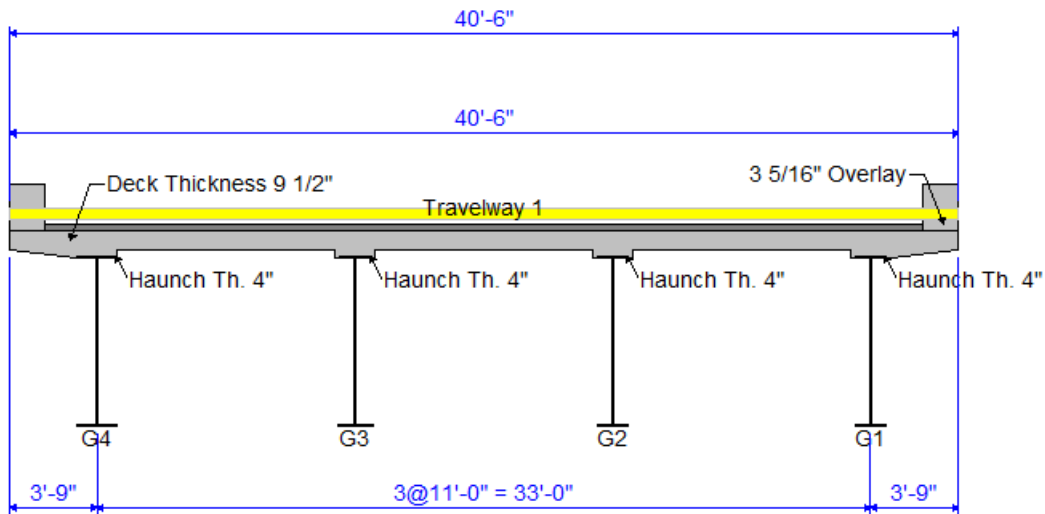
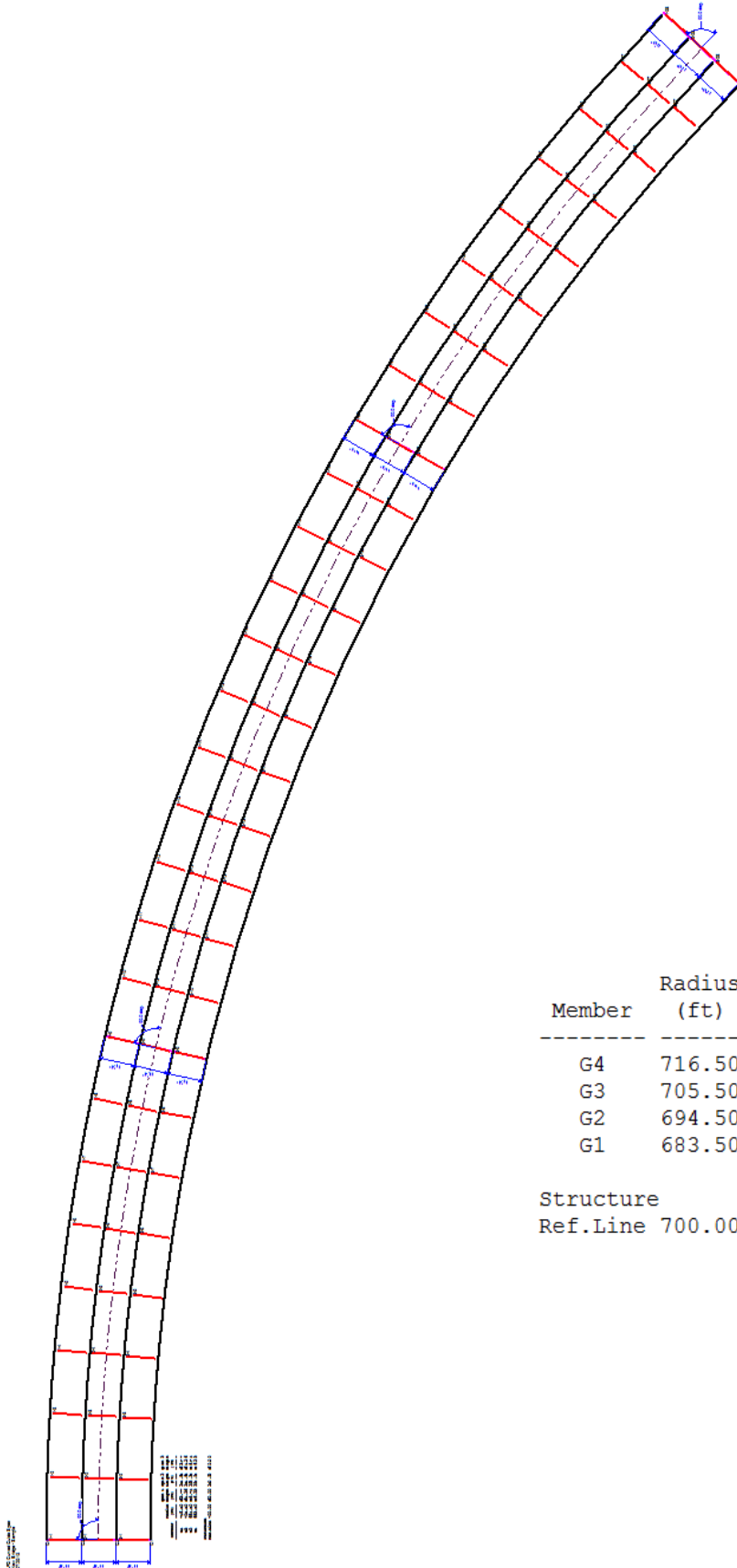


AASHTOWare Bridge Rating/Design Training

STL9 – Curved Steel 3D Example (BrR/BrD 6.5)

LFD Curved Guide Spec
New Bridge - Sample
07/29/13





Member	Radius (ft)	Span 1 Length (ft)	Span 2 Length (ft)	Span 3 Length (ft)
G4	716.50	163.77	214.95	163.77
G3	705.50	161.26	211.65	161.26
G2	694.50	158.74	208.35	158.74
G1	683.50	156.23	205.05	156.23

Structure	Ref.Line	700.00	160.00	210.00	160.00
Ref.Line	700.00	160.00	210.00	160.00	

AASHTOWare Bridge Rating/Design Training

STL9 – Curved Steel 3D Example (BrR/BrD 6.5)

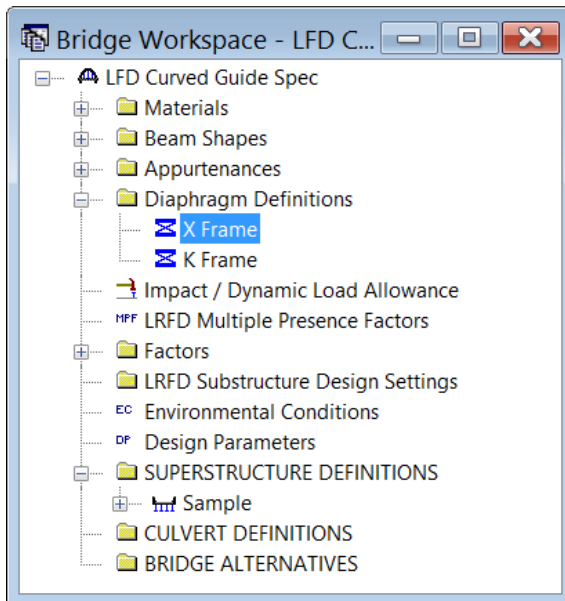
Topics Covered

- 3D analysis of a three span curved steel rolled beam bridge
- Diaphragm definitions
- 3D analysis settings
- 3D model

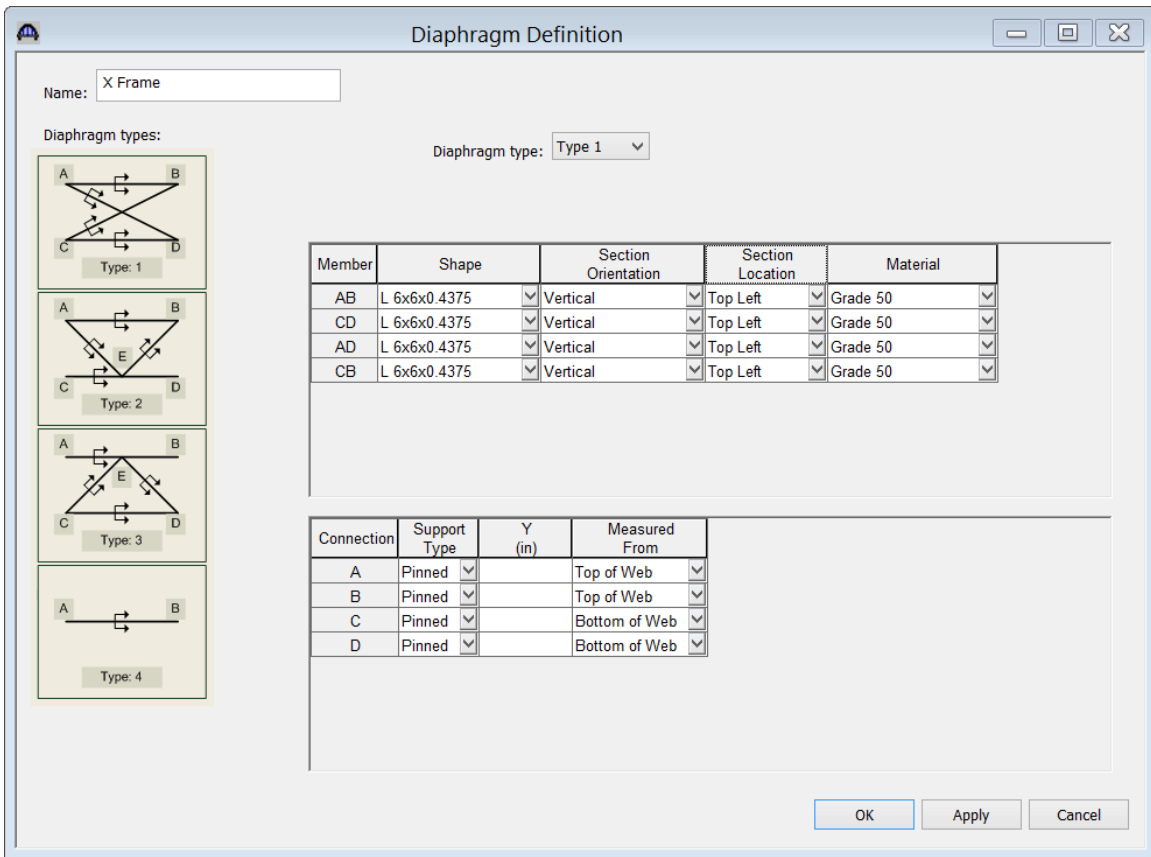
This example describes entering a curved steel rolled beam structure in BrDR and performing a 3D FEM analysis.

