AASHTOWare BrDR 7.6.0

Steel Tutorial

STL16 - LRFD 10th Edition Spec Update – Lateral Torsional Buckling Example

AASHTOWare Bridge Design and Rating Training

STL14 – LRFD 10th Edition Spec Update – Lateral Torsional Buckling Example

Summary

This tutorial demonstrates the implementation of the AASHTO LRFD 10th Edition Lateral Torsional Buckling (LTB) resistance calculations in AASHTOWare BrDR. The LRFD 10th Edition spec updates introduce substantial changes to the calculation of the lateral torsional buckling resistance for steel structures. These changes include:

- **Moment Gradient Modifier, Cb** – The spec update introduces new methods for computing the moment gradient modifier which use moments at quarter points in the unbraced region. Analysis points are added at the quarter points of all unbraced regions to compute these moments.
- **Non-Prismatic Unbraced Lengths** – The spec update adds Appendix D6.6 to assist in the calculation of LTB resistance of non-prismatic unbraced regions. Appendix D describes several methods for calculating the non-prismatic LTB resistance; AASHTOWare BrDR supports Method A and Method B.
- **Governing Cross Sections –** The LRFD 10th edition specifies the POI where LTB resistance is to be computed. Previous versions of the spec recommended comparing maximum actions and minimum capacities within the unbraced length for design checks where the flexural resistance is based on LTB. The updated spec says to evaluate LTB resistance at a single point, where $f_{bu}/(R_b R_h F_{yc})$ is maximum. And for Appendix A6 to consider the point where $M_u/(R_{pc} M_{yc})$ is maximum.

This tutorial will introduce the new spec article output. TrainingBridge2 from the sample database illustrates an example with a prismatic unbraced length and TrainingBridge3 from the sample database illustrates a non-prismatic unbraced length.

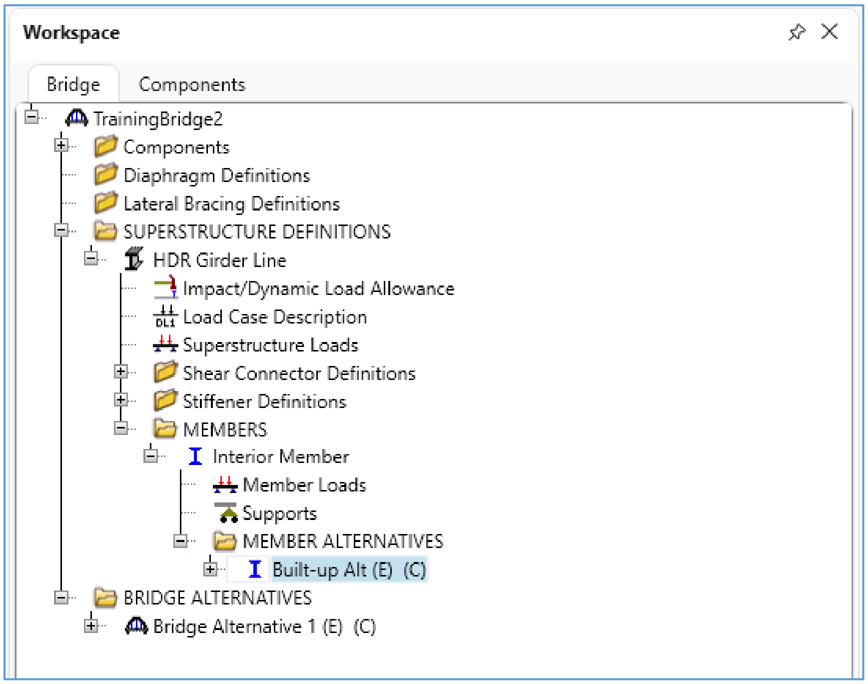
The steel member alternative has several control options for LRFD and LRFR analysis methods related to the LTB resistance calculation.

- **Consider concurrent moments in Cb calculation** – Select this option to use concurrent moments in the moment gradient modifier calculation. When using concurrent moments and the LRFD 10th edition, BrDR computes the quarter point moments using the load pattern corresponding to the maximum moment in the unbraced length. The Cb factor is computed using these concurrent moments. When this control option is not selected, maximized envelope moments are used.
- **Use compact web alternate Cb calculation** – Select this option to compute the moment gradient modifier using AISC equation C-F1-5. This calculation applies to unbraced lengths with compact webs, continuously laterally supported top flanges, and reverse curvature bending with no intermediate bracing along the bottom flange.
- **LTB Gamma E Method –** Select the method from Appendix D6.6 to compute the LTB resistance of non-prismatic unbraced regions. Options include Method A and Method B.

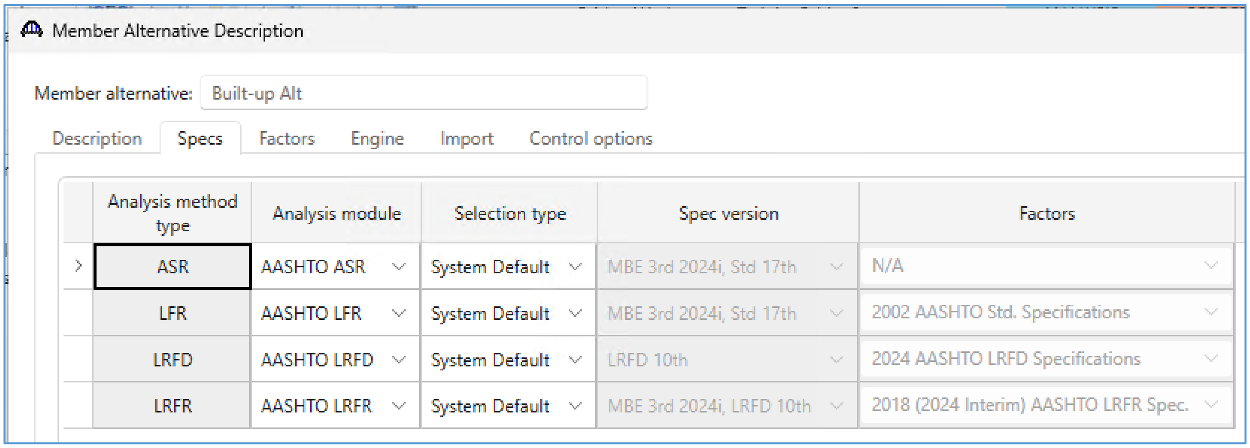
Prismatic Unbraced Regions

6.10.8.2.3 – Lateral Torsional Buckling Resistance

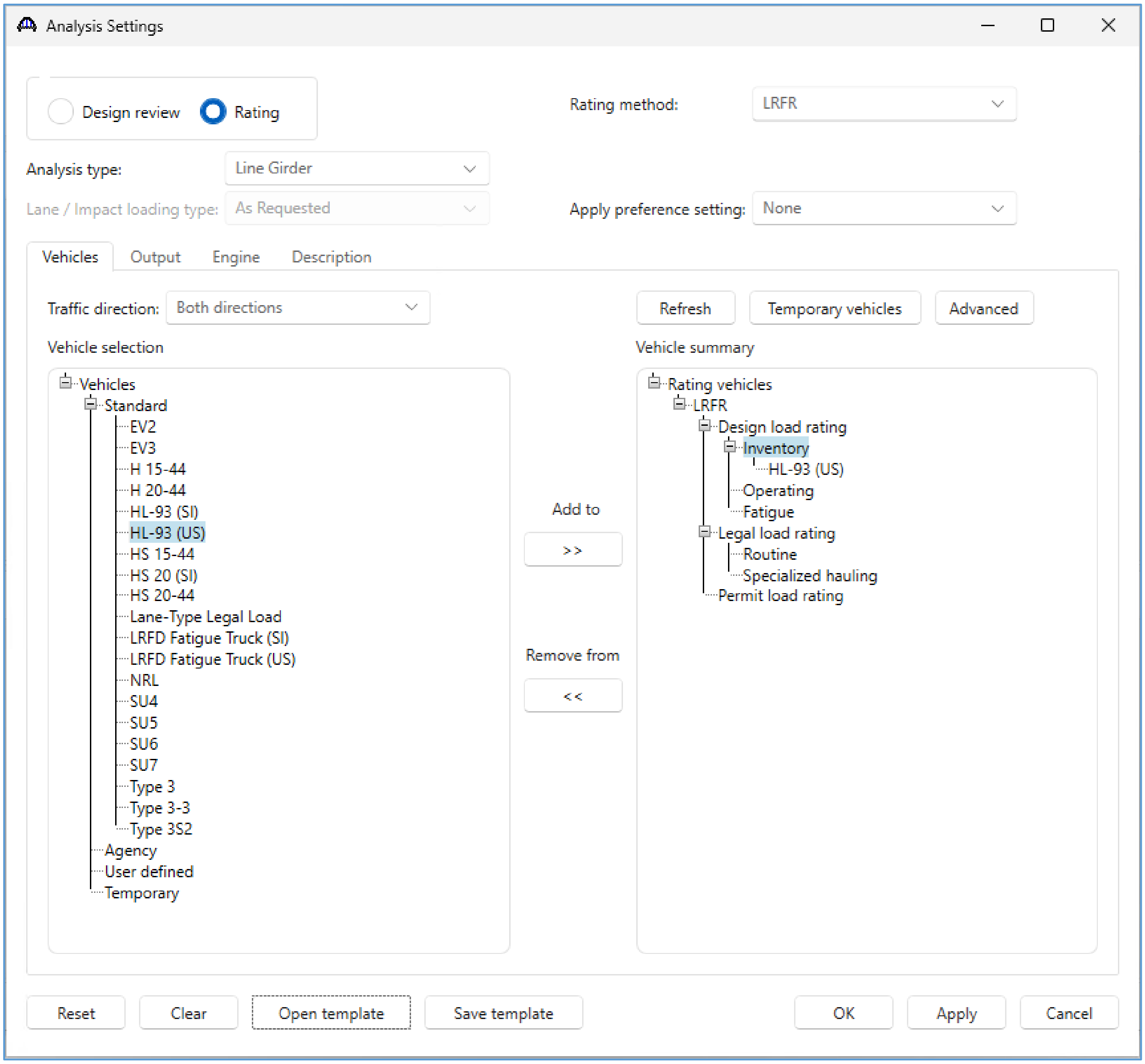
Open **TrainingBridge2** from the BrDR sample database. First, verify the member alternative is set to use the AASHTO LRFD 10th Edition spec for design and rating. Open the **Member Alternative Description** window by double clicking on the **Built-up Alt** member alternative.



