# AASHTOWare Bridge Design and Rating Training
# STL14 –LRFD Cb Calculation using Concurrent Moments Example

## Topics Covered

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

## Features (introduced in version 7.5.0):

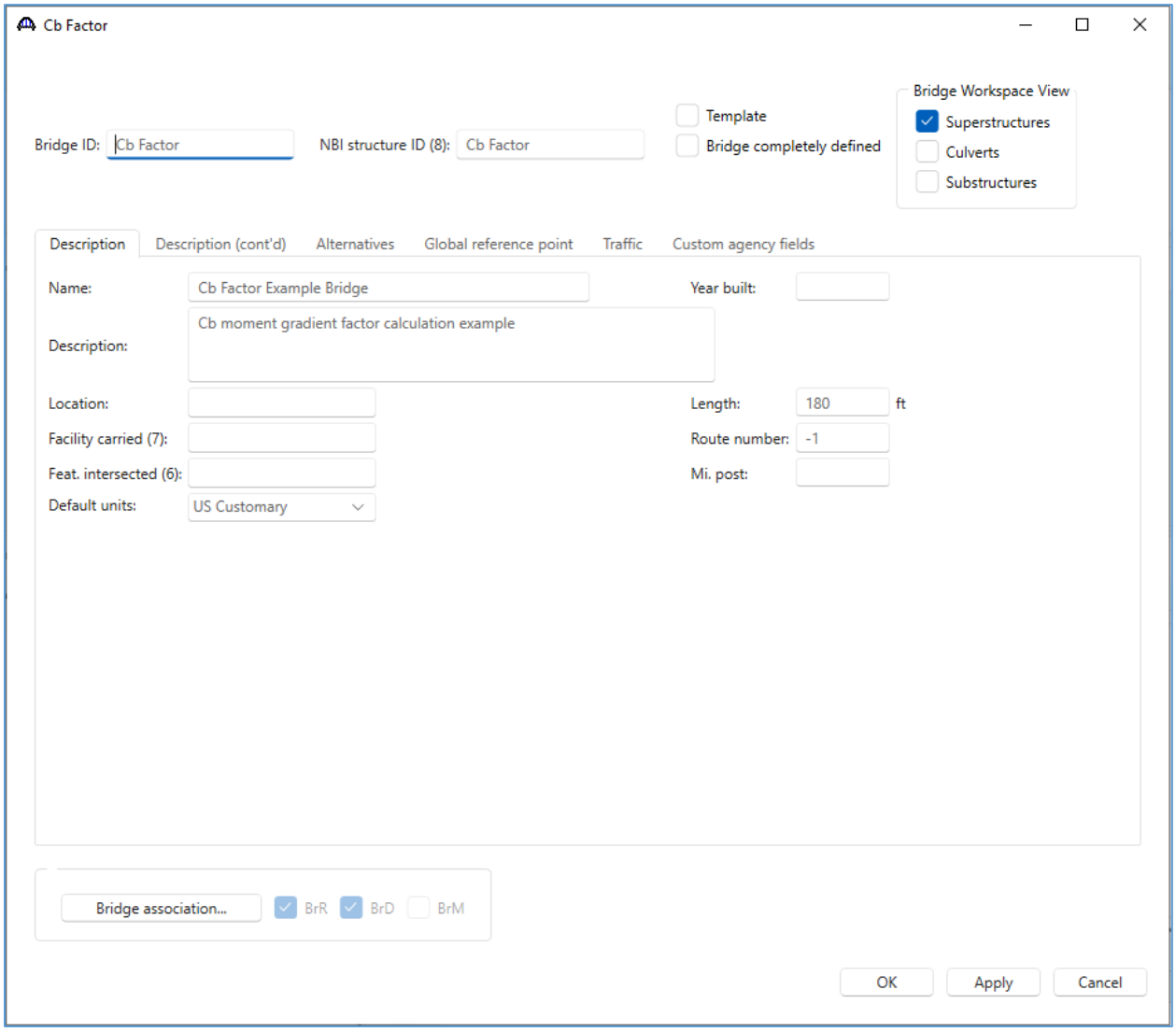
- LRFD Analysis Control option: “Consider concurrent moments in Cb calculation”
- LRFR Analysis Control option: “Consider concurrent moments in Cb calculation”

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.

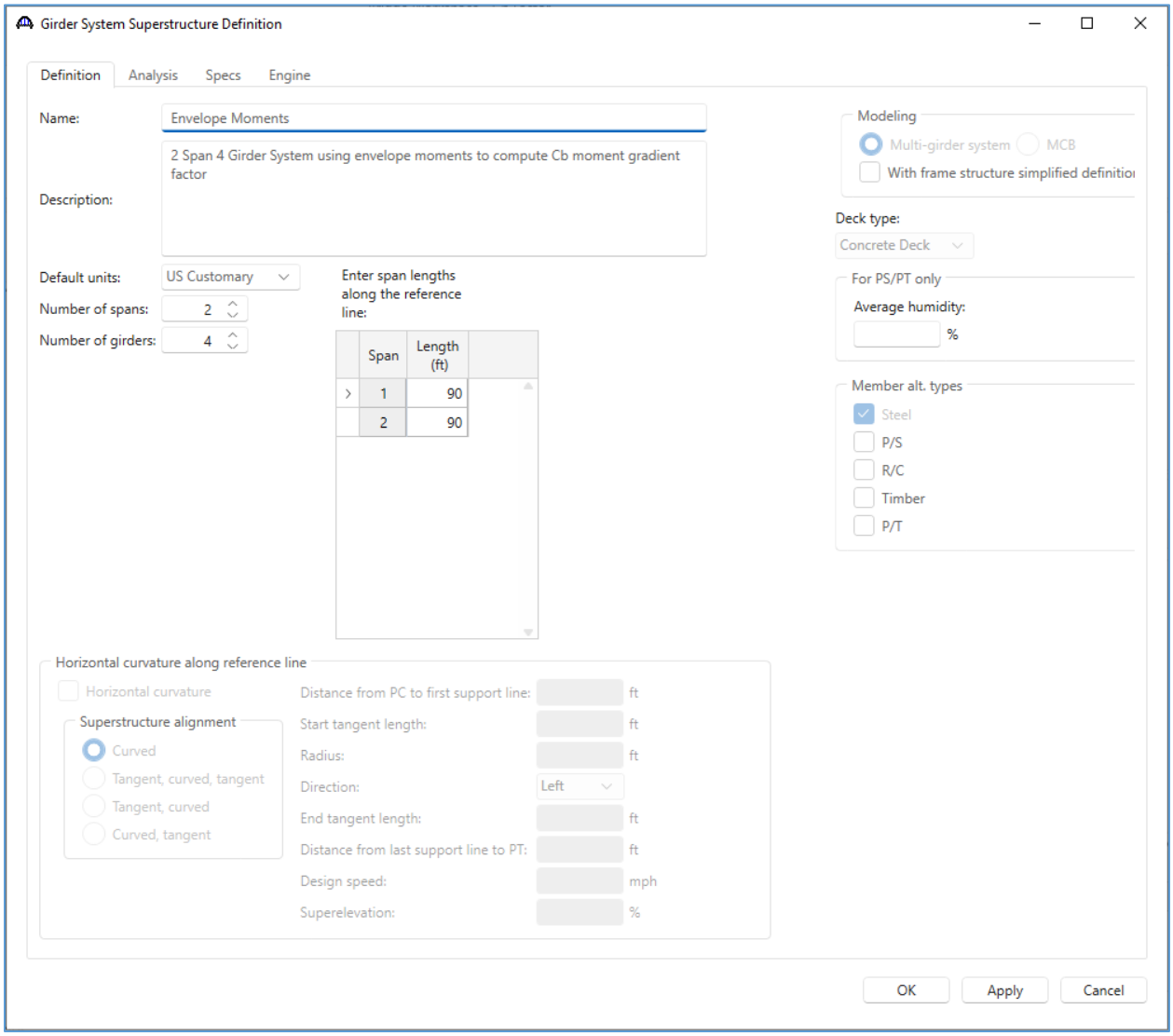
## Modify STL2 Example Bridge

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 apply the data and close the window.



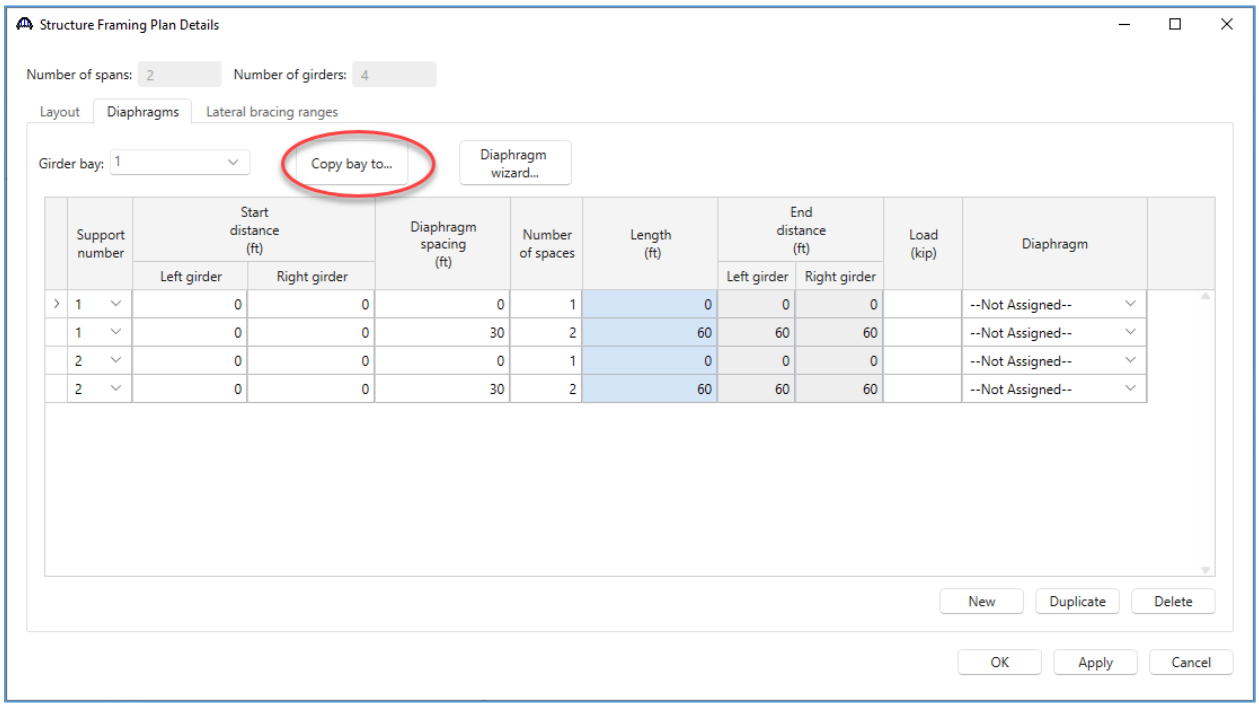
Open the **Superstructure Definition** window and update the superstructure name as shown below.



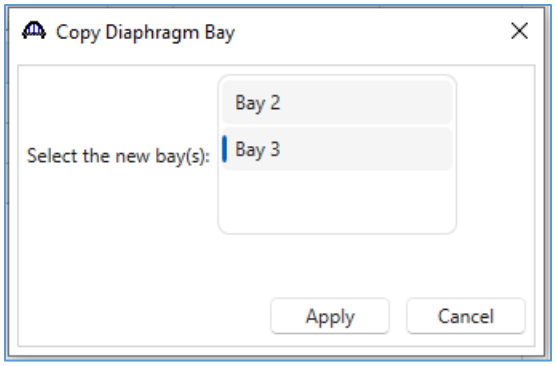
## Structure Framing Plan Details

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 apply the data and keep the window open. Then click on the **Copy bay to…** button and copy the diaphragms to **Bay 2** and **Bay 3** as shown below.

