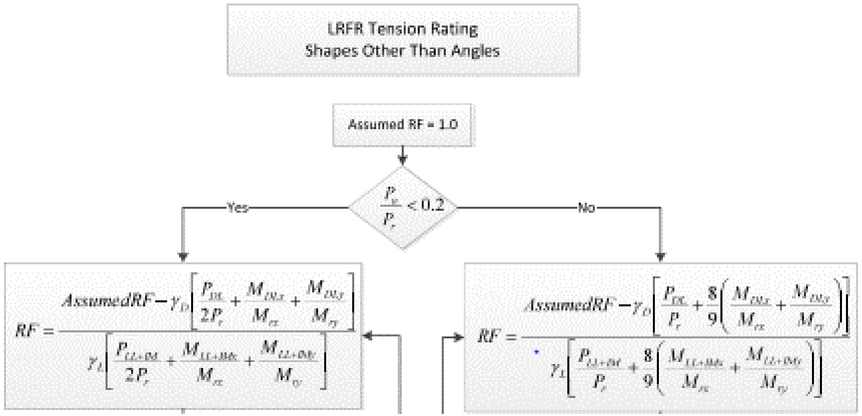
LFR

- Method of solution flow chart

N.A

LRFR

- Method of solution flow chart.



Conclusion

Future enhancement or clarification

LFR

- Tension capacity needs improvement. As a workaround capacity should be manually calculated and override to improve rating.
- Flexural capacity should be improved, or reason should be provided in the method of solution for deviating from AASHTO.
- Method of solution for Truss force effect with counter should be clarified.

LRFR

- BrR considers MPF=1.2 for single lane bridge as a default.
- BrR does not consider the effect of adjacent vehicle when performing rating.
- Method of solution for Truss force effect with counter should be clarified.
- BrR does not calculate rating factor for combined flexure and bending rating.