Import the file ‘STL9 – LFDCurvedGuideSpec.xml’ and open its Bridge Workspace. This bridge is the I-Girder design example presented in the appendix of the AASHTO Guide Specifications for Horizontally Curved Steel Girder Highway Bridges, 2003.

Open the Diaphragm Definition window shown below.

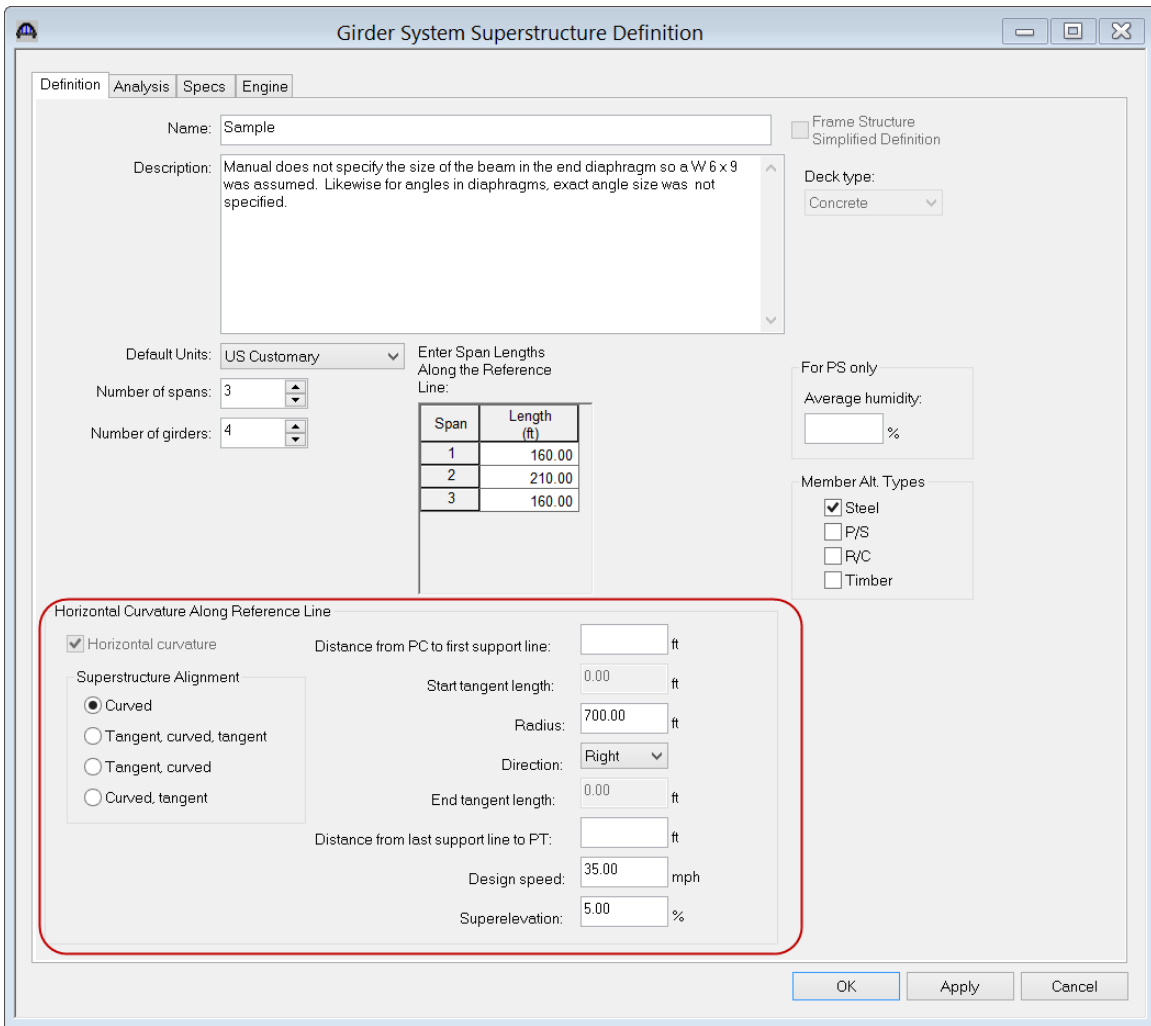


The following window shows a diaphragm definition that can be assigned to locations in the Framing Plan window. This is the same window that was introduced in 6.4.0 for 3D analysis of straight girder systems. There are no changes to it for 6.5.0.



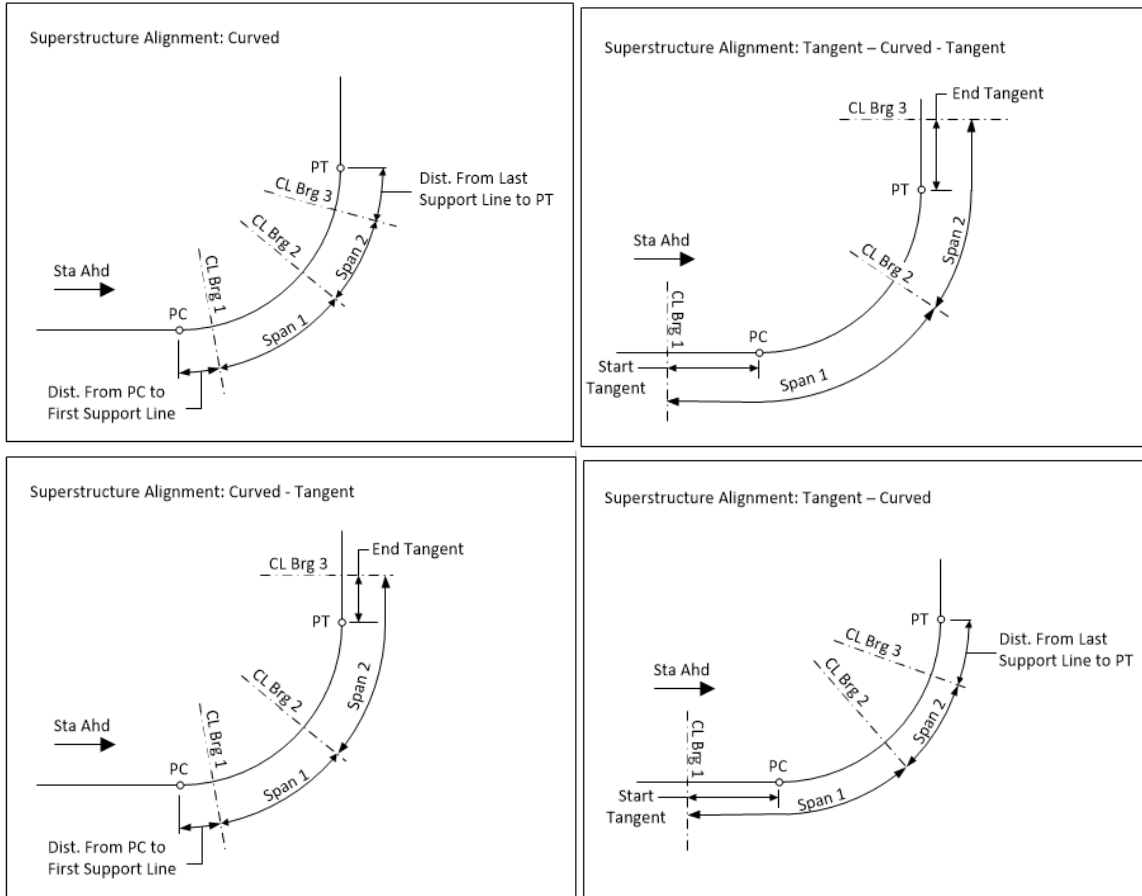
Steel bridges may contain any of the 4 types of diaphragm definitions. Straight concrete bridges may only contain Type 4 diaphragm definitions.

A horizontally curved girder system Superstructure Definition can now be created in BrDR 6.5. Only concentric girders with a constant deck width are supported. Only steel member alternatives can be created for a curved superstructure. The following shows the new controls to describe the curved geometry.



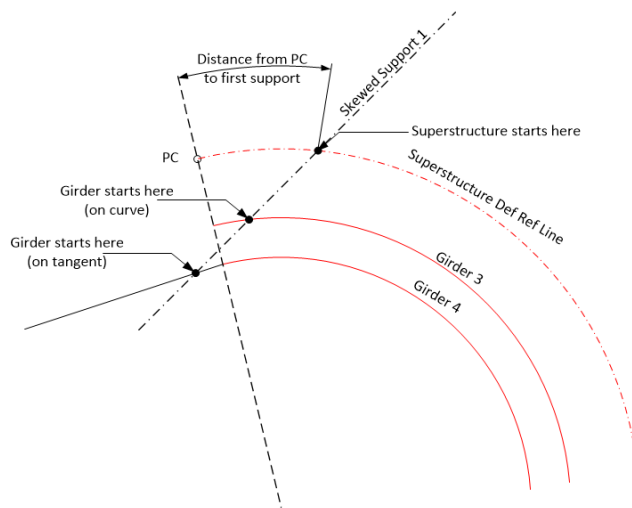
The design speed and superelevation are used to compute the centrifugal force effects on the truck live load. The high side of the roadway is assumed to be at the outside of the curve.