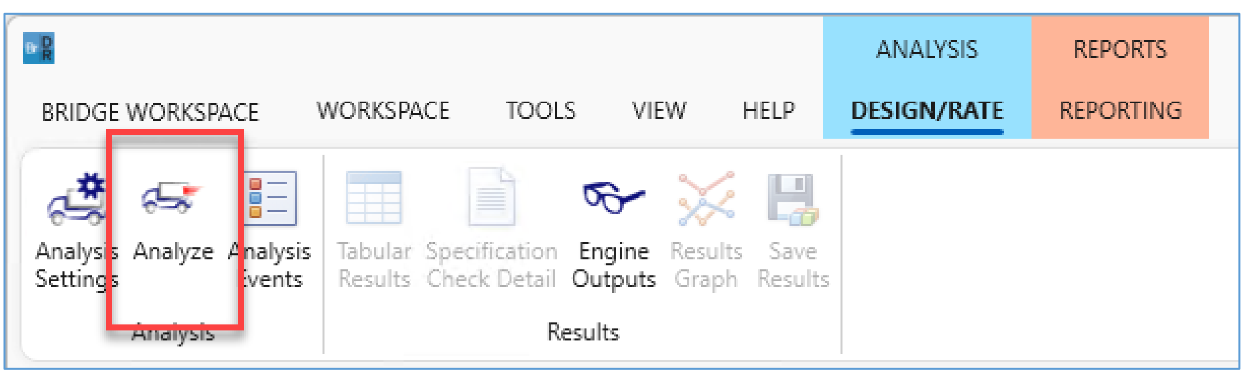
Under the **Specs** tab in the window, check that the **LRFD Analysis method type** is set to use the LRFD 10th edition spec version and that the **LRFR Analysis method type** is set to use the one of the MBE editions with the LRFD 10th edition spec version. These may already be set as the system default spec versions. If the system default is set to a different spec version, use the **Override** selection to set the AASHTO LRFD 10th edition for LRFD and LRFR.



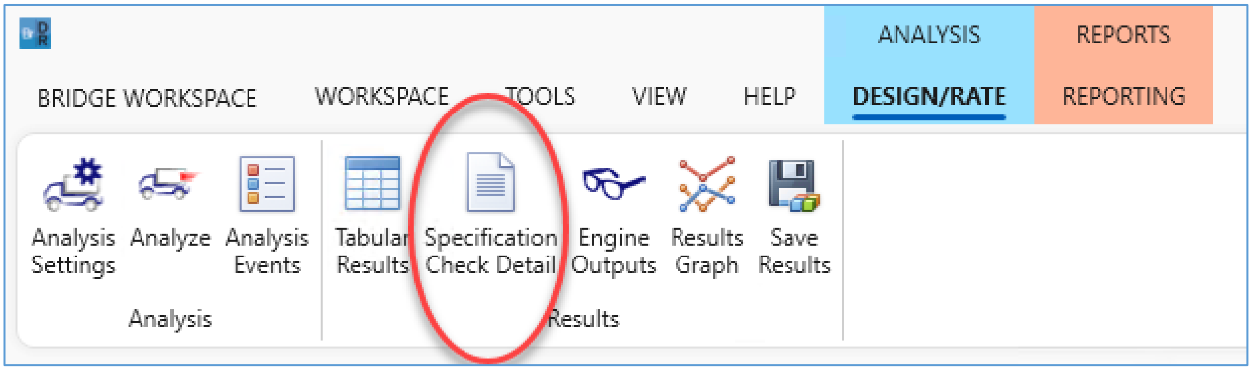
Analyze the **Built-up Alt** member alternative using the LRFR rating method and an HL-93 (US) vehicle in the inventory design load rating category.

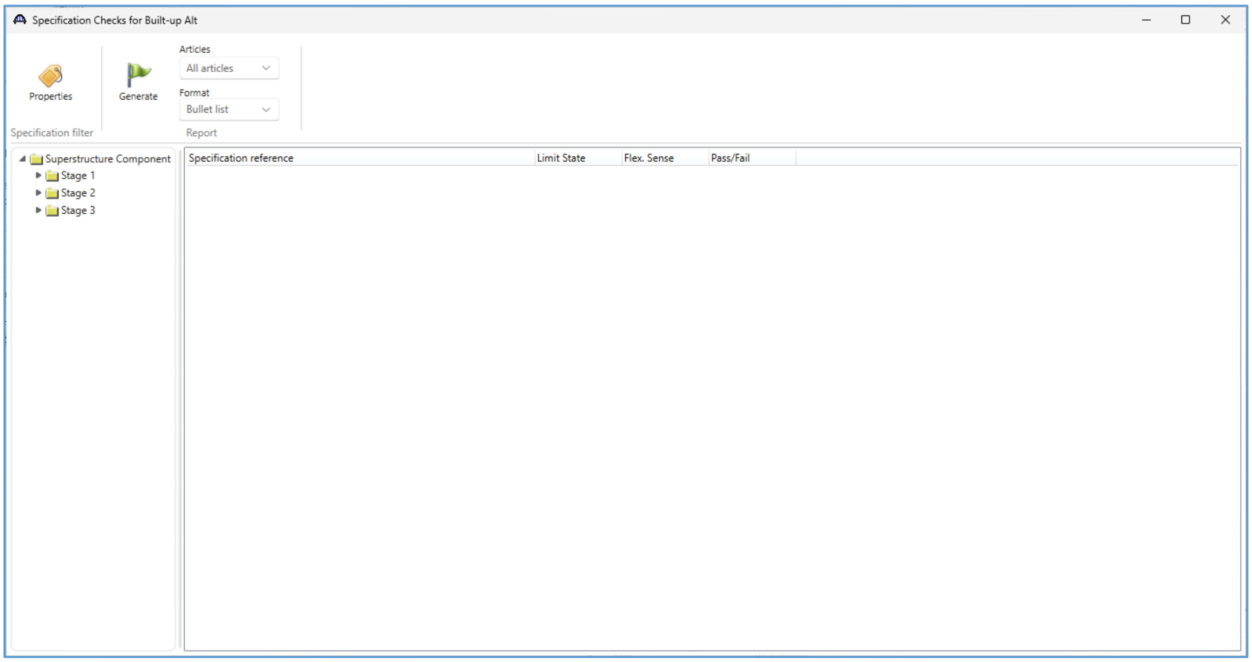


With the **Built-up Alt** member alternative selected, click on **Analyze** in the top ribbon to analyze the member alternative.

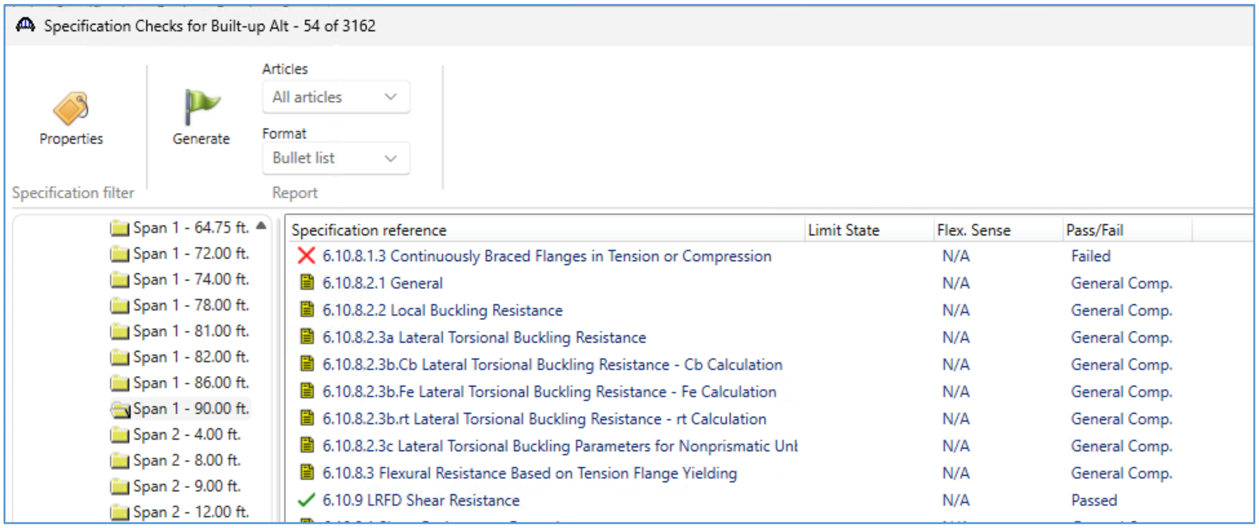


After the analysis is complete, select the **Specification Check Detail** button in the analysis ribbon to open the specification check calculations for the member alternative.