*Girder Bay 1:*

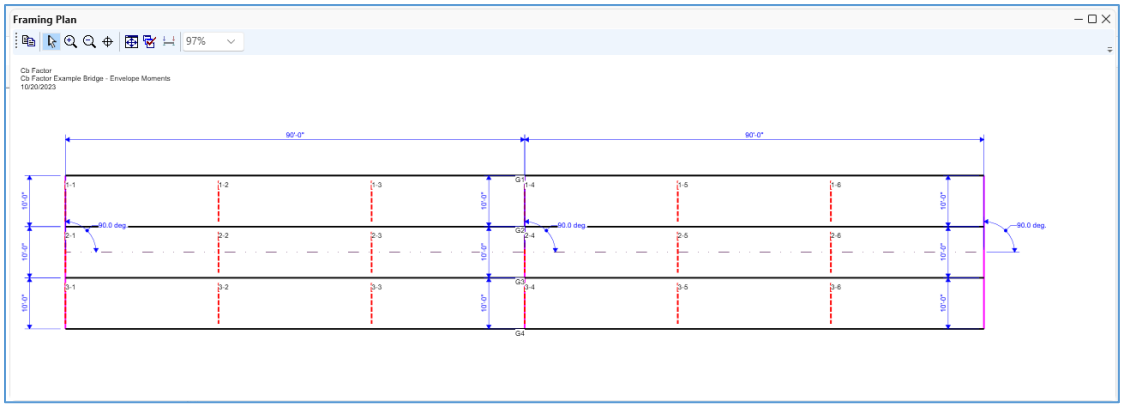



*Girder Bays 2 and 3:*



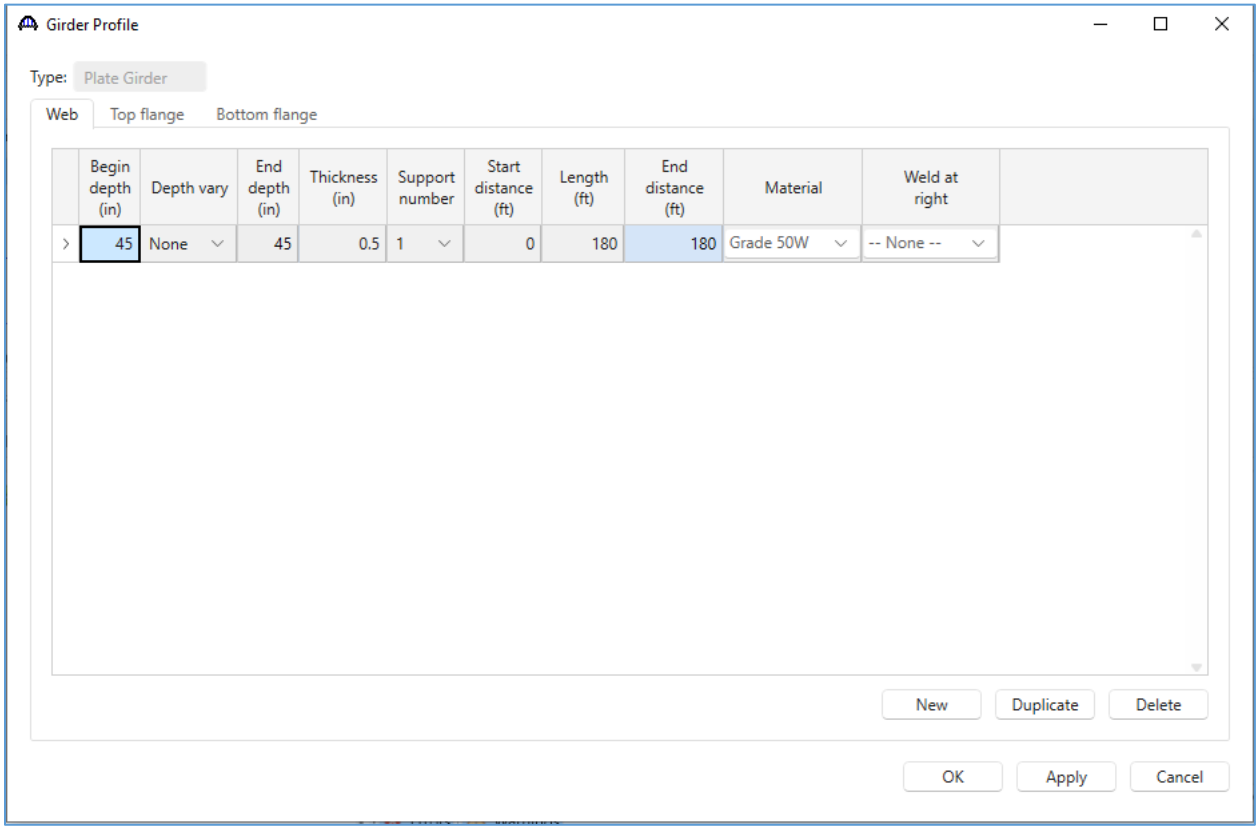
## Framing Plan Schematic

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

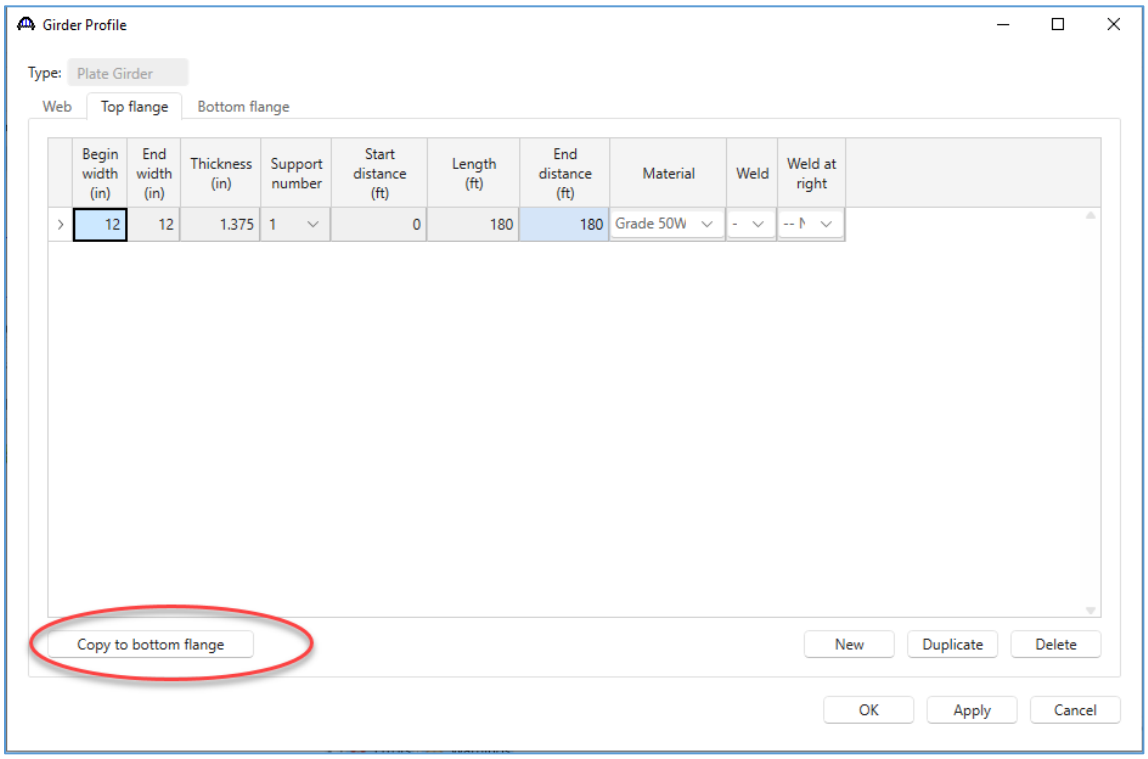


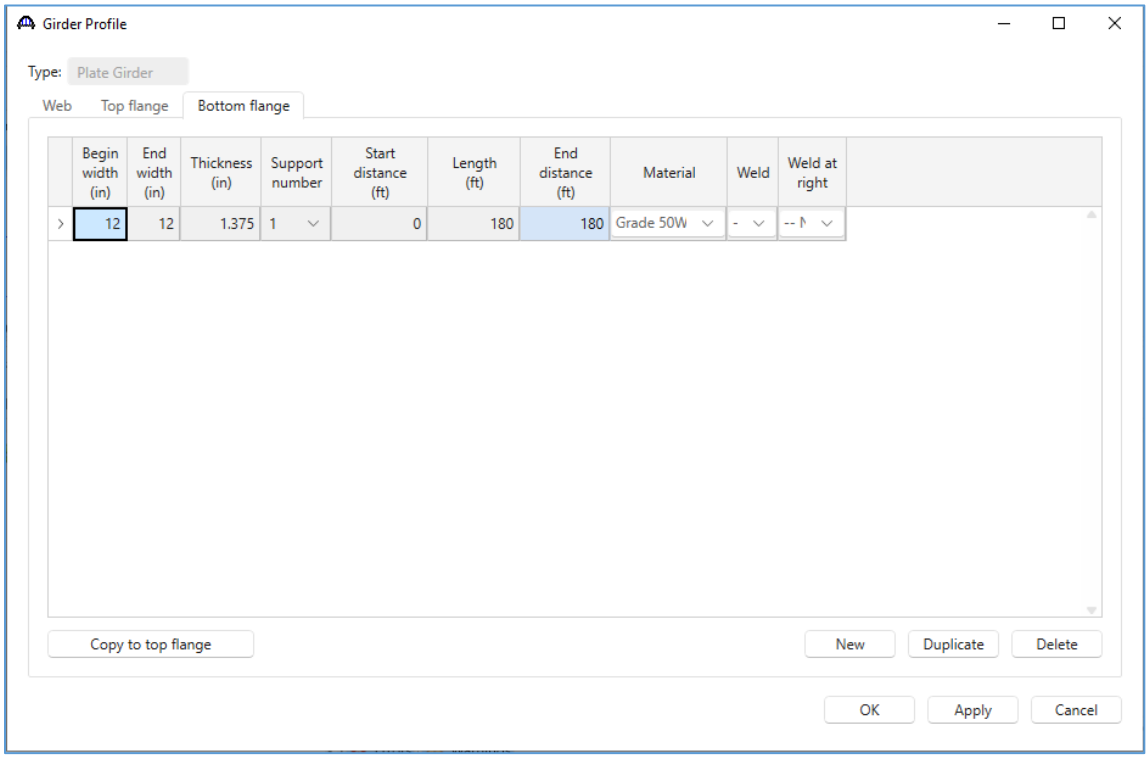

## Girder Profile

Update the **girder profile** for the **G2** member alternative in each tab as shown below.



