AASHTOWare BrDR 7.6.1

3D FEM Analysis Tutorial

Axial Rigidity Coefficient Example

3DFEM6 – Axial Rigidity Coefficient Example

AASHTOWare Bridge Design and Rating Training
3DFEM6-Axial-Rigidty-Coefficient-Example

Topics Covered

- Modifying 3DFEM2-Single-Span-Steel-3D-Example bridge
- Steel Diaphragm Connection Data Entry with Axial Rigidity Coefficient (ARC)
- Steel Diaphragm Spec Check Comparison

Features (Introduced in version 7.6.0 as a part of the LRFD 10th edition spec updates):

- LRFD/LRFR Axial Rigidity Coefficients

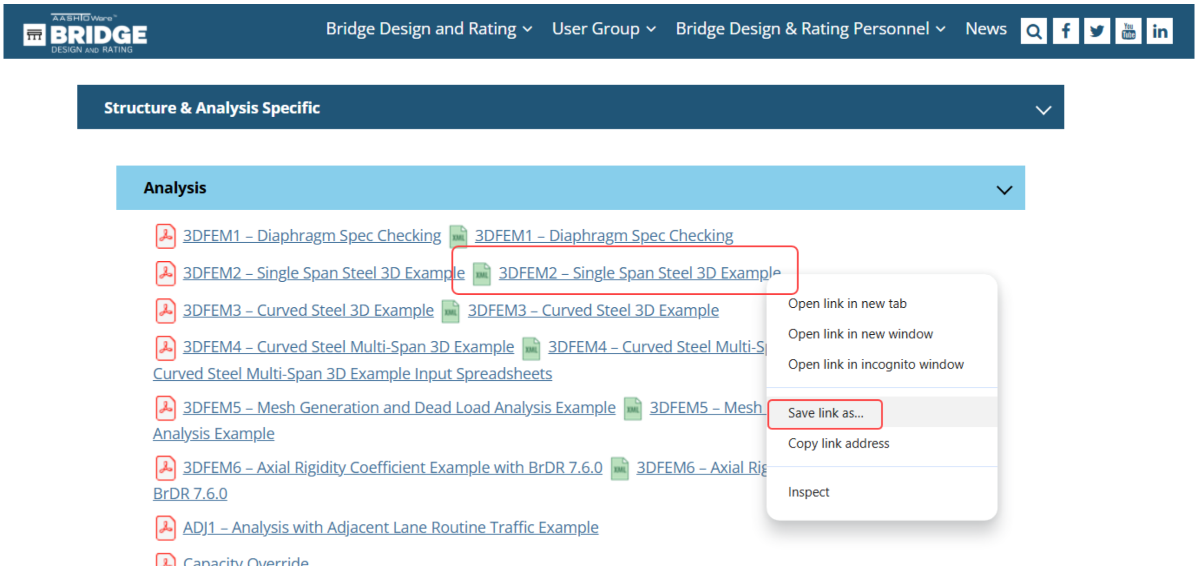
Member	Shape	Section orientation	Section location	Material	LRFD/LRFR axial rigidity coefficients		
					Non-composite	Composite (long term)	Composite (short term)
AB	L 4x4x1/2	Vertical	Top Left	Fy= 33 ks			
CD	L 4x4x1/2	Vertical	Top Left	Fy= 33 ks			
AD	L 4x4x1/2	Vertical	Top Left	Fy= 33 ks			
CB	L 4x4x1/2	Vertical	Top Left	Fy= 33 ks			

This tutorial demonstrates how to input Axial Rigidity Coefficients for different diaphragm members. In the 10th edition of the LRFD specifications, section 4.6.3.3.4c introduces equivalent axial rigidity in cross frame members. This gives the user the option to scale the axial terms from the stiffness matrix for steel cross frame members. Prior to version 7.6.0 of BrDR, users did not have the ability to enter in ARC coefficients for diaphragm members, as ARC values are introduced in the 10th edition of the LRFD specifications. In version 7.6.0 and beyond, the users will have this option. This may impact the computed axial forces within the diaphragm members. For single angle and horizontally oriented T-shaped diaphragm members, if the user does not enter axial rigidity coefficients, default values of 0.65 or 0.75 for non-composite or composite members respectively will be assumed. These default values are derived from section 4.6.3.3.4c of the specifications which state "the equivalent axial rigidity of single-angle and flange-connected tee-section cross-frame members to be taken as 0.65AE in the analysis model for the non-composite condition during construction." Additionally, "taken as 0.75AE in the analysis model for the composite condition."

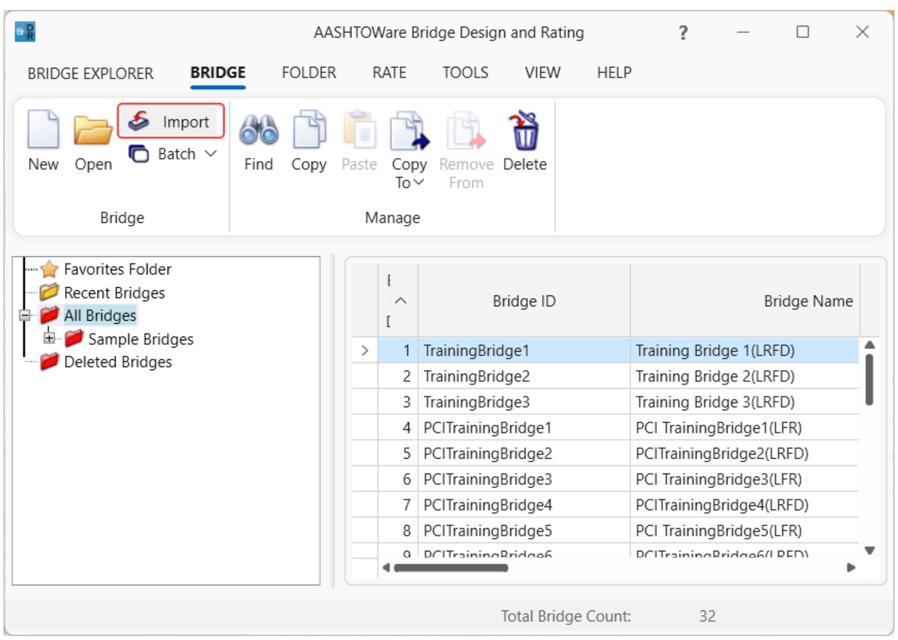
This bridge is a single span steel girder system with four rolled steel girders. Follow the steps to modify the structure definition. Two diaphragm member types, one with axial rigidity coefficient values < 1.0 and one with axial rigidity coefficient values = 1.0 will be input by the user and those results will be compared. Then one of the diaphragm member definitions will be modified, so that default behavior for axial rigidity coefficient values for single angle or horizontally oriented T-shaped members can be observed.

Modifying Steel Girder Bridge

Go to **AASHTO's** website to access the training files: https://aashtowarebrdr.org/bridge-rating-and-design/training/. Then, right click on **3DFEM2 – Single Span Steel 3D Example** and select **Save link as…**

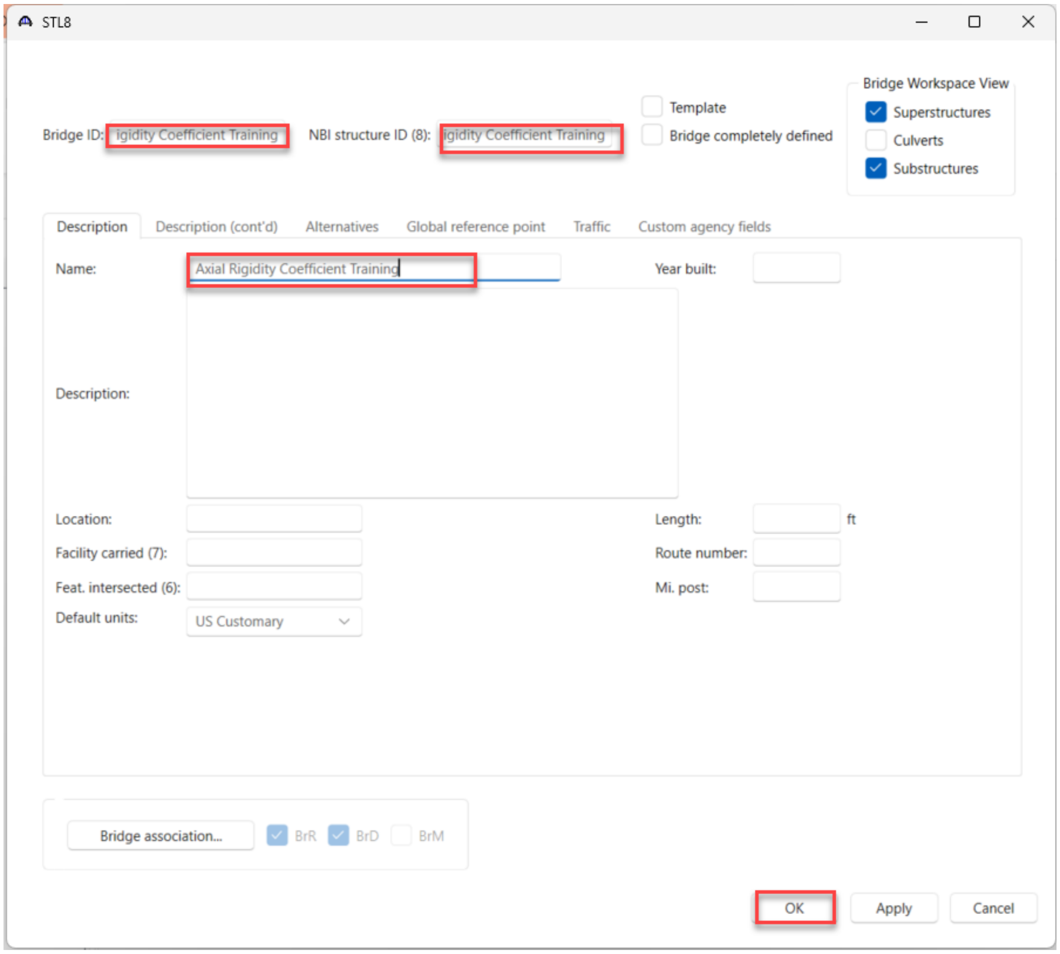


Once this is saved, it can be accessed in the next step to import into **BrDR**. From the **Bridge Explorer**, import the **3DFEM2-Single-Span-Steel-3D-Example.xml** file

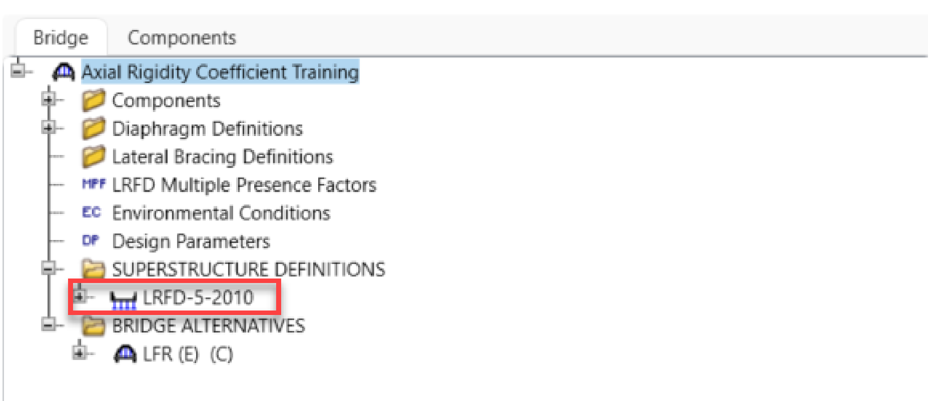


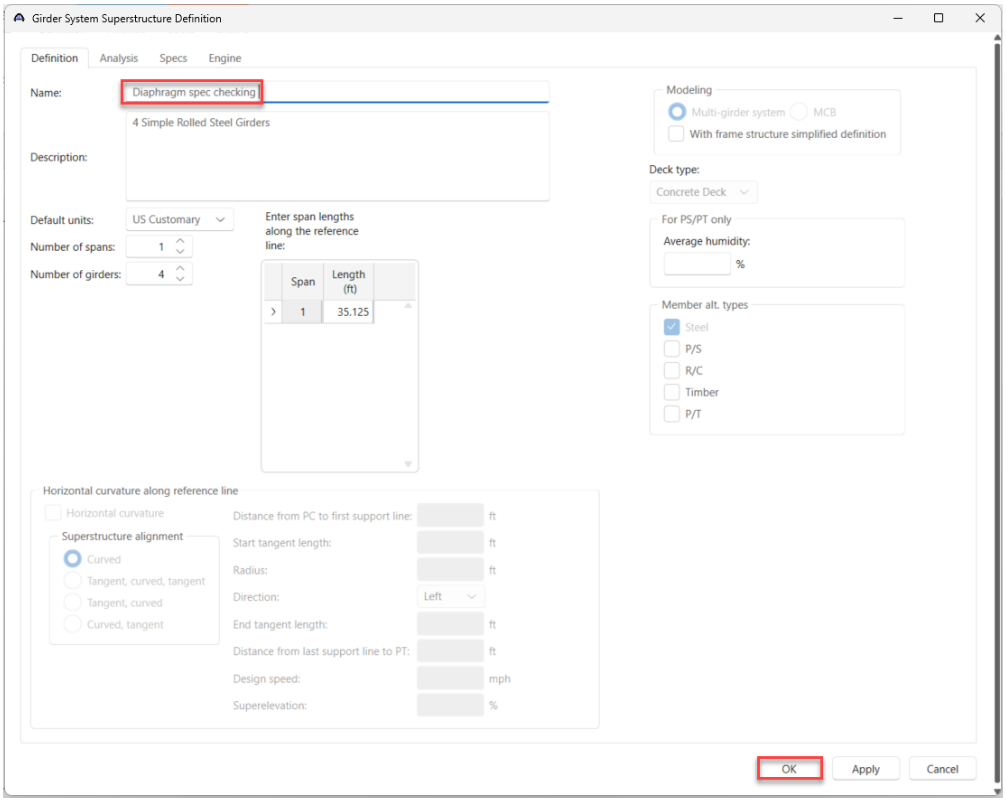
Modify Superstructure

Change the **Bridge ID** and **NBI structure ID**, **Axial Rigidity Coefficient Training,** and **Name** to **Axial Rigidity Coefficient Training**. Click **OK** to apply the changes and close the **Bridge** window.

