Comments for the RADBUG 2019 *Modeling Curved Girder Bridges in BrR* presentation

The modernized and legacy AASHTO 3D and 2D analysis engines in BrDR can analyze composite, non-composite and a combination of composite/non-composite regions in steel beams if consistent data is entered in the Deck Profile window's Deck Concrete and Shear Connectors tabs. Regions that are defined as "Composite" on the Shear Connectors tab should have corresponding regions on the Deck Concrete tab that have non-zero effective flange widths.

If a composite region is defined on the Shear Connectors tab and a corresponding region with an effective flange width equal to 0" is entered on the Deck Concrete tab, the following error message will appear:

Warning - Composite section properties are indicated but effective flange width equals zero!
Error - Error setting deck slab dimensions!
Error - Error creating the steel plate girder cross section! Analysis aborted!

Procedures, Issues & Solutions for Modeling Curved Girder Bridges in BrR

Annual RADBUG Meeting:
July 30 to 31, 2019

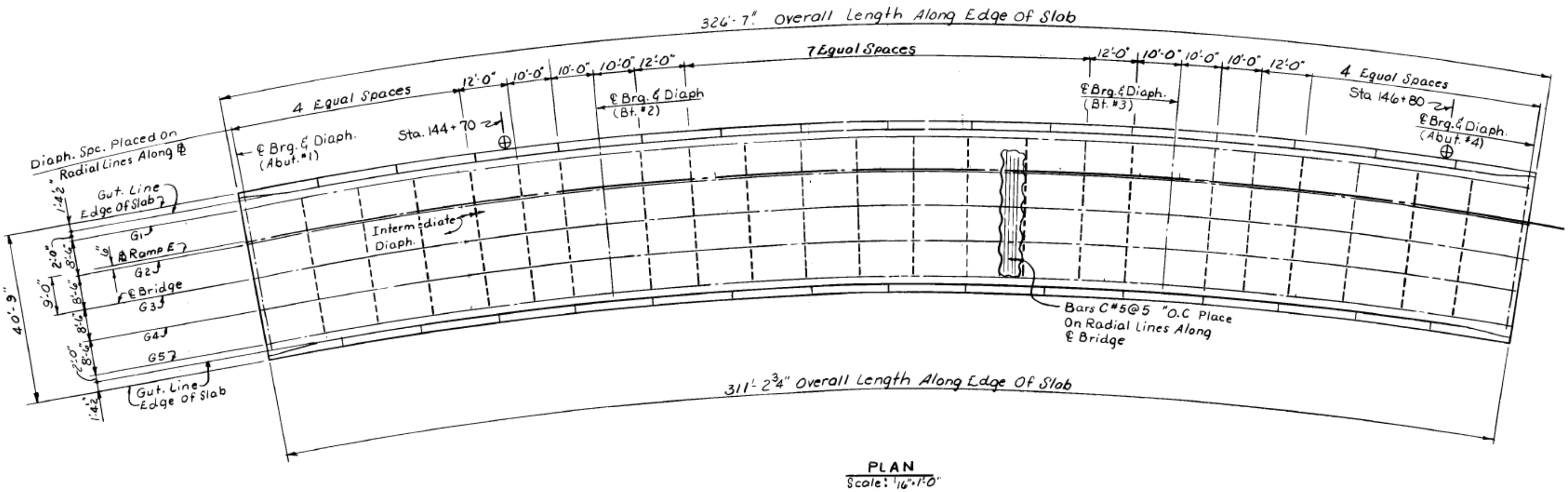
Michael Baker
INTERNATIONAL

We Make a Difference

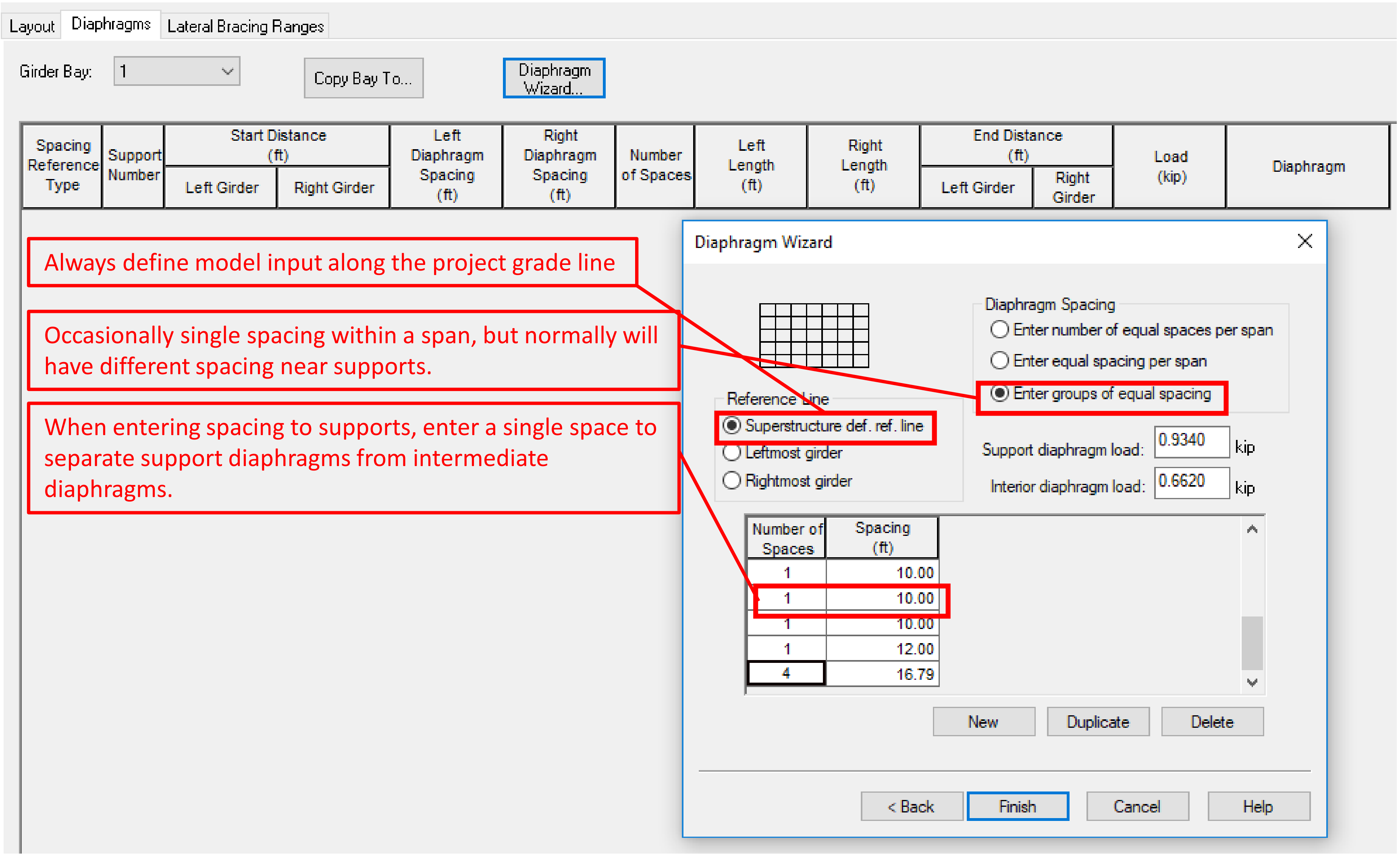
Building Curved Girder Models

Curved Girders on Radials (Supports with 0^{o} skew to tangent)

- Easiest type or curved girder bridge to model.
- Can use diaphragm wizard to locate positions.
- Relatively easy to calculate girder lengths (Rθ).
- Easy to locate girder transition locations.

