Steel Tutorial

STL14-LRFD Cb Calculation using Concurrent Moments in LRFR Rating Example

AASHTOWare Bridge Design and Rating Training

STL14 –LRFD Cb Calculation using Concurrent Moments in LRFR Rating Example

Topics Covered

- Modify STL2 Example Bridge
- Cb Calculation Control Option
- Cb Calculation Comparison

Features (introduced in version 7.5.0):

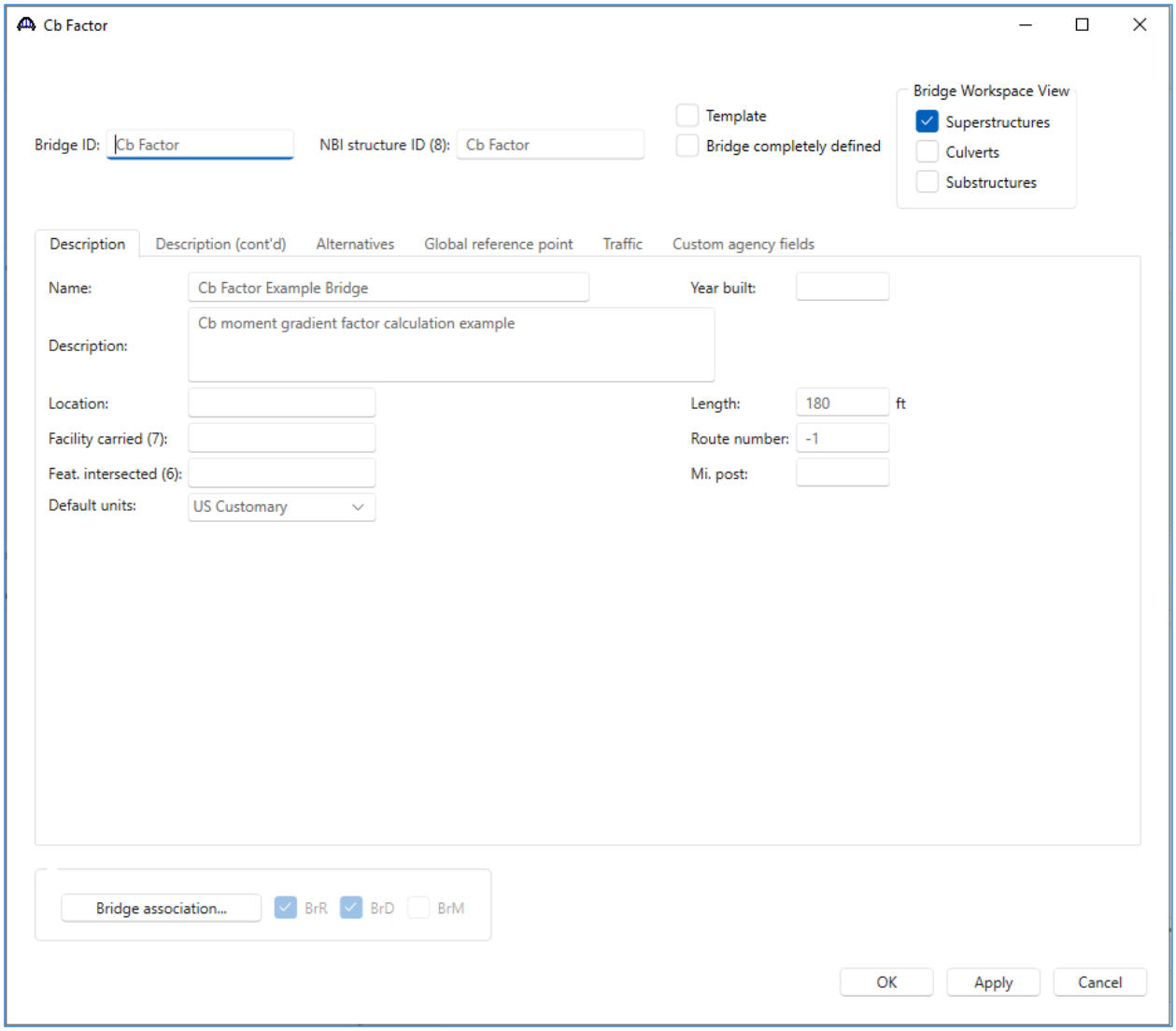
- LRFD Analysis Control option: “Consider concurrent moments in Cb calculation”
- LRFR Analysis Control option: “Consider concurrent moments in Cb calculation”

This tutorial demonstrates how to select the calculation method for the AASHTO LRFD Cb moment gradient factor. By default, the moment gradient factor is computed using the envelope actions at brace points. The control option to consider concurrent moments in Cb calculation will compute the factor using concurrent moments at brace points. The concurrent brace moment reports and the changes to the spec output for concurrent actions are presented.

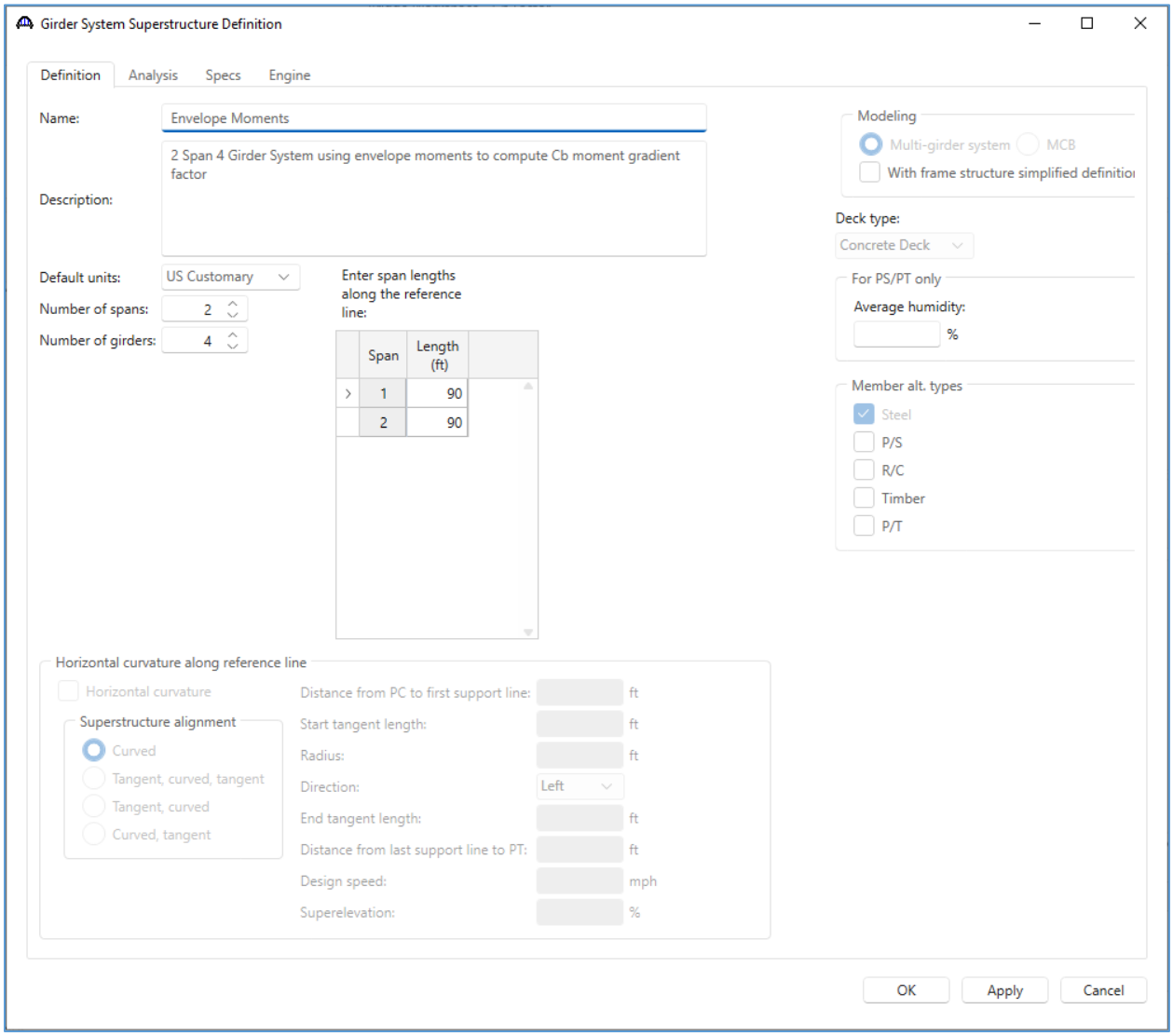
Modify STL2 Example Bridge

Start with the completed STL2 example bridge. This is a two-span steel girder system bridge with four girders. Follow the steps below to modify the structure definition. The moment gradient factor is used to compute the lateral torsional buckling resistance, so the girder is modified so that the lateral torsional buckling resistance controls the flexural capacity over the interior support.

Import the STL2 example bridge and open the copied structure. Update the Bridge ID, NBI structure ID, Name and Description. Select 'OK' to save the data to memory and close the window.



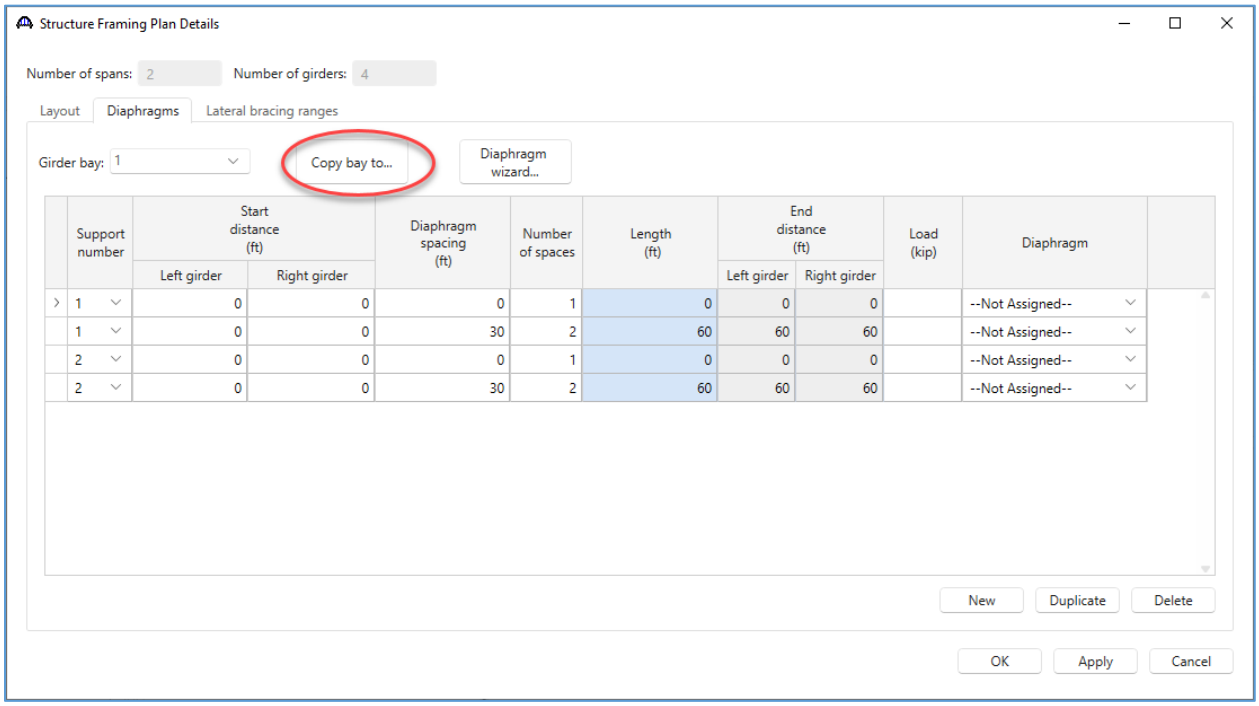
Open the **Structure Definition window** and update the superstructure name.