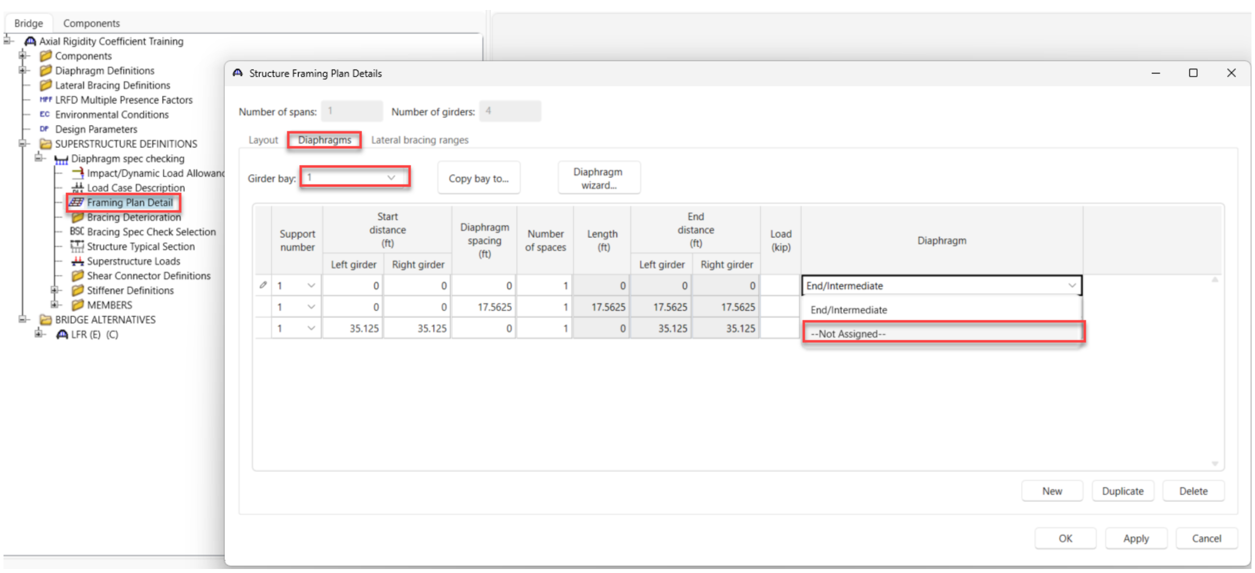


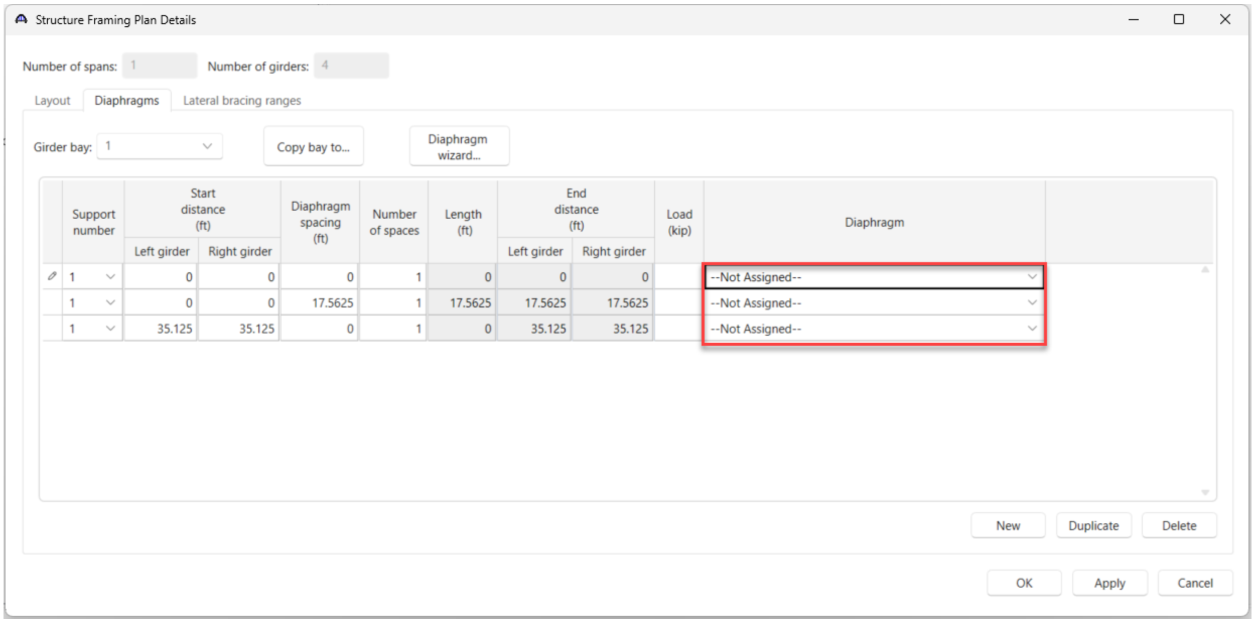
Next, change the superstructure name by double clicking on the **superstructure definition** and changing the name to **Diaphragm spec checking**. Then select **OK** to apply the changes and close the **Girder System Superstructure Definition** window.



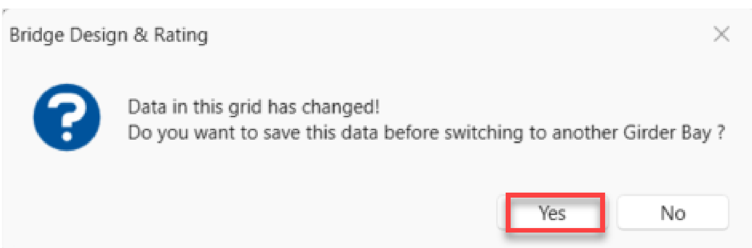


Next, open the **Framing Plan Detail** window by expanding **Diaphragm spec checking** and double-clicking **Framing Plan Detail**. Go to the **Diaphragms** tab and assign each diaphragm to **–Not Assigned––** for the diaphragm definition.

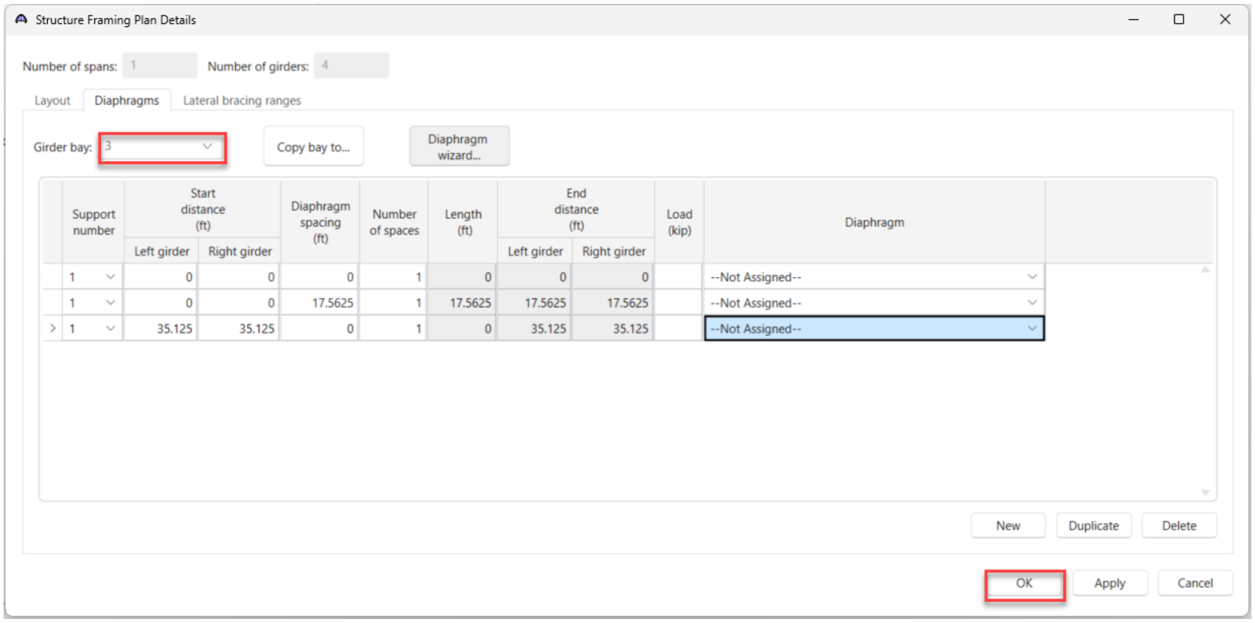




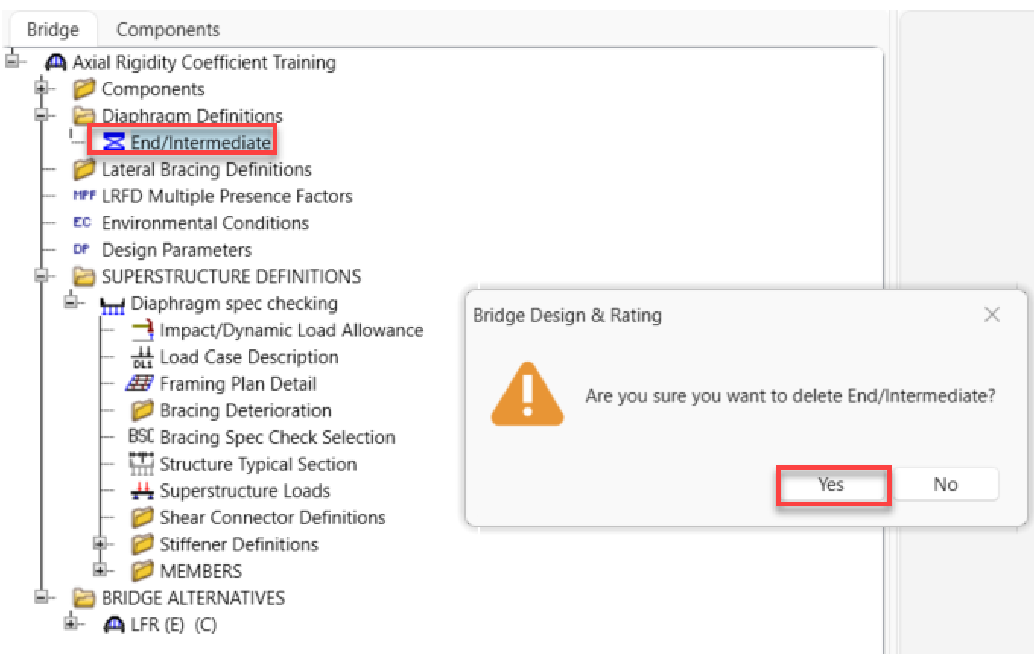
Repeat this step for **Girder Bay 2** and **3**. If this window appears when switching between girder bays, select **Yes** and continue.



Verify that all girder bays have **–Not Assigned--** selected for the diaphragm location and select **OK** to apply the changes and close the **Structure Framing Plan Details** window.

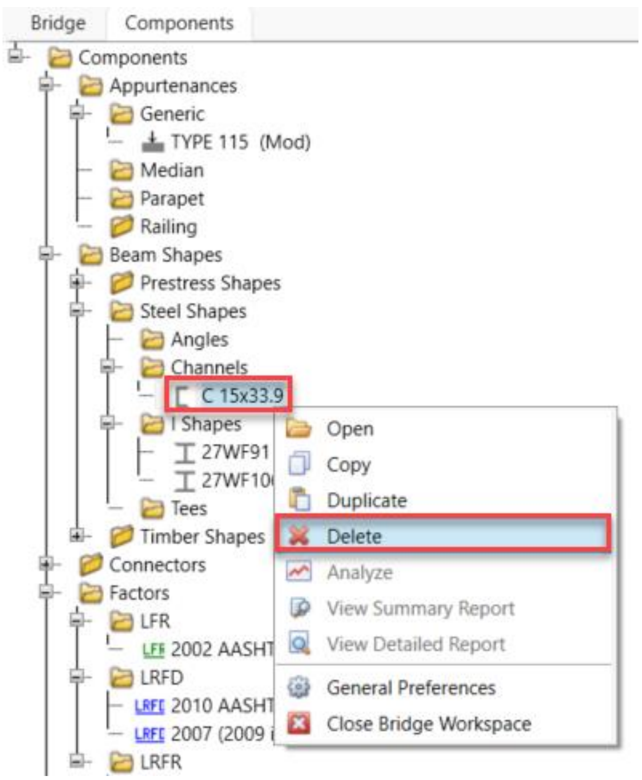


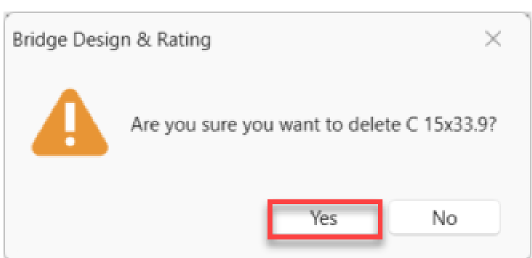
Next, delete the **diaphragm definition** by expanding the **Diaphragm Definitions** folder, then right clicking **End/Intermediate** and selecting **delete**. If the confirmation window pops up, select **Yes** and continue.



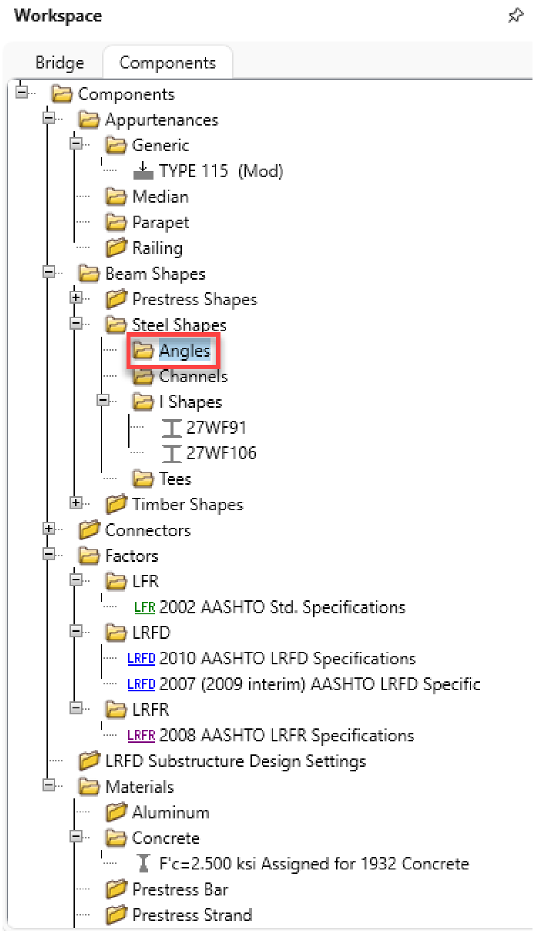
Diaphragm member steel shapes

Next, the Steel shapes need to be added to use for the diaphragms. In the **Components** tab of the **Bridge Workspace**, expand the **Beam Shapes** folder, then expand the **Steel Shapes** folder, then the expand **Channels** folder, finally right click and **delete** the **C 15x33.9** shape as this will not be needed anymore.