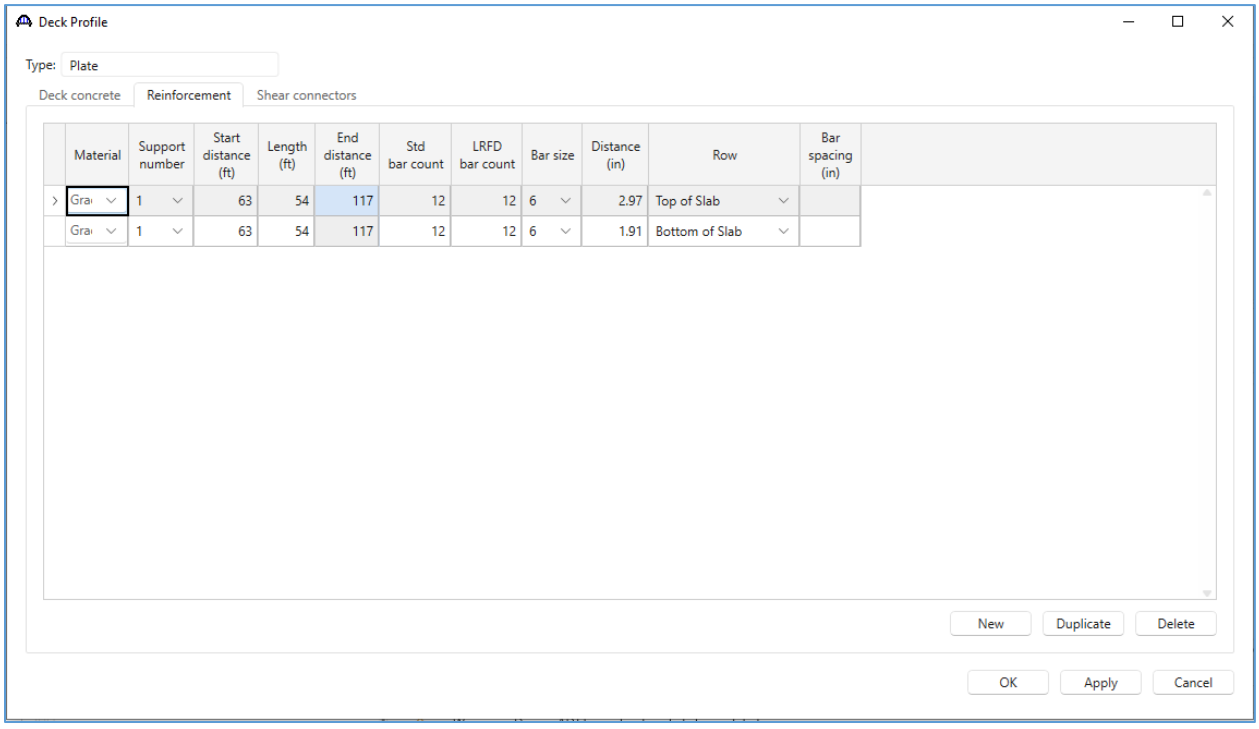
The top and bottom flange have the same definition, so to save time, the top flange can be input and then copied to the bottom flange with the **Copy to bottom flange** button. If there is any existing data for bottom flange, a warning will appear while copying. Click **OK** to proceed.



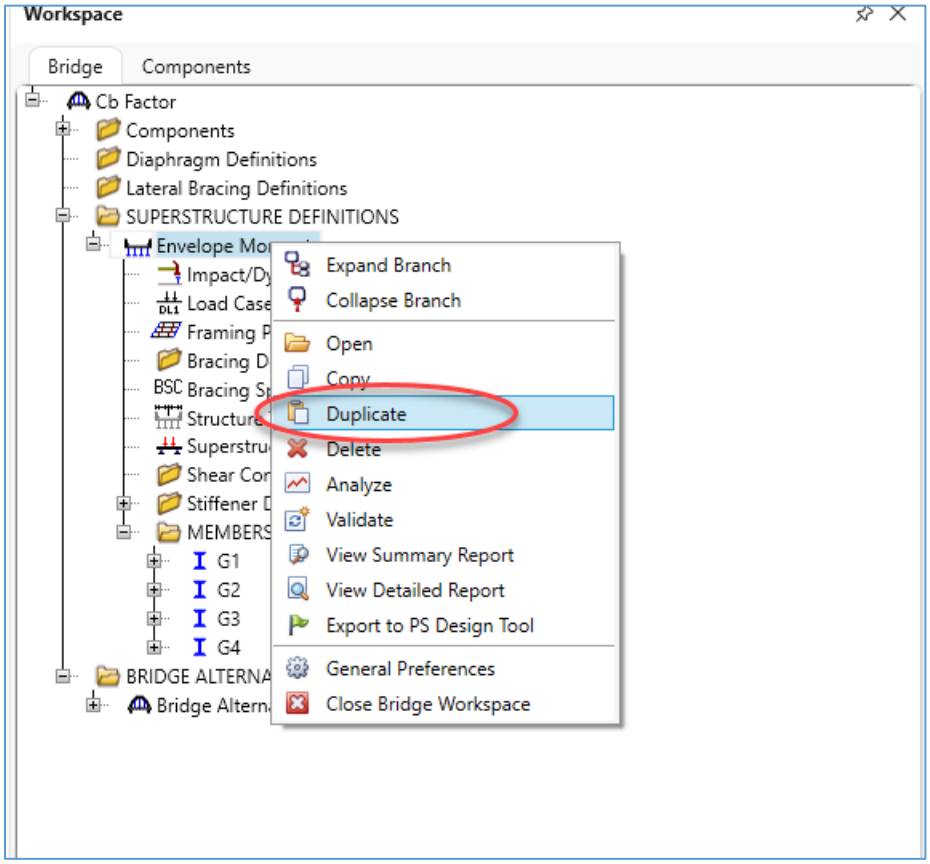
## Deck Profile

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

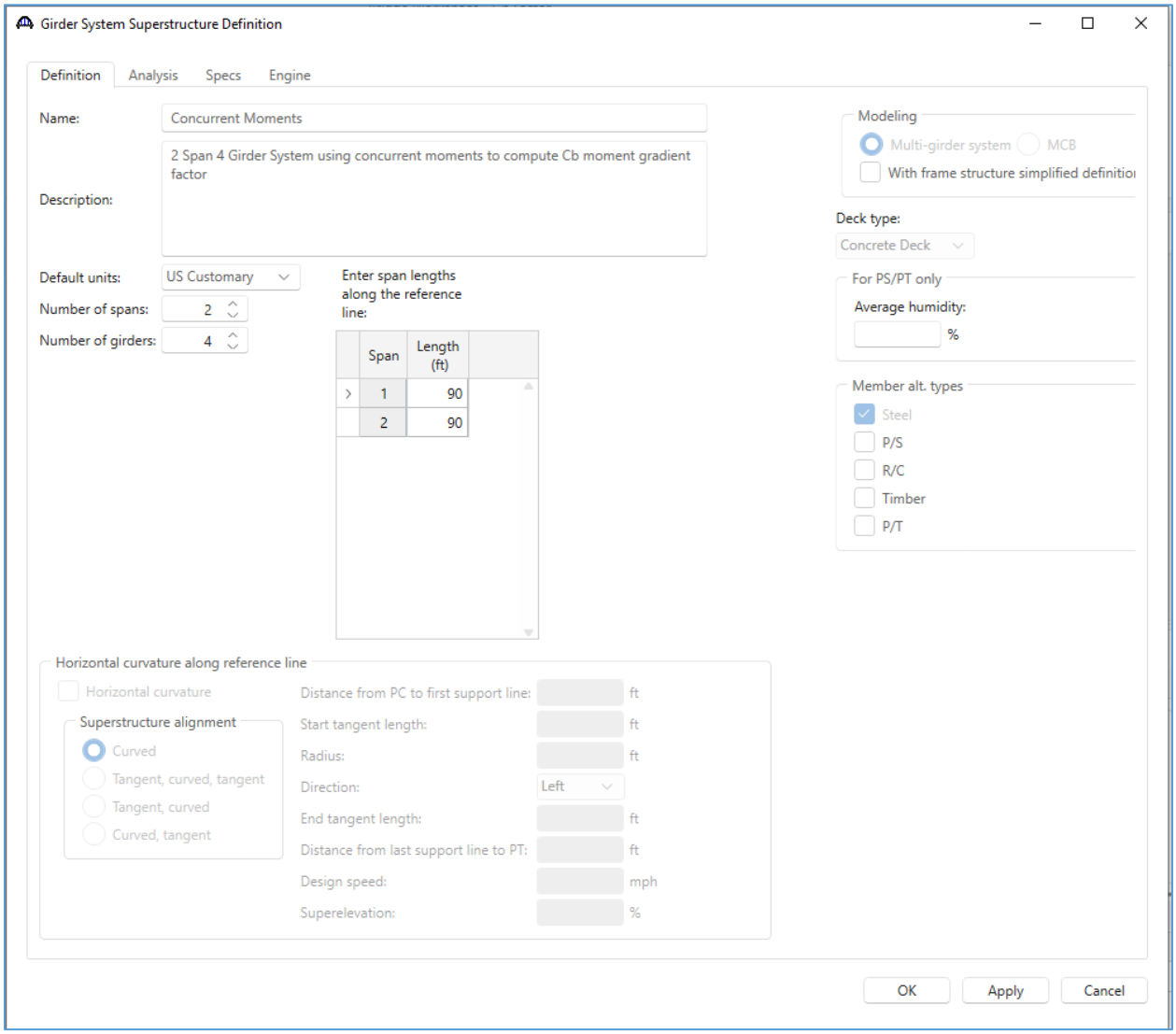


Duplicate the superstructure definition and modify the control options in the second structure to use concurrent moments for computing Cb.

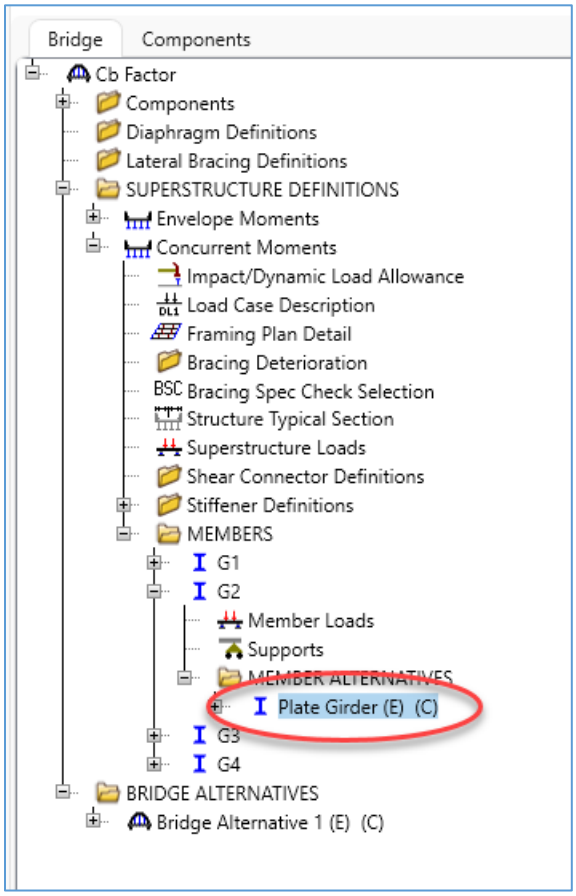
Right click on the **Envelope Moments** superstructure definition and select **Duplicate** from the menu to duplicate the superstructure definition.