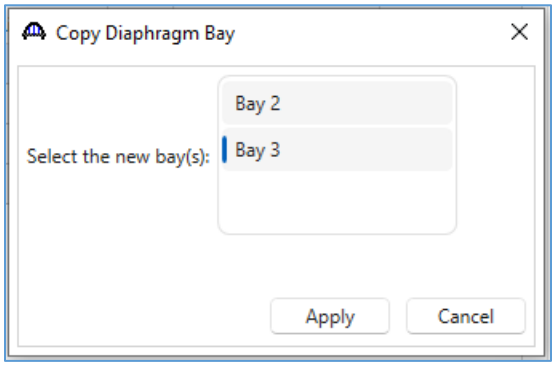
Structure Framing Plan Details

Within the **Framing Plan Detail window**, update the diaphragm definitions. Navigate to the Diaphragms tab and update the diaphragm spacing for Girder bay 1 as shown below. Select 'Apply' to save the data to memory and keep the window open. Then select 'Copy bay to…' and copy the diaphragms to Bay 2 and Bay 3.

Girder Bay 1:

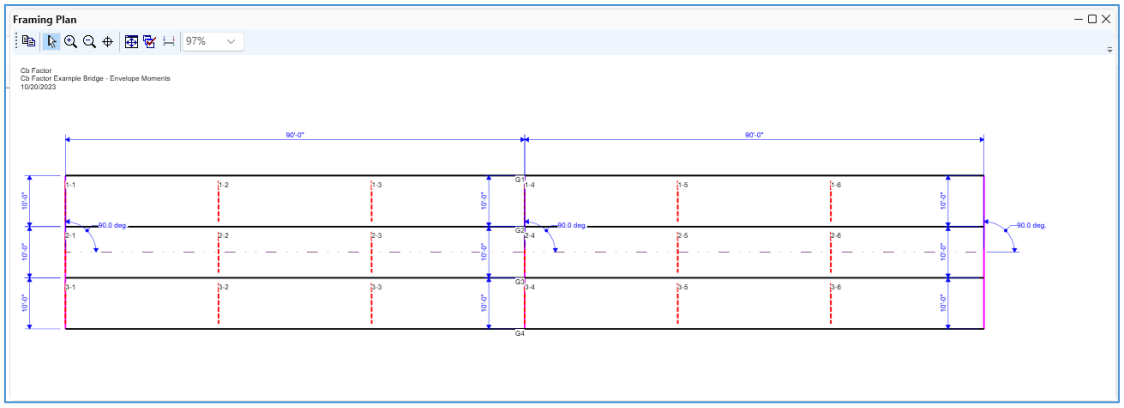


Girder Bays 2 and 3:



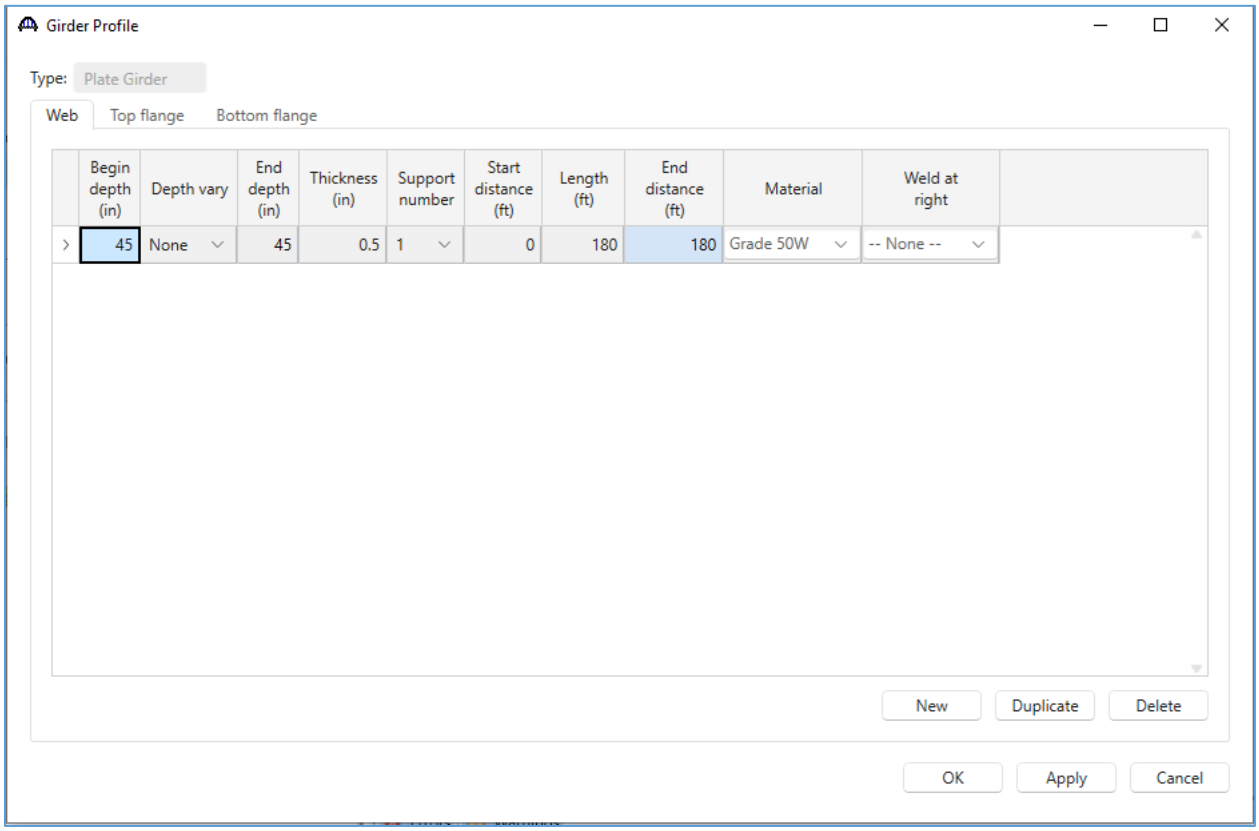
Framing Plan Schematic

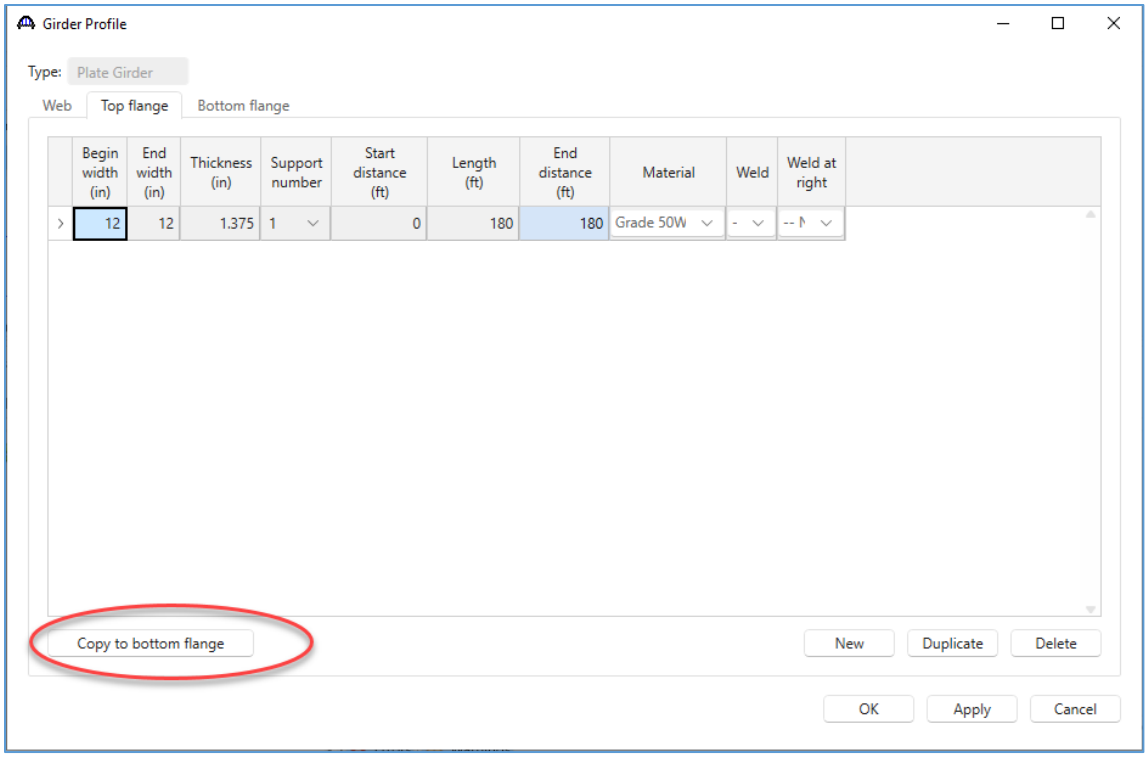
Review the **framing plan schematic** to verify the framing plan details are correct.

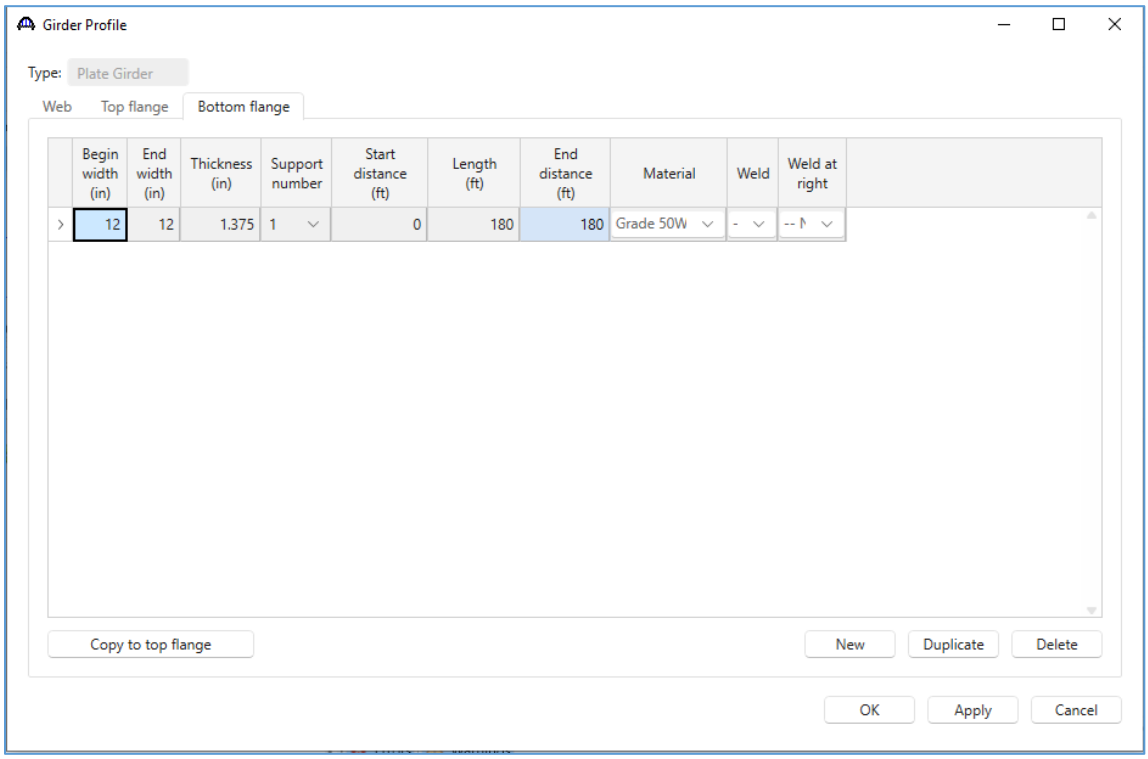


Girder Profile

Update the **girder profile** for the G2 member alternative. The top and bottom flange have the same definition, so to save time, the top flange can be input and then copied to the bottom flange with the 'Copy to bottom flange' button.