To view the calculations for the LTB resistance at the interior support, expand the spec check folder tree for ►Superstructure Component ►Stage 3 ►Built-up Alt ► Span 1 – 90.00 ft.

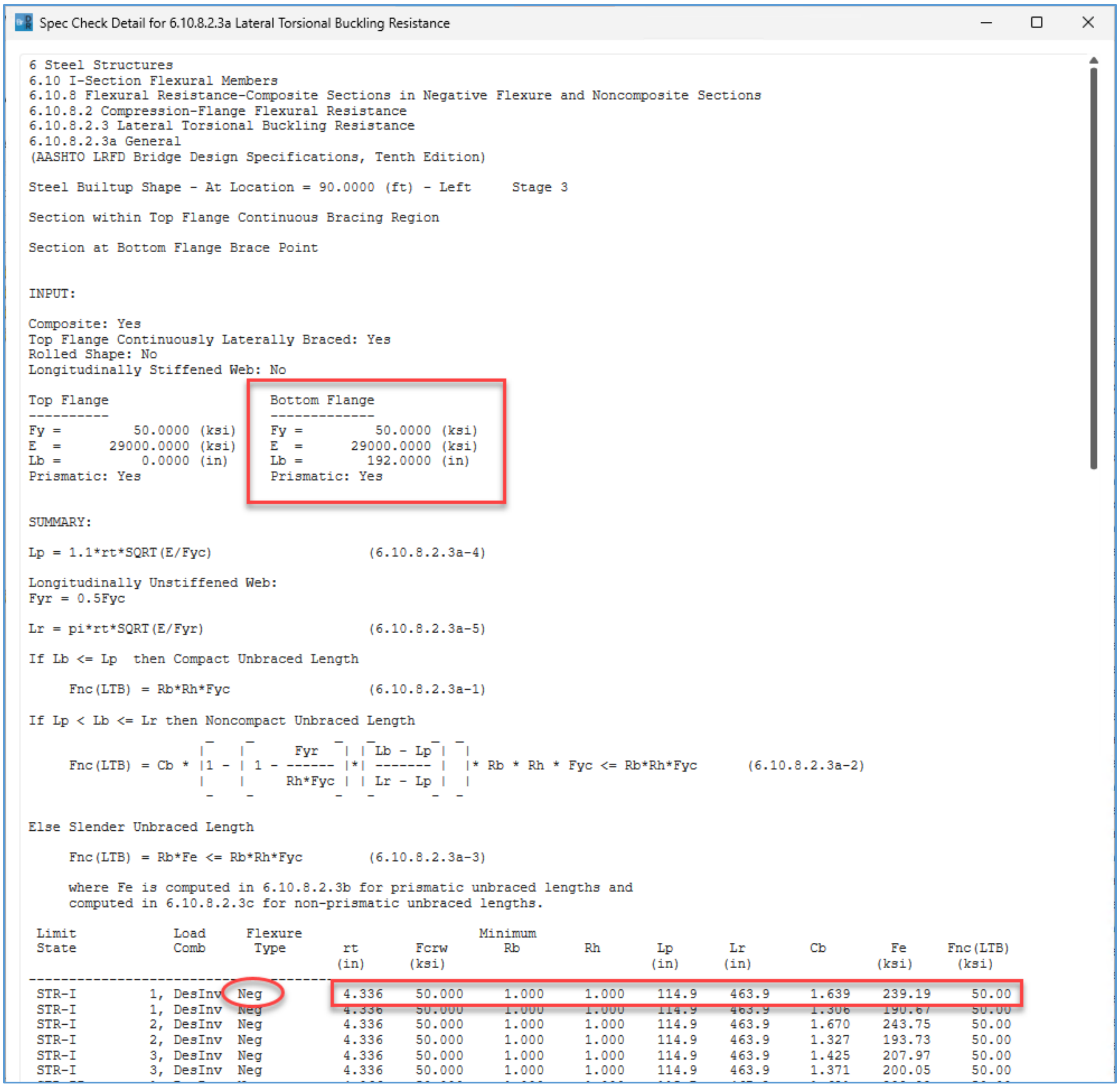


A good starting point when reviewing the 10th edition LTB calculations is to check the **6.10.8.2.3a Lateral Torsional Buckling Resistance** spec article. For each load case, this article will show the computed lateral torsional buckling resistance at the POI where $f_{bu}/(R_b R_h F_{yc})$ is maximum. Other locations within the unbraced length will display a message stating where the lateral torsional buckling capacity is computed. For example, the 6.10.8.2.3a Lateral Torsional Buckling Resistance article at 86.00 ft. shows the following:

```
 Limit            Load    Flexure                  Minimum
 State            Comb    Type       rt      Fcrw     Rb        Rh      Lp      Lr       Cb        Fe    Fnc(LTB)
                                     (in)    (ksi)                      (in)    (in)              (ksi)   (ksi)
--------------------------------------------------------------------------------------------------------------------
 STR-I          1, DesInv  Neg     Governing Cross Section at 90.00 (ft) - Left
 STR-I          1, DesInv  Neg     Governing Cross Section at 90.00 (ft) - Left
 STR-I          2, DesInv  Neg     Governing Cross Section at 90.00 (ft) - Left
 STR-I          2, DesInv  Neg     Governing Cross Section at 90.00 (ft) - Left
```

This indicates the LTB resistance is computed at the left side of the 90.00 ft. POI for the given unbraced region. This is the location where $f_{bu}/(R_b R_h F_{yc})$ is maximum in the unbraced length under consideration.

Open the **6.10.8.2.3a Lateral Torsional Buckling Resistance** spec article at the 90.00 ft. POI. For each load case where this POI is the point where $f_{bu}/(R_b R_h F_{yc})$ is maximum, the computed LTB capacity is shown. With the LRFD 10th edition specs there are different calculations for the lateral torsional buckling parameters (Cb, rt, and Fe) of prismatic and non-prismatic unbraced lengths. When the flexure type is positive check if the girder is prismatic between top flange brace points and when the flexure type is negative check if the girder is prismatic between bottom flange brace points. For this example, the girder is prismatic in the 192 in. unbraced length between brace points along the bottom flange. For prismatic unbraced lengths the lateral torsional buckling parameters are computed according to AASHTO LRFD 6.10.8.2.3b.


Spec Check Detail for 6.10.8.2.3a Lateral Torsional Buckling Resistance

```
6 Steel Structures
6.10 I-Section Flexural Members
6.10.8 Flexural Resistance-Composite Sections in Negative Flexure and Noncomposite Sections
6.10.8.2 Compression-Flange Flexural Resistance
6.10.8.2.3 Lateral Torsional Buckling Resistance
6.10.8.2.3a General
(AASHTO LRFD Bridge Design Specifications, Tenth Edition)

Steel Builtup Shape - At Location = 90.0000 (ft) - Left     Stage 3

Section within Top Flange Continuous Bracing Region

Section at Bottom Flange Brace Point


INPUT:

Composite: Yes
Top Flange Continuously Laterally Braced: Yes
Rolled Shape: No
Longitudinally Stiffened Web: No

Top Flange                           Bottom Flange
----------                           -------------
Fy =       50.0000 (ksi)             Fy =       50.0000 (ksi)
E  =    29000.0000 (ksi)             E  =    29000.0000 (ksi)
Lb =        0.0000 (in)              Lb =      192.0000 (in)
Prismatic: Yes                       Prismatic: Yes


SUMMARY:

Lp = 1.1*rt*SQRT(E/Fyc)                    (6.10.8.2.3a-4)

Longitudinally Unstiffened Web:
Fyr = 0.5Fyc

Lr = pi*rt*SQRT(E/Fyr)                     (6.10.8.2.3a-5)

If Lb <= Lp  then Compact Unbraced Length

     Fnc(LTB)  = Rb*Rh*Fyc                 (6.10.8.2.3a-1)

If Lp < Lb <= Lr then Noncompact Unbraced Length

                         _    _          _   _ _         _  _
                        |    |      Fyr   | |  Lb - Lp  |  |
     Fnc(LTB)  = Cb *   |1 - | 1 - ------ |*| -------   |  |* Rb * Rh * Fyc <= Rb*Rh*Fyc      (6.10.8.2.3a-2)
                        |    |    Rh*Fyc  | |  Lr - Lp  |  |
                         -    -          -   -         -  -

Else Slender Unbraced Length

     Fnc(LTB)  = Rb*Fe <= Rb*Rh*Fyc        (6.10.8.2.3a-3)

     where Fe is computed in 6.10.8.2.3b for prismatic unbraced lengths and
     computed in 6.10.8.2.3c for non-prismatic unbraced lengths.
```

Limit State	Load Comb	Flexure Type	rt (in)	Fcrw (ksi)	Minimum Rb	Rh	Lp (in)	Lr (in)	Cb	Fe (ksi)	Fnc(LTB) (ksi)
STR-I	1, DesInv	Neg	4.336	50.000	1.000	1.000	114.9	463.9	1.639	239.19	50.00
STR-I	1, DesInv	Neg	4.336	50.000	1.000	1.000	114.9	463.9	1.306	190.67	50.00
STR-I	2, DesInv	Neg	4.336	50.000	1.000	1.000	114.9	463.9	1.670	243.75	50.00
STR-I	2, DesInv	Neg	4.336	50.000	1.000	1.000	114.9	463.9	1.327	193.73	50.00
STR-I	3, DesInv	Neg	4.336	50.000	1.000	1.000	114.9	463.9	1.425	207.97	50.00
STR-I	3, DesInv	Neg	4.336	50.000	1.000	1.000	114.9	463.9	1.371	200.05	50.00

For detailed calculations of each of the LTB parameters for a prismatic unbraced length, review articles **6.10.8.2.3b.Cb Lateral Torsional Buckling Resistance – Cb Calculation**, **6.10.8.2.3b.Fe Lateral Torsional Buckling Resistance – Fe Calculation**, and **6.10.8.2.3b.rt Lateral Torsional Buckling Resistance – rt Calculation**. Similar to the general LTB resistance calculation, these parameters are only computed at the govering cross section for each unbraced length.