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

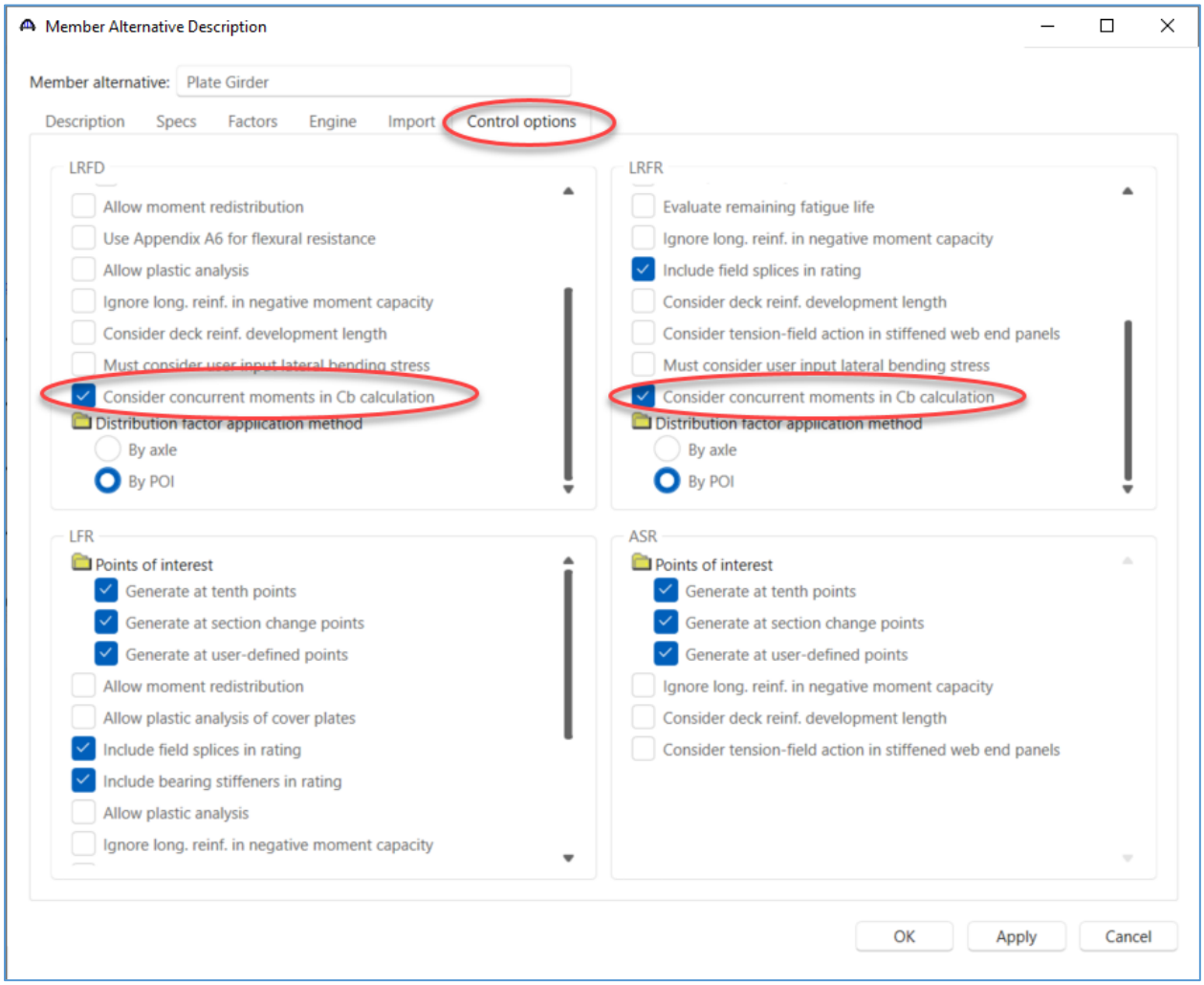


Expand the bridge workspace tree and open the **Member Alternative Description** window for the **G2 – Plate Girder** member alternative in the **Concurrent Moments** superstructure.

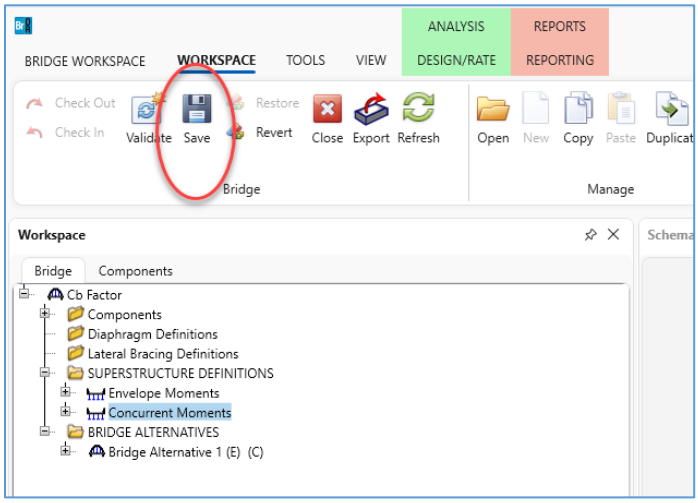


## Cb Calculation Control Option

Navigate to the **Control options** tab in the window and select the **LRFD** and **LRFR** control options to **Consider concurrent moments in Cb calculation**.



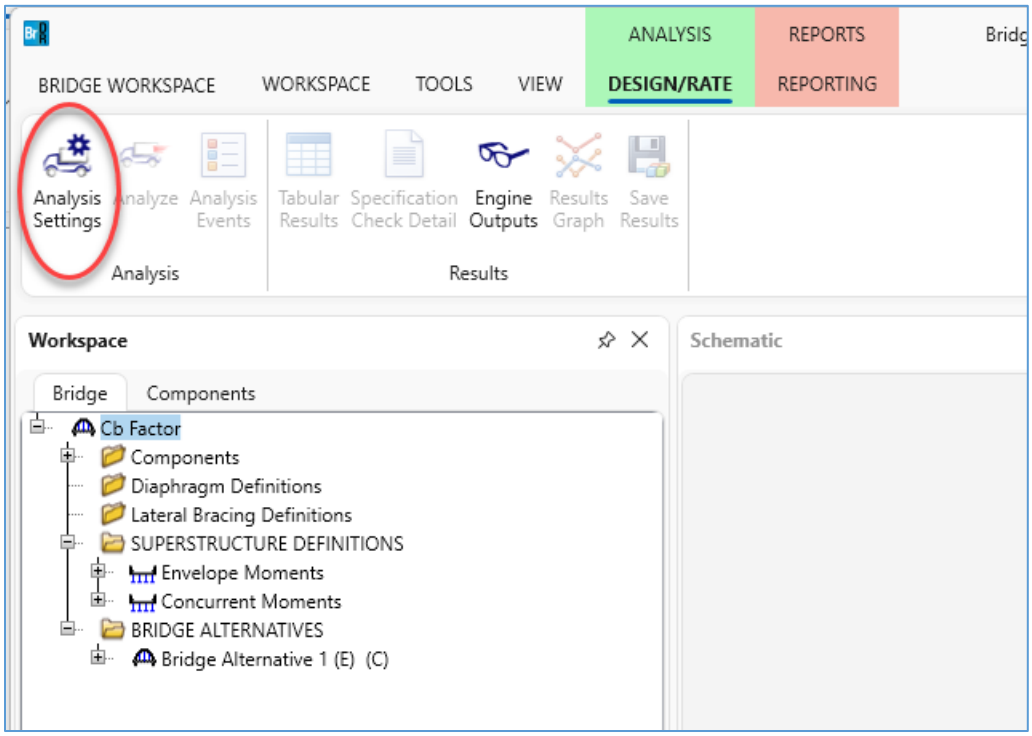
This completes the data entry for this example. Now is a good time to save the bridge to the database.



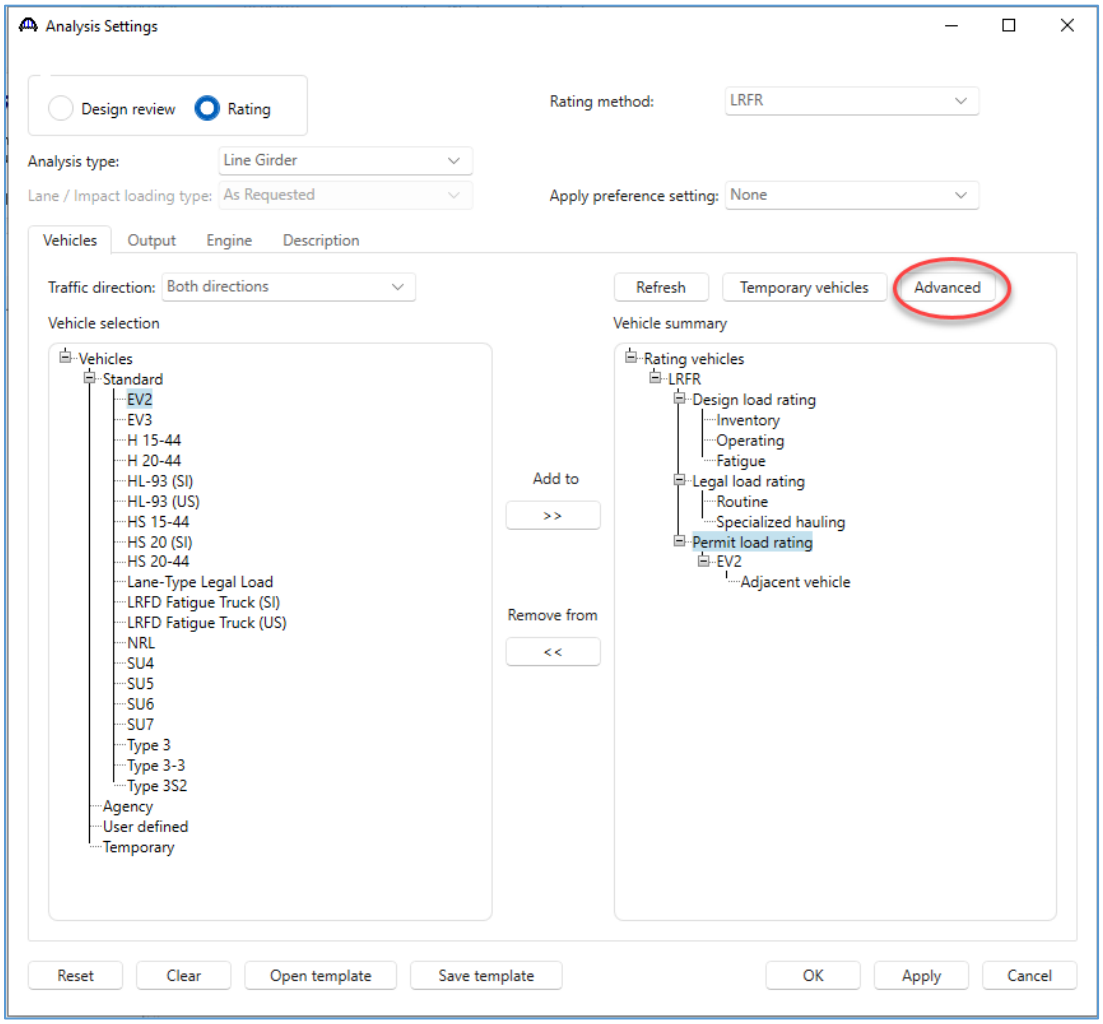
## Cb Calculation comparison

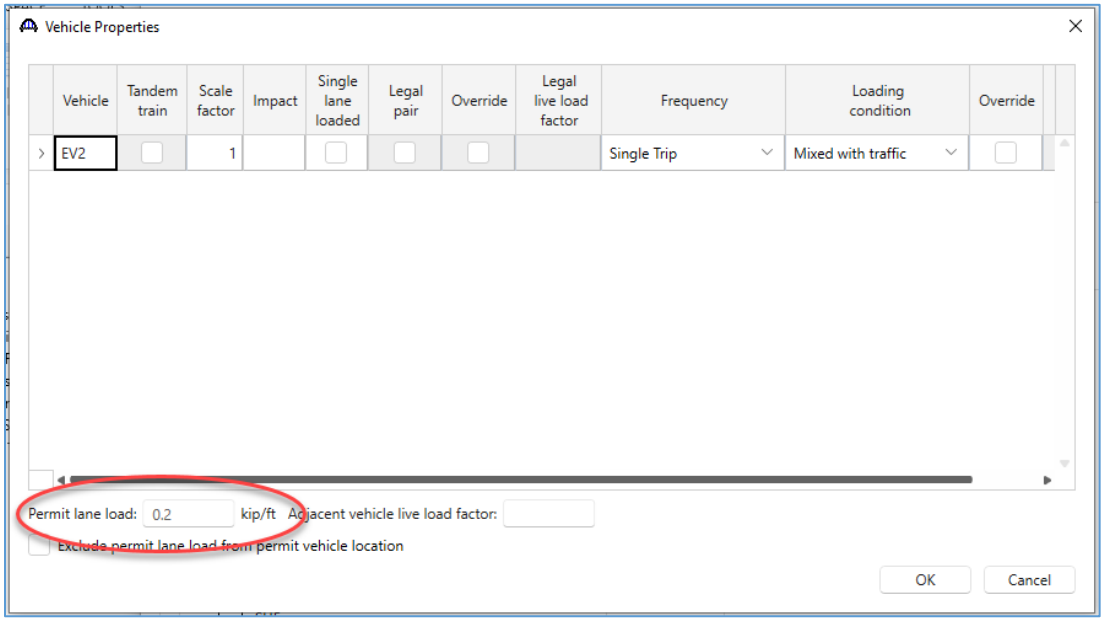
Follow the steps below to analyze the plate girder member alternative using envelope moments to compute Cb and the plate girder member alternative using concurrent moments to compute Cb.