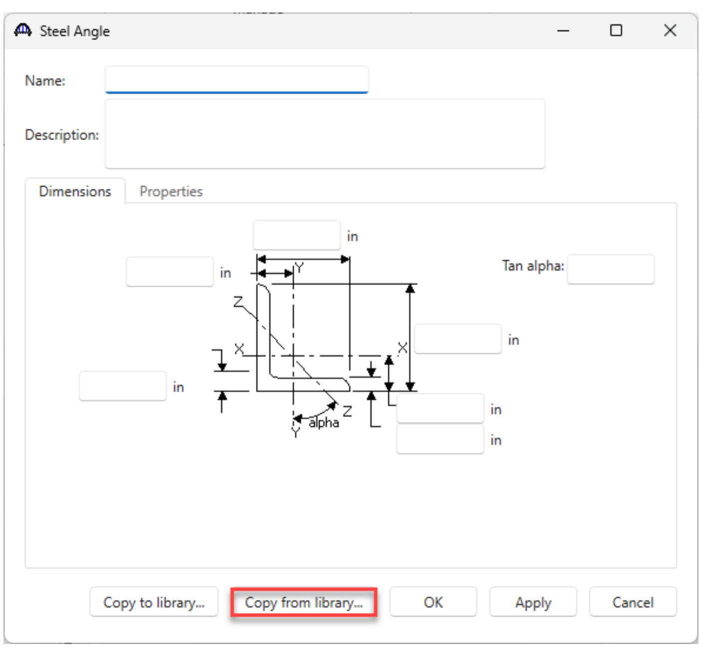




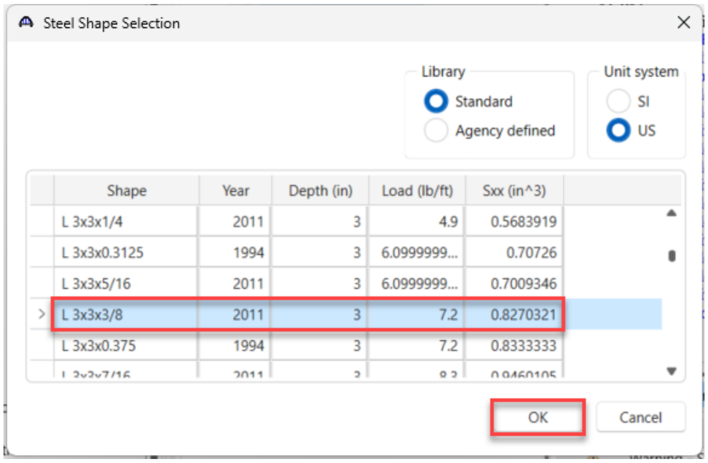
Next double click on the **Angles** folder or right click and select **new** to open the **Steel Angle** window.



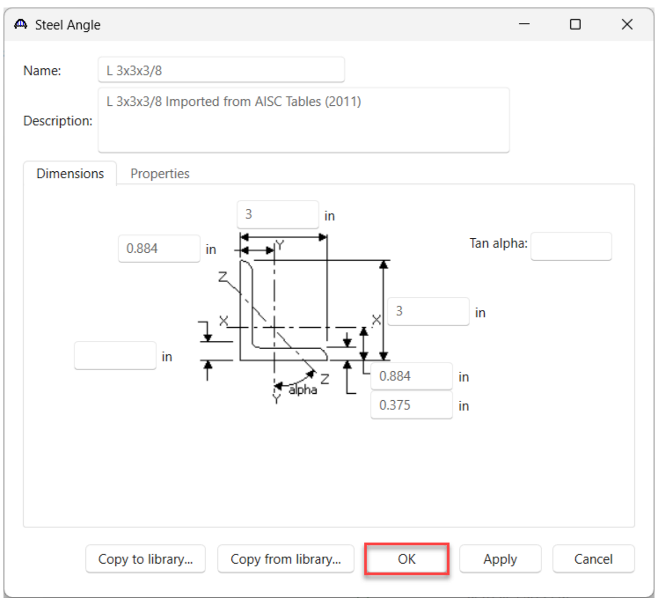
Then select **Copy from library…**



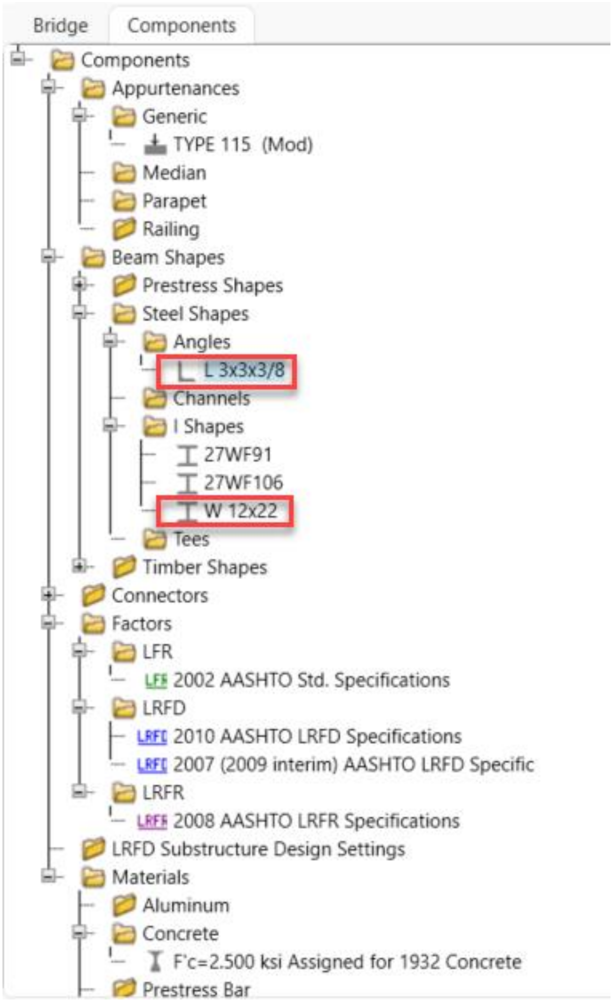
Scroll down to select **L 3x3x3/8.** Make sure to select the shape where the **Year** is **2011**. Then select **OK** to close the **Steel Shape Selection** window.



Then select **OK** to close the **Steel Angle** window.

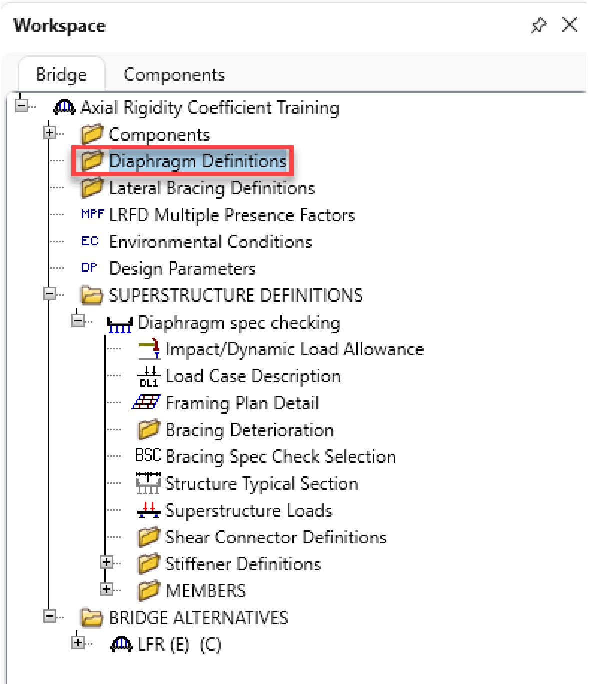


Repeat these steps to add a **W 12x22** shape, again making sure the **Year** is **2011**. The **Components** tab should now have the **L 3x3x3/8** and **W 12x22** shapes added to the **Beam Shapes** folder.

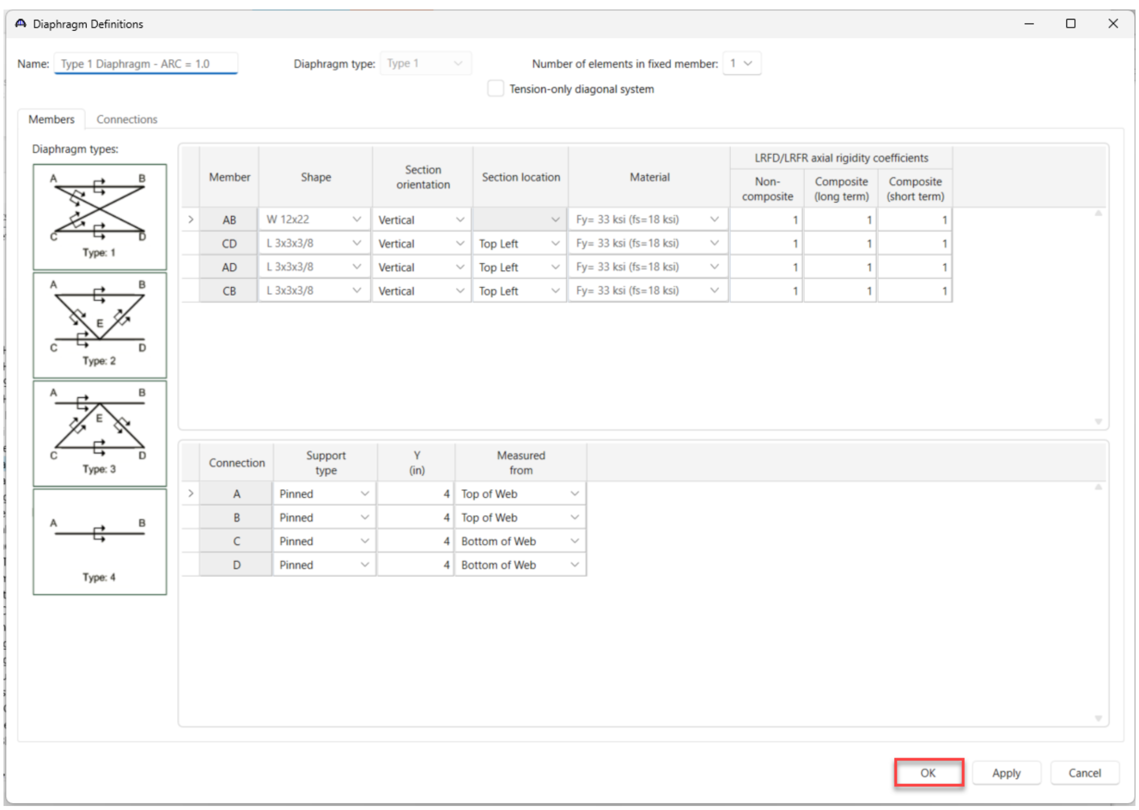

Bridge
Components
Components
Appurtenances
Generic
TYPE 115 (Mod)
Median
Parapet
Railing
Beam Shapes
Prestress Shapes
Steel Shapes
Angles
L 3x3x3/8
Channels
I Shapes
27WF91
27WF106
W 12x22
Tees
Timber Shapes
Connectors
Factors
LFR
2002 AASHTO Std. Specifications
LRFD
2010 AASHTO LRFD Specifications
2007 (2009 interim) AASHTO LRFD Specific
LRFR
2008 AASHTO LRFR Specifications
LRFD Substructure Design Settings
Materials
Aluminum
Concrete
F'c=2.500 ksi Assigned for 1932 Concrete
Prestress Bar

Diaphragm Definitions

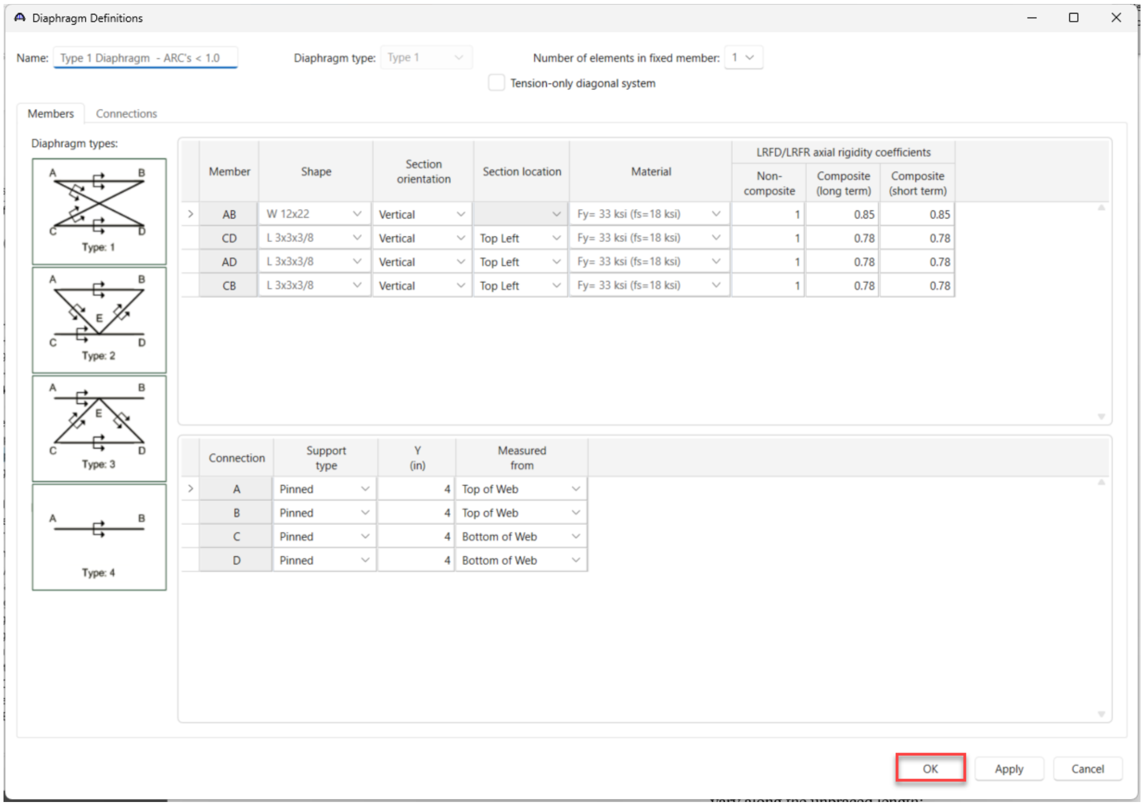
Navigate back to the **Bridge** tab of the **Bridge Workspace**, double click the **Diaphragm Definitions** folder to open up the **Diaphragm Definitions** window.