Specification reference	Limit State	Flex. Sense	Pass/Fail
6.10.8.1.1 Discretely Braced Flanges in Compression		N/A	Failed
NA 6.10.8.1.2 Discretely Braced Flanges in Tension		N/A	Not Applicable
6.10.8.1.3 Continuously Braced Flanges in Tension or Compression		N/A	Failed
6.10.8.2.1 General		N/A	General Comp.
6.10.8.2.2 Local Buckling Resistance		N/A	General Comp.
6.10.8.2.3a Lateral Torsional Buckling Resistance		N/A	General Comp.
6.10.8.2.3b.Cb Lateral Torsional Buckling Resistance - Cb Calculation		N/A	General Comp.
6.10.8.2.3b.Fe Lateral Torsional Buckling Resistance - Fe Calculation		N/A	General Comp.
6.10.8.2.3b.rt Lateral Torsional Buckling Resistance - rt Calculation		N/A	General Comp.
6.10.8.2.3c Lateral Torsional Buckling Parameters for Nonprismatic Unb		N/A	General Comp.
6.10.8.3 Flexural Resistance Based on Tension Flange Yielding		N/A	General Comp.
6.10.9 LRFD Shear Resistance		N/A	Passed

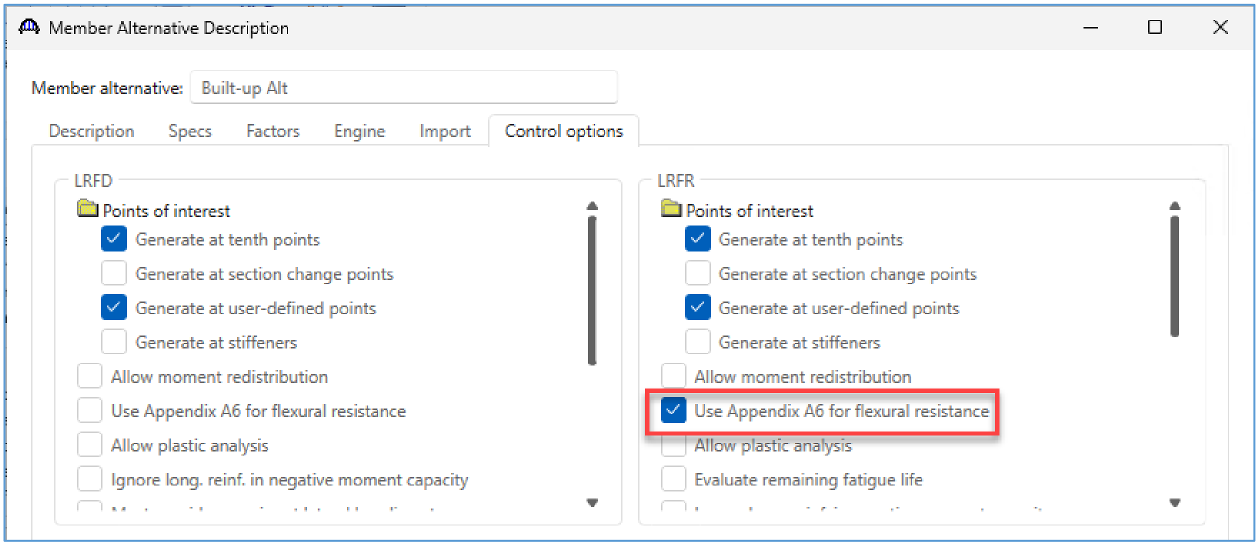
The calculations for Fe and rt for prismatic unbraced lengths are similar to the corresponding calculations from previous LRFD spec versions, but the calculation for the moment gradient modifier, Cb, is different.

```
Bot Flange Left Brace Location              =   74.00 (ft)
Bot Flange Quarter Brace Location       (A) =   78.00 (ft)
Bot Flange Mid Brace Location           (B) =   82.00 (ft)
Bot Flange Three Quarter Brace Location (C) =   86.00 (ft)
Bot Flange Right Brace Location             =   90.00 (ft)

SUMMARY:

                12.5*Mmax
Cb = -------------------------------          (6.10.8.2.3b-1)
      2.5*Mmax + 3*Ma + 4*Mb + 3*Mc


 Limit            Load      Flexure    Moment     Moment     Moment     Moment
 State            Comb       Type        A          B          C         Max        Cb
                                      (kip-in)   (kip-in)   (kip-in)   (kip-in)

-------------------------------------------------------------------------------------------
 STR-I           1, DesInv    Neg       -7495     -14756     -21511     -28478      1.639
 STR-I           1, DesInv    Neg      -30488     -37218     -44723     -52977      1.306
 STR-I           2, DesInv    Neg       -6820     -14127     -21668     -28478      1.670
 STR-I           2, DesInv    Neg      -27321     -33889     -41232     -49323      1.327
 STR-I           3, DesInv    Neg      -12987     -17743     -22907     -28478      1.425
```

Appendix A6.3.3 – Lateral Torsional Buckling Resistance

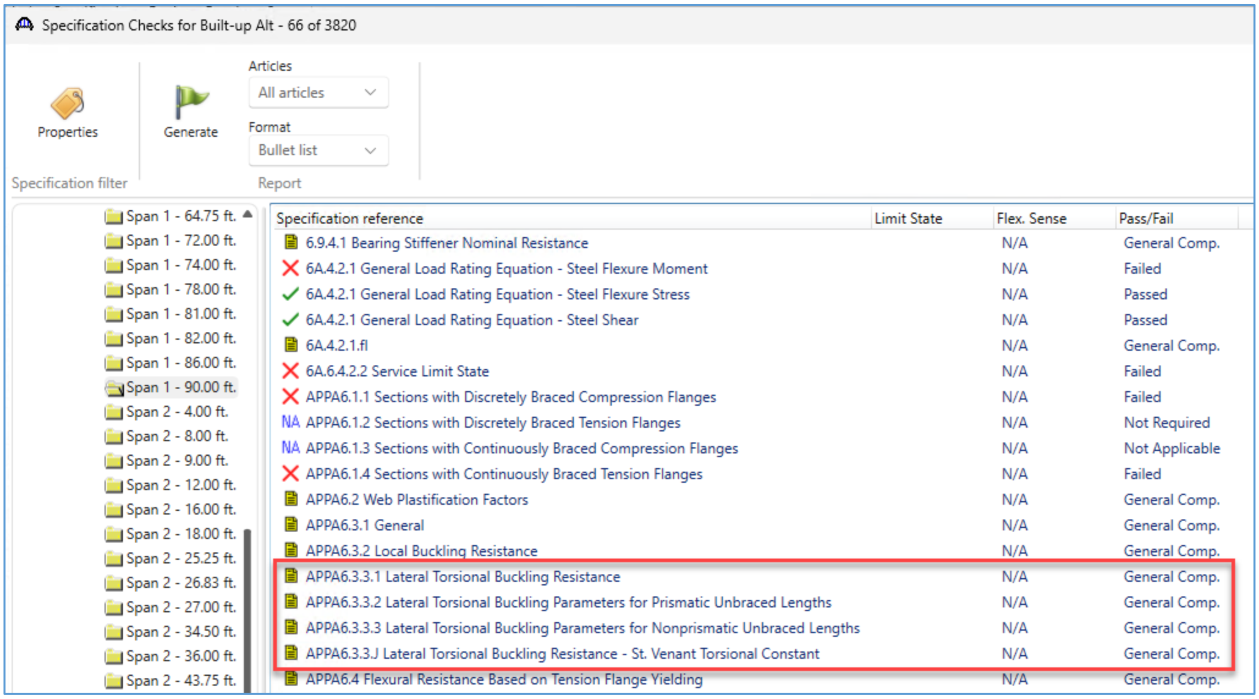
When the member alternative control option to **Use Appendix A6 for flexural resistance** is selected, BrDR will compute the LTB capacity according to Appendix A6.3.3.

Open the **Member Alternative Description** window and select the LRFR **Use Appendix A6 for flexural resistance** control option to consider Appendix A6 for the **Built-up Alt** member alternative.



Select **OK** to apply the changes and close the window. Reanalyze the member alternative with the same LRFR rating settings.