The following types of horizontal alignments are supported:

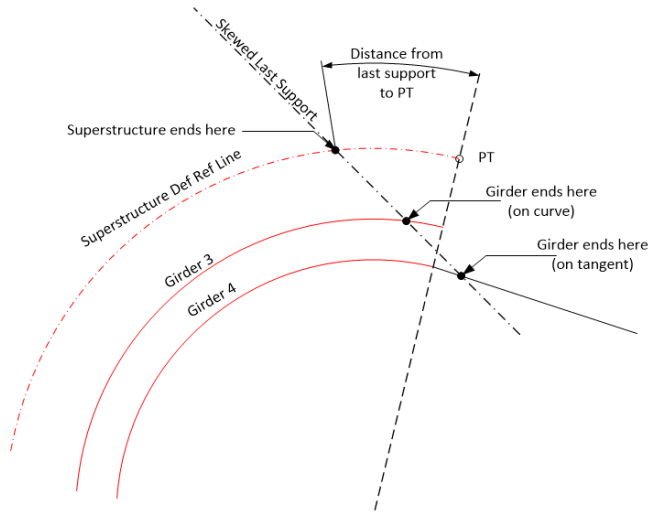


The Distance from PC to First Support Line and Distance from Last Support Line to PT are necessary to determine the member lengths when the first or last support line is skewed.

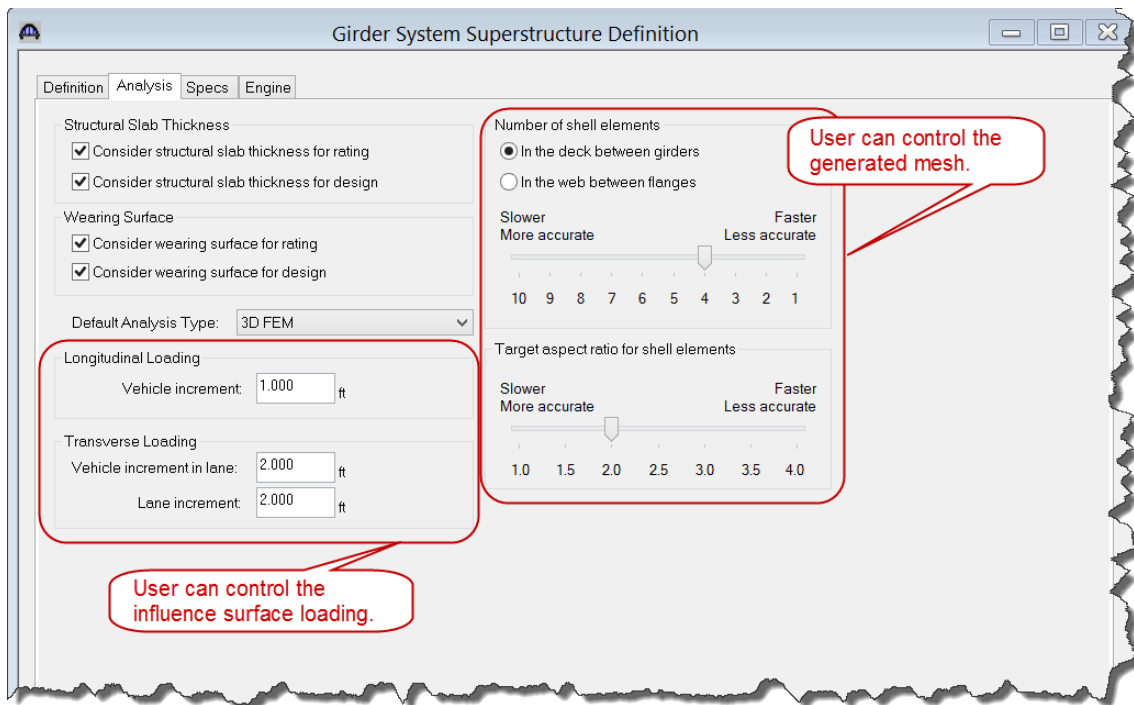
If the member starts before the defined PC location, that portion of the member is assumed to be tangent to the curve at the defined PC location. See Girder 4 in the following sketch.



If the member ends after the defined PT location, that portion of the member is assumed to be tangent to the curve at the defined PT location. See Girder 4 in the following sketch.



The Superstructure Definition window contains the following settings to control the 3D analysis.



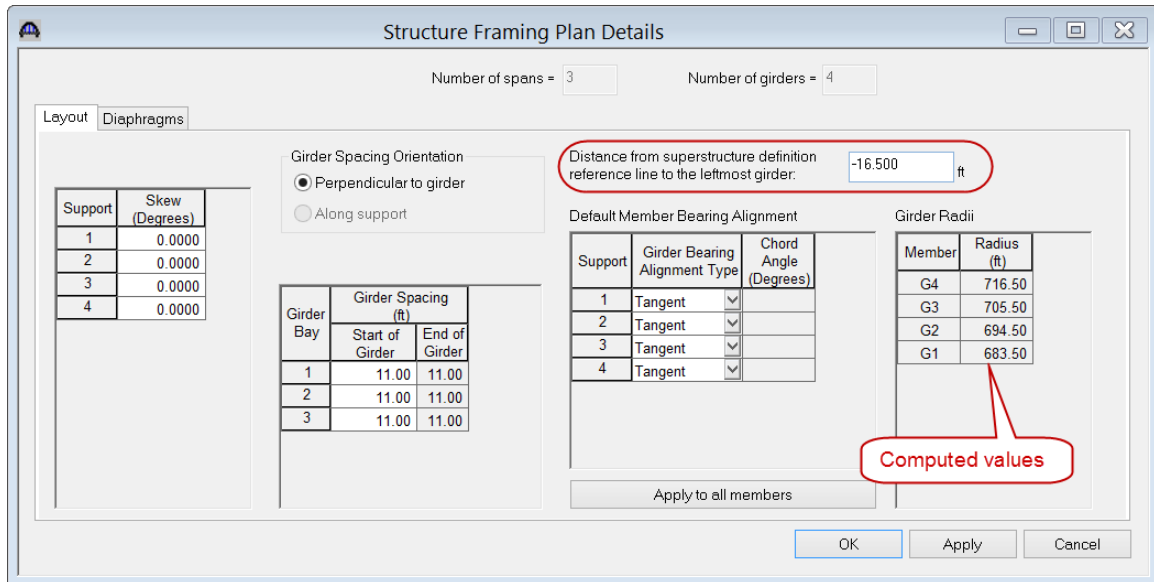
The analysis of all member alternatives in the superstructure definition will use the following engine and specification set on the Specs tab. An exception to this is LFD rating of curved systems. The LFD rating is performed in accordance with the “AASHTO Guide Specifications for Horizontally Curved Steel Girder Highway Bridges 2003”.

The screenshot shows a software window titled "Girder System Superstructure Definition" with tabs for "Definition", "Analysis", "Specs", and "Engine". The "Specs" tab is active, displaying a table with the following data:

Analysis Method Type	Analysis Module	Selection Type	Spec Version	Factors
ASD	AASHTO ASD	System Default	MBE 2nd 2013i, Std 17th	N/A
LFD	AASHTO LFD	System Default	MBE 2nd 2013i, Std 17th	2002 AASHTO Std. Specifications
LRFD	AASHTO LRFD	System Default	LRFD 6th 2013i	2012 AASHTO LRFD Specifications
LRFR	AASHTO LRFR	System Default	MBE 2nd 2013i, LRFD 6th 2013i	2011 (2013 Interim) AASHTO LRFR Spec.

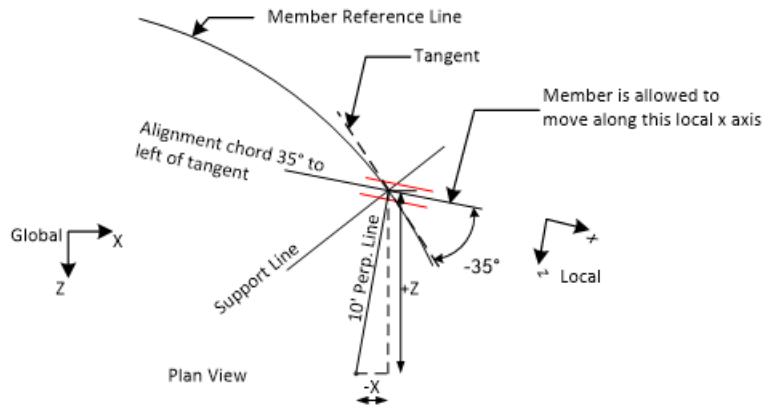
Open the Framing Plan Details: Layout tab to see how the girders are located in the structure typical section.

A new field is available for curved girder systems to locate the leftmost girder relative to the superstructure definition reference line. Enter a negative value if the leftmost girder is to the left of the superstructure definition reference line. This along with the entered girder spacing determines the computed radii of the girders.



Bearings are oriented in a local coordinate system at each member support in curved girder systems. The user is able to enter default values for the orientation of the Member Support constraints on this window and then apply them to all members. This is a shortcut feature to allow for ease of data entry. The constraints can be modified on the Member Support window as necessary. The constraint settings on this window are not used in the analysis, the constraint settings on the Member Support window are used instead.

Select 'Tangent' if the local x axis for bearing alignment is parallel to the tangent of the member reference line at the support. Select 'Chord' if the local x axis for the bearing alignment is parallel to a specified chord angle from the tangent of the member reference line at the support. The following sketch shows an example of defining a bearing alignment along a chord.