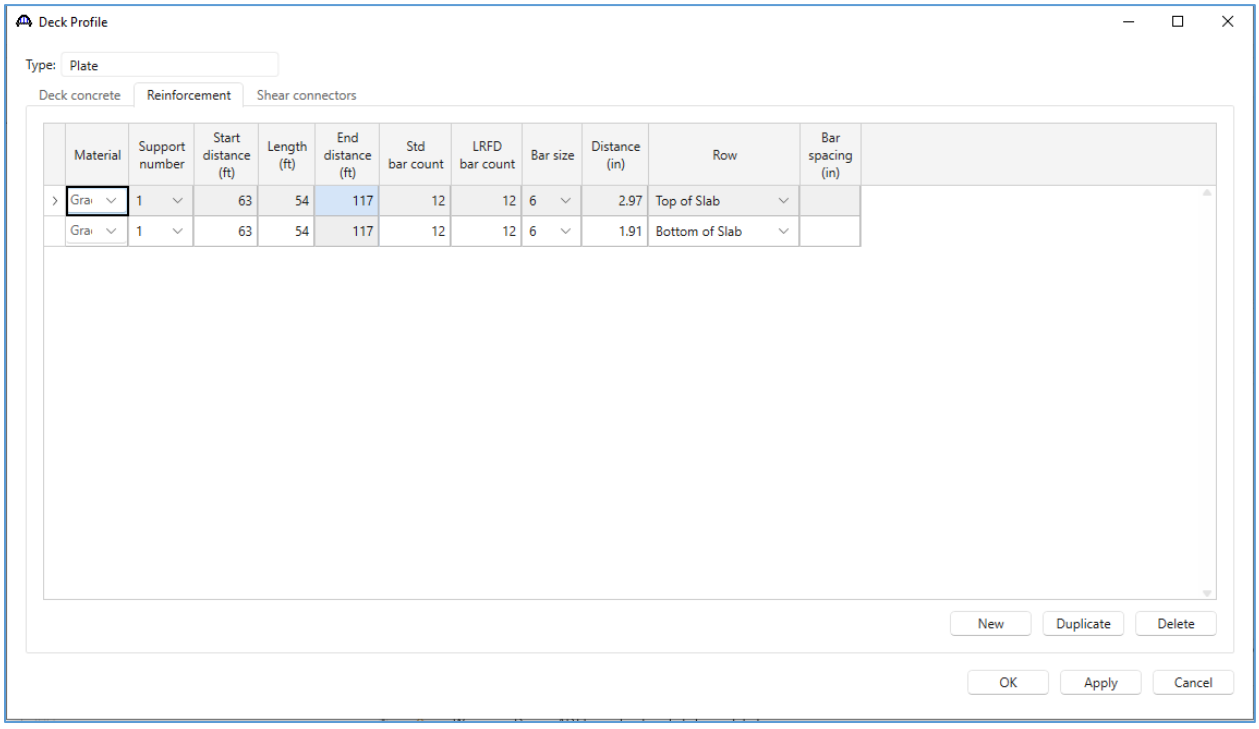



Girder Profile
Type: Plate Girder
Web
Top flange
Bottom flange
Begin width (in)
End width (in)
Thickness (in)
Support number
Start distance (ft)
Length (ft)
End distance (ft)
Material
Weld
Weld at right
12
12
1.375
1
0
180
180
Grade 50W
Copy to bottom flange
New
Duplicate
Delete
OK
Apply
Cancel


Girder Profile
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
12
12
1.375
1
0
180
180
Grade 50W
Copy to top flange
New
Duplicate
Delete
OK
Apply
Cancel

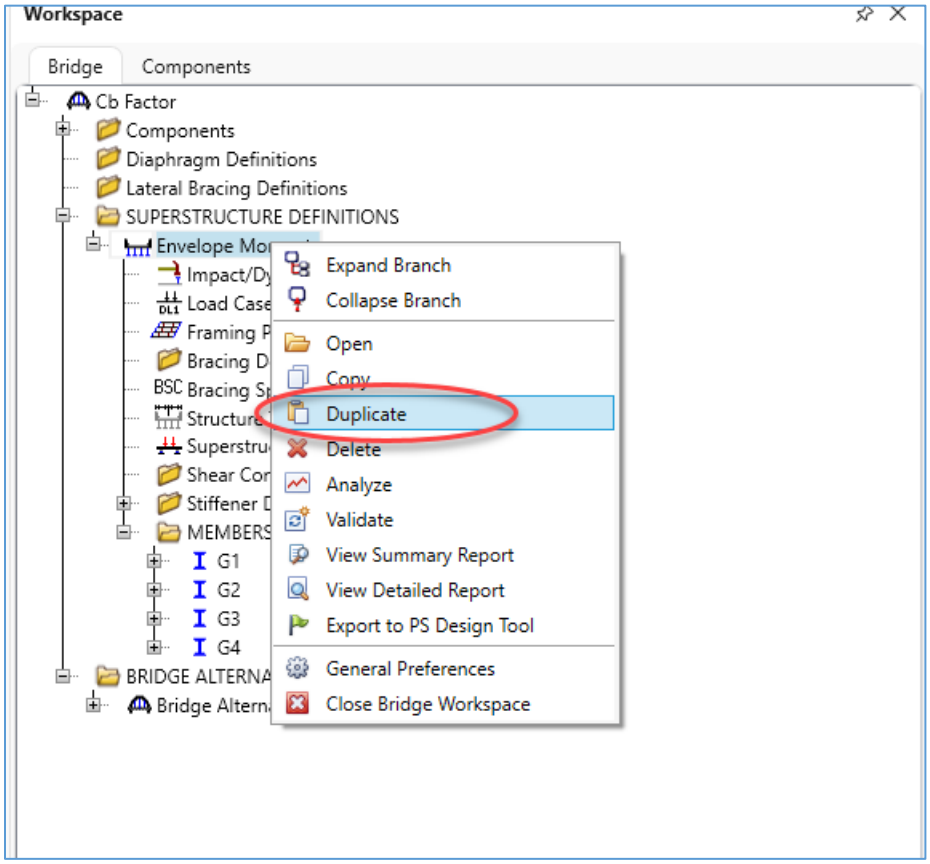
Deck Profile

Update the reinforcement within the **Deck Profile window** to satisfy the AASHTO LRFD 6.10.1.7 requirements.

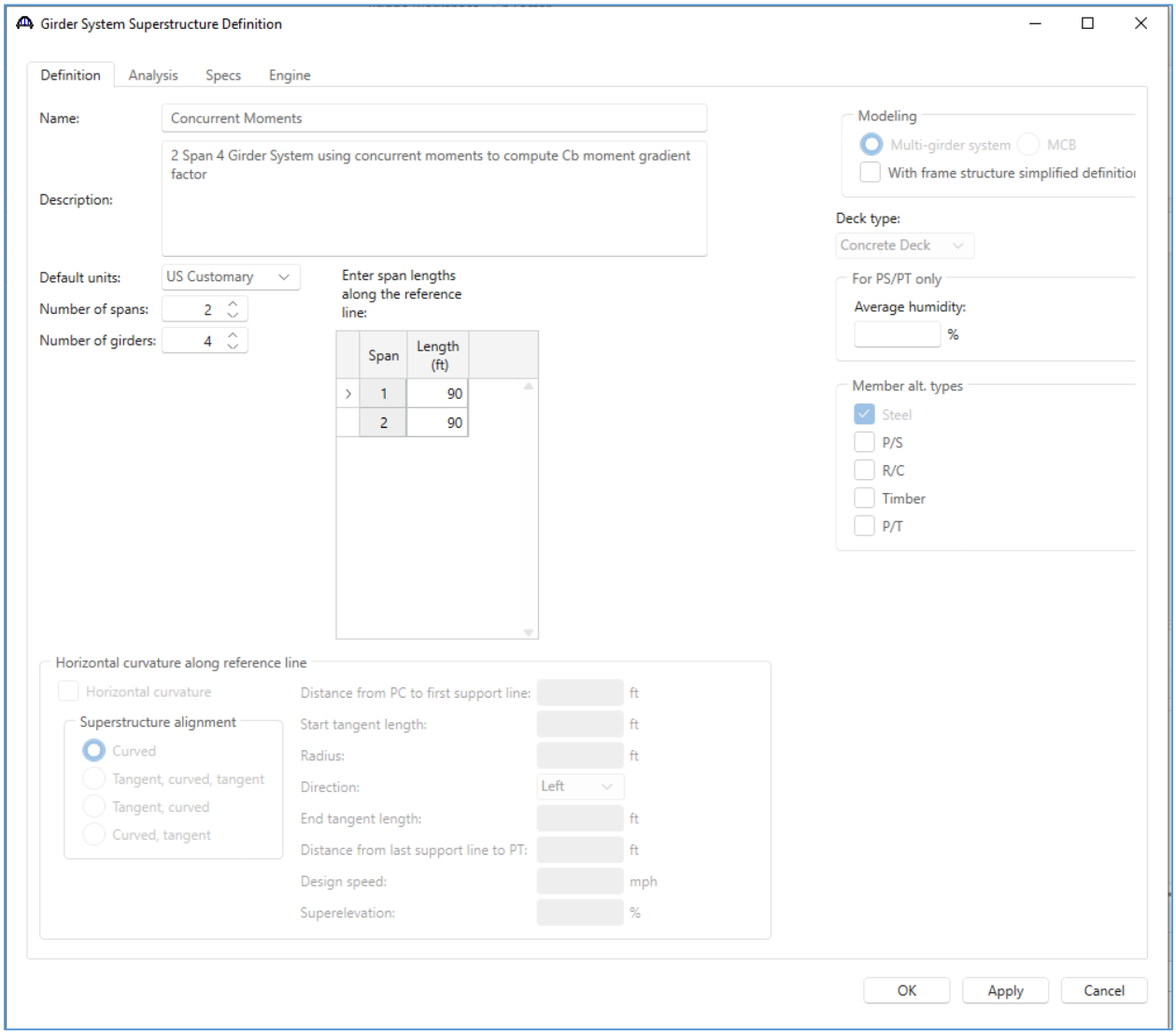


Duplicate the superstructure definition and modify the control options in the second structure to use concurrent moments for computing Cb.