Similar to the section 6.10.8.2.3 LTB calculations, the Appendix A6 calculations compute LTB resistance for both prismatic and non-prismatic unbraced lengths. The **APPA6.3.3.1 Lateral Torsional Buckling Resistance** spec article has the general LTB calculations for the member. Results are only computed at the POI where $M_u/(R_{pc}M_{yc})$ is maximum. Detailed calculations for the LTB parameters are shown in the other APPA6.3.3 spec articles.



One additional consideration with the 10th edition specs is the Appendix A6 applicablity. The **6.10.6.2.3 Composite Sections in Negative Flexure and Noncomposite Sections** spec article reports on the Appendix A6 applicablity at each POI. With the 10th edition specs, the article A6 criteria needs to be satisfied at all points within the unbraced length for Appendix A6 to be considered.

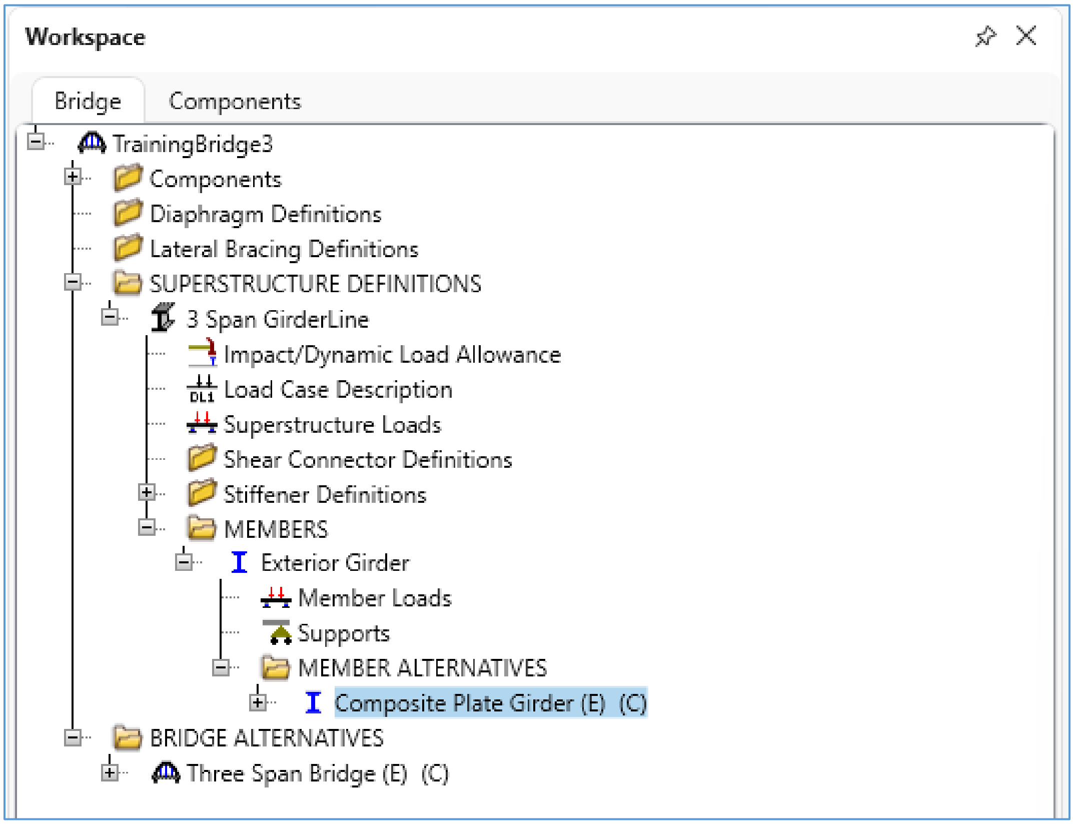
Close **TrainingBridge2.**

There is no need to save any changes to the model.

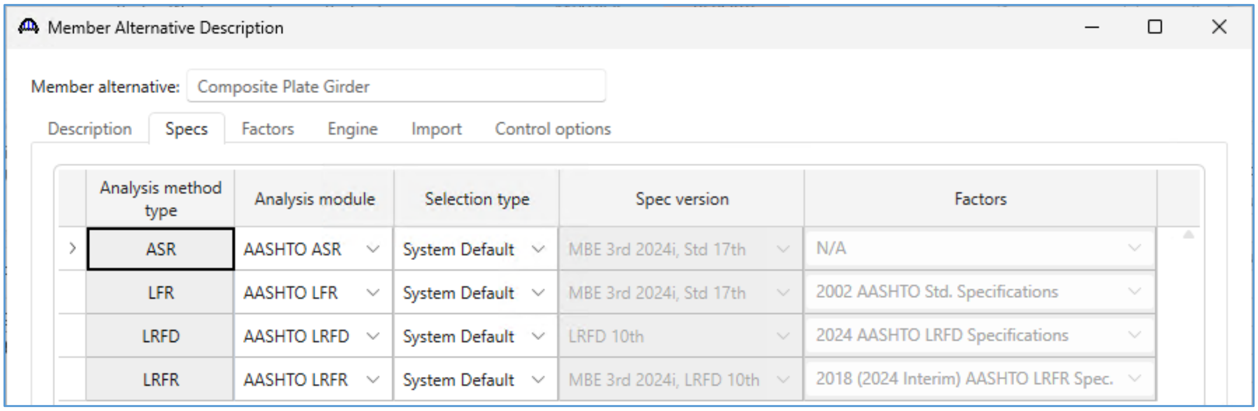
Non-Prismatic Unbraced Regions

6.10.8.2.3 – Lateral Torsional Buckling Resistance

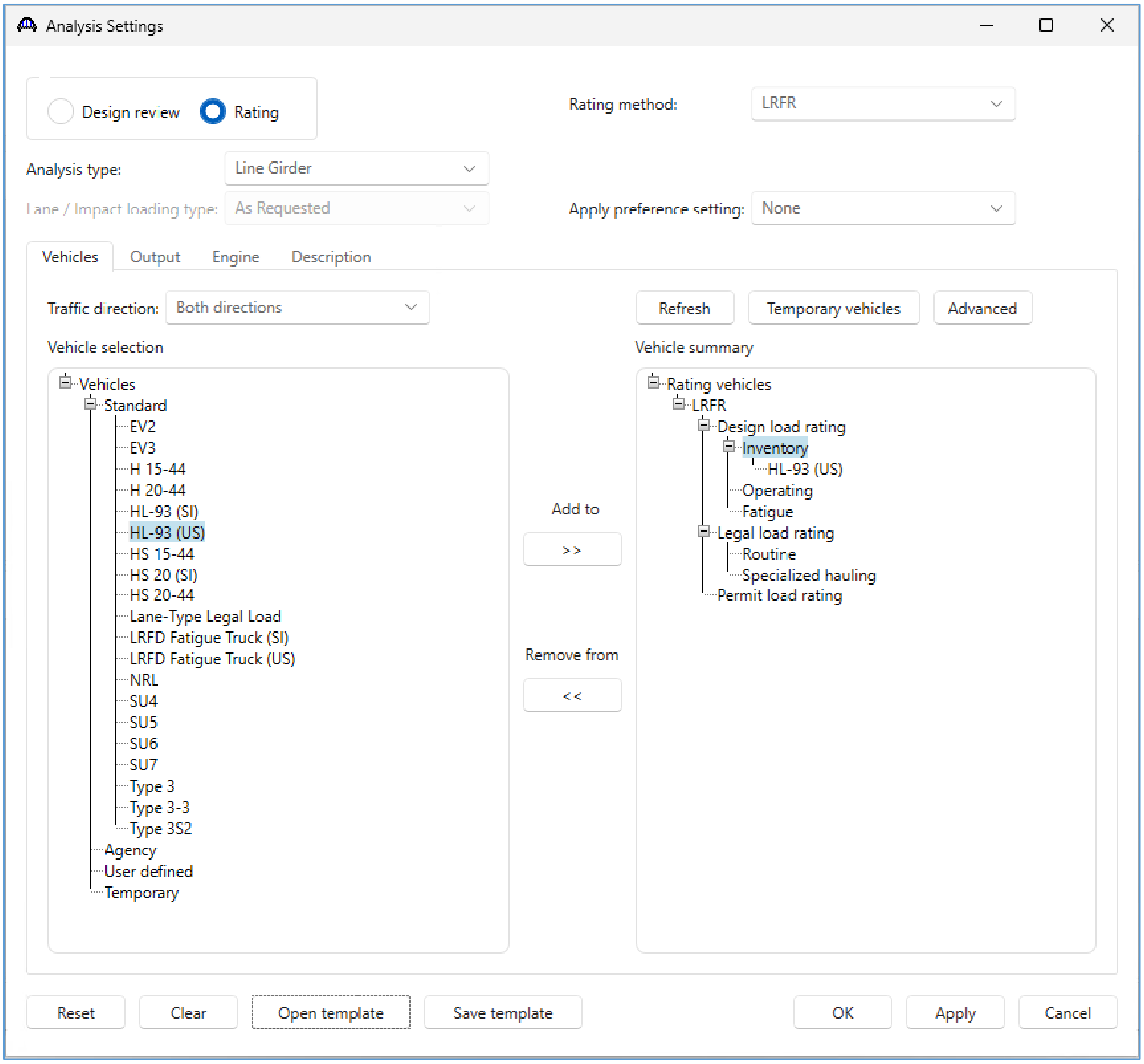
Open **TrainingBridge3** from the BrDR sample database. First, verify the member alternative is set to use the AASHTO LRFD 10th Edition spec for design and rating. Open the **Member Alternative Description** window by double clicking on the **Composite Plate Girder** member alternative.