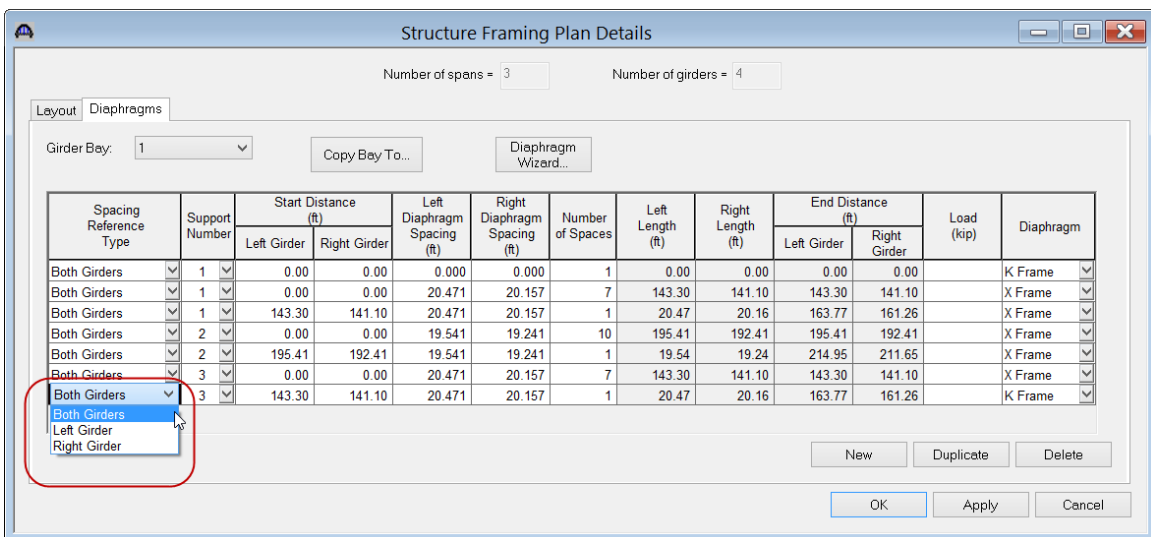
Open the Framing Plan Details: Diaphragms tab to see how diaphragm definitions are assigned to the framing plan. The weight of the diaphragms will be computed by the software and applied to the 3D model.

Diaphragms in curved girder systems can be located by one of 3 methods:

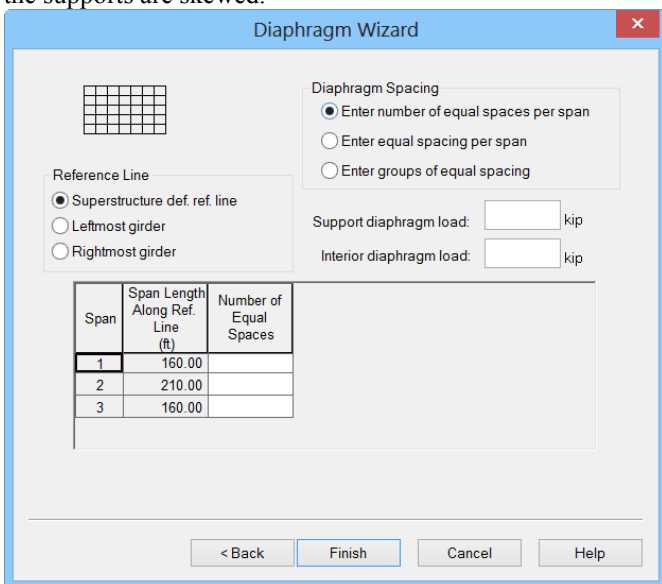
- entering the spacing along both girders of the bay
- entering the spacing along the left girder of the bay
- entering the spacing along the right girder of the bay

The spacing reference type ‘Both’ must be used when the diaphragms are not radial to either girder. This spacing reference type may also be used when the diaphragms are radial as shown in this example.

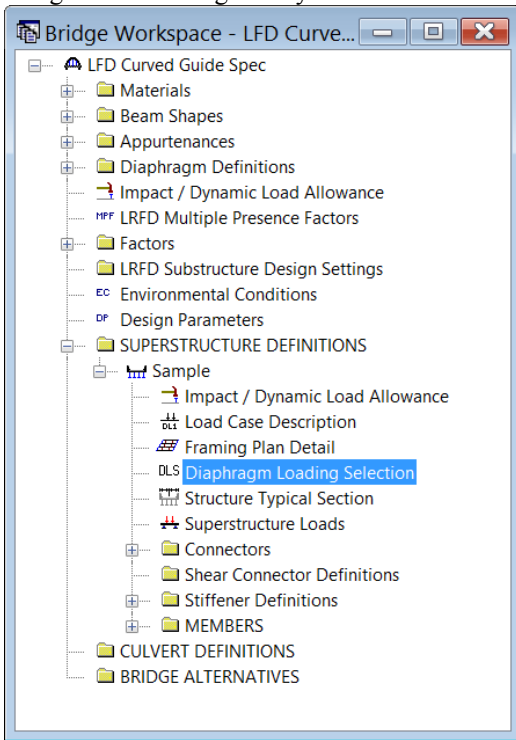
If the diaphragms are located by entering the spacing along the left or right girder of the bay, the resulting diaphragm location on the alternate girder will be computed by the program by casting a line perpendicular to the tangent of the specified girder at each spacing interval.



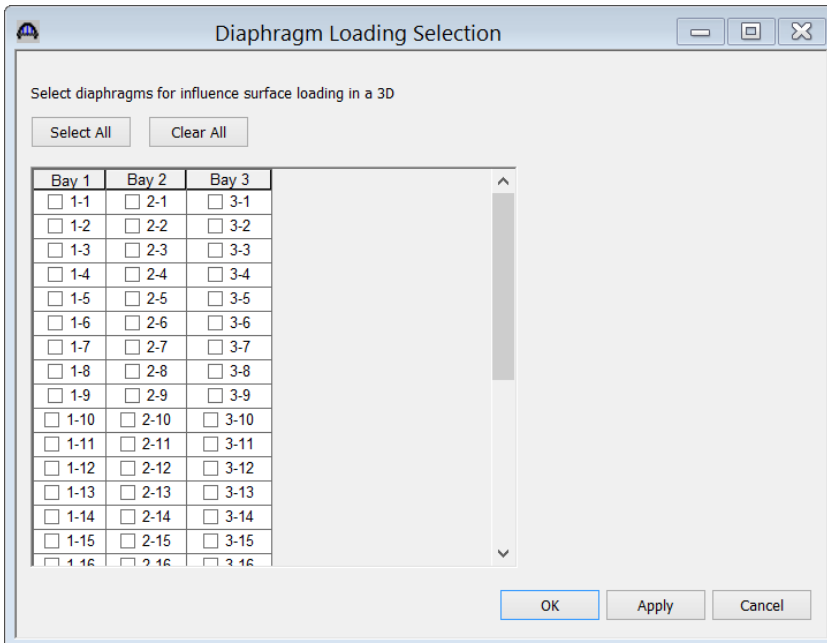
A wizard is available to create the diaphragm locations for the user. The wizard is not available if any of the supports are skewed.



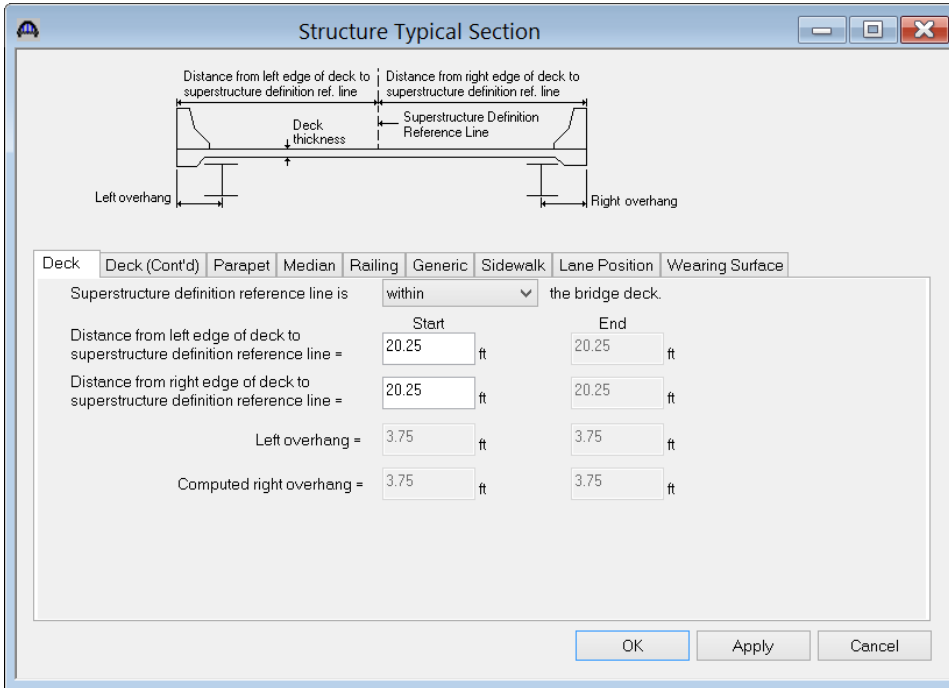
A new window to identify which diaphragms should be loaded for live load is now available for both straight and curved girder systems.



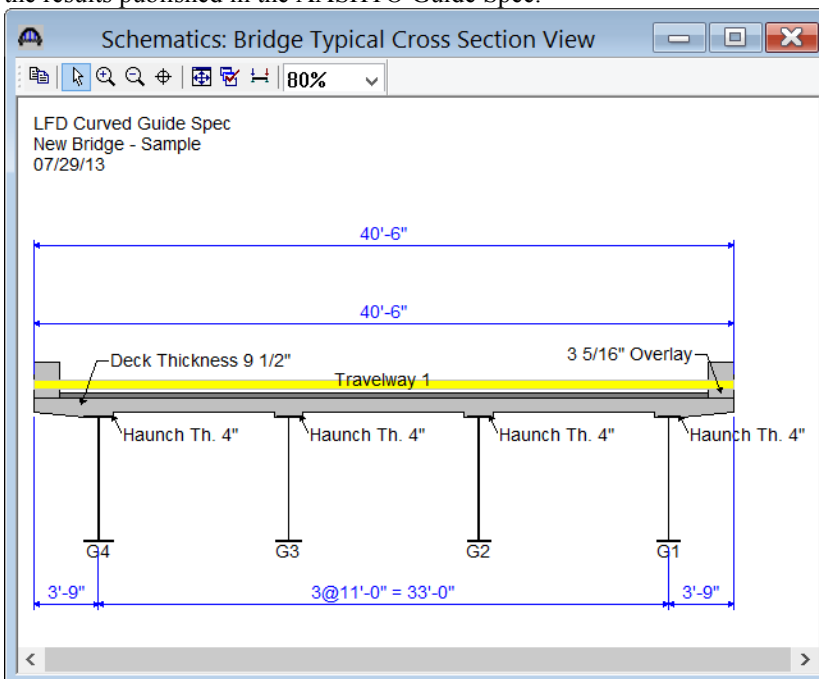
This window contains a listing of each diaphragm location in the superstructure definition. The first number is the bay number and the second number is the numerical id of the diaphragm starting with 1 for the diaphragm at the start of the bay. Selecting a diaphragm in this window will result in influence surfaces for the diaphragm members being generated and then loaded with the live load. Including a lot of diaphragms in the live load analysis can greatly affect the run time and amount of memory needed for the analysis. Note that the diaphragms are always included in the FE model. This checkbox only controls if the diaphragm members are loaded for live load.