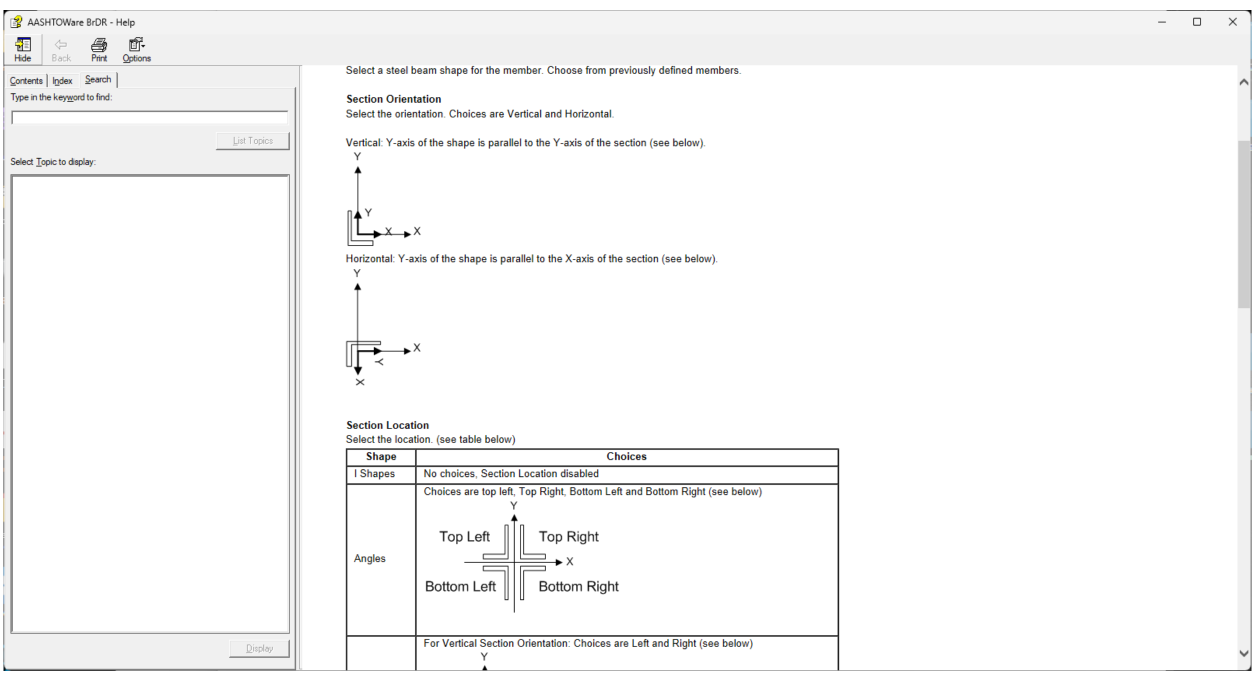
Leave **Type 1** selected for the diaphragm type and enter in the following data, then select **OK**.



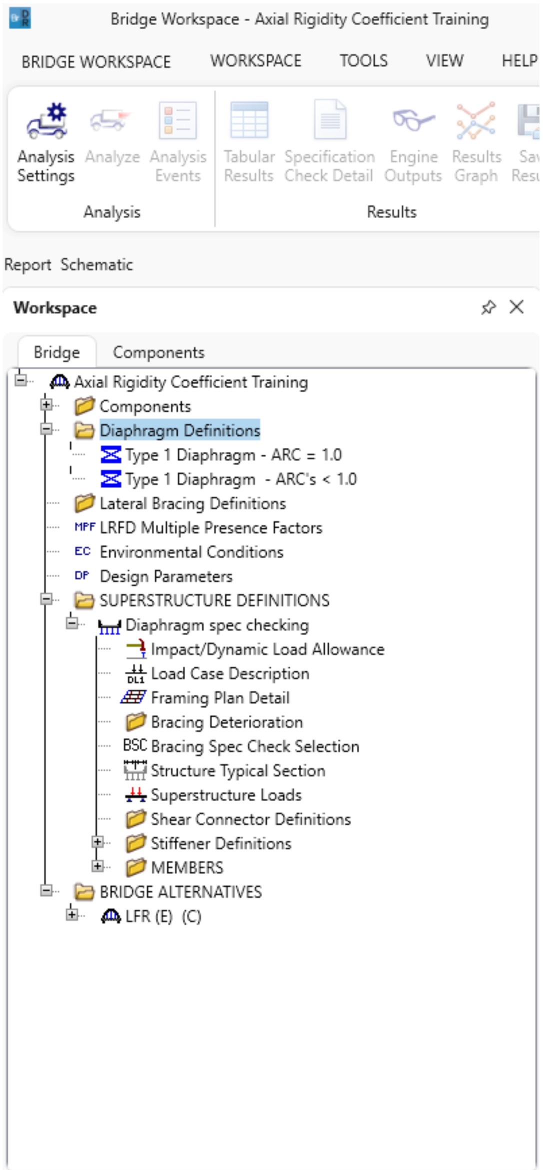
Repeat these steps to add a second diaphragm definition, this time with some ARC values < 1.0.



The following sketch from the **AASHTOWare BrDR Help** illustrates the **Section Orientation** and **Section Location** selection. This can be accessed by hitting the **F1** key on this window.

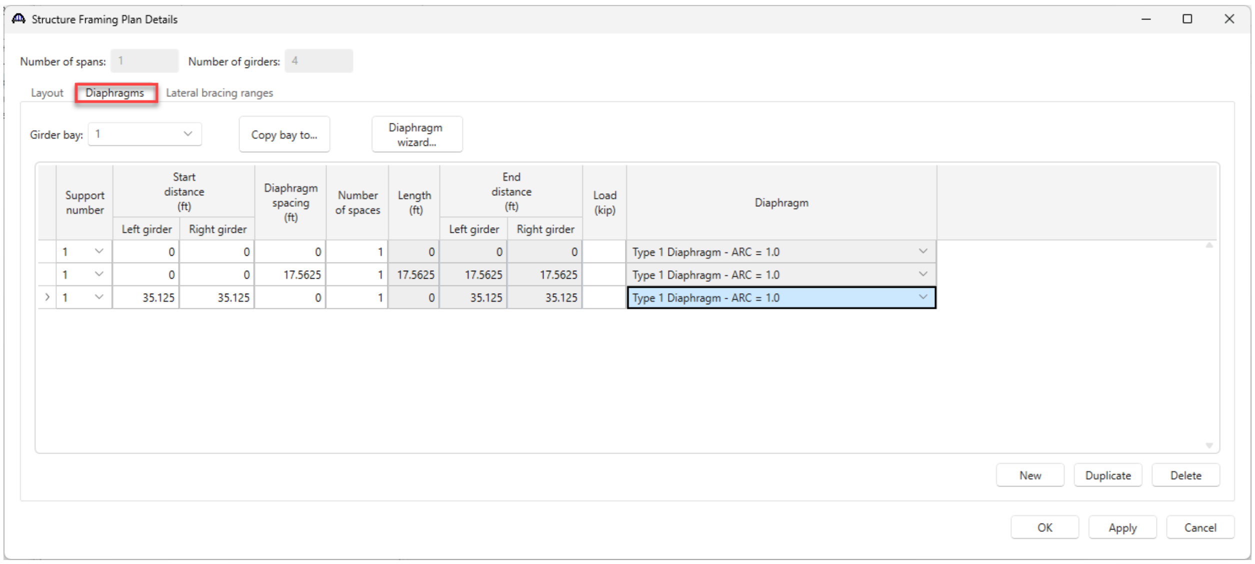


The two new diaphragm definitions should now be located within the **Diaphragm Definitions** folder.

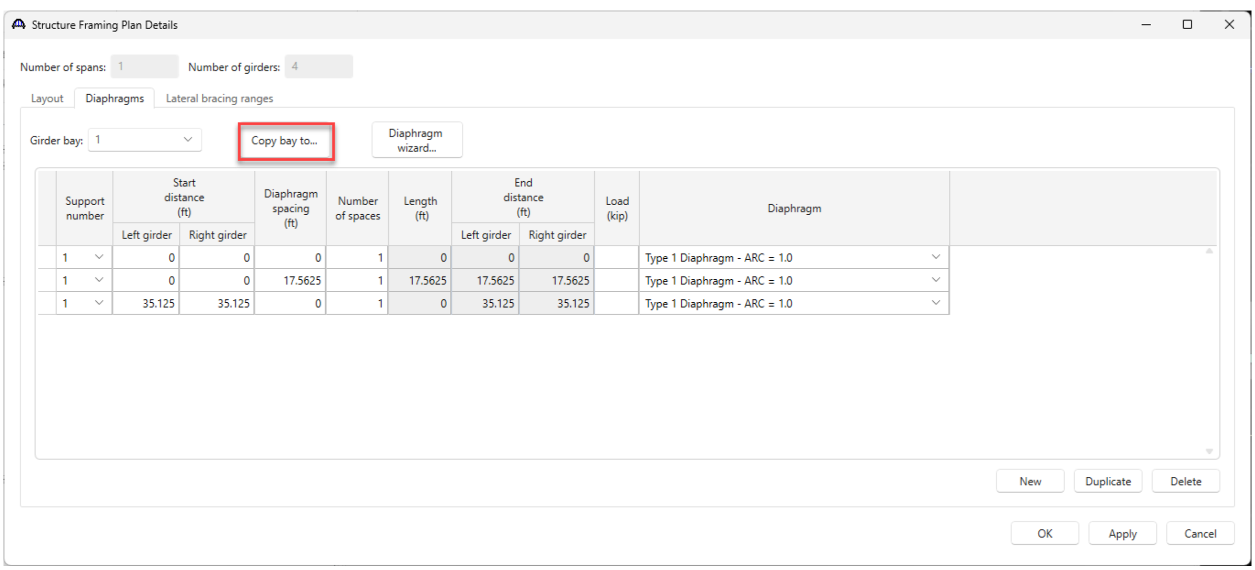


Framing plan details – Diaphragm spec checking

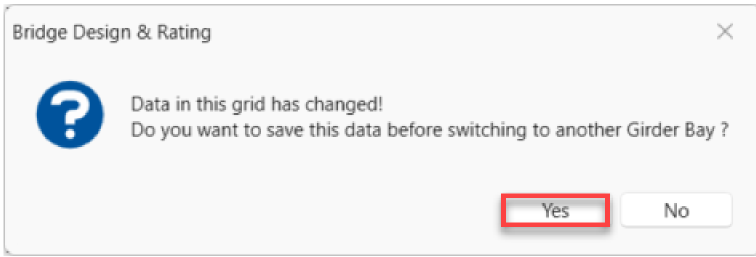
Now that the diaphragm definitions have been added to the **Bridge Workspace**, they can be assigned to the exisiting diaphragm locations. Double click on **Framing Plan Detail** to open up the **Structure Framing Plan Details** widow for this superstructure. Click on the **Diaphragms** tab within this window and assign each location in **Girder Bay 1** with the **Type 1 Diaphragm – ARC = 1.0** definition that was created earlier.



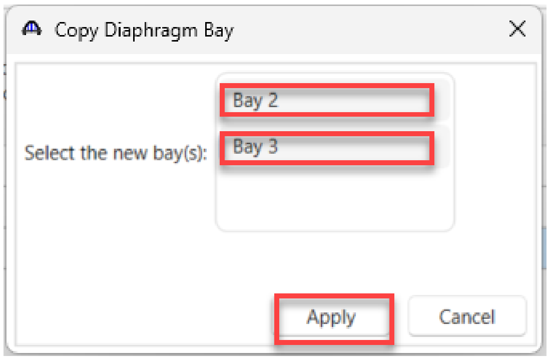
After assigning each diaphragm location in **Girder Bay 1** with the **Type 1 Diaphragm – ARC = 1.0** definition, select **Copy bay to...** and copy this data over to the other bays.



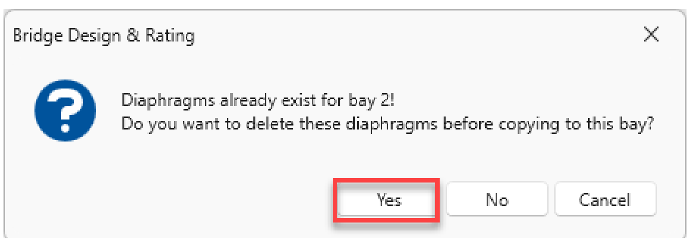
If this window pops up:

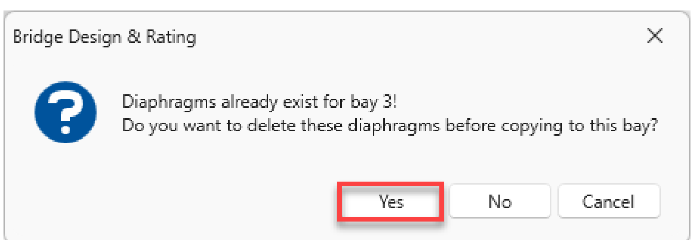


Select **Yes** and coninue. Then select **Bay 2** and **Bay 3**, then select **Apply**.

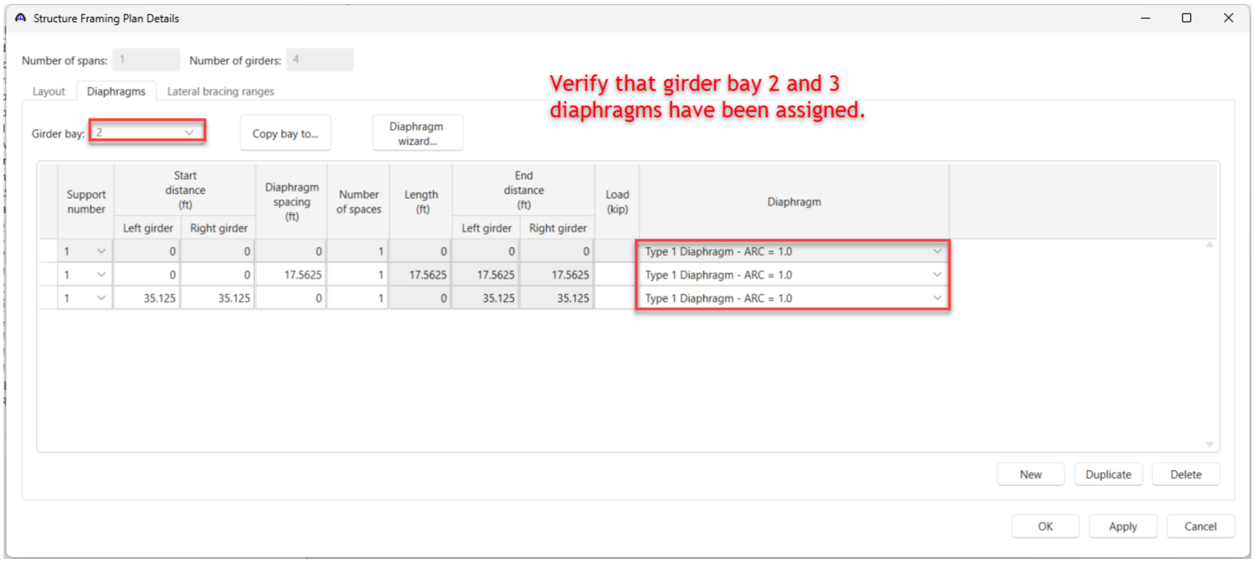


A window will pop up and ask if it's okay to delete these diaphragms before copying. This is okay since the diaphragm data is the same for girder bays 2 and 3. Select **Yes** and continue.