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.



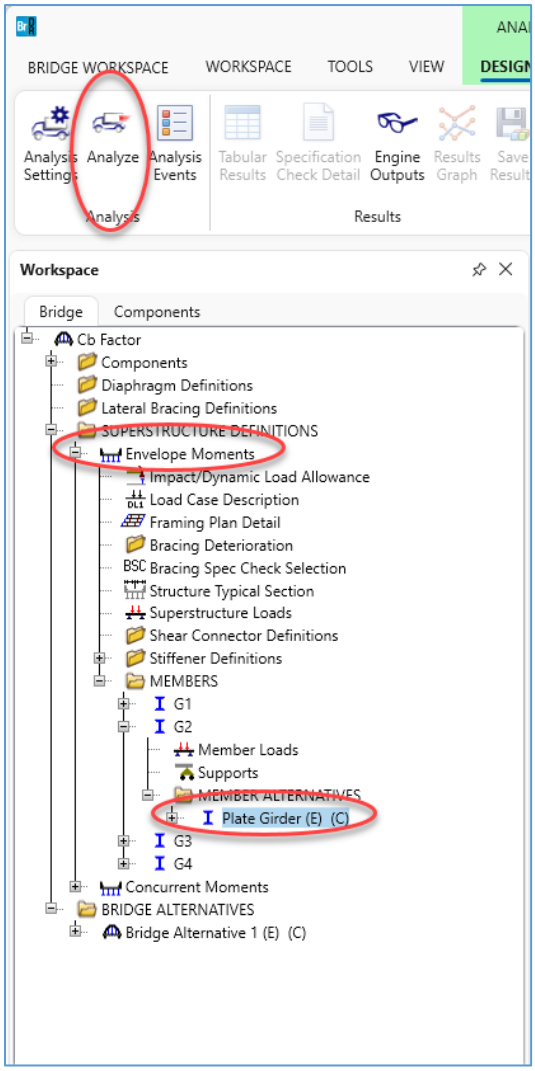
## Analysis Settings



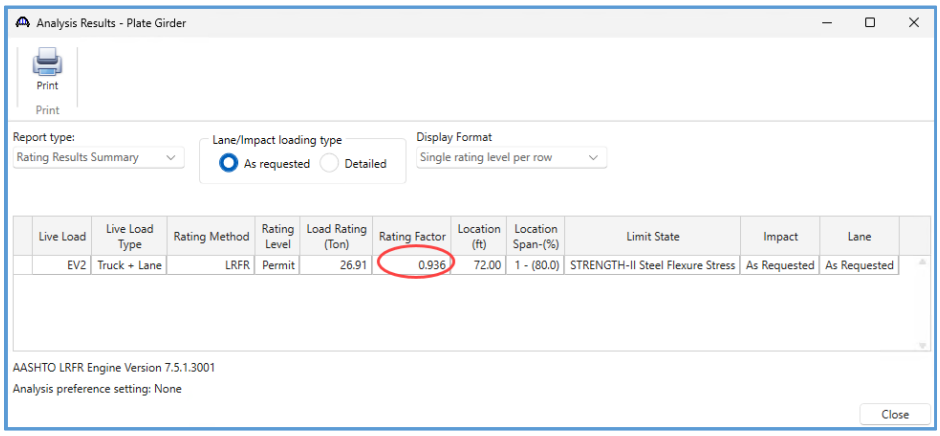



## Analyzing Girder with Envelope Moment Cb Calculation

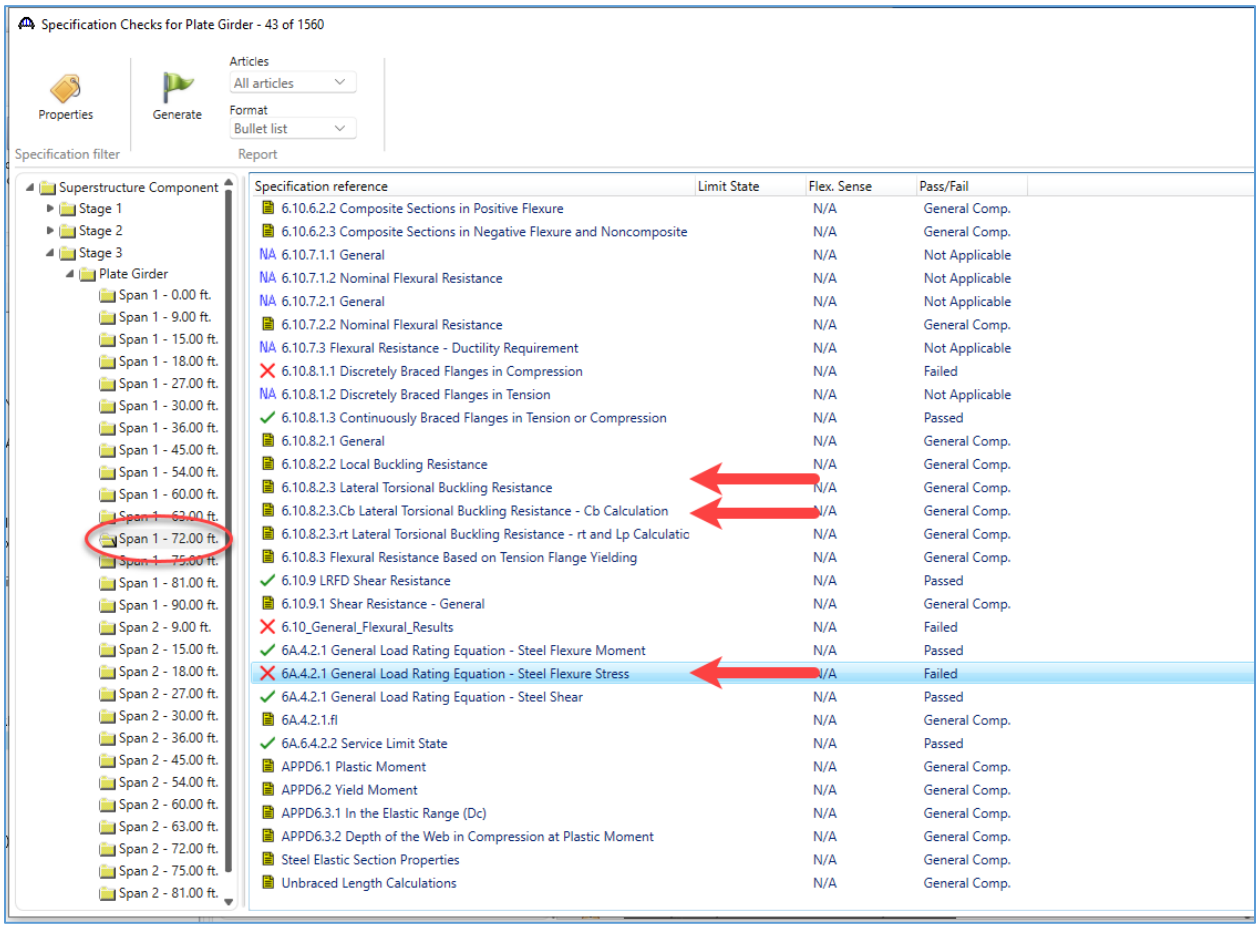
Analyze the plate girder member alternative within the **Envelope Moments** superstructure.



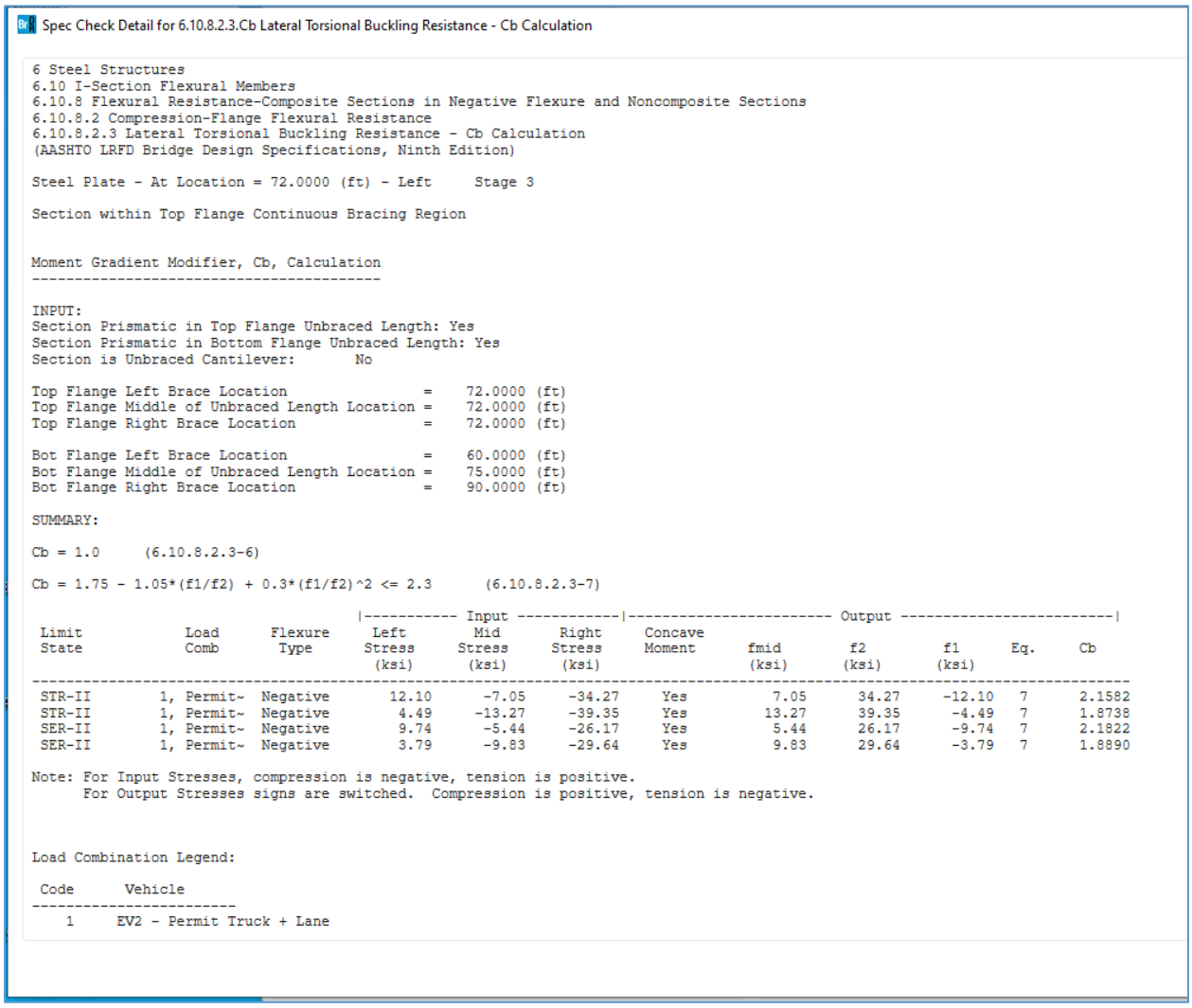
After the analysis is complete, review the results. Open the **Tabular Results** window to view the critical rating factor.