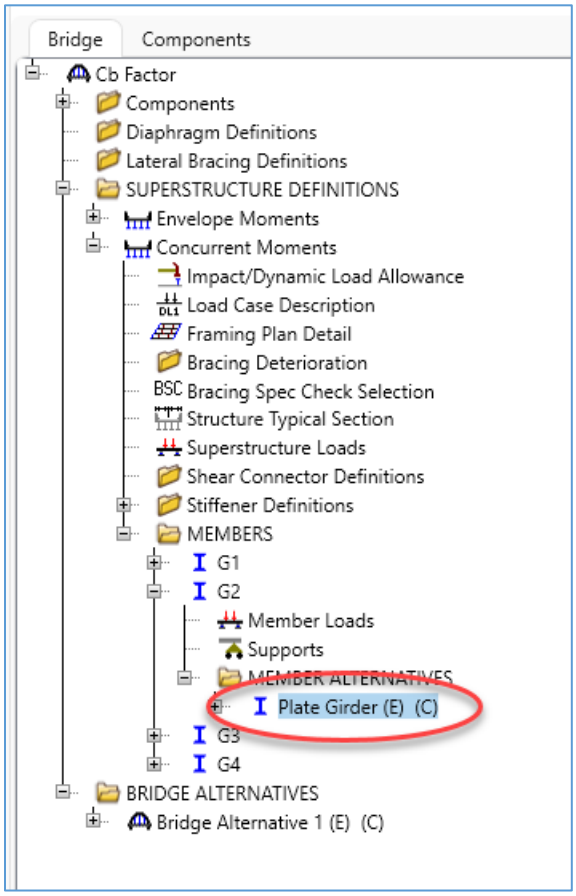
Right click on the ‘Envelope Moments’ superstructure definition and select ‘Duplicate’ from the menu to duplicate the superstructure definition.



Rename the new superstructure definition within the **superstructure definition window**.

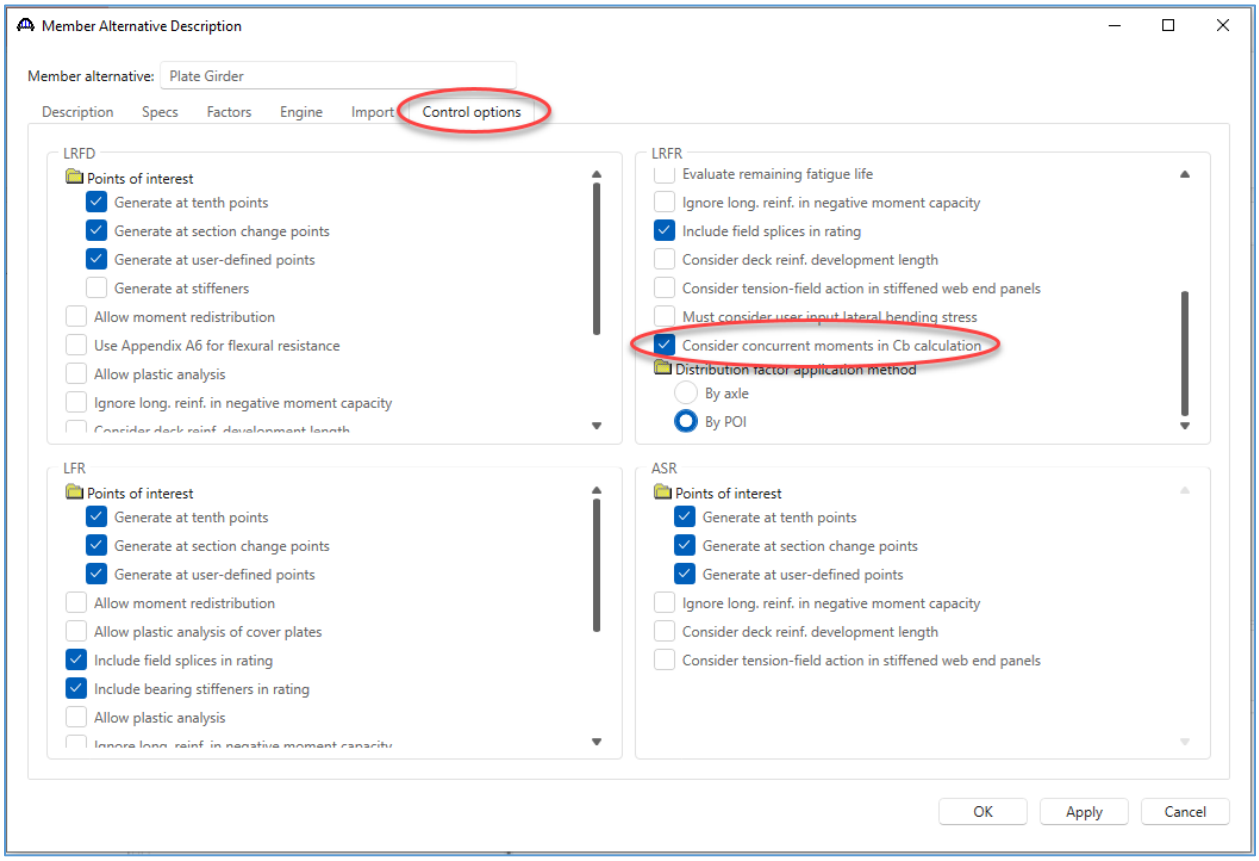


Expand the bridge workspace tree and open the **member alternative window** for the G2 – Plate Girder member alternative in the Concurrent Moments superstructure.

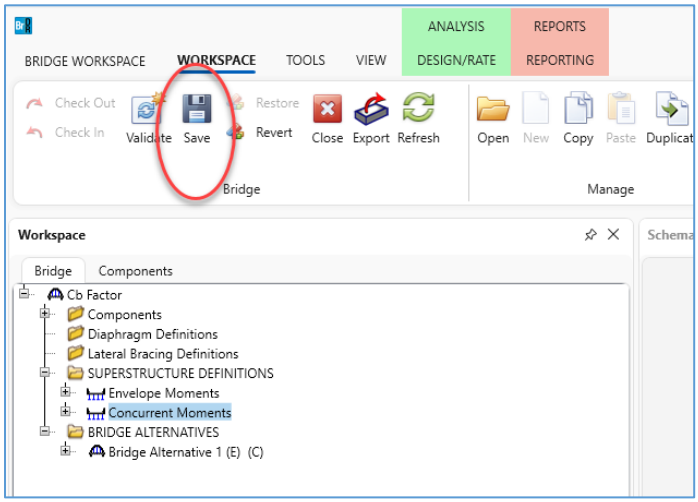


Cb Calculation Control Option

Navigate to the control options tab in the window and select the LRFR control option to 'Consider concurrent moments in Cb calculation.'



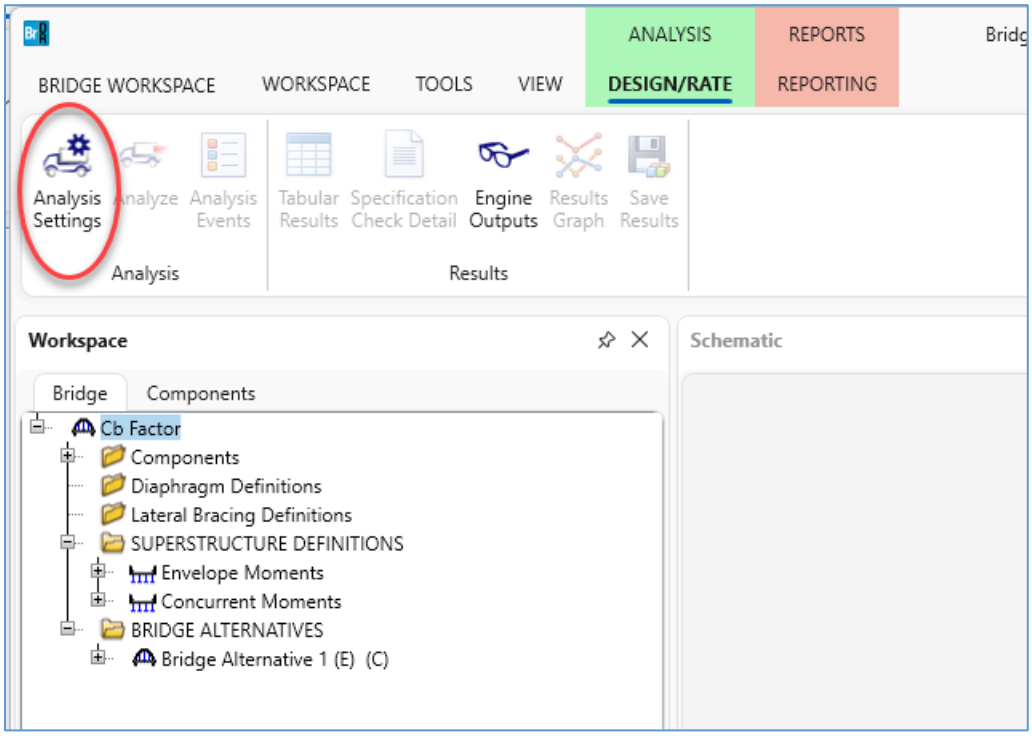
This completes the data entry for this example. Now would be a good time to save the bridge to the database if you haven't already done so.