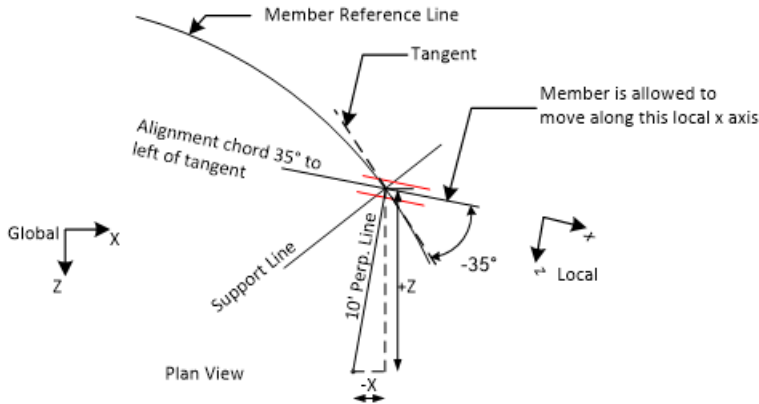
The Structure Typical Section contains the following changes for curved girder systems. The width of the deck must be constant along the length of the structure. The overhangs are computed based on the distance from the superstructure definition reference line to the leftmost girder and girder spacing entered on the Framing Plan window and the deck width entered here.



Note in the schematic that for this example bridge, the travelway has been entered to the out to out deck width instead of between the parapets. This was done to match how the structure was loaded in the appendix of the AASHTO Guide Spec so that results of live loading could be compared between BrDR and the results published in the AASHTO Guide Spec.



Open the Member Supports window to see how bearings can be oriented for curved girder systems. For curved girder systems bearings are oriented in a local coordinate system at each member support. Select 'Tangent' if the local x axis for bearing alignment is parallel to the tangent of the member reference line at the support. Select 'Chord' if the local x axis for the bearing alignment is parallel to a specified chord angle from the tangent of the member reference line at the support. The following sketch shows an example of defining a bearing alignment along a chord.



Supports

Bearing alignment:

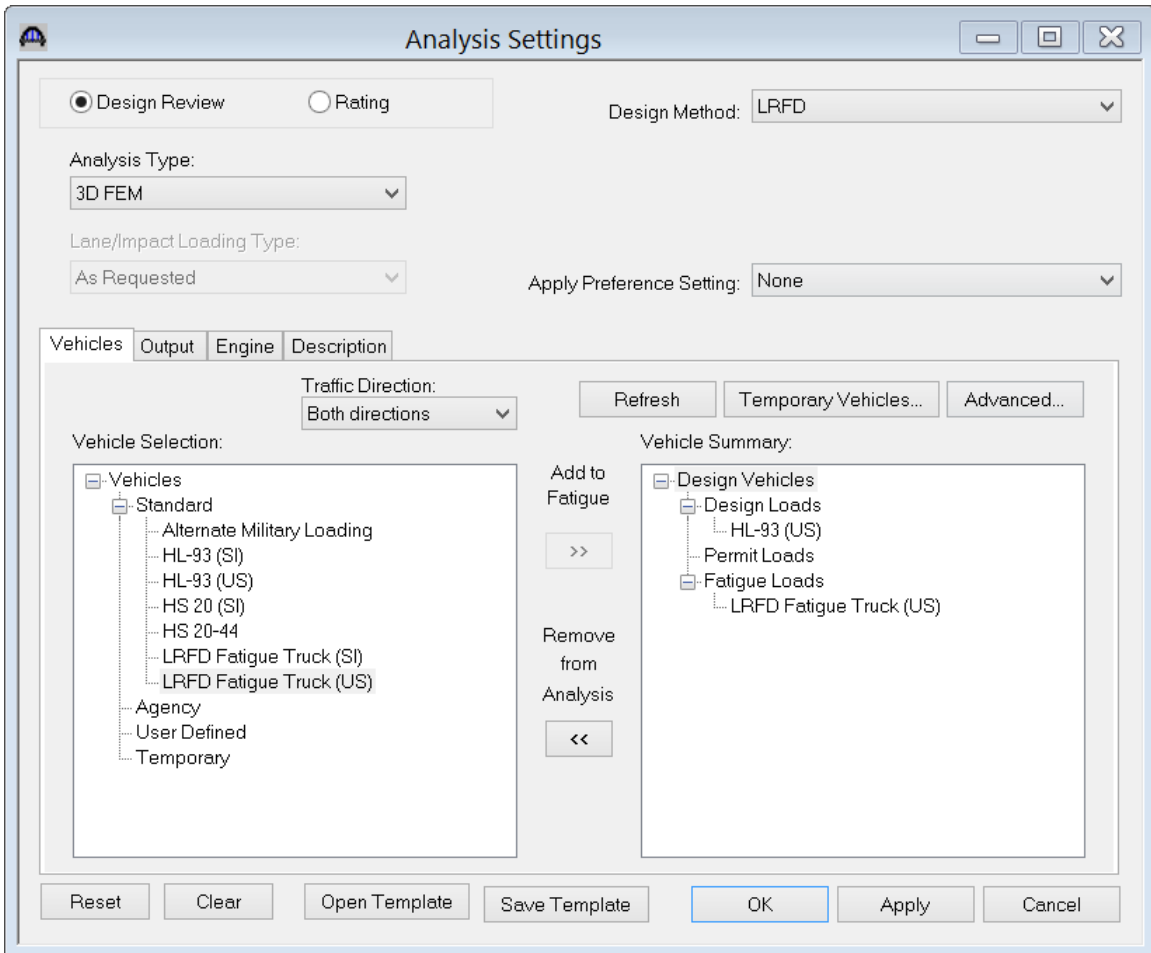
Support Number	Girder Bearing Alignment Type	Chord Angle (Degrees)
1	Tangent	
2	Tangent	
3	Tangent	
4	Tangent	

General Elastic

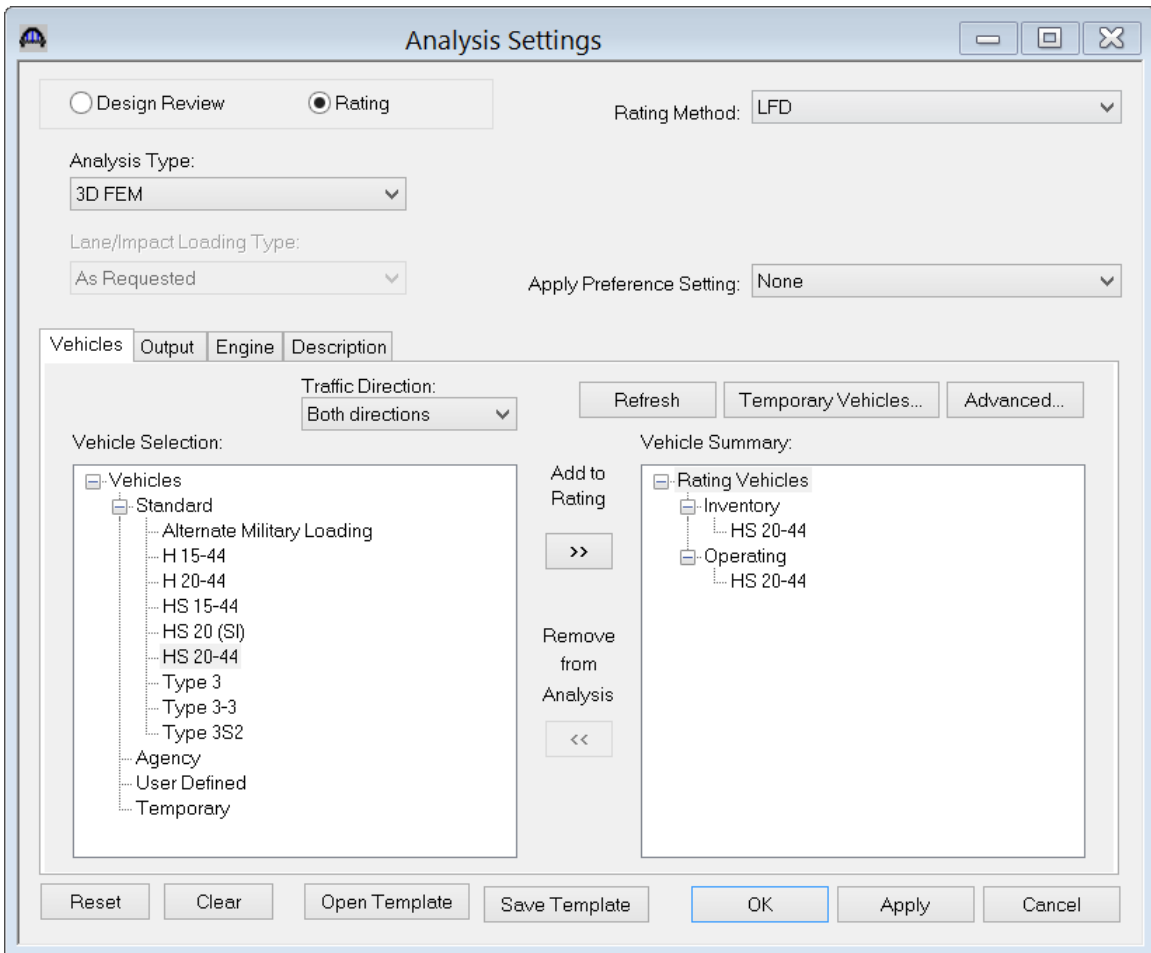
Support Number	Support Type	Local Translation Constraints			Local Rotation Constraints		
		X	Y	Z	X	Y	Z
1	Roller	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Roller	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Roller	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Roller	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

It is not recommended that users launch an analysis in training as due to the large number of degrees of freedom in this example, analysis runtime will require a 64 bit PC and adequate memory that is likely not available on attendee laptops.