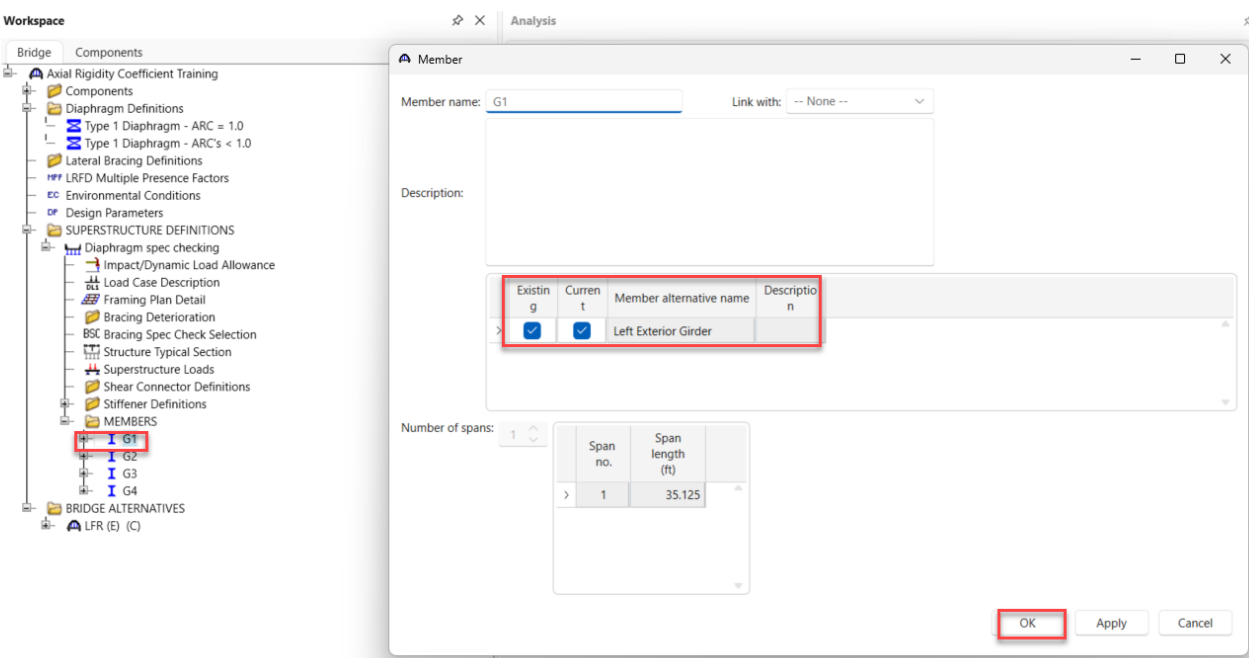


After these bays have been successfully copied, select the drop down list for Girder bay and verify that girder bay 2 & 3 diaphragms have been assigned.



Then select **OK** to apply the changes and close the **Structure Framing Plan Details** window.

Next, double click **G1** to open the **Member** window. Then make sure **Existing** and **Current** check boxes are checked. Select **OK** to close the window.

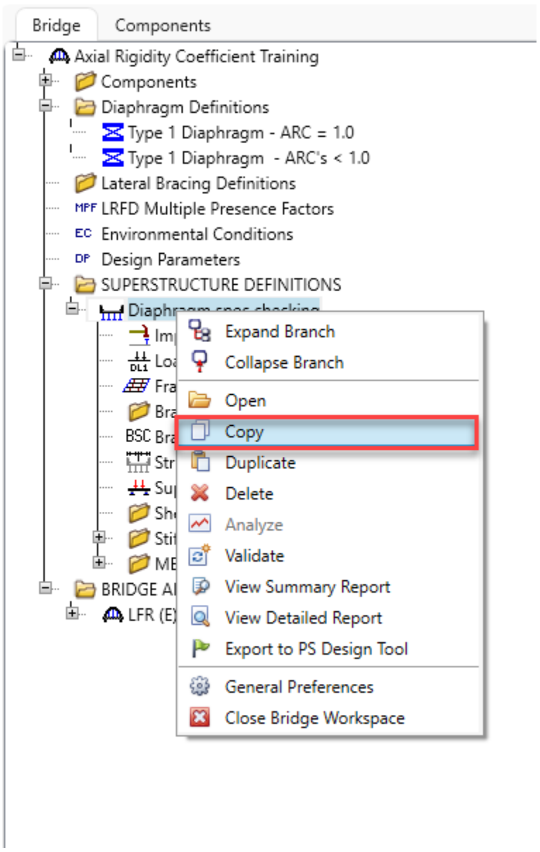


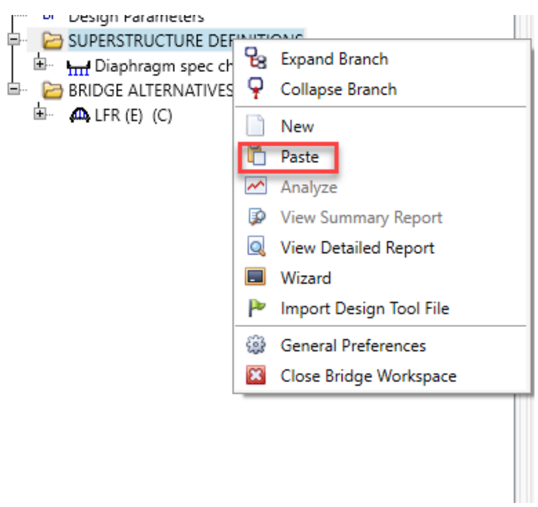
Open the remaining girders 2 through 4 to make sure **Existing** and **Current** check boxes are checked.

Copy superstructure

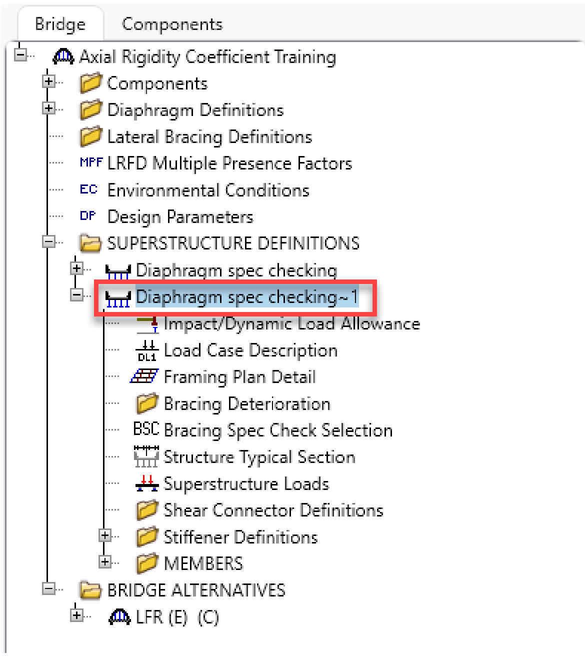
Diaphragm spec checking superstructure now has a diaphragm definition assigned to each location with the ARC values all set to 1.0. This superstructure can now be copied over and only the ARC values will need to be modified to compare diaphragm spec check results.

Right click on **Diaphragm spec checking** superstructure and select **Copy**. Then seelct the **SUPERSTRUCTURE DEFINITIONS** folder and right click to **paste** the superstructure.

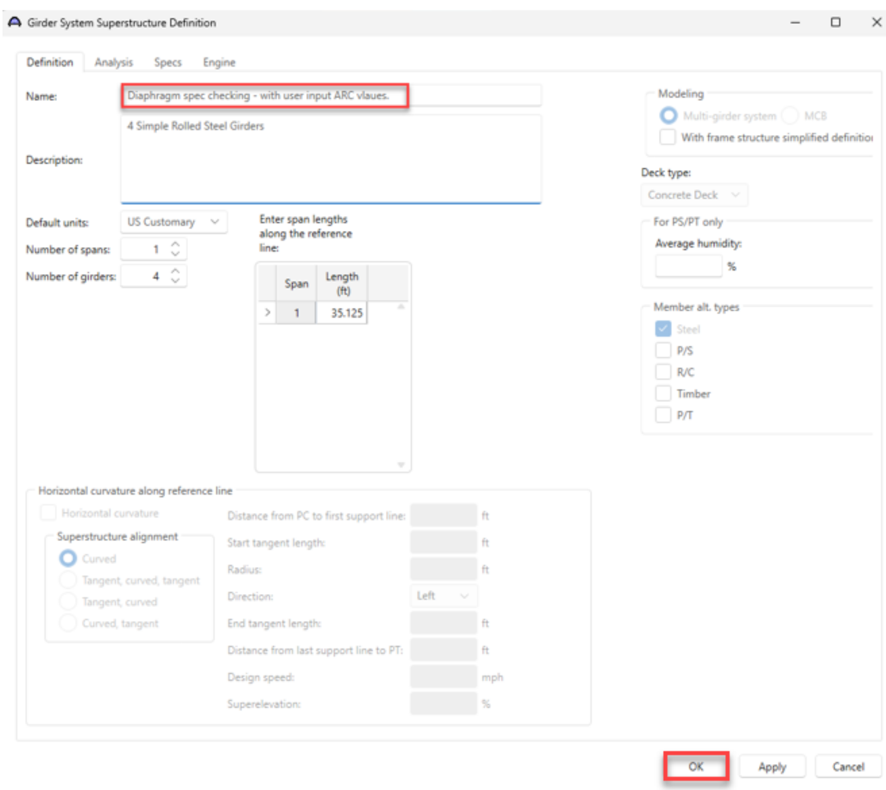




Now double click on the superstructure definition that was created.

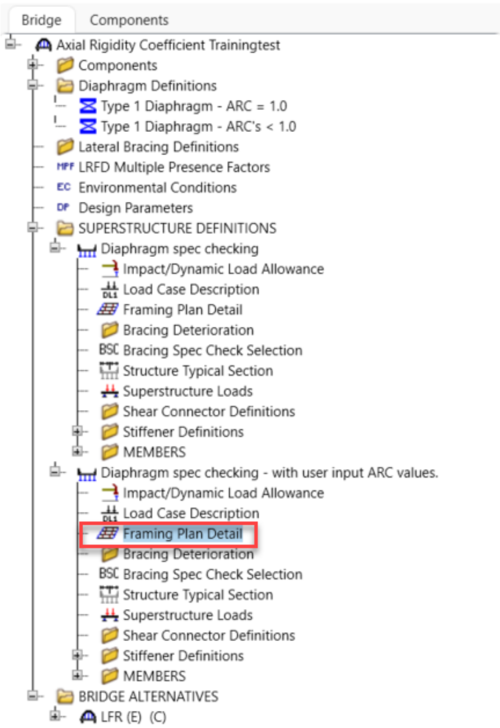


Change the superstructure name to the following and select **OK**.