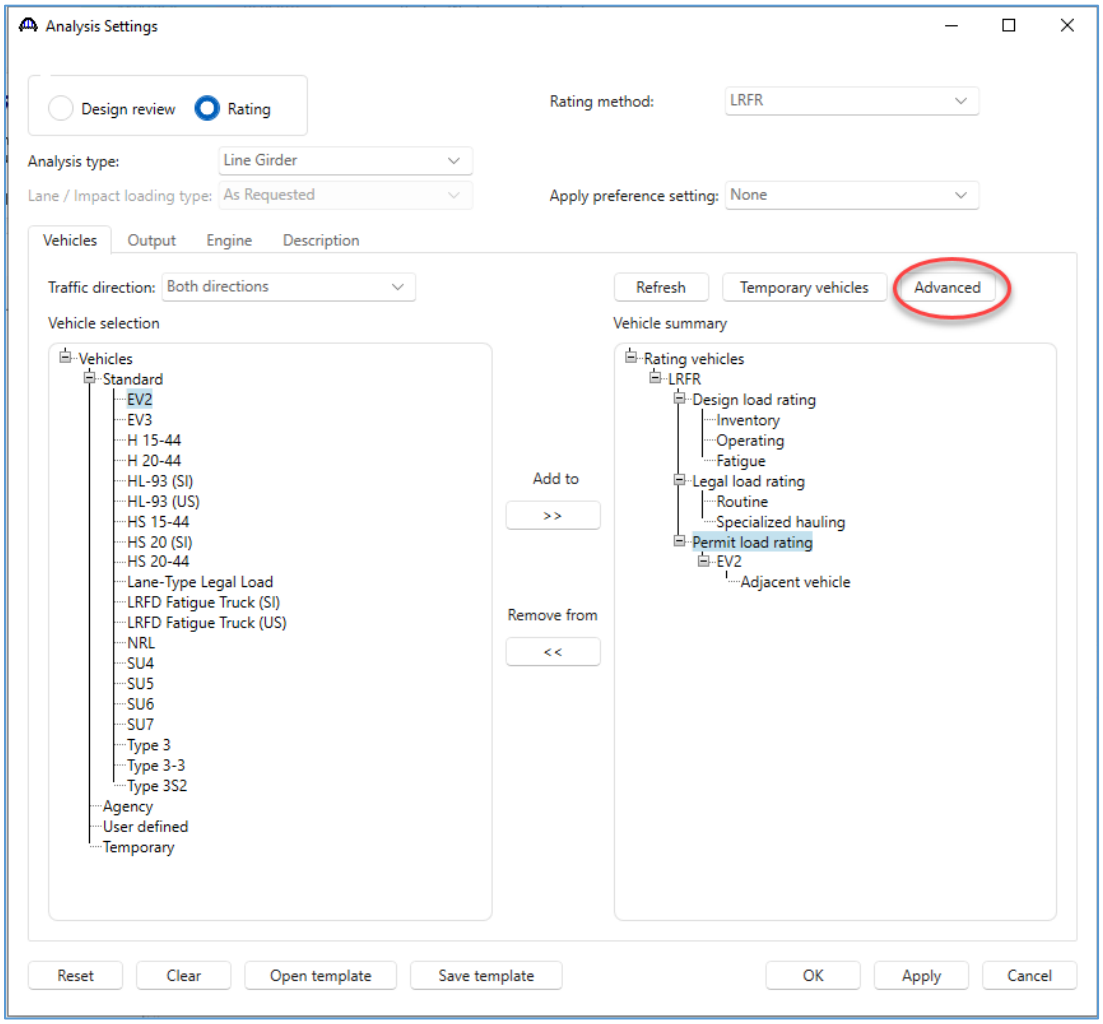
Cb Calculation comparison

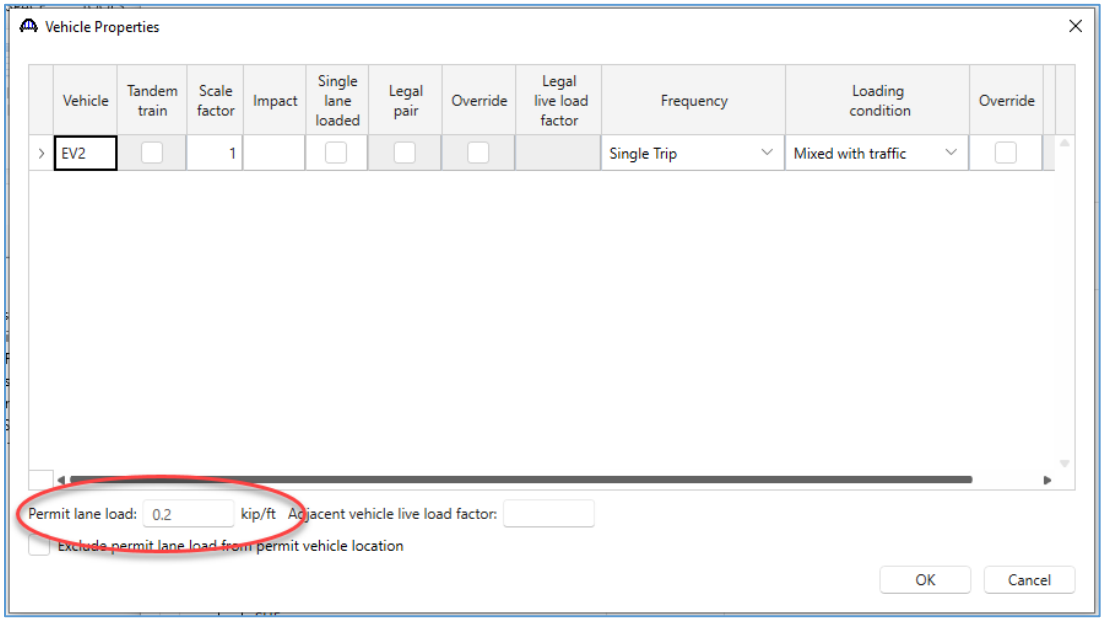
Follow the steps below to analyze the plate girder member alternative using envelope moments to compute Cb and the plate girder member alternative using concurrent moments to compute Cb.

Open the **analysis settings window** and add an EV2 vehicle to the LRFR permit load rating category. In the advanced options define a 200plf permit lane load.



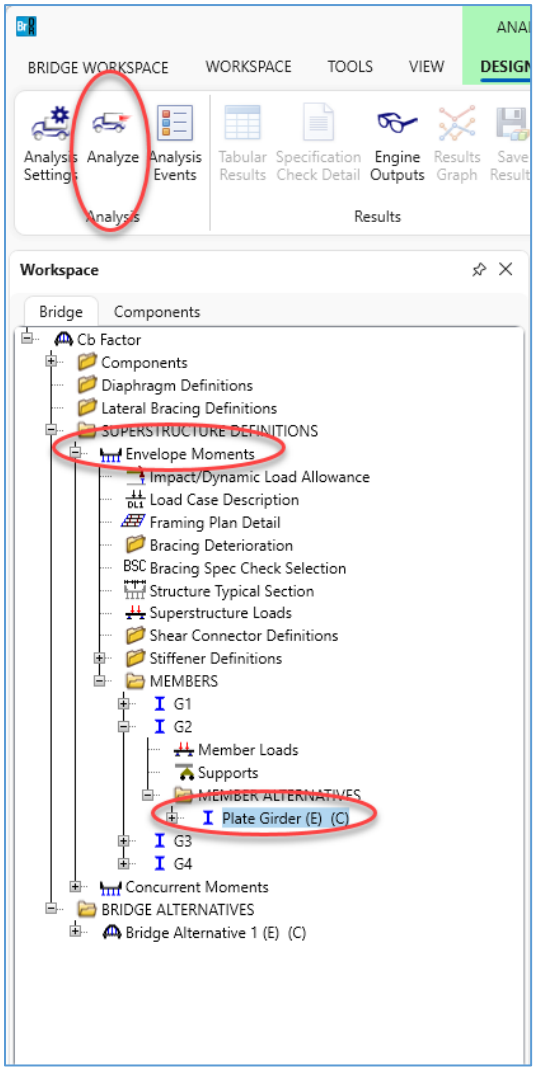
Analysis Settings



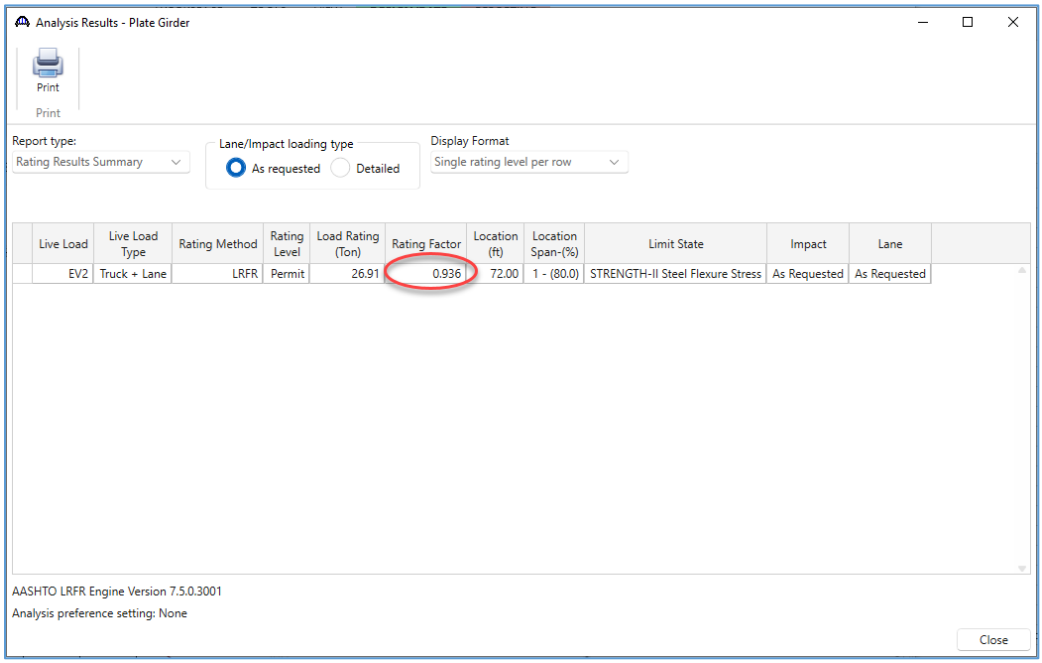


Analyzing Girder with Envelope Moment Cb Calculation

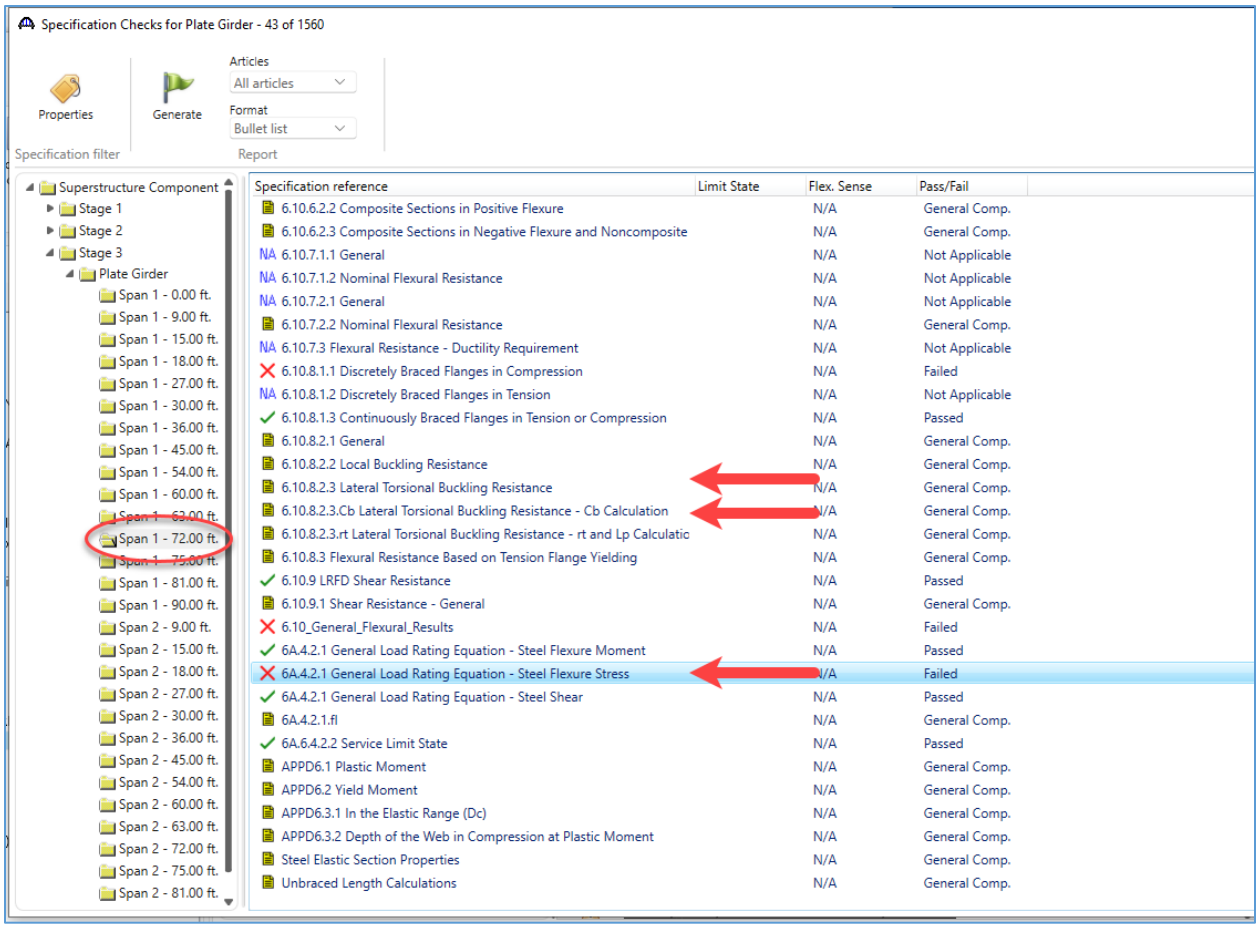
Analyze the plate girder member alternative within the Envelope Moments superstructure.