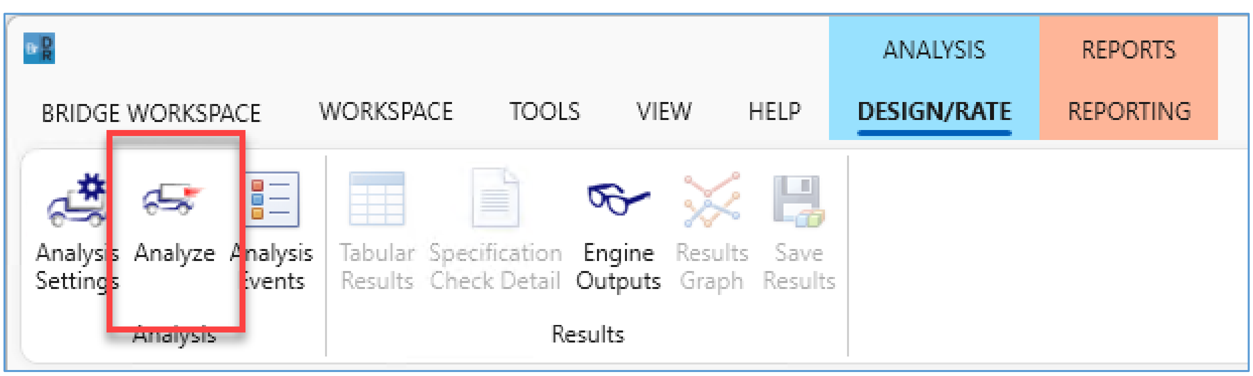
Under the **Specs** tab in the window, check that the **LRFD Analysis method type** is set to use the LRFD 10^{th} edition spec version and that the **LRFR Analysis method type** is set to use the one of the MBE editions with the LRFD 10^{th} edition spec version. These may already be set as the system default spec versions. If the system default is set to a different spec version, use the **Override** selection to set the AASHTO LRFD 10^{th} edition for LRFD and LRFR.



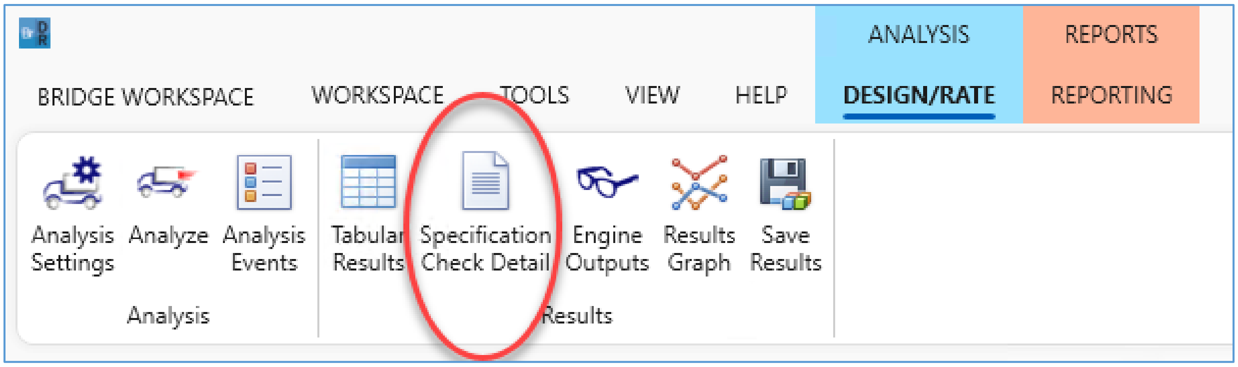
Analyze the **Composite Plate Girder** member alternative using the LRFR rating method and an HL-93 (US) vehicle in the inventory design load rating category.

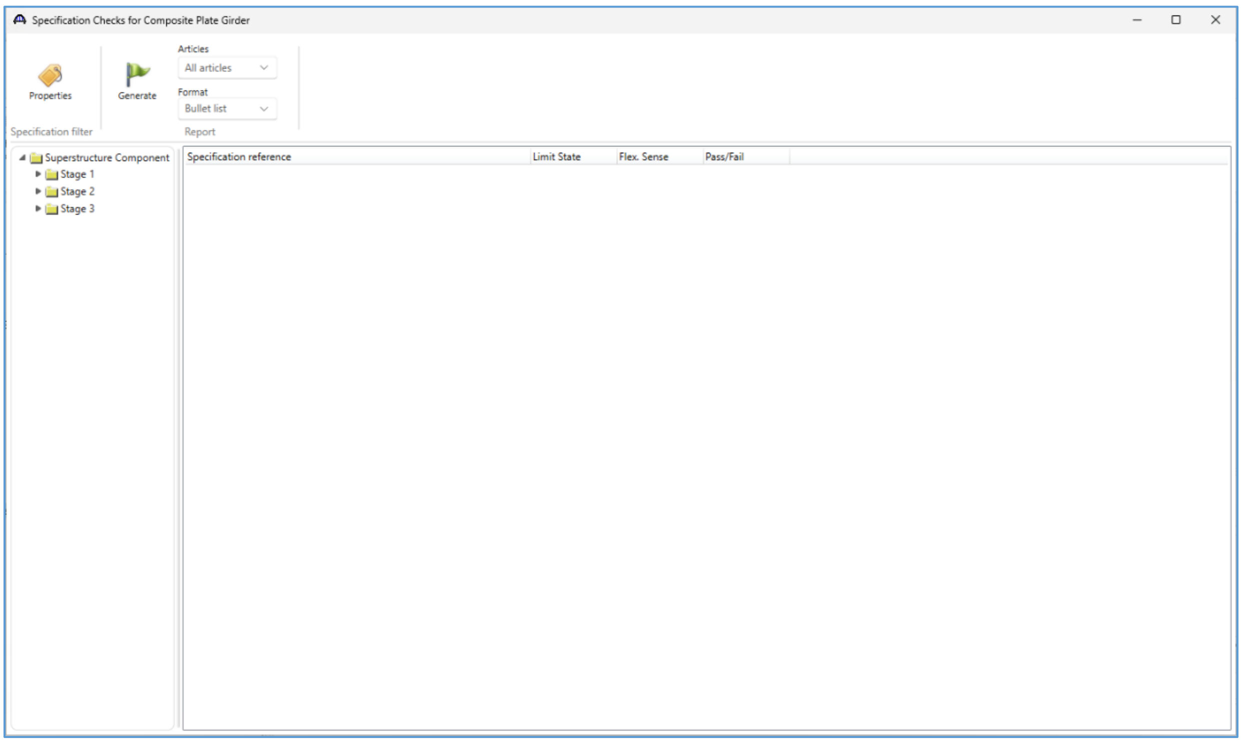


With the **Composite Plate Girder** member alternative selected, click on **Analyze** in the top ribbon to analyze the member alternative.

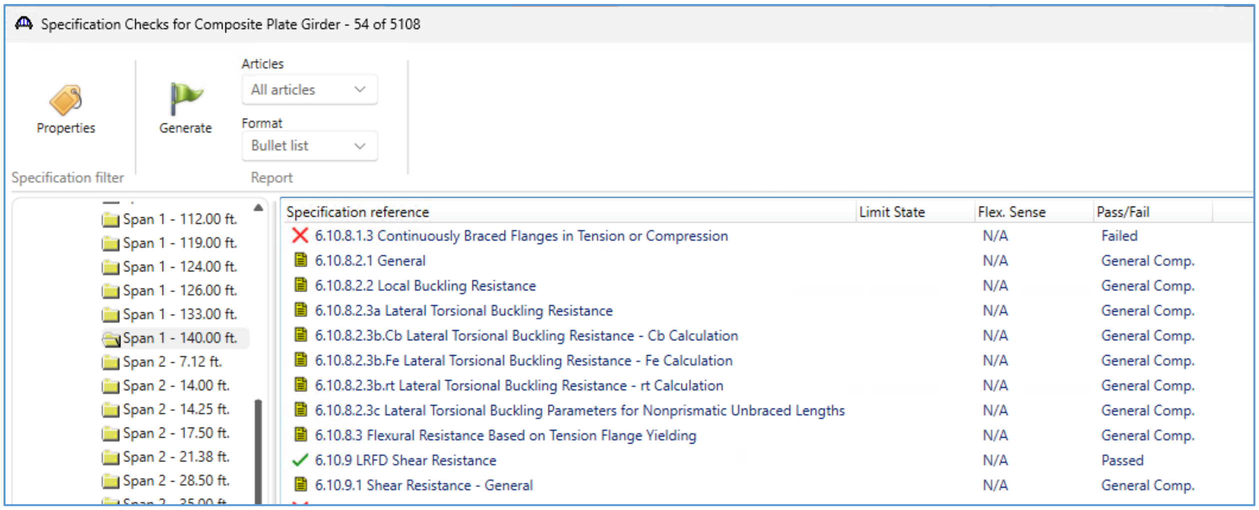


After the analysis is complete, select the **Specification Check Detail** button in the analysis ribbon to open the specification check calculations for the member alternative.