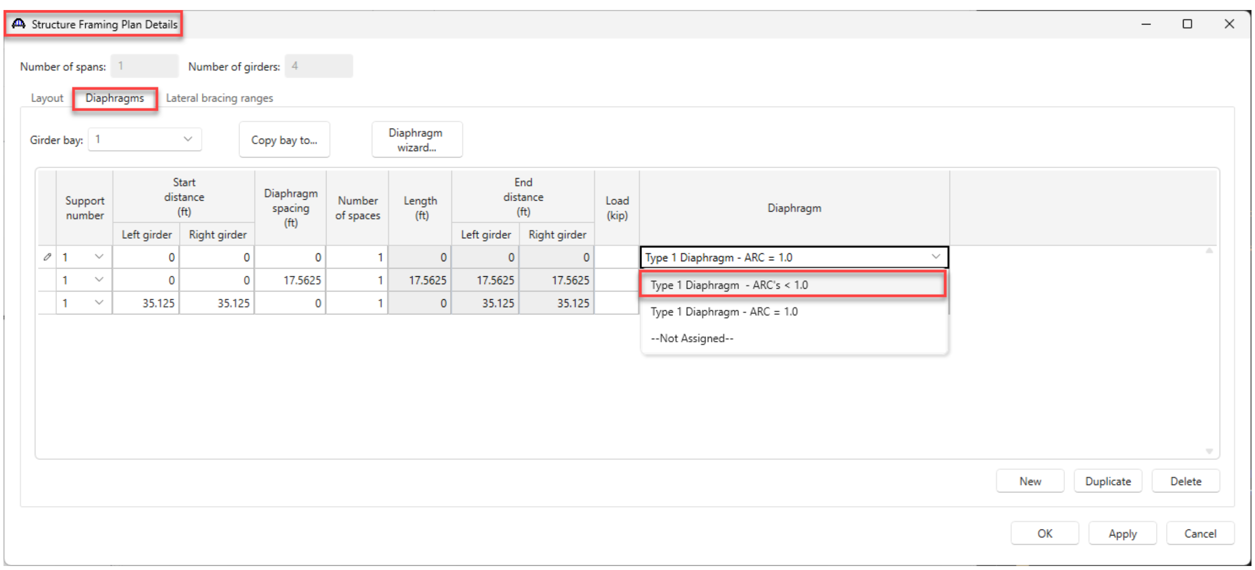


Framing plan details – Diaphragm spec checking – with user input ARC values

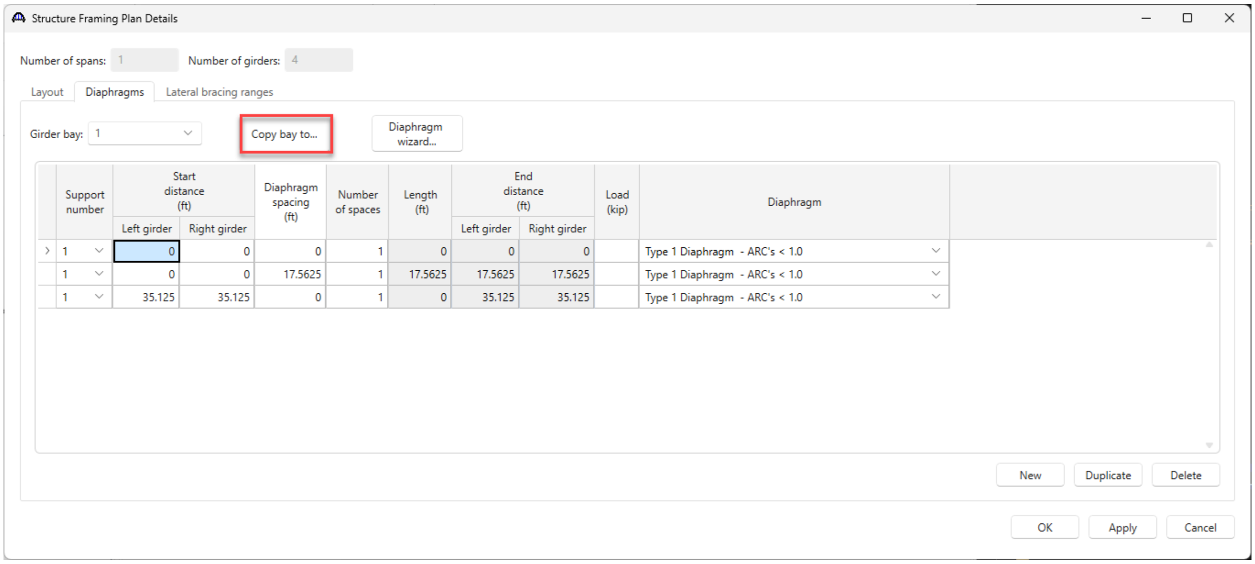
Now expand **Diaphragm spec checking – with user input ARC values** superstructure and double click on **Framing Plan Detail** to open the **Structure Framing Plan Details** window.



Switch over to the Diaphragms tab and begin assigning diaphragms to **Type 1 Diaphragm – ARC's < 1.0**.



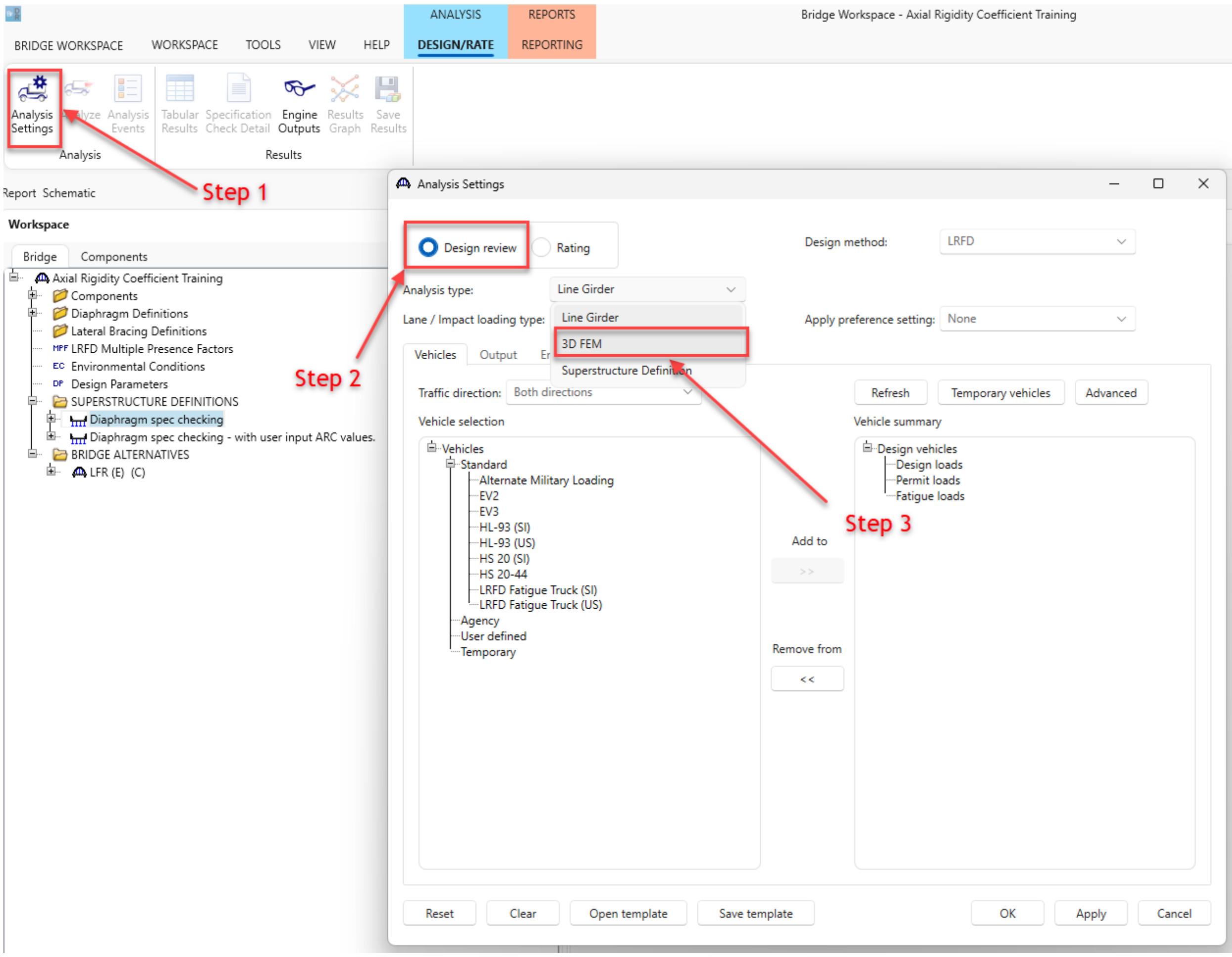
Once **Girder bay 1** is completed, the other two girder bays can be copied over similar to when the diaphragms were assigned for the **Diaphragm spec checking** superstructure. To do this, use the **Copy bay to…** button like previously.



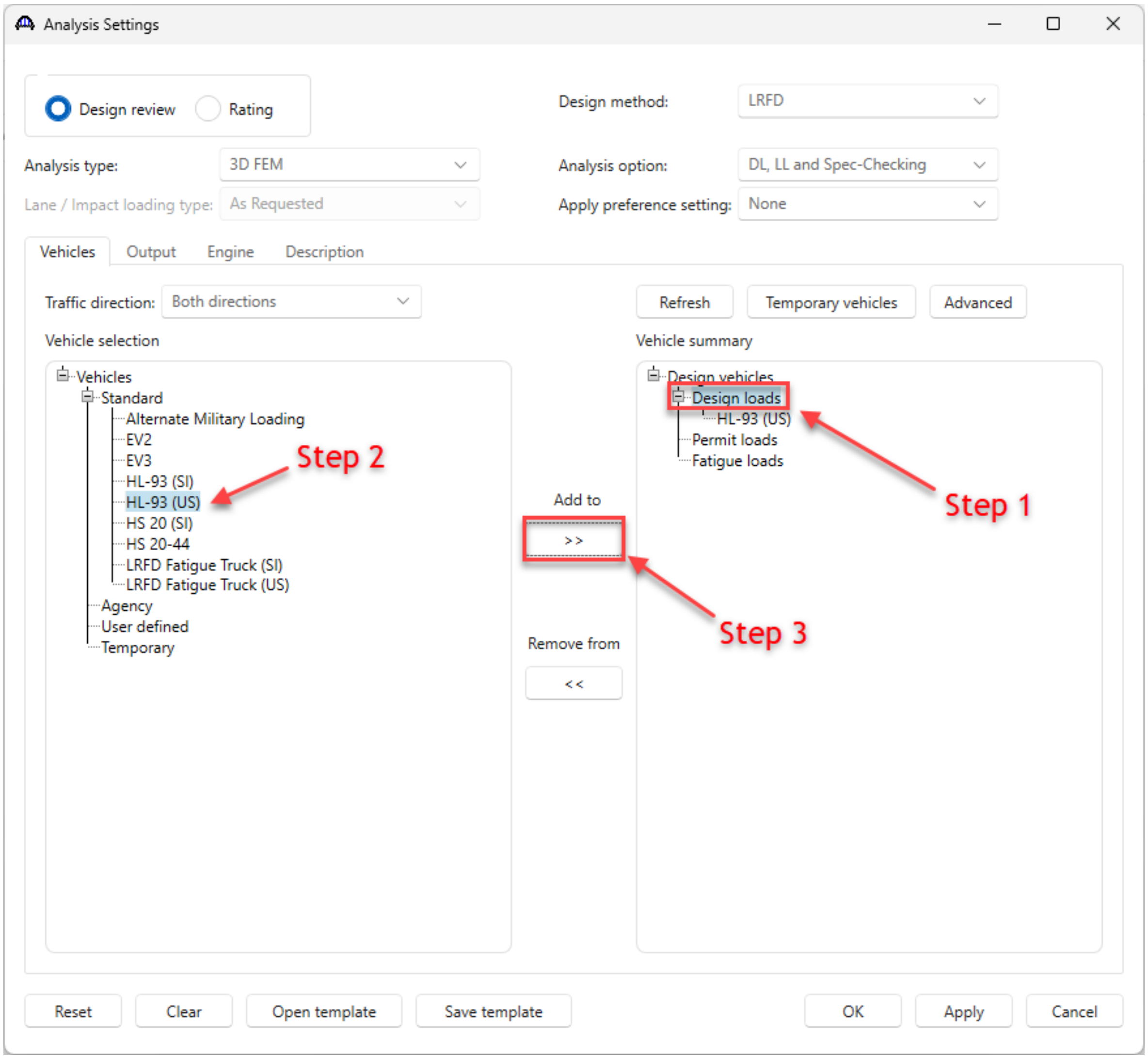
Diaphragm spec checking comparison

Analysis Settings

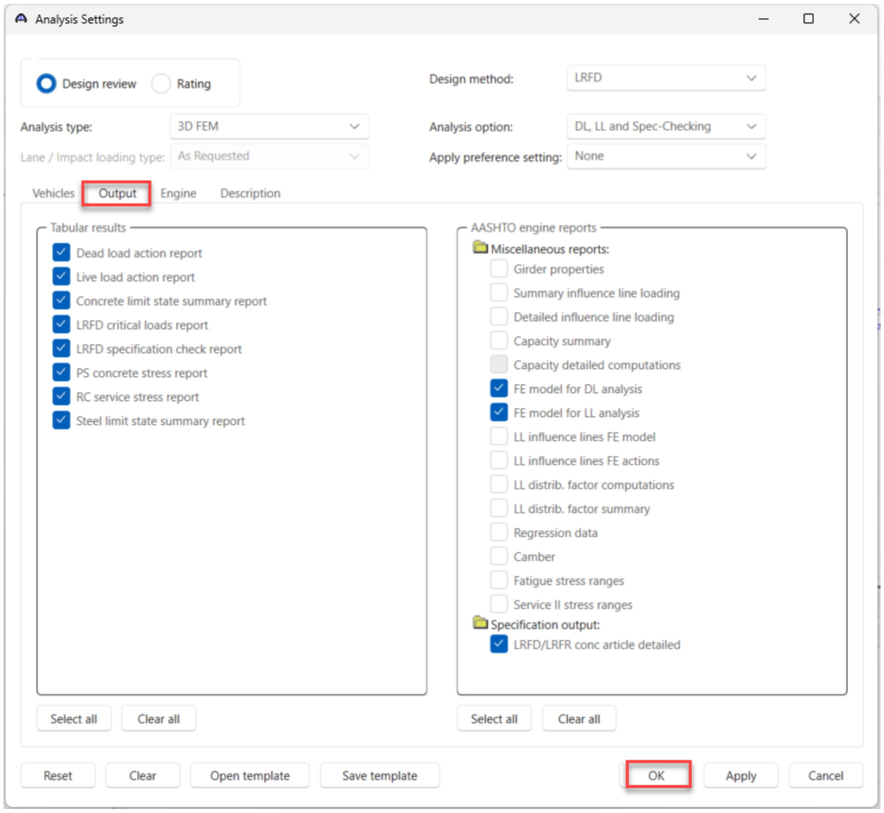
Now it's time to set up the analysis. Open the **Analysis Settings** window by clicking on **Analysis Settings** in the upper left corner of the **Bridge workspace**. Then, click on the **Design review** radio button. Next, click on the drop down menu to select the **Analysis type** and select **3D FEM**.



After **3D FEM** is selected for **Analysis type**, click on the **Design loads** to select **Vehicle Summary** and click on **HL-93 (US)** to select the vehicle, then select the **> >** button to add the **HL-93 (US)** vehicle to the Design loads.

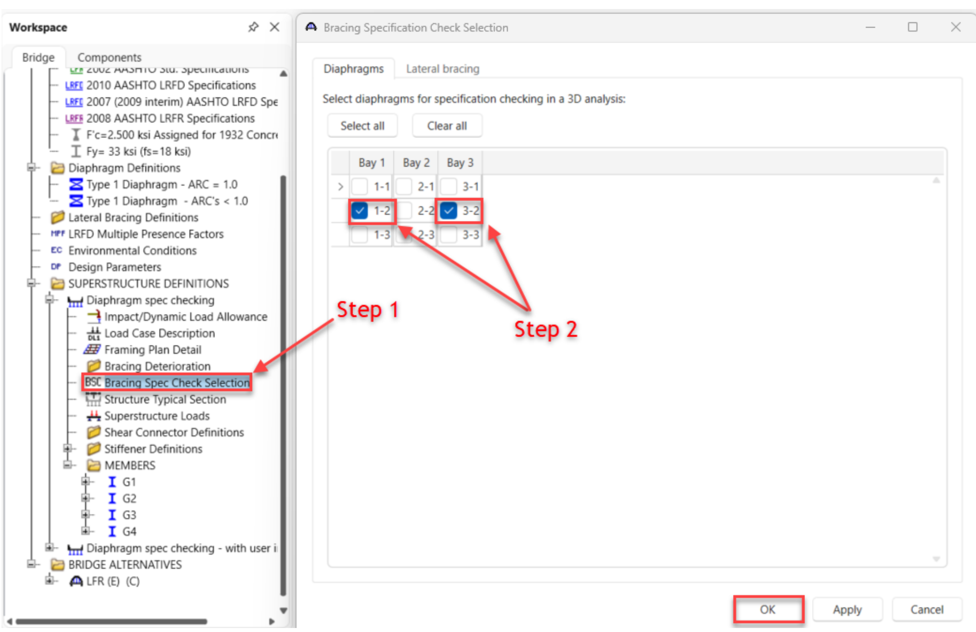


Next, select the **Output** tab and make sure the following items are checked.