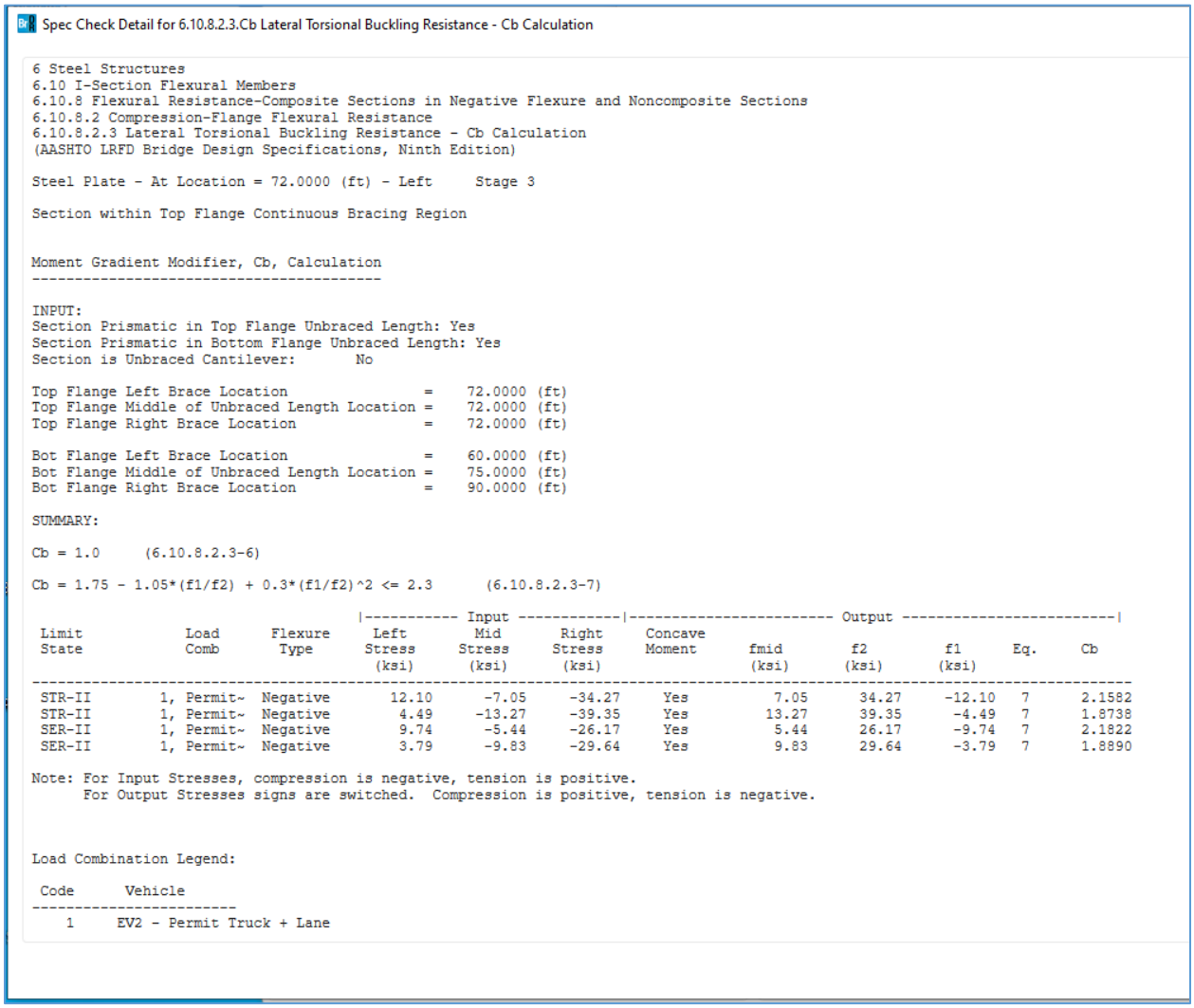
After the analysis is complete, review the results. Open the **tabular results window** to view the critical rating factor.



Open the **Specification Check Detail window** to review the specification calculations for the controlling location.



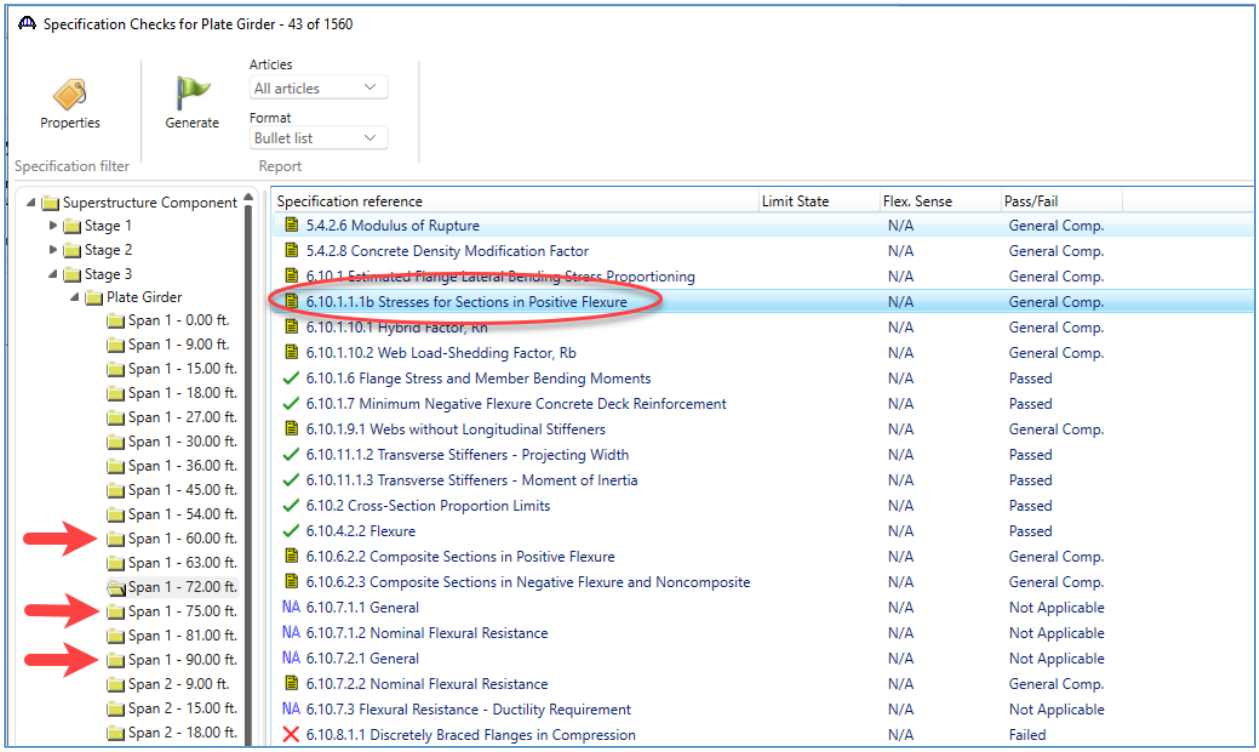
The rating is controlled by lateral torsional buckling within the negative flexure region over the interior pier. The Cb factor is computed in 6.10.8.2.3.Cb Lateral Torsional Buckling Resistance – Cb Calculation. Open this article to view the envelope Cb calculations.



Spec Check Detail for 6.10.8.2.3.Cb Lateral Torsional Buckling Resistance - Cb Calculation