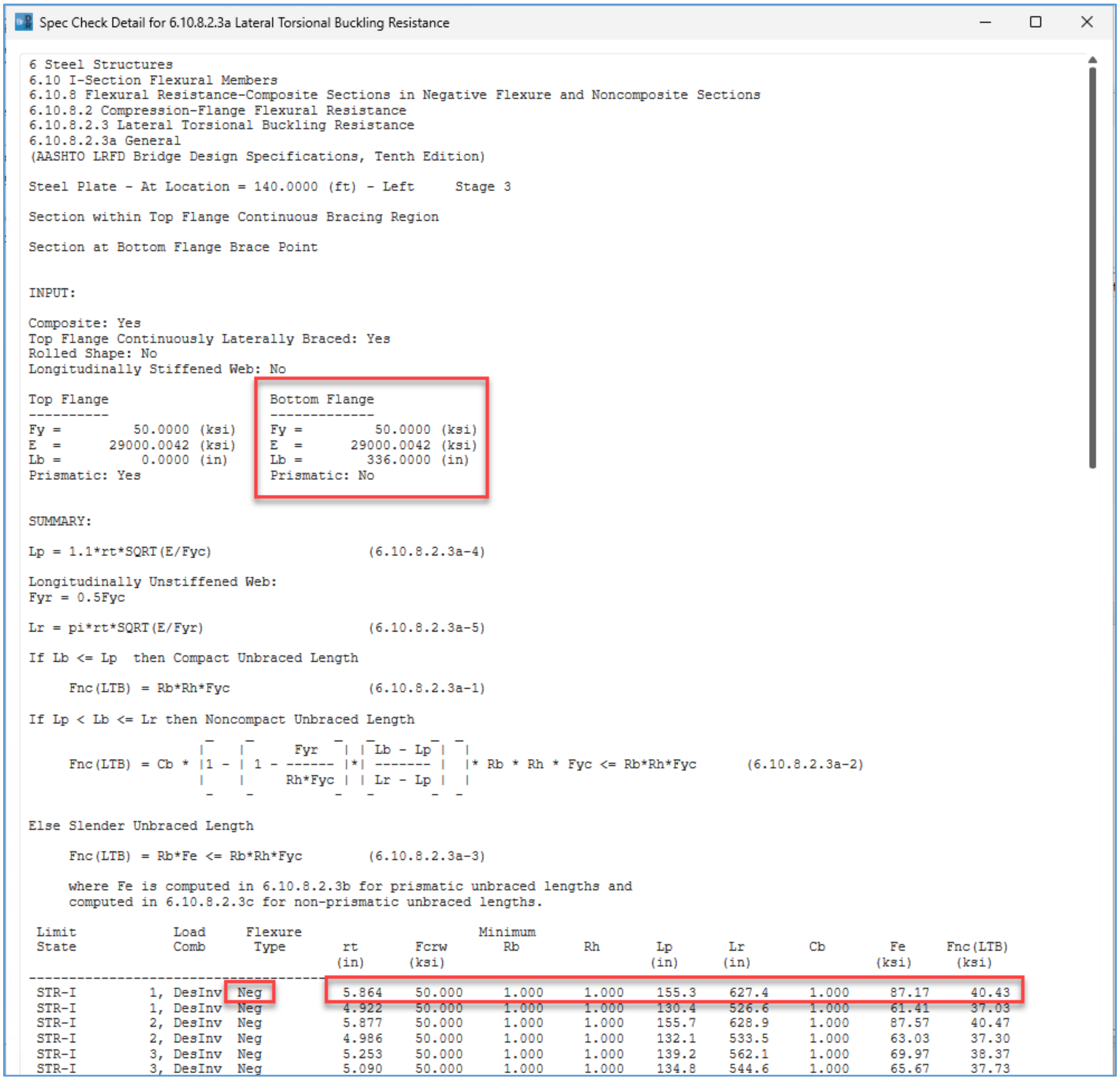




To view the calculations for the LTB resistance at the first interior support, expand the spec check folder tree for ►Superstructure Component ►Stage 3 ►Composite Plate Girder ► Span 1 – 140.00 ft.



As with the prismatic unbraced length calculations, a good starting point is to open the **6.10.8.2.3a Lateral Torsional Buckling Resistance** spec article. In this case, the spec article indicates that for negative flexure the girder is non-prismatic between brace points along the bottom flange. This means the LTB parameters, Cb, Fe, and rt, are computed according to AASHTO LRFD 6.10.8.2.3c instead of 6.10.8.2.3b.



Spec Check Detail for 6.10.8.2.3a Lateral Torsional Buckling Resistance

```
6 Steel Structures
6.10 I-Section Flexural Members
6.10.8 Flexural Resistance-Composite Sections in Negative Flexure and Noncomposite Sections
6.10.8.2 Compression-Flange Flexural Resistance
6.10.8.2.3 Lateral Torsional Buckling Resistance
6.10.8.2.3a General
(AASHTO LRFD Bridge Design Specifications, Tenth Edition)

Steel Plate - At Location = 140.0000 (ft) - Left     Stage 3

Section within Top Flange Continuous Bracing Region

Section at Bottom Flange Brace Point


INPUT:

Composite: Yes
Top Flange Continuously Laterally Braced: Yes
Rolled Shape: No
Longitudinally Stiffened Web: No

Top Flange                    Bottom Flange
----------                    -------------
Fy =        50.0000 (ksi)     Fy =        50.0000 (ksi)
E  =     29000.0042 (ksi)     E  =     29000.0042 (ksi)
Lb =         0.0000 (in)      Lb =       336.0000 (in)
Prismatic: Yes                Prismatic: No


SUMMARY:

Lp = 1.1*rt*SQRT(E/Fyc)                (6.10.8.2.3a-4)

Longitudinally Unstiffened Web:
Fyr = 0.5Fyc

Lr = pi*rt*SQRT(E/Fyr)                 (6.10.8.2.3a-5)

If Lb <= Lp  then Compact Unbraced Length

     Fnc(LTB) = Rb*Rh*Fyc              (6.10.8.2.3a-1)

If Lp < Lb <= Lr then Noncompact Unbraced Length
                     _    _        _   _       _  _
                    |    |     Fyr  | | Lb - Lp |  |
     Fnc(LTB) = Cb * |1 - | 1 - ------ |*| ------- |  |* Rb * Rh * Fyc <= Rb*Rh*Fyc      (6.10.8.2.3a-2)
                    |    |    Rh*Fyc | | Lr - Lp |  |
                     -    -        -   -       -  -

Else Slender Unbraced Length

     Fnc(LTB) = Rb*Fe <= Rb*Rh*Fyc       (6.10.8.2.3a-3)

     where Fe is computed in 6.10.8.2.3b for prismatic unbraced lengths and
     computed in 6.10.8.2.3c for non-prismatic unbraced lengths.
```

Limit State	Load Comb	Flexure Type	rt (in)	Fcrw (ksi)	Minimum Rb	Rh	Lp (in)	Lr (in)	Cb	Fe (ksi)	Fnc(LTB) (ksi)
STR-I	1, DesInv	Neg	5.864	50.000	1.000	1.000	155.3	627.4	1.000	87.17	40.43
STR-I	1, DesInv	Neg	4.922	50.000	1.000	1.000	130.4	526.6	1.000	61.41	37.03
STR-I	2, DesInv	Neg	5.877	50.000	1.000	1.000	155.7	628.9	1.000	87.57	40.47
STR-I	2, DesInv	Neg	4.986	50.000	1.000	1.000	132.1	533.5	1.000	63.03	37.30
STR-I	3, DesInv	Neg	5.253	50.000	1.000	1.000	139.2	562.1	1.000	69.97	38.37
STR-I	3, DesInv	Neg	5.090	50.000	1.000	1.000	134.8	544.6	1.000	65.67	37.73

Open the **6.10.8.2.3c Lateral Torsional Buckling Parameters for Nonprismatic Unbraced Lengths** spec article to view the detailed calculations for the LTB parameters.

```
SUMMARY:

Cb = 1.0                        (6.10.8.2.3c-1)

Fe = gammaE * fbu               (6.10.8.2.3c-2)

rt = Lb / pi * SQRT(Fe / E)     (6.10.8.2.3c-3)
```

Limit State	Load Comb	Flexure Type	gammaE	fbu (ksi)	Fe (ksi)	rt (in)
STR-I	1, DesInv	Neg	3.682	23.674	87.166	5.864
STR-I	1, DesInv	Neg	1.202	51.090	61.413	4.922
STR-I	2, DesInv	Neg	3.587	24.416	87.575	5.877

The elastic lateral torsional bucking load ratio, γ_e, is computed according to AASHTO LRFD Appendix D6.6. AASHTOWare BrDR supports Method A and Method B calculations for the elastic LTB load ratio. The calculation method is selected based on the control option for the member alternative. By default, members are assigned to use Method A.