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

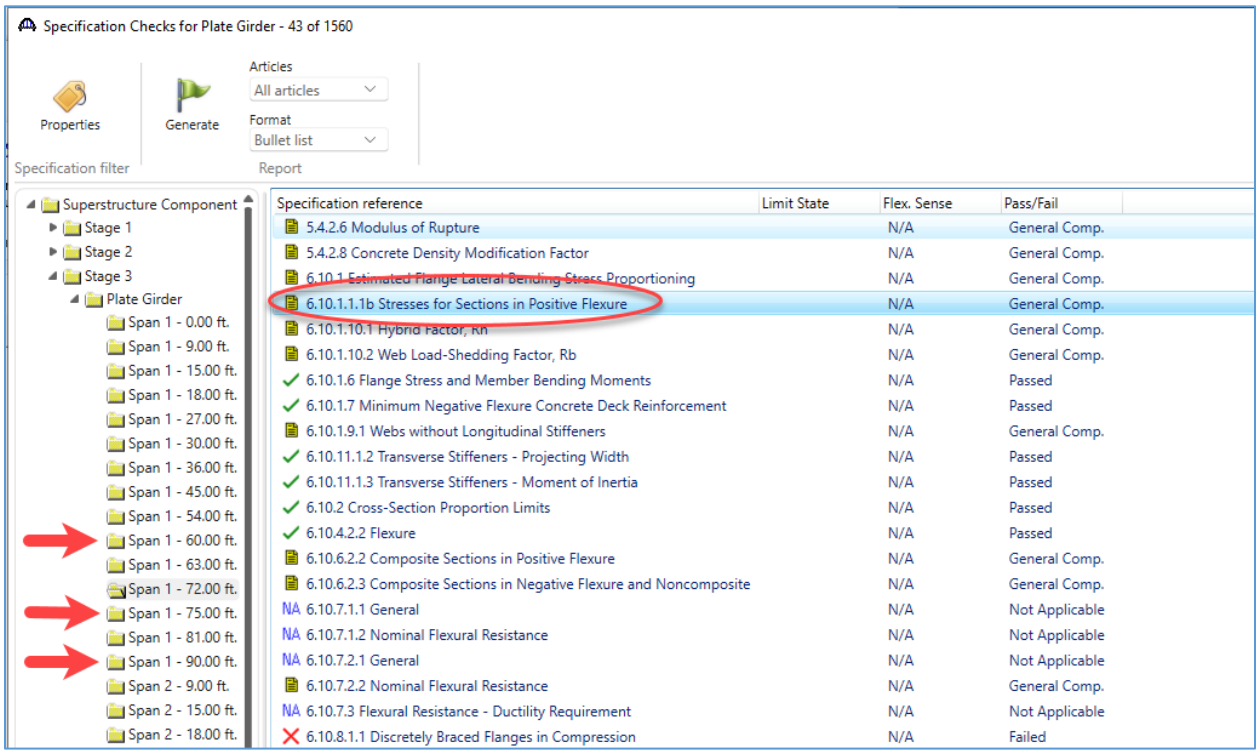
```
6 Steel Structures
6.10 I-Section Flexural Members
6.10.8 Flexural Resistance-Composite Sections in Negative Flexure and Noncomposite Sections
6.10.8.2 Compression-Flange Flexural Resistance
6.10.8.2.3 Lateral Torsional Buckling Resistance - Cb Calculation
(AASHTO LRFD Bridge Design Specifications,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

| Limit State | Load Comb | Flexure Type | Input: Left Stress (ksi) | Input: Mid Stress (ksi) | Input: Right Stress (ksi) | Input: Concave Moment | Output: fmid (ksi) | Output: f2 (ksi) | Output: f1 (ksi) | Output: Eq. | Output: Cb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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:
```

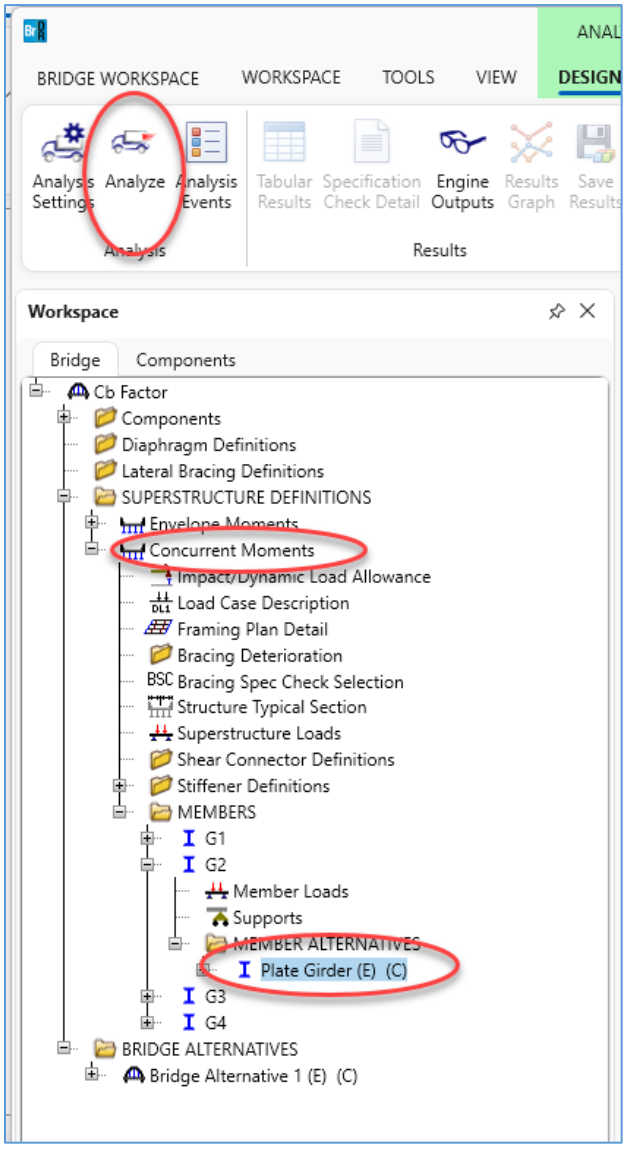
| Code | Vehicle |
|---|---|
| 1 | EV2 - Permit Truck + Lane |

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.

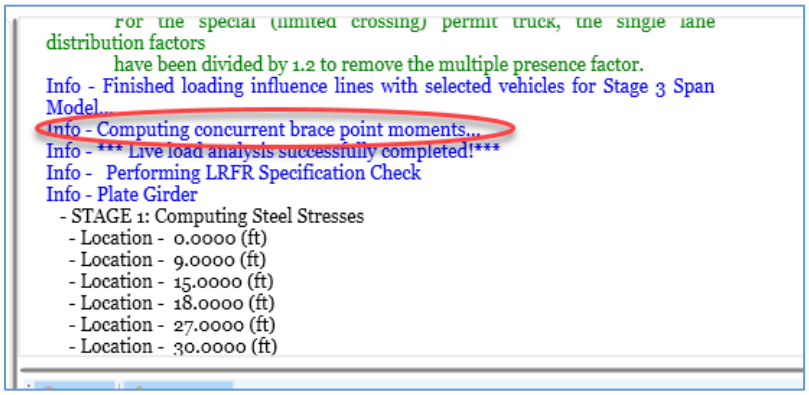


## Analyzing Girder with Concurrent Moment Cb Calculation

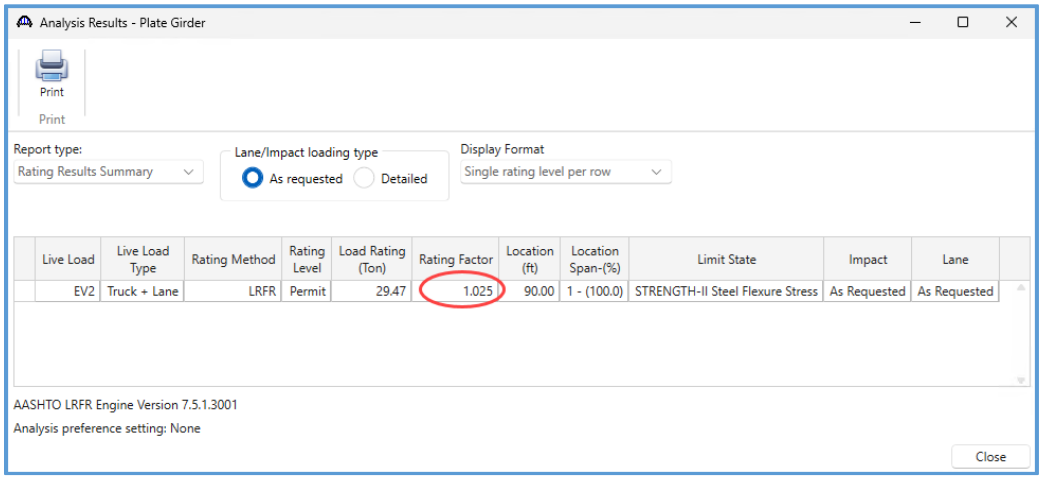
Next, analyze the **G2 – Plate Girder** member alternative within the **Concurrent Moments** superstructure.



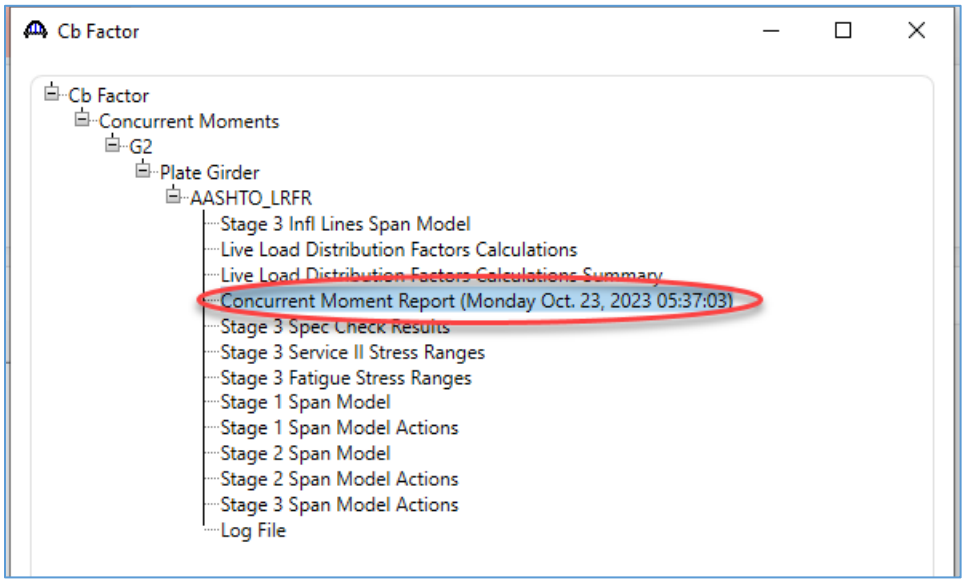

The analysis progress log will indicate when program is loading the concurrent moments at brace points.