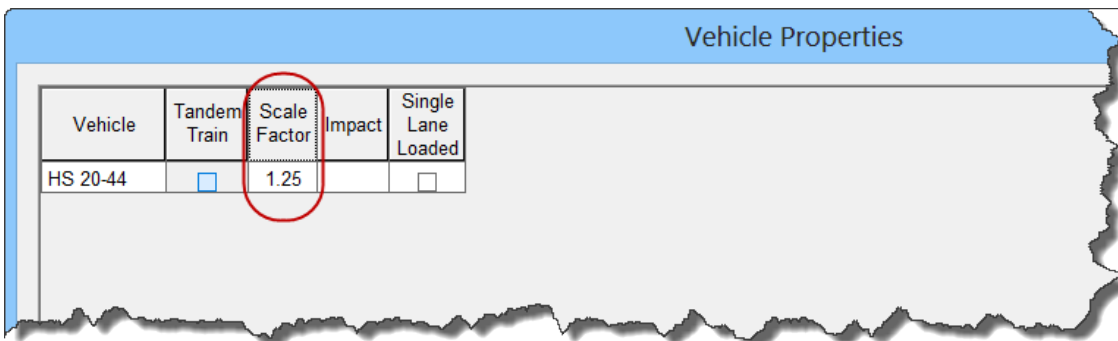
For the Bridge Design training, open the Analysis Settings window and make the following selections for an HL93 Design Review:



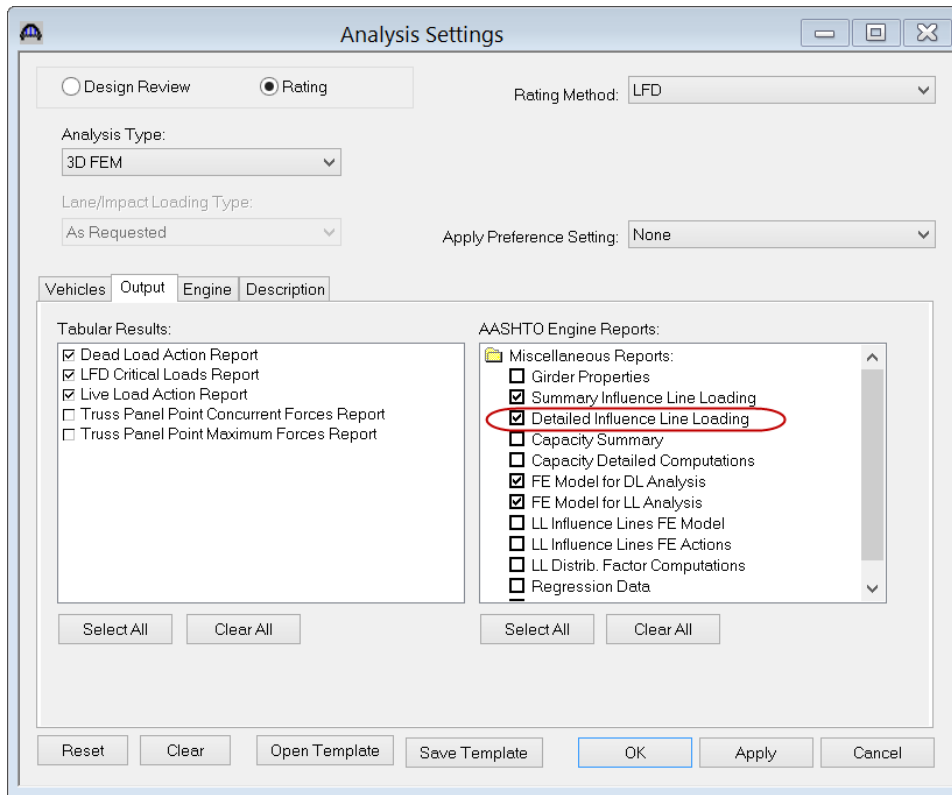
For the Bridge Rating training, open the Analysis Settings window and make the following selections:



The example in the AASHTO Guide Specification is for an HS25 loading. To produce this loading, enter a scale factor of 1.25 in the Advanced Vehicle Properties window:



For both training sessions, select the following output controls. Be sure to check the ‘Detailed Influence Line Loading’ to be able to view the centrifugal force calculations.

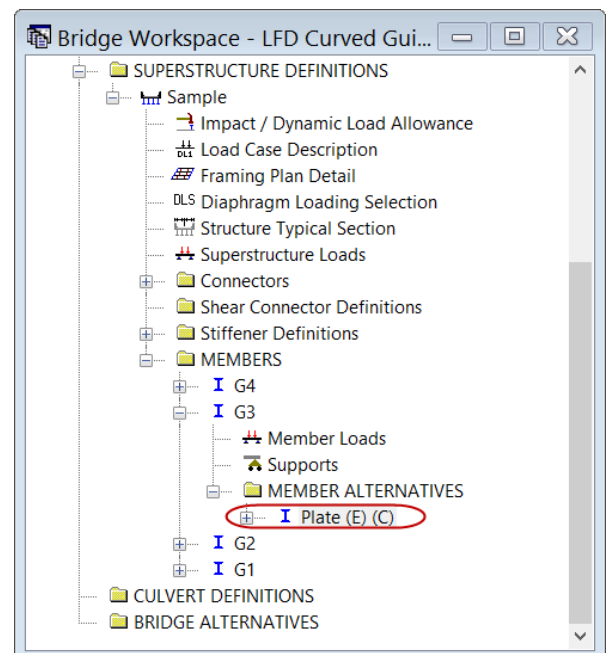


This example now shows the results from a 3D LFD rating. It is not recommended that users launch an analysis in training as due to the large number of degrees of freedom in this example, analysis runtime will require a 64 bit PC and adequate memory that is likely not available on attendee laptops.

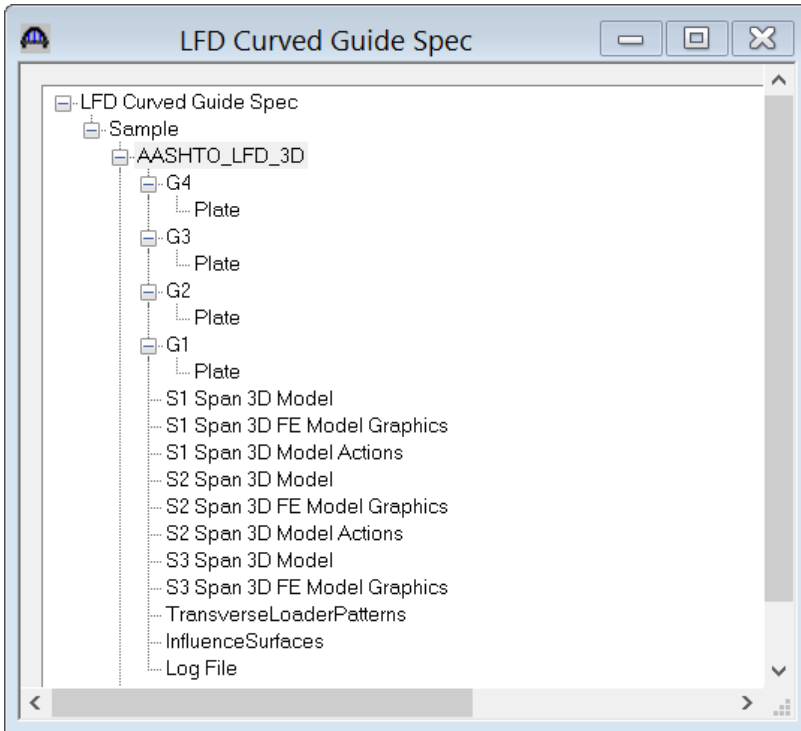
The software develops the 3D model using the member alternative marked as Existing for each member. If the member does not have a member alternative marked as Existing and only has 1 member alternative, that member alternative is used for the 3D model. If the member has no member alternative marked as Existing and more than 1 member alternative, the analysis will not be performed.

When the analysis is launched for the superstructure definition, spec checking and rating is only performed for member alternatives marked as Existing. When the analysis is launched for a single member alternative (as shown here), the spec checking and rating will only be performed for that member alternative.

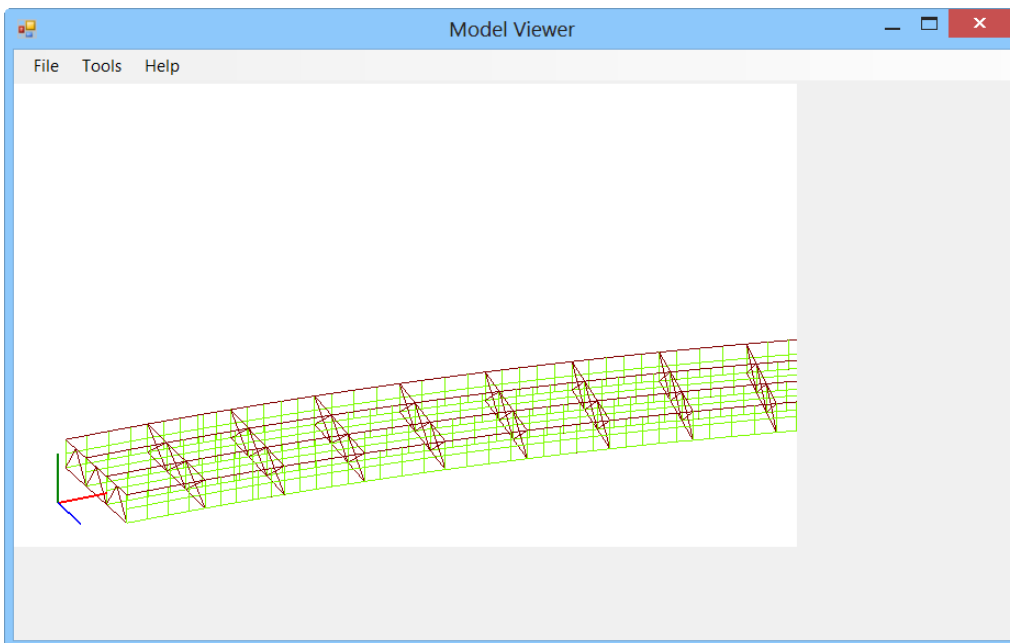
A new feature for both straight and curved girder system FE analysis is the ability to reuse existing FEA results. The program will generate new dead load and live load influence surface FE models and compare the models to previous models. If the models compare exactly then the FEA results will be reused. The live load will be applied to the previous influence surfaces. This leads to a greatly reduced runtime on successive runs.