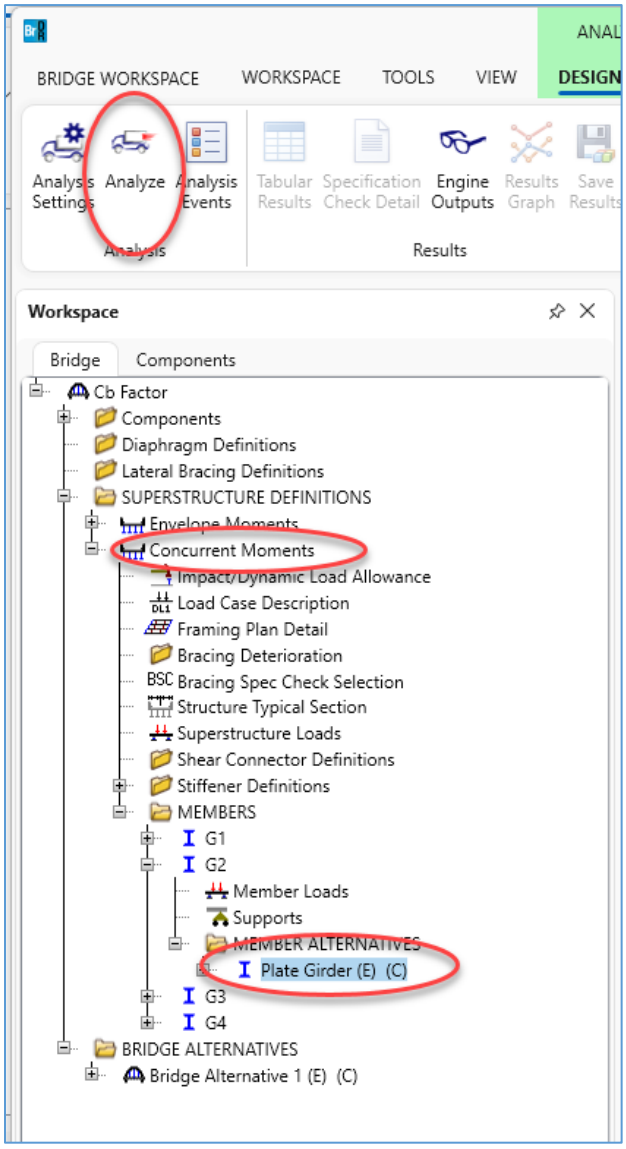
```
6 Steel Structures
6.10 I-Section Flexural Members
6.10.8 Flexural Resistance-Composite Sections in Negative Flexure and Noncomposite Sections
6.10.8.2 Compression-Flange Flexural Resistance
6.10.8.2.3 Lateral Torsional Buckling Resistance - Cb Calculation
(AASHTO LRFD Bridge Design Specifications,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

Steel Plate - At Location = 72.0000 (ft) - Left     Stage 3

Section within Top Flange Continuous Bracing Region


Moment Gradient Modifier, Cb, Calculation
-----------------------------------------

INPUT:
Section Prismatic in Top Flange Unbraced Length: Yes
Section Prismatic in Bottom Flange Unbraced Length: Yes
Section is Unbraced Cantilever:       No

Top Flange Left Brace Location                =    72.0000 (ft)
Top Flange Middle of Unbraced Length Location =    72.0000 (ft)
Top Flange Right Brace Location               =    72.0000 (ft)

Bot Flange Left Brace Location                =    60.0000 (ft)
Bot Flange Middle of Unbraced Length Location =    75.0000 (ft)
Bot Flange Right Brace Location               =    90.0000 (ft)

SUMMARY:

Cb = 1.0     (6.10.8.2.3-6)

Cb = 1.75 - 1.05*(f1/f2) + 0.3*(f1/f2)^2 <= 2.3      (6.10.8.2.3-7)

                                |---------- Input ------------|---------------------- Output ------------------------|
 Limit            Load      Flexure     Left        Mid       Right     Concave
 State            Comb       Type      Stress      Stress     Stress    Moment      fmid        f2         f1      Eq.     Cb
                                         (ksi)       (ksi)      (ksi)                (ksi)       (ksi)      (ksi)
-------------------------------------------------------------------------------------------------------------------------
 STR-II        1, Permit~  Negative       12.10       -7.05     -34.27     Yes          7.05       34.27     -12.10   7      2.1582
 STR-II        1, Permit~  Negative        4.49      -13.27     -39.35     Yes         13.27       39.35      -4.49   7      1.8738
 SER-II        1, Permit~  Negative        9.74       -5.44     -26.17     Yes          5.44       26.17      -9.74   7      2.1822
 SER-II        1, Permit~  Negative        3.79       -9.83     -29.64     Yes          9.83       29.64      -3.79   7      1.8890

Note: For Input Stresses, compression is negative, tension is positive.
      For Output Stresses signs are switched.  Compression is positive, tension is negative.


Load Combination Legend:

 Code      Vehicle
-----------------------
    1     EV2 - Permit Truck + Lane
```

Since each of these load cases has negative flexure, the bottom flange brace points are used to compute Cb. The computed brace point stresses are computed within the 6.10.1.1.1b Stresses article for the POI at the brace point. Here, the left brace stresses are computed within the 6.10.1.1.1b article at the Span 1 – 60 ft POI on the right side, the mid stresses are computed at Span 1 – 75 ft and the right brace stresses are computed at 90 ft left.

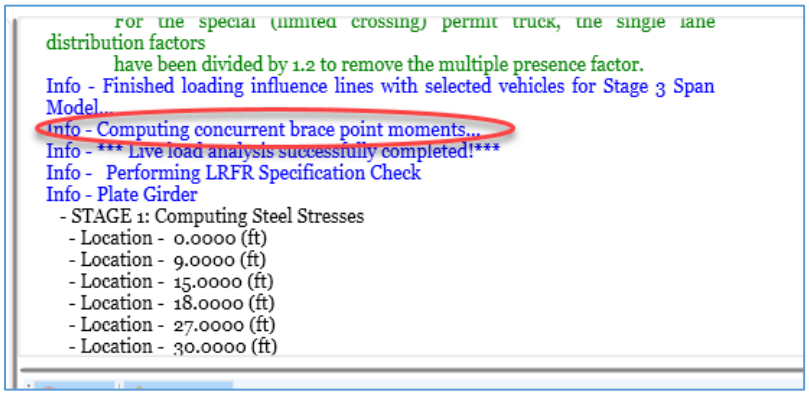


Analyzing Girder with Concurrent Moment Cb Calculation

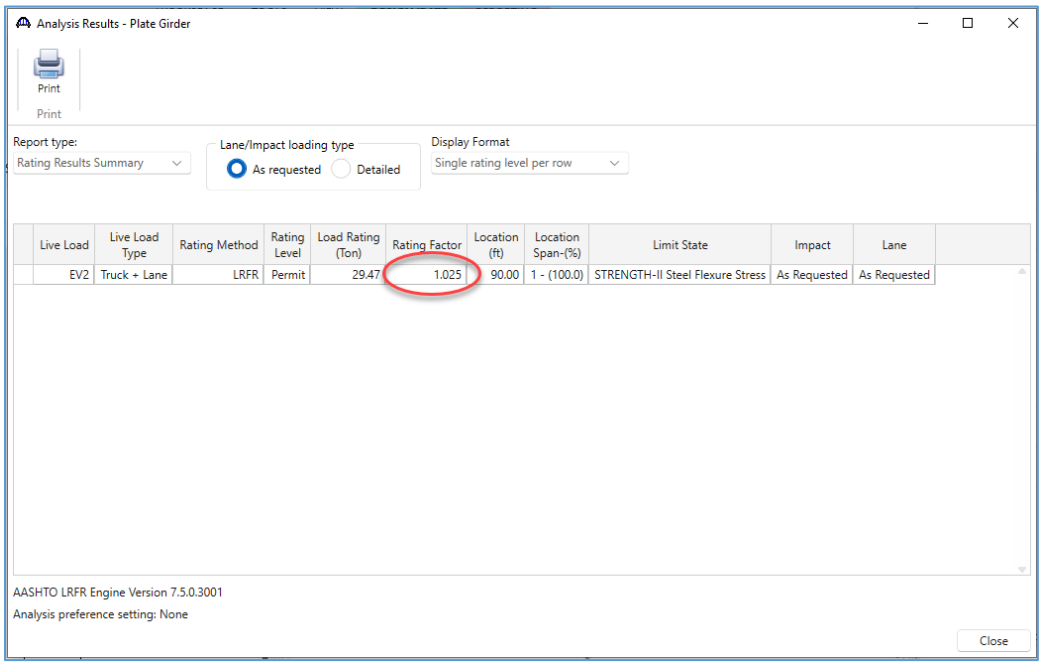
Next, analyze the G2 – plate girder member alternative within the concurrent moment superstructure.



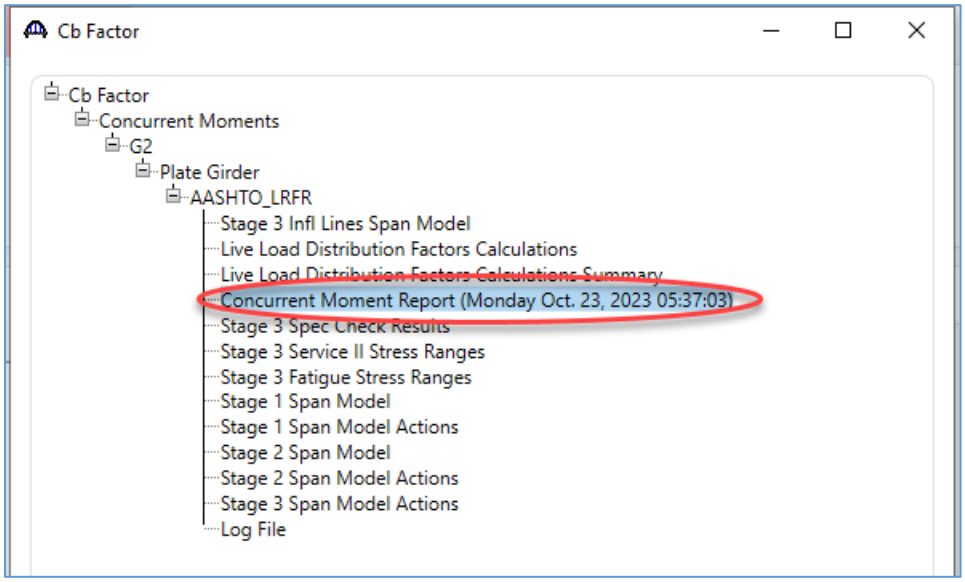
The analysis progress log will indicate when program is loading the concurrent moments at brace points.



Review the tabular results to see the critical rating factor. Using concurrent moments, the rating factor improves from 0.936 to 1.025.

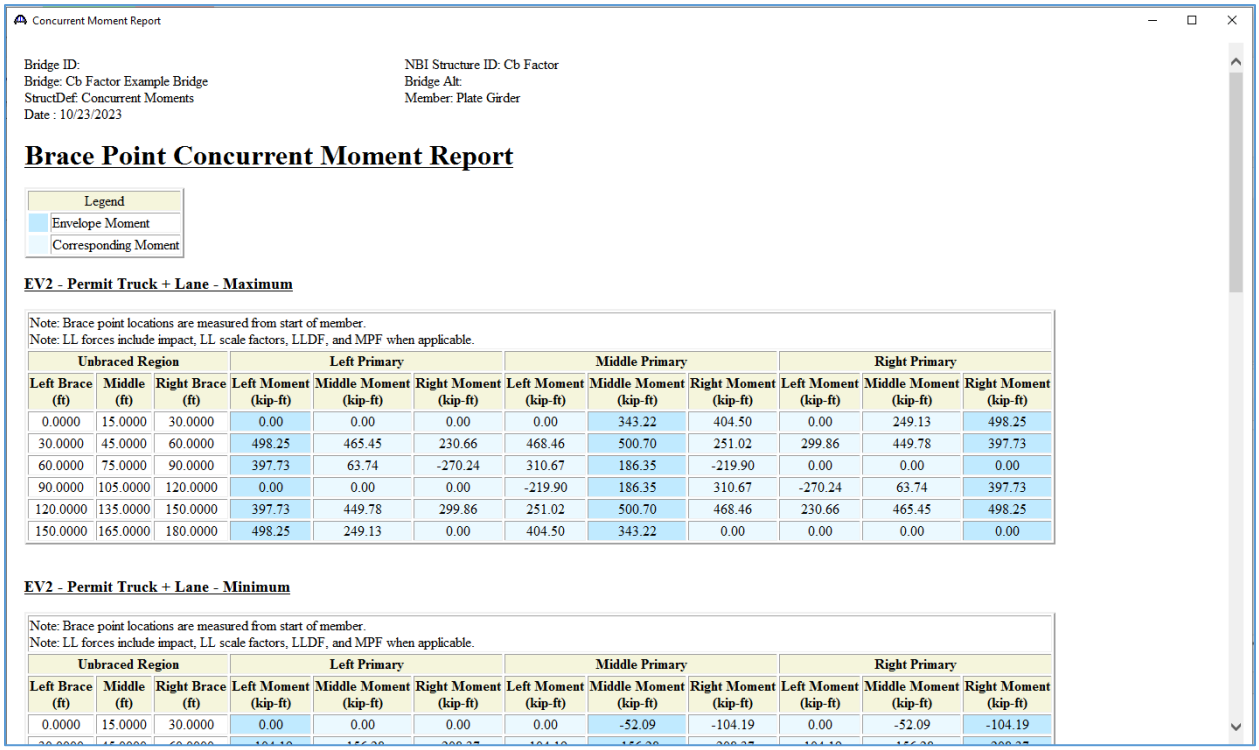


The engine outputs will include a Concurrent Moment Report which details the computed corresponding moments within all unbraced regions on the member.