Selecting diaphragms for spec checking

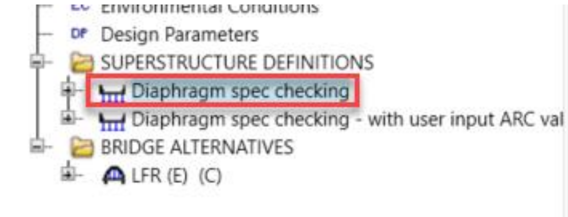
Next within the **Diaphragm spec checking** superstructure double click on **Bracing Spec Check Selection** to open the **Bracing Spec Check Selection** window. Then select diaphragms **1-2** and **3-2**. Then select **OK** to close the window.

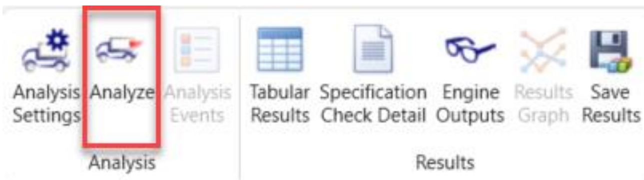


Follow these same steps to add the diaphragms **1-2** and **3-2** for the **Diaphragm spec checking – with user input ARC values** superstructure.

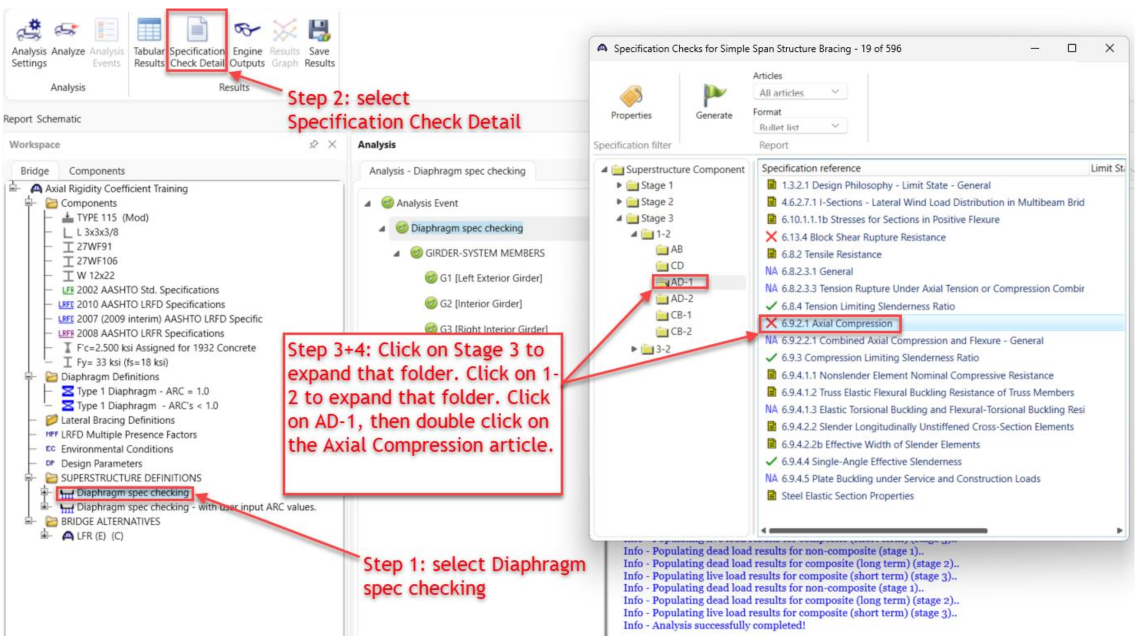
Analyzing Diaphragm spec checking superstructure

Finally, select the **Diaphragm spec checking** superstructure and select **Analyze**.

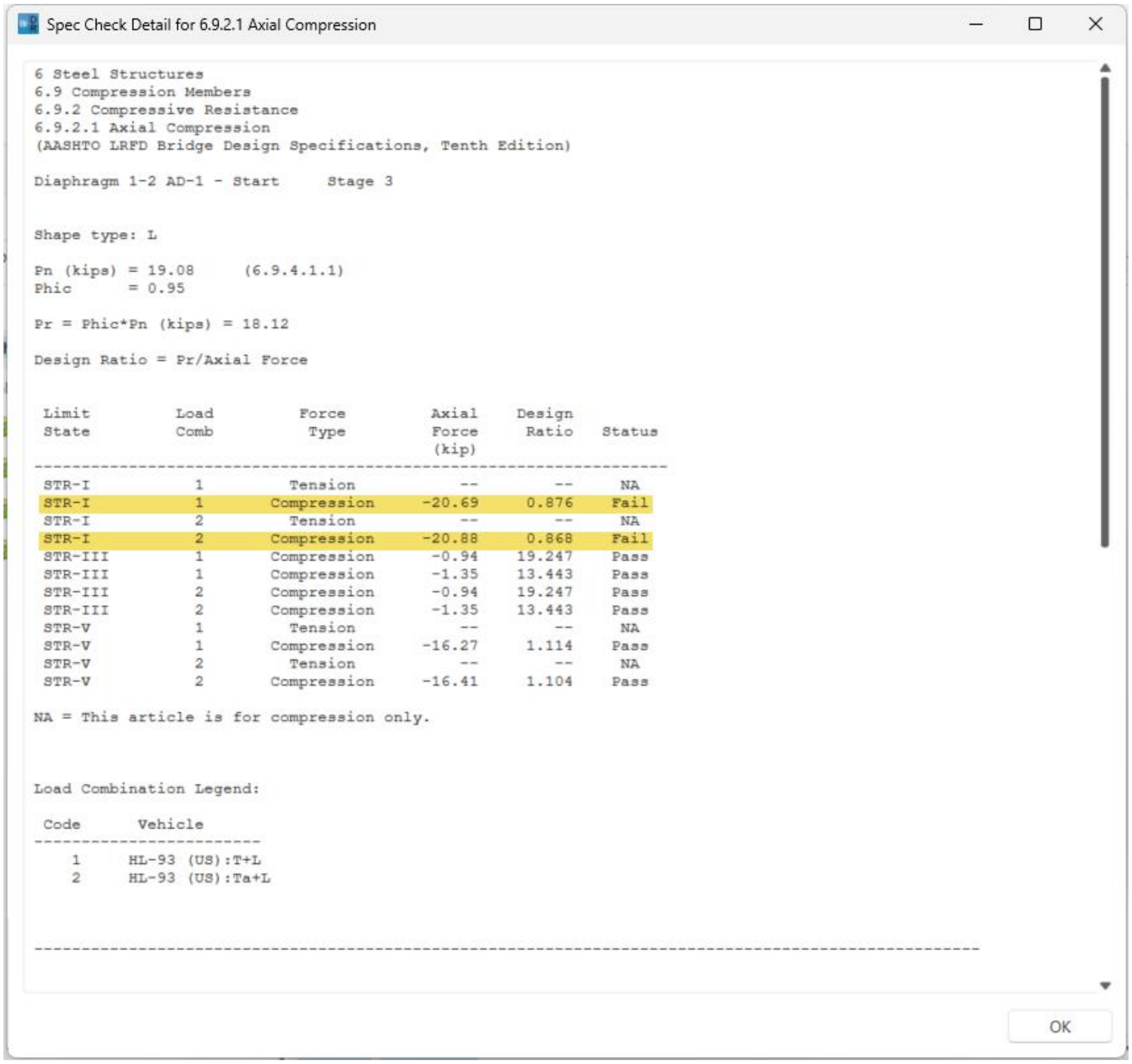




After the analysis has completed, open article **6.9.2.1 – Axial Compression** for Diaphragm **1-2**, member **AD-1**. Follow these steps to open the article output.



Article 6.9.2.1 – Axial Compression for diaphragm **1-2**, member **AD-1** has two load cases that fail the spec check for this diaphragm member.



Spec Check Detail for 6.9.2.1 Axial Compression

```
6 Steel Structures
6.9 Compression Members
6.9.2 Compressive Resistance
6.9.2.1 Axial Compression
(AASHTO LRFD Bridge Design Specifications, Tenth Edition)

Diaphragm 1-2 AD-1 - Start     Stage 3


Shape type: L

Pn (kips) = 19.08      (6.9.4.1.1)
Phic      = 0.95

Pr = Phic*Pn (kips) = 18.12

Design Ratio = Pr/Axial Force
```

Limit State	Load Comb	Force Type	Axial Force (kip)	Design Ratio	Status
STR-I	1	Tension	--	--	NA
STR-I	1	Compression	-20.69	0.876	Fail
STR-I	2	Tension	--	--	NA
STR-I	2	Compression	-20.88	0.868	Fail
STR-III	1	Compression	-0.94	19.247	Pass
STR-III	1	Compression	-1.35	13.443	Pass
STR-III	2	Compression	-0.94	19.247	Pass
STR-III	2	Compression	-1.35	13.443	Pass
STR-V	1	Tension	--	--	NA
STR-V	1	Compression	-16.27	1.114	Pass
STR-V	2	Tension	--	--	NA
STR-V	2	Compression	-16.41	1.104	Pass

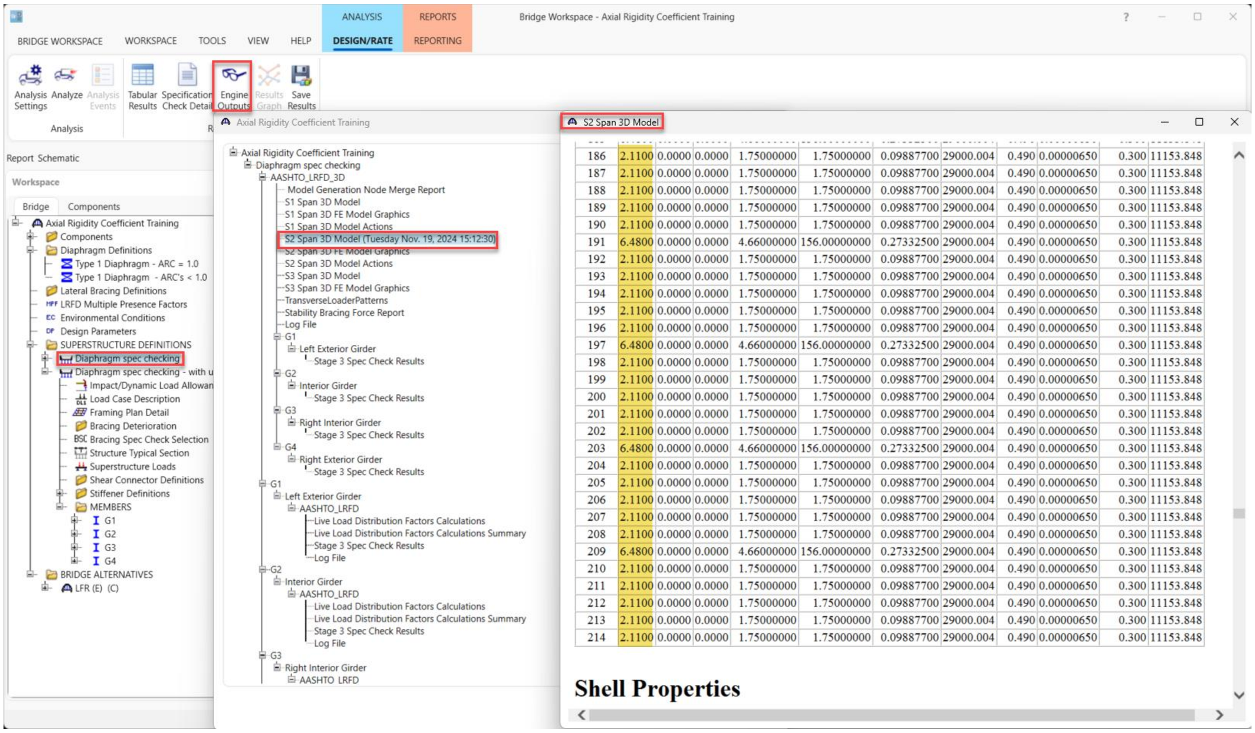
NA = This article is for compression only.

Load Combination Legend:

Code	Vehicle
1	HL-93 (US):T+L
2	HL-93 (US):Ta+L

OK

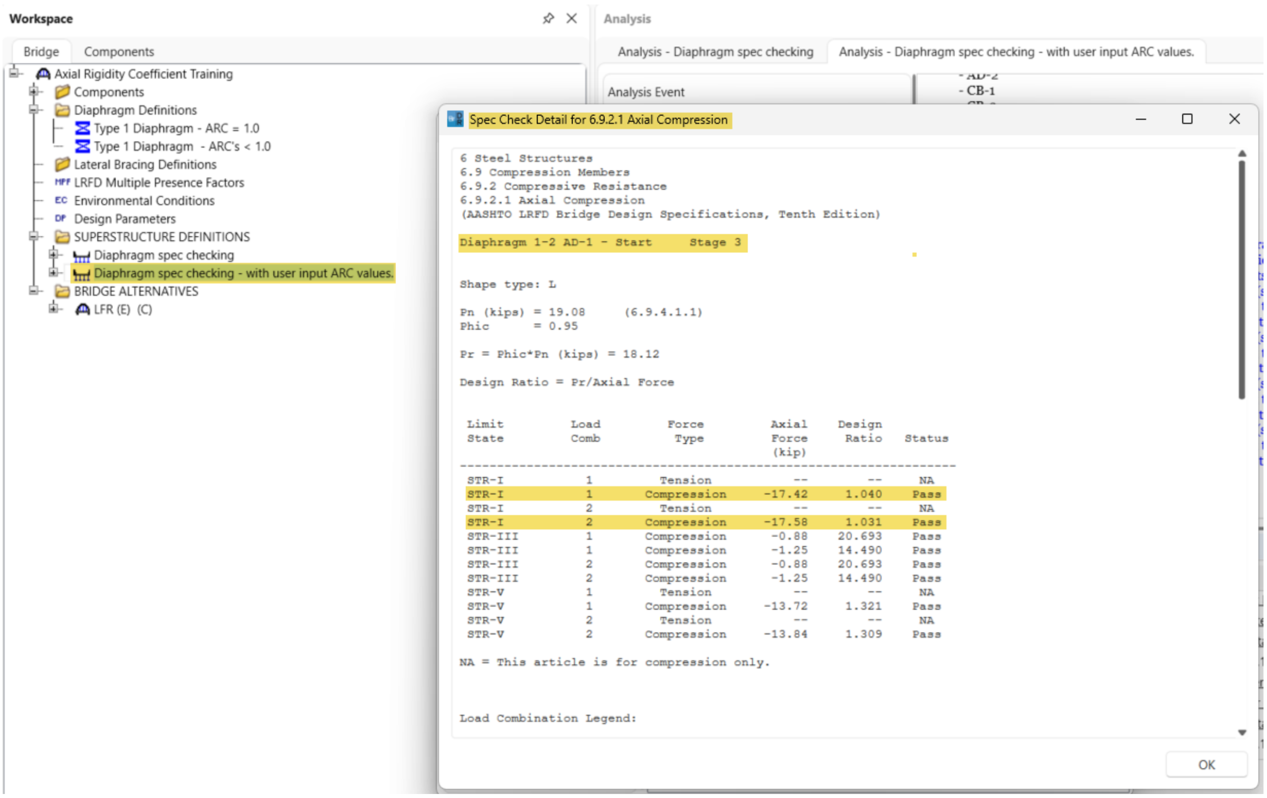
The effect that the axial rigidity coefficients have is in the FE model on the cross-frame member areas. To look at the individual beam element properties, click on **Diaphragm spec checking** superstructure, click on **Engine Outputs**, then double click on **S2 Span 3D Model** to bring up the stage 2 beam properties that were calculated for each individual beam element. Scroll to the section labeled **Beam Properties**. The second column shows the area of the individual beam elements. The diaphragm member areas are shown at the bottom of this table.