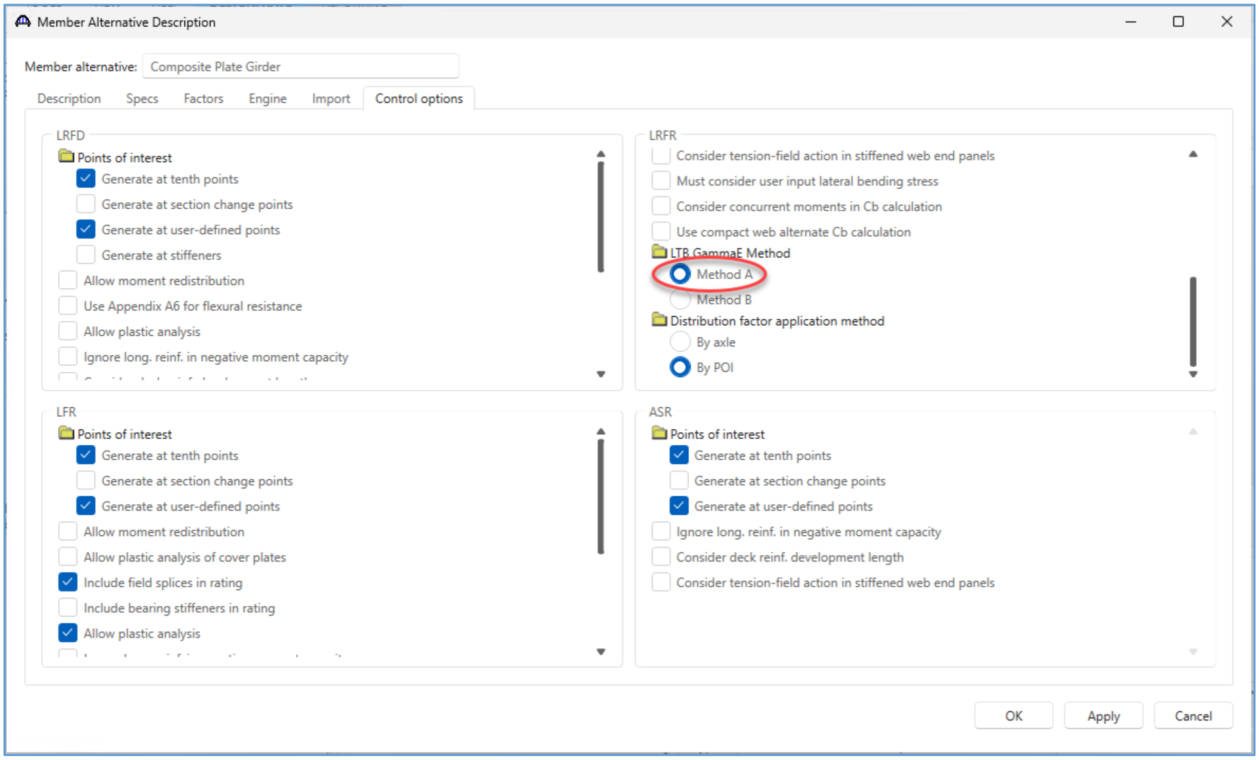
Appendix A6.3.3 – Lateral Torsional Buckling Resistance

When Appendix A6 is used to compute the LTB capacity of a non-prismatic unbraced length, the same process can be used to view the results.

The **APPA6.3.3.1 Lateral Torsional Buckling Resistance** spec article has the general LTB calculations for the member. To view the detailed calculations for the non-prismatic parameters open article **APPA6.3.3.3 Lateral Torsional Buckling Parameters for Nonprismatic Unbraced Lengths**. The parameters are computed based on the elastic LTB load ratio, γ_e, as computed in Appendix D6.6 using Method A or Method B.

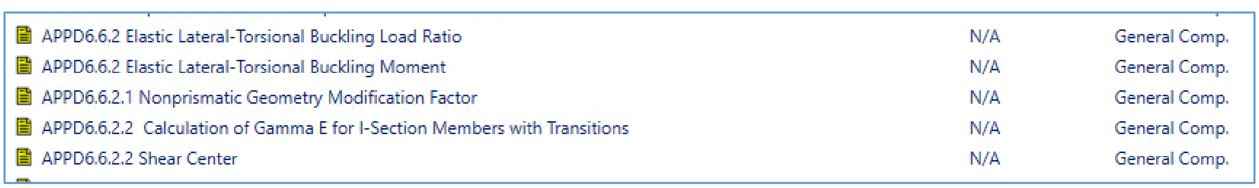
Appendix D6.6.2 – Calculation of the Elastic Lateral-Torsional Buckling Load Ratio, γ_e – Method A

Set the load ratio calculation type to **Method A** for the **Composite Plate Girder** member alternative. Open the **Member Alternative Description** window for the **Composite Plate Girder** by double clicking on the **Composite Plate Girder** node in the bridge workspace tree. Under the **Control options** tab, make sure the **Method A** LTB GammaE Method control option is selected for LRFR.



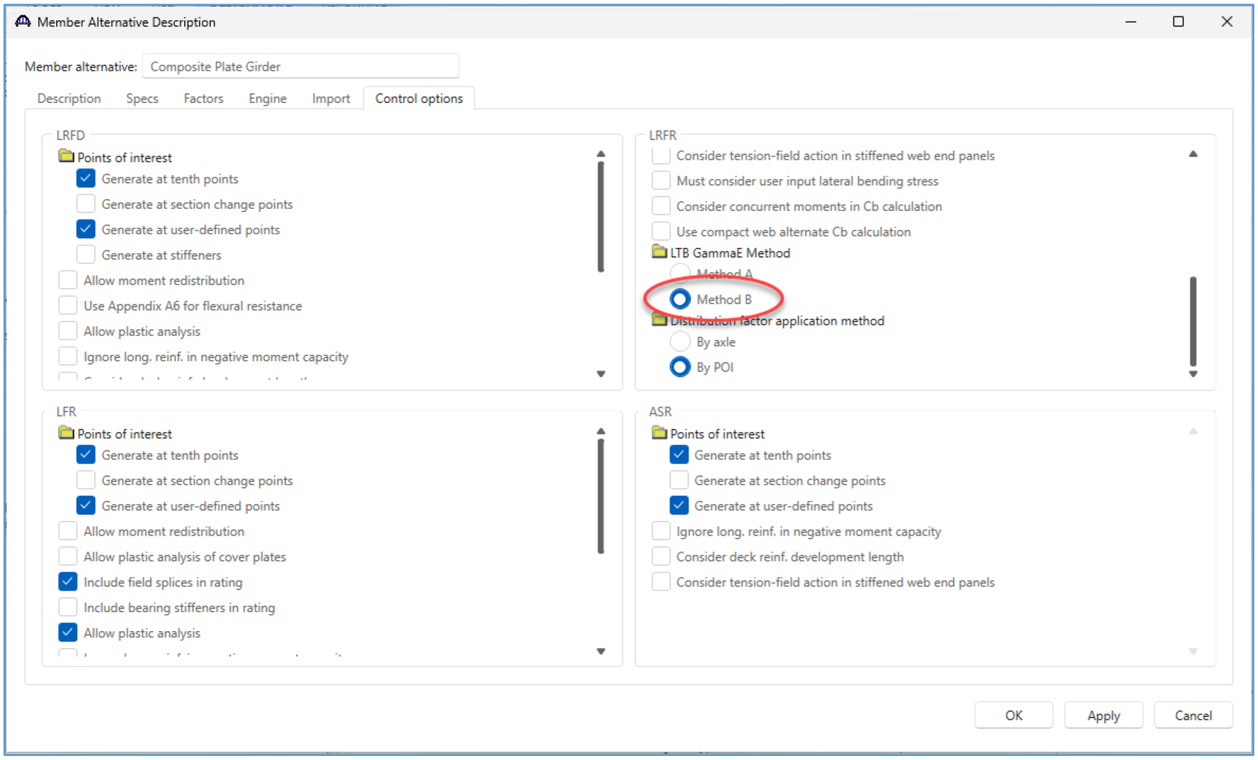
If any changes are made to the control options, select **OK** to apply the changes and close the window.

After analyzing the member alternative, the spec check calculations will include articles related to the Method A calculations. When the elastic LTB load ratio is computed according to Method A, the following spec articles will include details on how γ_e is computed.



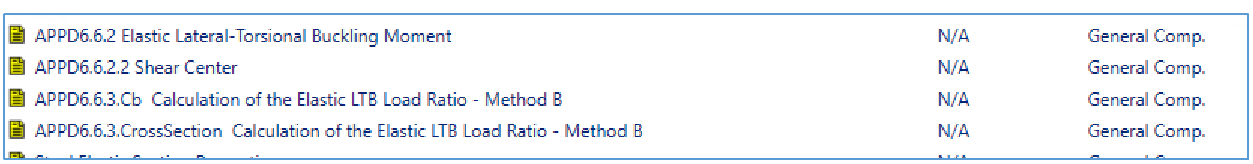
Appendix D6.6.3 – Calculation of the Elastic Lateral-Torsional Buckling Load Ratio, γ_e – Method B

Now set the load ratio calculation type to **Method B** for the **Composite Plate Girder** member alternative. Open the **Member Alternative Description** window for the **Composite Plate Girder** by double clicking on the **Composite Plate Girder** node in the bridge workspace tree. Under the **Control options** tab, make sure the **Method B** LTB GammaE Method control option is selected for LRFR.



If any changes are made to the control options, select **OK** to apply the changes and close the window.

When the elastic LTB load ratio is computed according to Method B, the following spec articles will include details on how γ_e is computed. Note that Method B uses a weighted average cross section approach when computing the elastic LTB load ratio. In some instances, the cross-section variation input in BrDR may include transitions which differ from the expected variation for the Method B interpolation equations. For these cases, BrDR will revert to Method A for the load ratio calculation. This is why some of the prerequisite Method A calculations are also included here.



APPD6.6.2 Elastic Lateral-Torsional Buckling Moment	N/A	General Comp.
APPD6.6.2.2 Shear Center	N/A	General Comp.
APPD6.6.3.Cb Calculation of the Elastic LTB Load Ratio - Method B	N/A	General Comp.
APPD6.6.3.CrossSection Calculation of the Elastic LTB Load Ratio - Method B	N/A	General Comp.