Brace Point Concurrent Moment Report

Open the Concurrent Moment Report to view the computed corresponding moments at brace points.



Concurrent Moment Report

Bridge ID:
Bridge: Cb Factor Example Bridge
StructDef: Concurrent Moments
Date : 10/23/2023

NBI Structure ID: Cb Factor
Bridge Alt:
Member: Plate Girder

Brace Point Concurrent Moment Report

Legend
Envelope Moment
Corresponding Moment

EV2 - Permit Truck + Lane - Maximum

Note: Brace point locations are measured from start of member.
Note: LL forces include impact, LL scale factors, LLDF, and MPF when applicable.

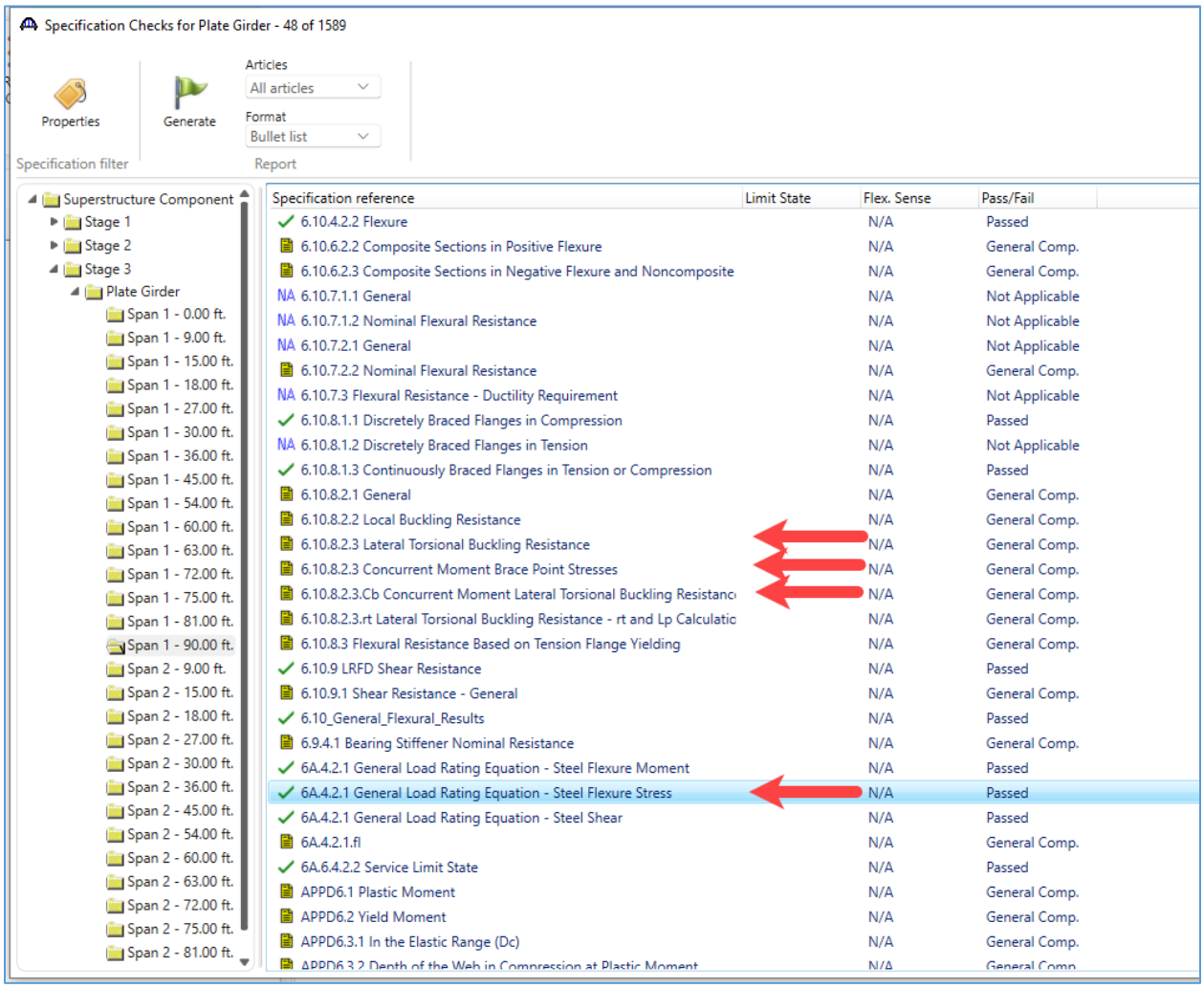
Unbraced Region			Left Primary			Middle Primary			Right Primary		
Left Brace (ft)	Middle (ft)	Right Brace (ft)	Left Moment (kip-ft)	Middle Moment (kip-ft)	Right Moment (kip-ft)	Left Moment (kip-ft)	Middle Moment (kip-ft)	Right Moment (kip-ft)	Left Moment (kip-ft)	Middle Moment (kip-ft)	Right Moment (kip-ft)
0.0000	15.0000	30.0000	0.00	0.00	0.00	0.00	343.22	404.50	0.00	249.13	498.25
30.0000	45.0000	60.0000	498.25	465.45	230.66	468.46	500.70	251.02	299.86	449.78	397.73
60.0000	75.0000	90.0000	397.73	63.74	-270.24	310.67	186.35	-219.90	0.00	0.00	0.00
90.0000	105.0000	120.0000	0.00	0.00	0.00	-219.90	186.35	310.67	-270.24	63.74	397.73
120.0000	135.0000	150.0000	397.73	449.78	299.86	251.02	500.70	468.46	230.66	465.45	498.25
150.0000	165.0000	180.0000	498.25	249.13	0.00	404.50	343.22	0.00	0.00	0.00	0.00

EV2 - Permit Truck + Lane - Minimum

Note: Brace point locations are measured from start of member.
Note: LL forces include impact, LL scale factors, LLDF, and MPF when applicable.

Unbraced Region			Left Primary			Middle Primary			Right Primary		
Left Brace (ft)	Middle (ft)	Right Brace (ft)	Left Moment (kip-ft)	Middle Moment (kip-ft)	Right Moment (kip-ft)	Left Moment (kip-ft)	Middle Moment (kip-ft)	Right Moment (kip-ft)	Left Moment (kip-ft)	Middle Moment (kip-ft)	Right Moment (kip-ft)
0.0000	15.0000	30.0000	0.00	0.00	0.00	0.00	-52.09	-104.19	0.00	-52.09	-104.19

Open the **Specification Check Detail window** to review the specification calculations. The articles indicated with arrows below are particularly relevant to the LTB rating.



The brace point stresses for envelope actions are computed in the 6.10.1.1.1b stresses article. An additional article is included when the concurrent actions are enabled to compute the brace point stresses for concurrent actions. This is the 6.10.8.2.3 Concurrent Moment Brace Point Stresses article. As with the envelope stresses, these stresses are computed at the POI corresponding to the actual brace point location.

The Cb concurrent moment calculation article computes Cb for each loading scenario, left brace envelope, mid brace envelope and right brace envelope.

Spec Check Detail for 6.10.8.2.3.Cb Concurrent Moment Lateral Torsional Buckling Resistance - Cb Calculation

```
Cb = 1.75 - 1.05*(f1/f2) + 0.3*(f1/f2)^2 <= 2.3     (6.10.8.2.3-7)

Cb calculation for loading left brace
-------------------------------------
```

			Input				Output				
Limit State	Load Comb	Flexure Type	Left Stress (ksi)	Mid Stress (ksi)	Right Stress (ksi)	Concave Moment	fmid (ksi)	f2 (ksi)	f1 (ksi)	Eq.	Cb
STR-II	1, PermitSpec	Neg	12.10	-8.61	-38.14	Yes	8.61	38.14	-12.10	7	2.1134
STR-II	1, PermitSpec	Neg	4.49	-13.25	-38.74	Yes	13.25	38.74	-4.49	7	1.8758
SER-II	1, PermitSpec	Neg	9.74	-6.64	-28.81	Yes	6.64	28.81	-9.74	7	2.1390
SER-II	1, PermitSpec	Neg	3.79	-9.82	-29.23	Yes	9.82	29.23	-3.79	7	1.8910

```
Note: For Input Stresses, compression is negative, tension is positive.
      For Output Stresses signs are switched. Compression is positive, tension is negative.

Cb calculation for loading mid brace
------------------------------------
```

			Input				Output				
Limit State	Load Comb	Flexure Type	Left Stress (ksi)	Mid Stress (ksi)	Right Stress (ksi)	Concave Moment	fmid (ksi)	f2 (ksi)	f1 (ksi)	Eq.	Cb
STR-II	1, PermitSpec	Neg	11.08	-7.05	-37.42	Yes	7.05	37.42	-11.08	7	2.0871
STR-II	1, PermitSpec	Neg	4.68	-13.27	-38.96	Yes	13.27	38.96	-4.68	7	1.8806
SER-II	1, PermitSpec	Neg	8.88	-5.44	-28.32	Yes	5.44	28.32	-8.88	7	2.1088
SER-II	1, PermitSpec	Neg	3.90	-9.83	-29.37	Yes	9.83	29.37	-3.90	7	1.8949

```
Note: For Input Stresses, compression is negative, tension is positive.
      For Output Stresses signs are switched. Compression is positive, tension is negative.

Cb calculation for loading right brace
--------------------------------------
```

			Input				Output				
Limit State	Load Comb	Flexure Type	Left Stress (ksi)	Mid Stress (ksi)	Right Stress (ksi)	Concave Moment	fmid (ksi)	f2 (ksi)	f1 (ksi)	Eq.	Cb
STR-II	1, PermitSpec	Neg	7.42	-9.52	-34.27	Yes	9.52	34.27	-7.42	7	1.9913
STR-II	1, PermitSpec	Neg	12.30	-8.96	-39.35	Yes	8.96	39.35	-12.30	7	2.1075
SER-II	1, PermitSpec	Neg	5.83	-7.27	-26.17	Yes	7.27	26.17	-5.83	7	1.9989
SER-II	1, PermitSpec	Neg	9.90	-6.88	-29.64	Yes	6.88	29.64	-9.90	7	2.1342

```
Note: For Input Stresses, compression is negative, tension is positive.
      For Output Stresses signs are switched. Compression is positive, tension is negative.
```

The article summary indicates the Cb factor which is used for each load case.

```
Cb calculation summary
----------------------
```

Limit State	Load Comb	Cb	Critical Concurrent Loading
STR-II	1, PermitSpec	2.1134	Left brace
STR-II	1, PermitSpec	2.1075	Right brace
SER-II	1, PermitSpec	2.1390	Left brace
SER-II	1, PermitSpec	2.1342	Right brace

```
Note: Use Cb corresponding to brace point with largest compressive stress.
```