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

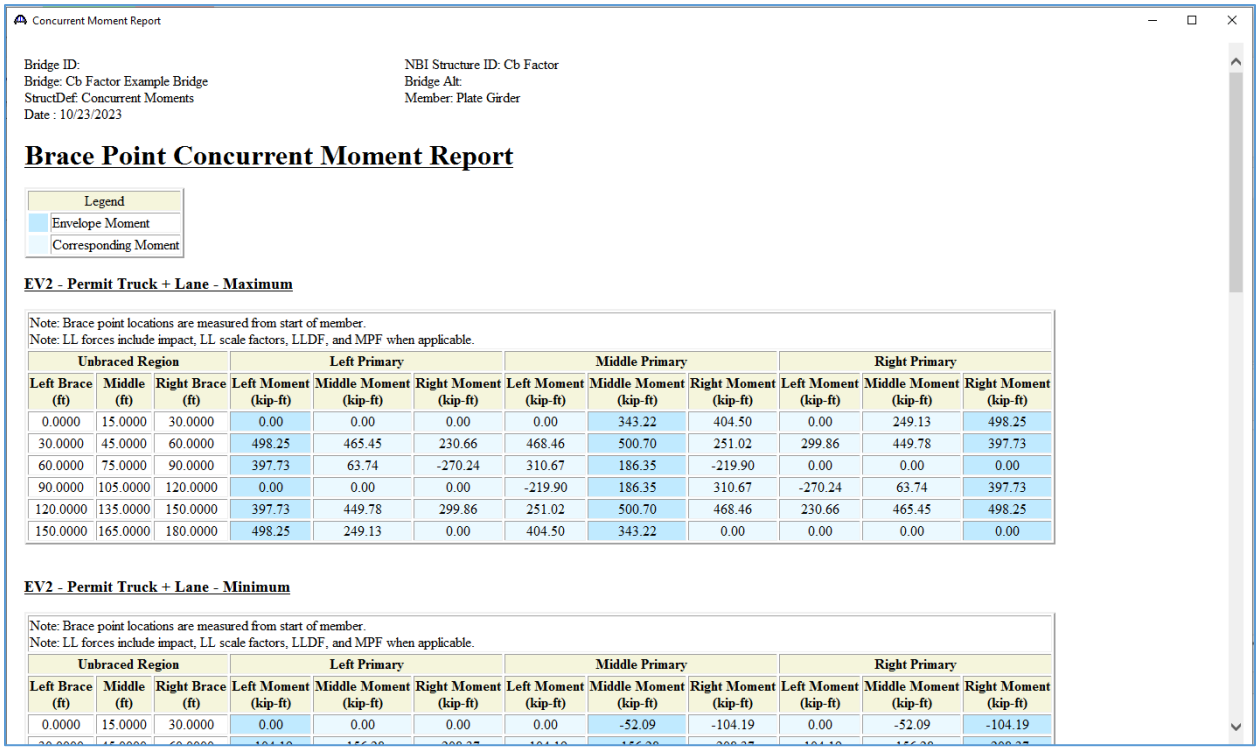



The **Engine Outputs** will include a **Concurrent Moment Report** which details the computed corresponding moments within all unbraced regions on the member.



## 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 |

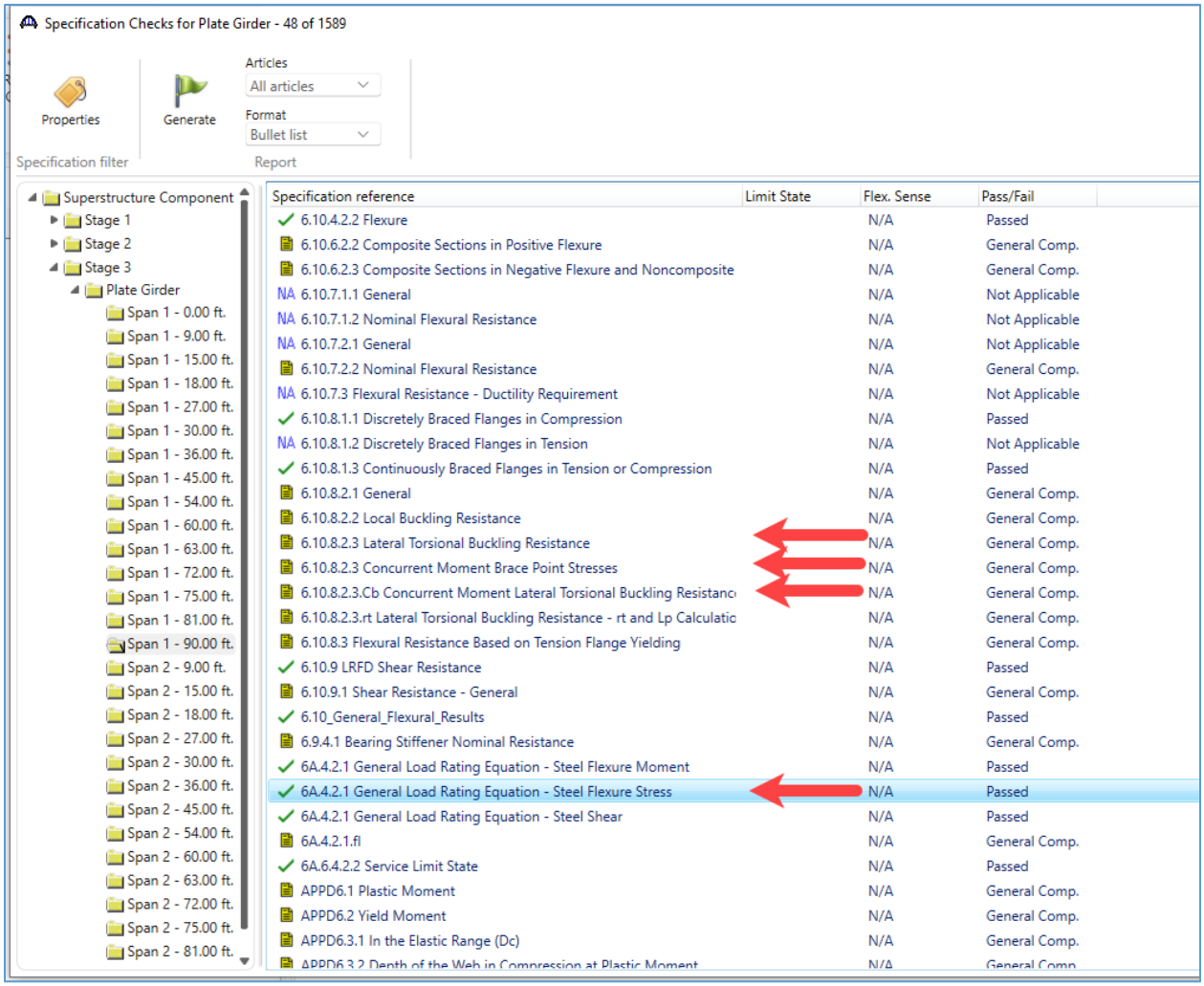
**EV2 - Permit Truck + Lane - Minimum**

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 |

## Specification Check Detail

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

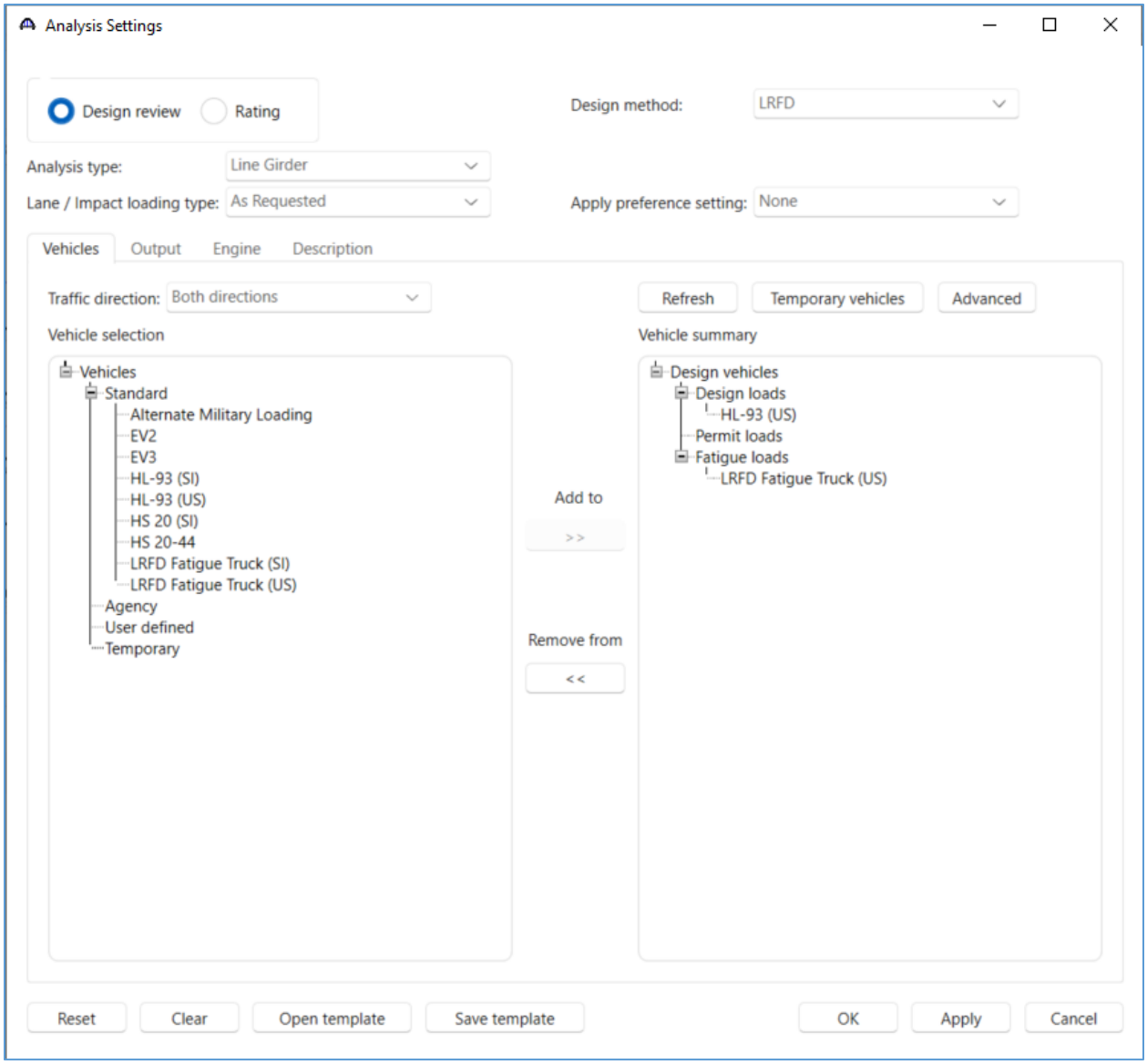
```
Cb = 1.75 - 1.05*(f1/f2) + 0.3*(f1/f2)^2 <= 2.3      (6.10.8.2.3-7)

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

                                    |---------- Input ----------|---------- Output ----------|
 Limit              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, 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              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, 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              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, 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.

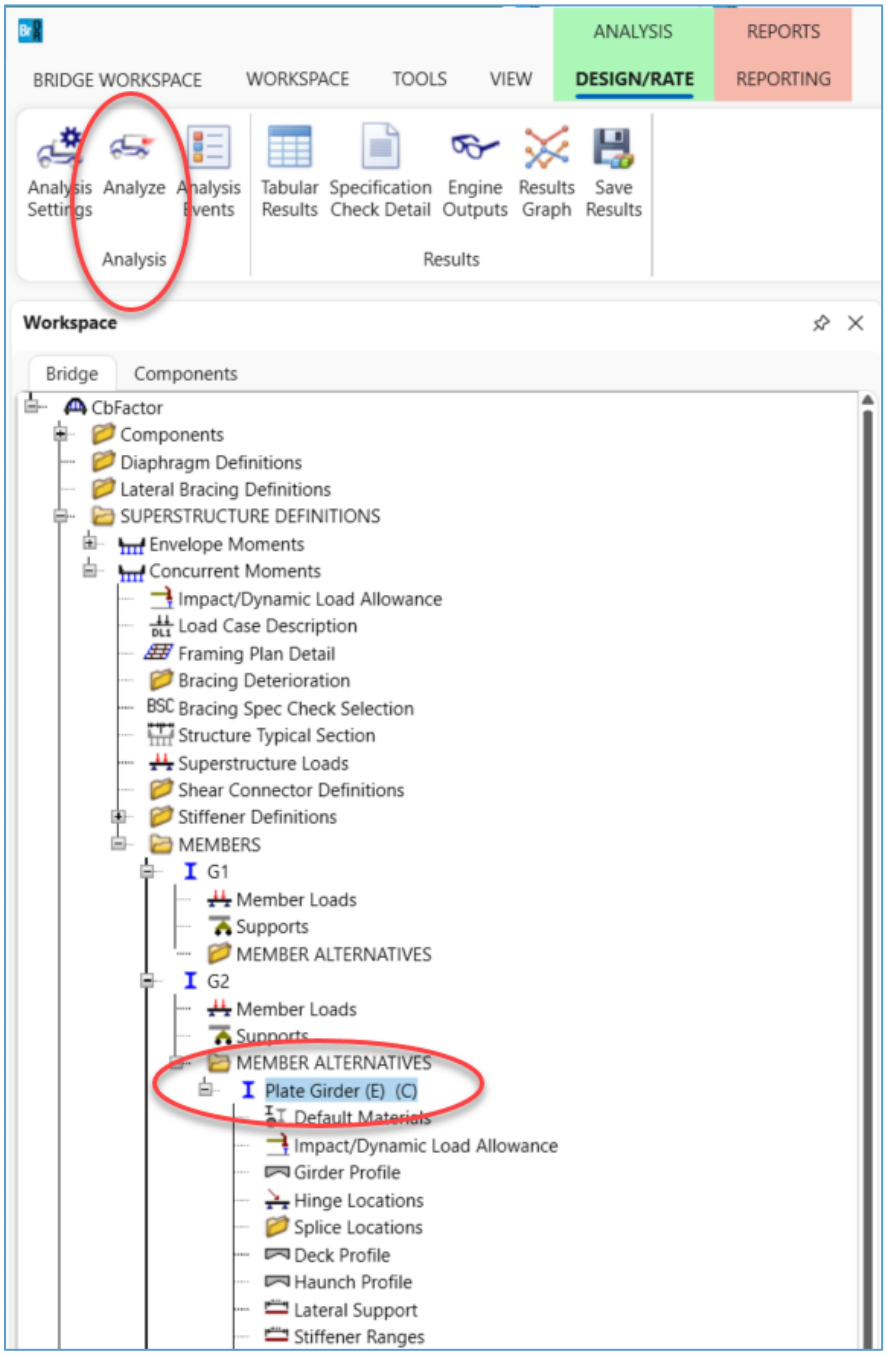
```
Cb calculation summary
----------------------