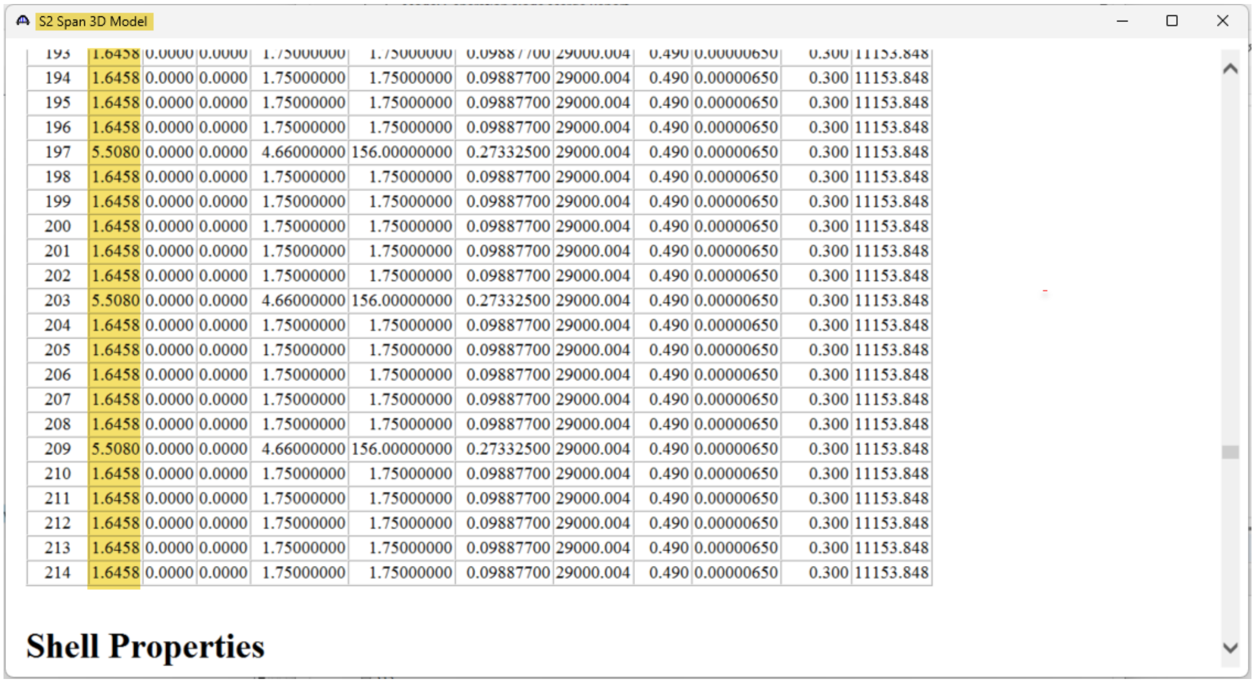
In the following steps, the analysis will be run on the **Diaphragm spec checking – with user input ARC values** and the scaled areas can be observed there.

Analyzing Diaphragm spec checking – with user input ARC values superstructure

To see the effect the ARC values have on the spec check results, run the same exact analysis on the **Diaphragm spec checking – with user input ARC values** superstructure. The results for this superstructure can be seen in the following screenshot



This article passes for the same diaphragm member and same load cases. For the AD-2 diaphragm member, the stage 2 ARC value was input at 0.78 which reduced the axial stiffness on the diaphragm member. As the axial stiffness was reduced, this reduced the axial compression for this member. To see where the coefficients are used, open the **S2 Span 3D Model** file in the **Engine Outputs**. The areas of the individual cross frame members can be observed. Notice that the last few diaphragm member areas have been reduced to **1.6458 in^2** which is equal to **2.11 in^2 * 0.78**.



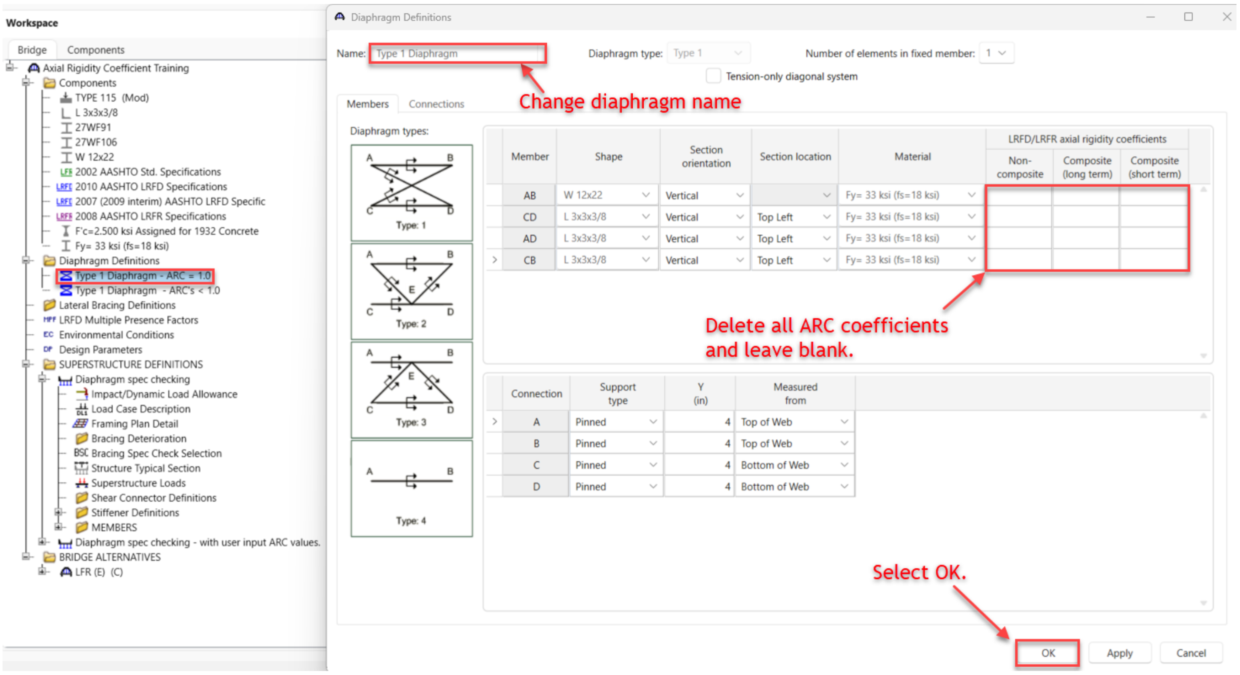
193	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
194	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
195	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
196	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
197	5.5080	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
198	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
199	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
200	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
201	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
202	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
203	5.5080	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
204	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
205	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
206	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
207	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
208	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
209	5.5080	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
210	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
211	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
212	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
213	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
214	1.6458	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848

Shell Properties

Modifying ARC values in diaphragm definition window for Diaphragm spec checking superstructure

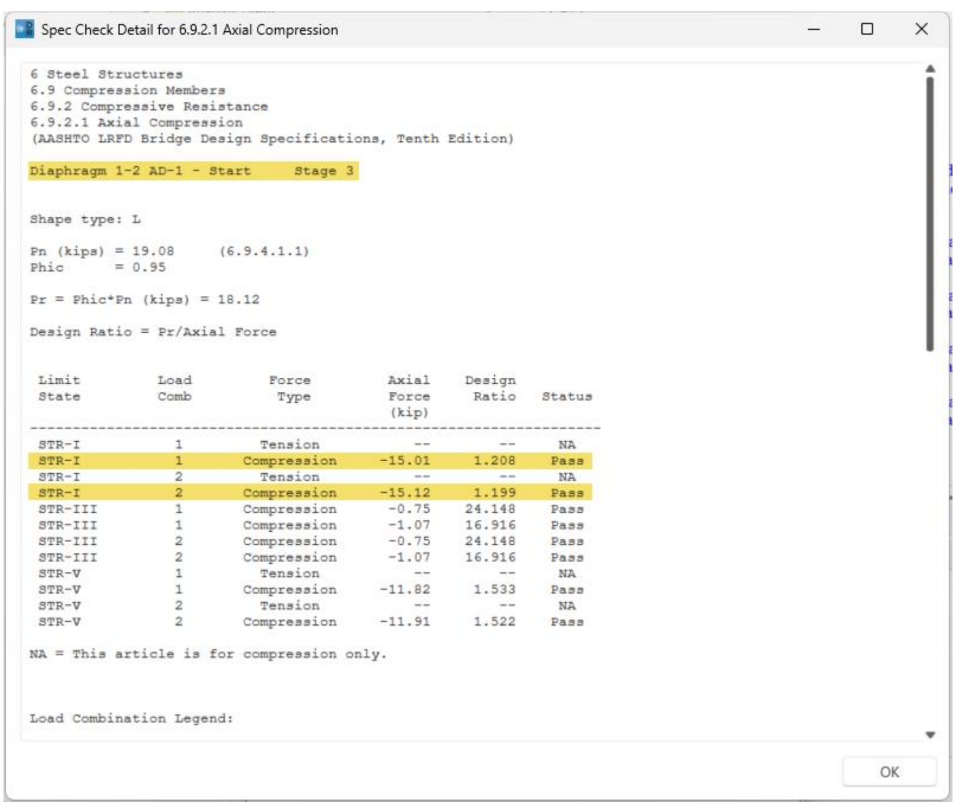
If the **3DFEM6-Axial-Rigidity-Coefficient-Example.xml** was imported, the following steps will need to be followed to observe the default behavior for ARC values.

If ARC values are deleted and left blank and the diaphragm members are either single angle or horizontally oriented T-shaped, default coefficient values of 0.65 or 0.75 for non-composite or composite members respectively will be assumed. To see this behavior, double click on **Type 1 Diaphragm – ARC = 1.0**, change the name to **Type 1 Diaphragm**, delete all the ARC coefficients, and select **OK**.



Analyzing Diaphragm spec checking superstructure with default ARC behavior

Since this diaphragm definition is already assigned to the **Diaphragm spec checking** superstructure diaphragms, the analysis can be run again without needing to change anything else. The following results can be observed for this scenario.



Spec Check Detail for 6.9.2.1 Axial Compression

6 Steel Structures
6.9 Compression Members
6.9.2 Compressive Resistance
6.9.2.1 Axial Compression
(AASHTO LRFD Bridge Design Specifications, Tenth Edition)

Diaphragm 1-2 AD-1 - Start Stage 3

Shape type: L

Pn (kips) = 19.08 (6.9.4.1.1)
Phic = 0.95

Pr = Phic*Pn (kips) = 18.12

Design Ratio = Pr/Axial Force

Limit State	Load Comb	Force Type	Axial Force (kip)	Design Ratio	Status
STR-I	1	Tension	--	--	NA
STR-I	1	Compression	-15.01	1.208	Pass
STR-I	2	Tension	--	--	NA
STR-I	2	Compression	-15.12	1.199	Pass
STR-III	1	Compression	-0.75	24.148	Pass
STR-III	1	Compression	-1.07	16.916	Pass
STR-III	2	Compression	-0.75	24.148	Pass
STR-III	2	Compression	-1.07	16.916	Pass
STR-V	1	Tension	--	--	NA
STR-V	1	Compression	-11.82	1.533	Pass
STR-V	2	Tension	--	--	NA
STR-V	2	Compression	-11.91	1.522	Pass

NA = This article is for compression only.

Load Combination Legend:

OK

Note, that the axial compression forces are now even lower on diaphragm **1-2**, member **AD-1** because axial rigidity coefficients of 0.65 have been assumed compared to 0.78 from before. Again, looking at the **S2 Span 3D Model** file in the **Engine Outputs**, looking at the last few beam elements, the reduced area is **1.3715 in^2 = 2.11 in^2 * 0.65**.

S2 Span 3D Model

185	6.4800	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
186	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
187	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
188	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
189	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
190	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
191	6.4800	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
192	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
193	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
194	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
195	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
196	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
197	6.4800	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
198	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
199	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
200	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
201	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
202	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
203	6.4800	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
204	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
205	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
206	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
207	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
208	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
209	6.4800	0.0000	0.0000	4.66000000	156.00000000	0.27332500	29000.004	0.490	0.00000650	0.300	11153.848
210	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
211	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
212	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
213	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848
214	1.3715	0.0000	0.0000	1.75000000	1.75000000	0.09887700	29000.004	0.490	0.00000650	0.300	11153.848

Shell Properties

When reducing the area for the beam elements in the FE model, this will effectively reduce the axial stiffness for the cross-frame member beam elements which matches the intent of the 10^{th} edition spec updates. Scaling the area instead of scaling the modulus of elasticity ensures that only the axial stiffness is reduced and not both the axial and flexural stiffness. The area for determining member capacities will not be reduced in the engine. This also ensures that the scaled areas that are used to calculate the member forces will not influence the individual member capacities.