The following shows the output files created by the 3D LFD rating. Similar files are created for a 3D LRFD design review.

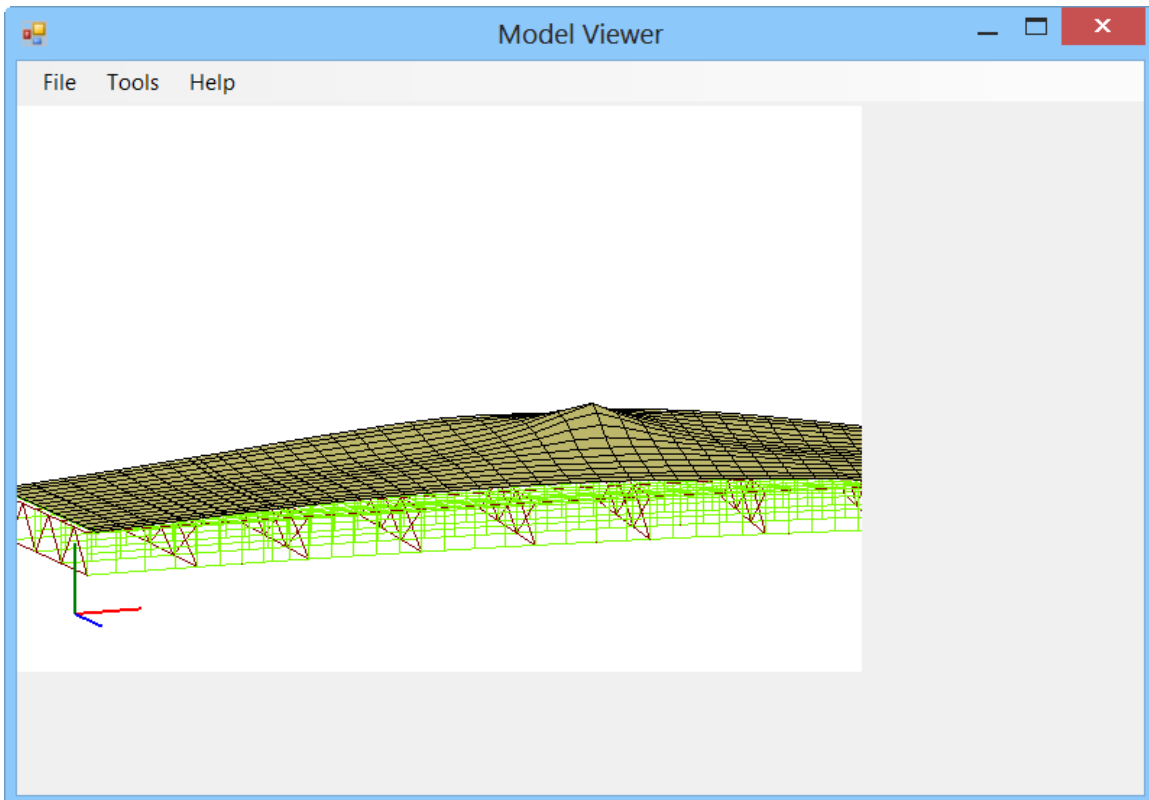
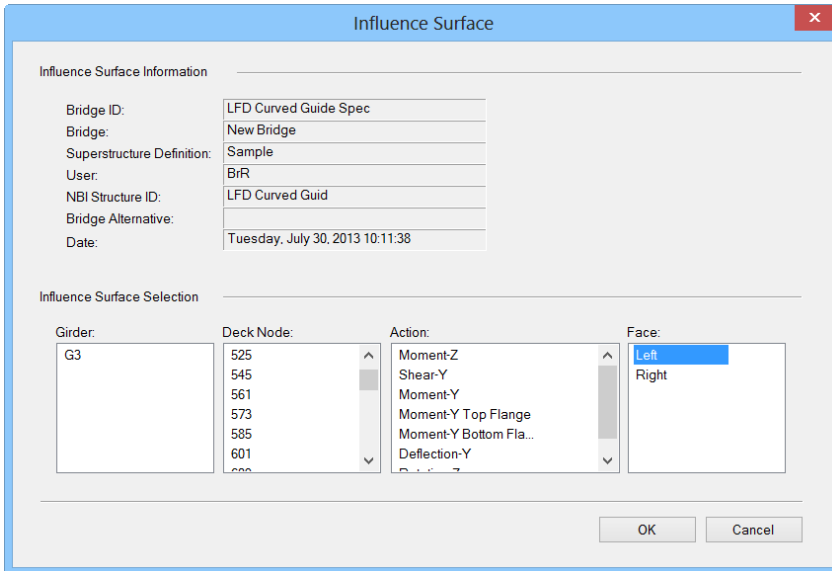


The “3D Model” files list the data for the models including nodes, members, properties and loads. The “3D Model Actions” files list the FE results (reactions, element actions, displacements) for the models. The “Model Graphics” files can be opened to graphically view the FE models. The following shows the graphics for the Stage 1 model which contains the steel beams and diaphragms.



Node and element numbers can be turned on from the Tools menu. The mouse controls manipulation of the view. Zoom by rolling the mouse wheel. Translate by pushing down the mouse wheel. Rotate by pushing down the left mouse button.

The generated influence surfaces for the unit live loading can be viewed by selecting the Stage 3 Graphics model and then selecting File/Open/”Influence Surfaces.sur”. An influence surface for viewing can be chosen by selecting Tools/Change Influence Surface and then selecting desired actions.



Tabular results and spec check details can be viewed for the member alternatives that were analyzed.

Bridge Design/Rating - LFD Curved Guide Spec

Bridge Explorer (27 Bridge Design/Rating bridges retrieved for the current folder, all rows retrieved)

Bridge Workspace - LFD Curved Guide Spec

Analysis Results - Plate

Report Type: Dead Load Actions | Stage: Non-composite (Stage 1) | Dead Load Case: Self Load (Stage 1.D.DC)

Span	Location (ft)	% Span	Moment (kip-ft)	Shear (kip)	Axial (kip)	Reaction (kip)	X Deflection (in)	Y Deflection (in)
1	0.00	0.0	-0.10	14.99	-0.00	15.73	0.0000	-0.0000
1	16.13	10.0	217.58	12.01	0.00		0.0000	-0.2131
1	32.25	20.0	355.71	6.75	0.00		0.0000	-0.3861
1	48.38	30.0	418.56	2.20	0.00		0.0000	-0.4953
1	64.50	40.0	408.99	-2.12	0.00		0.0000	-0.5293
1	80.63	50.0	328.61	-6.53	0.00		0.0000	-0.4896
1	96.75	60.0	178.13	-10.86	0.00		0.0000	-0.3904
1	112.88	70.0	-44.25	-15.46	0.00		0.0000	-0.2579
1	121.00	75.0	-183.16	-17.54	0.00		0.0000	-0.1905
1	129.01	80.0	-341.91	-20.61	0.00		0.0000	-0.1299
1	141.16	87.5	-625.85	-22.96	0.00		0.0000	-0.0573
1	145.13	90.0	-736.80	-27.93	0.00		0.0000	-0.0400
1	161.26	100.0	-1263.69	-35.02	0.00	74.81	0.0000	-0.0000
2	0.00	0.0	-1263.95	34.59	-0.00	74.81	0.0000	-0.0000
2	19.21	9.1	-657.91	26.40	0.00		0.0000	-0.0704

AASHTO LFR 3D Engine Version 6.5.0.3001
Analysis Preference Setting: None

Bridge Design/Rating - LFD Curved Guide Spec

Bridge Explorer (27 Bridge Design/Rating bridges retrieved for the current folder, all rows retrieved)

Bridge Workspace - LFD Curved Guide Spec

Specification Checks for Plate - 21 of 1158

Specification Reference	Limit State	Flex. Sense	Pass/Fail
5.1 Flanges With One Web - General		N/A	General ...
5.2.1 Compact Flanges		N/A	General ...
5.2.2 Non-Compact Flanges		N/A	Not App...
5.3 Partially Braced Tension Flanges		N/A	Not App...
5.4 Continuously Braced Flanges		N/A	General ...
6.2.1 Unstiffened Webs - Bending Stresses		N/A	General ...
6.2.2 Unstiffened Webs - Shear Stresses		N/A	General ...
6.3 Transversely Stiffened Webs		N/A	General ...
6.3.1 Transversely Stiffened Webs - Bending Stresses		N/A	Not App...
6.3.2 Transversely Stiffened - Shear Stresses		N/A	Not App...
6.4.1 Longitudinally and Transversely Stiffened Webs ...		N/A	Not App...
6.4.2 Longitudinally and Transversely Stiffened Webs ...		N/A	Not App...
9.5 I-Girders Permanent Deflection		N/A	General ...
Bending Stress Rating		N/A	Passed
Depth of web in compression in the Elastic Range (D...		N/A	General ...
Flange Bending Stress Rating		N/A	Passed
LFD General Steel Flexural Results		N/A	General ...
LFD Steel Elastic Section Properties		N/A	General ...
Steel Stresses for Sections in Positive Flexure		N/A	General ...
Web Bending Stress Rating		N/A	Passed
Web Shear Rating		N/A	Failed

The results of the HS25 rating are shown below:

Live Load	Live Load Type	Rating Method	Inventory Load Rating (Ton)	Operating Load Rating (Ton)	Inventory Rating Factor	Operating Rating Factor	Inventory Location (ft)	Inventory Location Span-%	Operating Location (ft)	Operating Location Span-%	Inventory Limit State	Operating Limit State	In
HS 20-44	Lane	LFD	14.25	23.80	0.317	0.529	372.91	3 - (0.0)	372.91	3 - (0.0)	Design Shear - Steel	Shear - Steel	As R
HS 20-44	Axle Load	LFD	20.37	34.01	0.453	0.756	534.16	3 - (100.0)	534.16	3 - (100.0)	Design Shear - Steel	Shear - Steel	As R