 Limit              Load
 State              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.
```

## LRFD Design Review

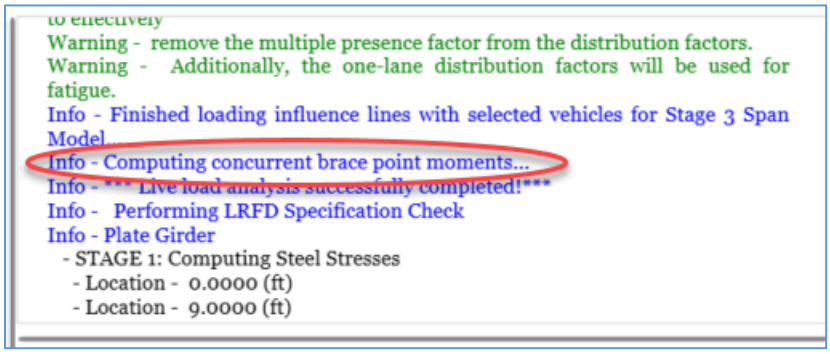
Open the **Analysis Settings window**. Open the **HL 93 Design Review** template to perform a design review using concurrent moments to compute the Cb factor.



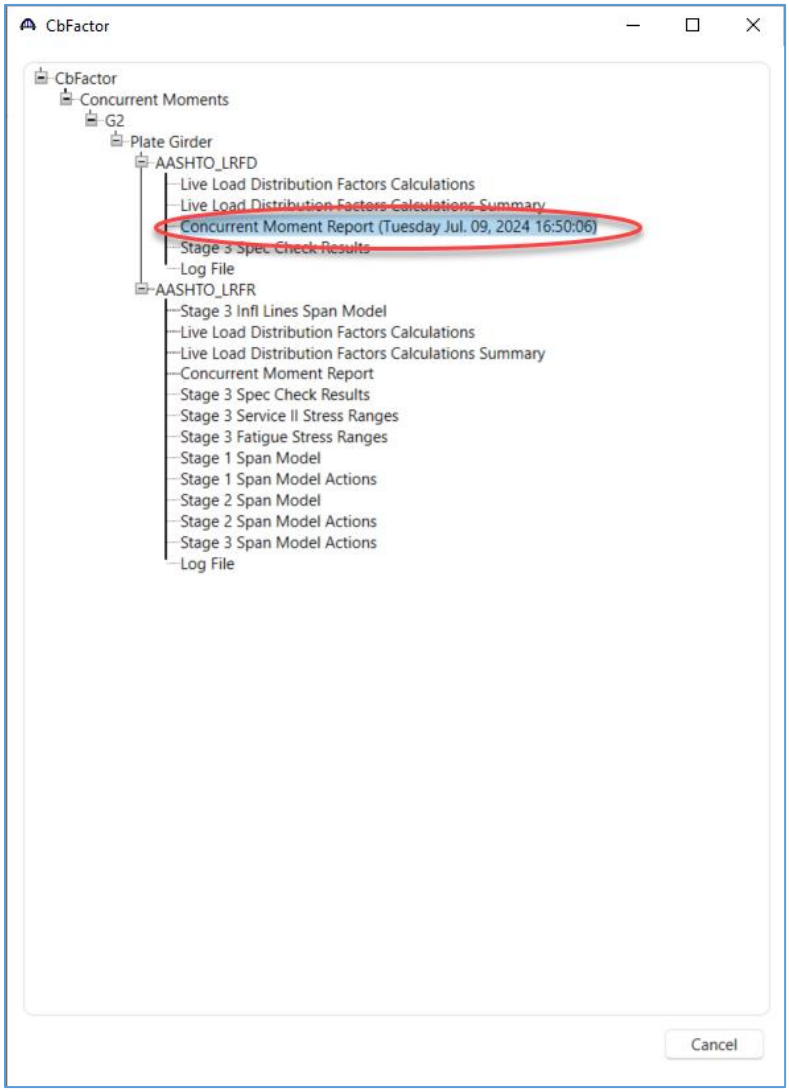
Analyze the **Plate Girder** member alternative under **G2** for the **Concurrent Moments** superstructure definition.



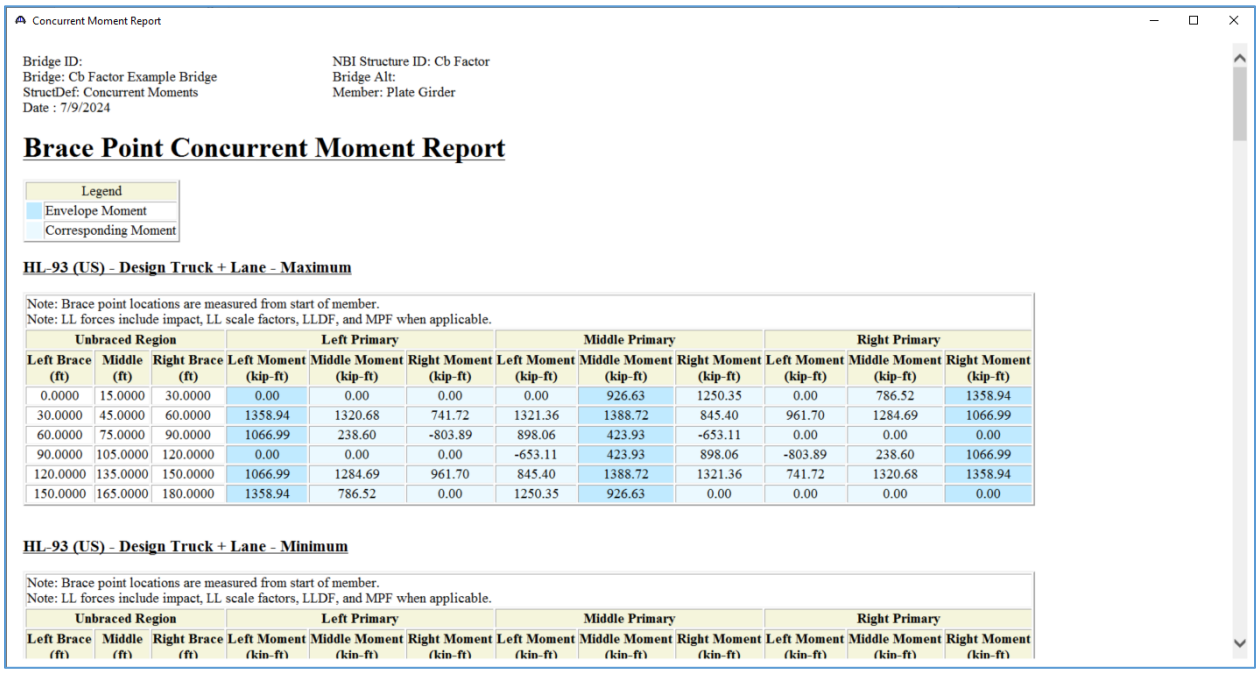
The analysis progress log will indicate when the program computes the concurrent brace point moments.




The **Engine Outputs** window includes a **Concurrent Moment Report** which shows the computed envelope and corresponding moments for each unbraced region along the member.



Open the report to review the computed actions. The report includes tables for each component of the vehicle live load. For the design vehicle this includes the load components such as truck and lane and the design combinations such as 90% truck pair plus lane.



Concurrent Moment Report

Bridge ID:
Bridge: Cb Factor Example Bridge
StructDef: Concurrent Moments
Date : 7/9/2024

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

## Brace Point Concurrent Moment Report

| Legend |
|---|
| Envelope Moment |
| Corresponding Moment |

**HL-93 (US) - Design 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 | 926.63 | 1250.35 | 0.00 | 786.52 | 1358.94 |
| 30.0000 | 45.0000 | 60.0000 | 1358.94 | 1320.68 | 741.72 | 1321.36 | 1388.72 | 845.40 | 961.70 | 1284.69 | 1066.99 |
| 60.0000 | 75.0000 | 90.0000 | 1066.99 | 238.60 | -803.89 | 898.06 | 423.93 | -653.11 | 0.00 | 0.00 | 0.00 |
| 90.0000 | 105.0000 | 120.0000 | 0.00 | 0.00 | 0.00 | -653.11 | 423.93 | 898.06 | -803.89 | 238.60 | 1066.99 |
| 120.0000 | 135.0000 | 150.0000 | 1066.99 | 1284.69 | 961.70 | 845.40 | 1388.72 | 1321.36 | 741.72 | 1320.68 | 1358.94 |
| 150.0000 | 165.0000 | 180.0000 | 1358.94 | 786.52 | 0.00 | 1250.35 | 926.63 | 0.00 | 0.00 | 0.00 | 0.00 |

**HL-93 (US) - Design 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) |