AASHTO LFR 3D Engine Version 6.5.0.3001
Analysis Preference Setting: None

The centrifugal force effect calculations can be found in the detailed influence surface loading files found in the following directory:

File Explorer Path: BrDR65 > LFDCurvedGuideSpec > Sample > AASHTO_LFD_3D > G3 > Plate > S3 Span > Data

File Name: INVOPR_Axle Load Forward_0_Moment Z.txt

Vehicle Description: HS 20-44 - Truck

Axle	Spacing (ft)	Distance to First Axle (ft)
1	0.00	0.00
2	14.00	14.00
3	14.00	28.00

Axle	Wheel	Spacing (ft)	Load (kip)
1	1	-3.000	5.00
2	1	-3.000	20.00
2	2	3.000	20.00
3	1	-3.000	20.00
3	2	3.000	20.00

Total load = 90Kips
Total length = 28Feet
Maximum width = Left 3.000Feet, Right 3.000Feet, Total 6.000Feet

Centrifugal Force and Superelevation Data:
Curve to right
Design Speed = 35.00 (mph)
Superelevation 5.00 (%)
Centrifugal force applied 6.00 (ft) above the deck

POI (0.000,-5.500) ft Moment Z Influence Surface

Axle	Wheel	X (ft)	Z (ft)	Surface Ordinate (unit)	Wheel Load (kip)	curve factor (unit)	Action	FE Element
Front Axle Position (-0.071,-15.252) L to R								
0	1	0.00	-18.25	-0.0325	5.64	1.1288	-0.183	123
Total = Max 0.000, Total = Min -0.163, Total = -0.163								
Front Axle Position (0.929,-15.228) L to R								
0	1	1.00	-18.23	-0.0296	5.64	1.1288	-0.167	123
0	2	0.86	-12.23	0.1151	4.36	0.8712	0.501	369
Total = Max 0.576, Total = Min -0.148, Total = 0.428								

Notes:
- Contains detailed influence surface loading data for the truck applied to a lane with its left edge at 0' from the left edge of the deck.
- Wheel factors due to centrifugal force and superelevation

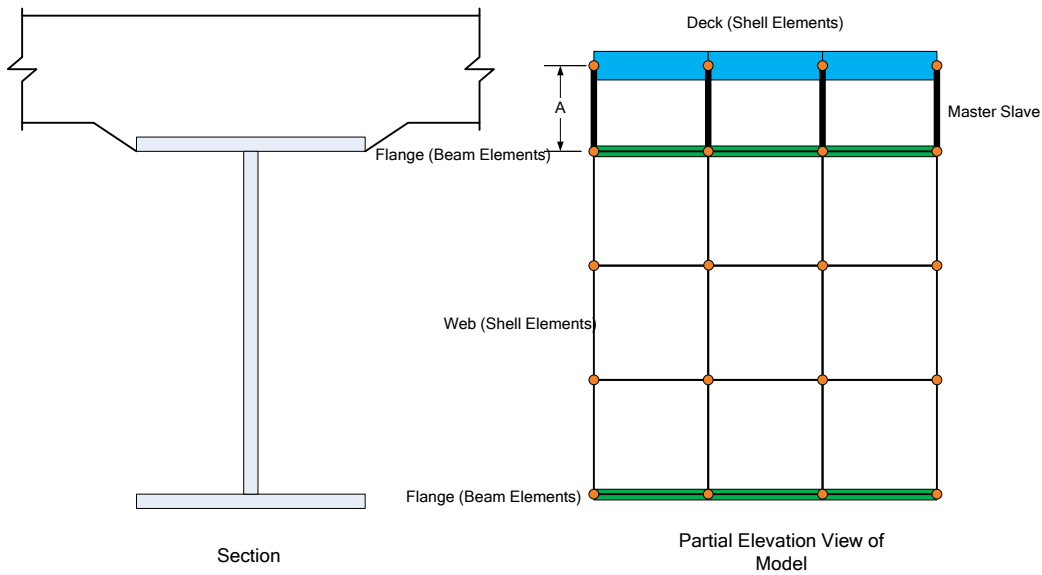
3D Model

The modeling techniques used are the result of a survey of researchers and practitioners and review of several software packages.

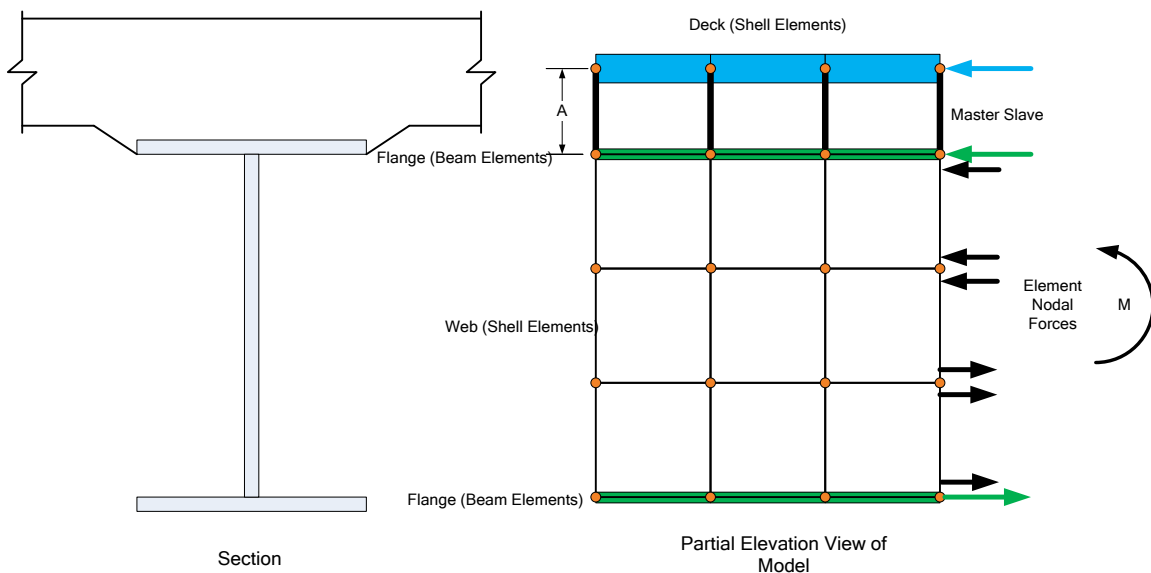
Steel beams are modeled with:

- Shell elements for the deck
- Beam elements for the top and bottom flanges
- Shell elements for the web

For a curved girder system, the deck nodes and top flange nodes are connected by way of a master-slave constraint. For straight girder systems a rigid link is used to connect these nodes.



The moment at a beam cross section is calculated by solve the equilibrium equations at that section. This moment is then used in the specification check articles in the same way that it would for a line girder analysis.



Mesh Generation

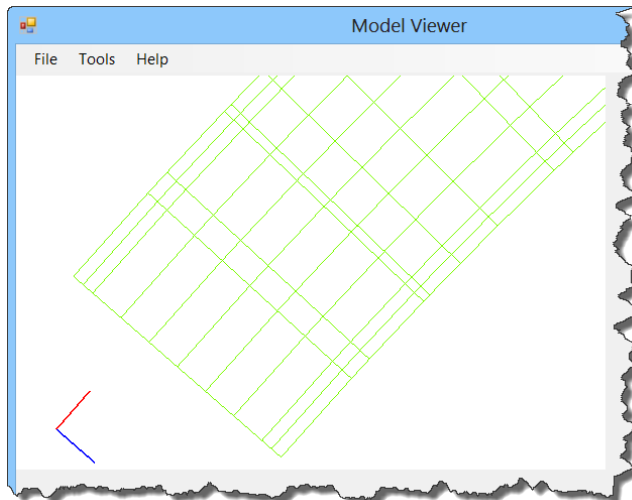
The FE model created by BrR/BrD will contain nodes at the following locations:

- Cross section property change points
- Span tenth points
- Support locations
- Diaphragm locations
- User defined points of interest

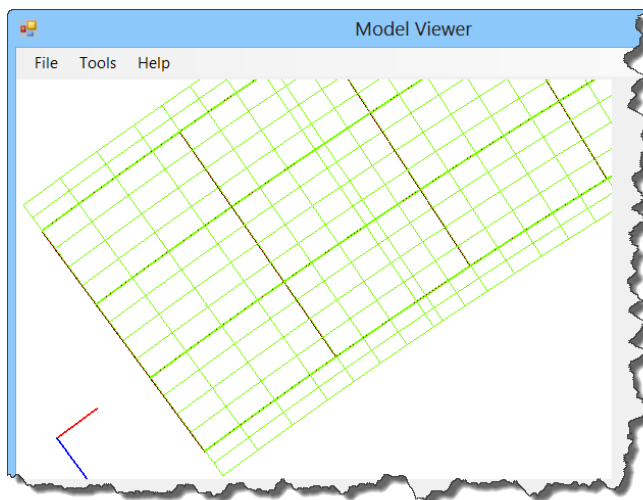
The user controls the mesh generation by the controls previously shown on the Superstructure Definition: Analysis tab. The software creates the mesh following the number of elements selected between beams or within the web of a steel beam and the target aspect ratio entered by the user. The presence of nodes at the locations listed above may result in some elements falling outside the target aspect ratio.

The following plan views show how the mesh for this example can be controlled by the user.

2 shells between beams, target aspect ratio = 4



4 shells between beams, target aspect ratio = 2



Loading

The program computes all of the dead loads acting on the beam including the self-weight of the beam, user defined appurtenances on the structure typical section, wearing surfaces, diaphragms and user defined member loads. Composite dead loads are applied directly to the deck shells in the 3D model in their actual location. They are not distributed to the girders based on the choices available in the Superstructure Loads window.

The Stage 3 FE model is loaded with unit loads at each deck node within the travelway to generate influence surfaces for the beam. Lane positions and combinations are determined based on the travelway and the transverse loading parameters set by the user on the Superstructure Definition: Analysis Settings tab. The influence surfaces are then loaded with the selected vehicles to find the maximum live load effects.

Results

The following graphs illustrate the relative agreement of the BrDR results with those published in the AASHTO Guide Spec appendix for this example.