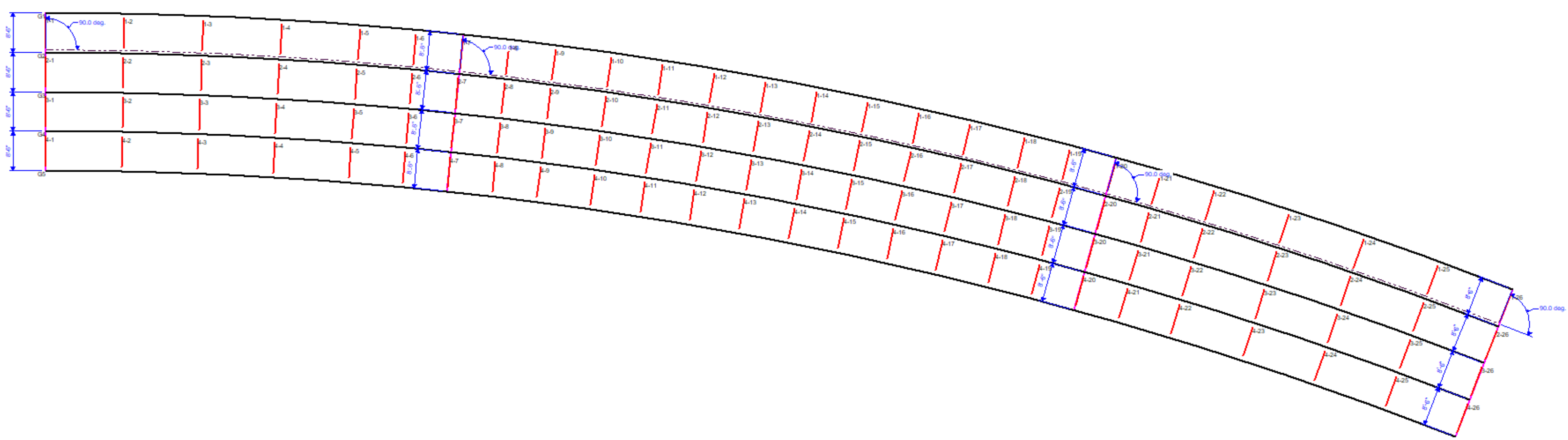


Diaphragm Input for Radial Curved Bridges



Diaphragm Input for Radial Curved Bridges

- After using wizard, verify that the diaphragms are in the correct position by viewing the schematics
- Note that will still need to edit diaphragm input
  - Will need to assign proper diaphragm definitions.
  - Will need to adjust weights as BrR has trouble identifying support diaphragm locations.
  - May need to adjust last spacing to allow for end diaphragm assignment.



Editing Diaphragm input

Layout | Diaphragms | Lateral Bracing Ranges

Girder Bay: 1 | Copy Bay To... | Diaphragm Wizard...

Generated by BrR

Spacing Reference Type	Support Number	Start Distance (ft) Left Girder	Start Distance (ft) Right Girder	Left Diaphragm Spacing (ft)	Right Diaphragm Spacing (ft)	Number of Spaces	Left Length (ft)	Right Length (ft)	End Distance (ft) Left Girder	End Distance (ft) Right Girder	Load (kip)	Diaphragm
Both Gir	1	0.00	0.00	0.000	0.000	1	0.00	0.00	0.00	0.00	0.9340	-- Not Assigned --
Both Gir	1	0.00	0.00	16.948	16.782	4	67.79	67.13	67.79	67.13	0.6620	-- Not Assigned --
Both Gir	1	79.90	79.12	0.000	0.000	1	0.00	0.00	79.90	79.12	0.9340	-- Not Assigned --
Both Gir	2	0.00	0.00	0.000	0.000	1	0.00	0.00	0.00	0.00	0.9340	-- Not Assigned --
Both Gir	2	0.00	0.00	10.093	9.994	2	20.19	19.99	20.19	19.99	0.6620	-- Not Assigned --
Both Gir	2	32.30	31.98	0.000	0.000	1	0.00	0.00	32.30	31.98	0.9340	-- Not Assigned --
Both Gir	2	32.30	31.98	11.247	11.136	7	78.73	77.95	111.02	109.94	0.6620	-- Not Assigned --
Both Gir	2	123.13	121.93	0.000	0.000	1	0.00	0.00	123.13	121.93	0.9340	-- Not Assigned --
Both Gir	2	133.23	131.92	0.000	0.000	1	0.00	0.00	133.23	131.92	0.9340	-- Not Assigned --
Both Gir	3	0.00	0.00	0.000	0.000	1	0.00	0.00	0.00	0.00	0.9340	-- Not Assigned --
Both Gir	3	10.09	9.99	0.000	0.000	1	0.00	0.00	10.09	9.99	0.9340	-- Not Assigned --
Both Gir	3	22.20	21.99	0.000	0.000	1	0.00	0.00	22.20	21.99	0.9340	-- Not Assigned --
Both Gir	3	22.20	21.99	16.948	16.782	4	67.79	67.13	90.00	89.11	0.6620	-- Not Assigned --

Diaphragm Definitions are not assigned

Some of the support weights assigned to wrong diaphragms.

Adjust last diaphragm to include last support

Layout | Diaphragms | Lateral Bracing Ranges

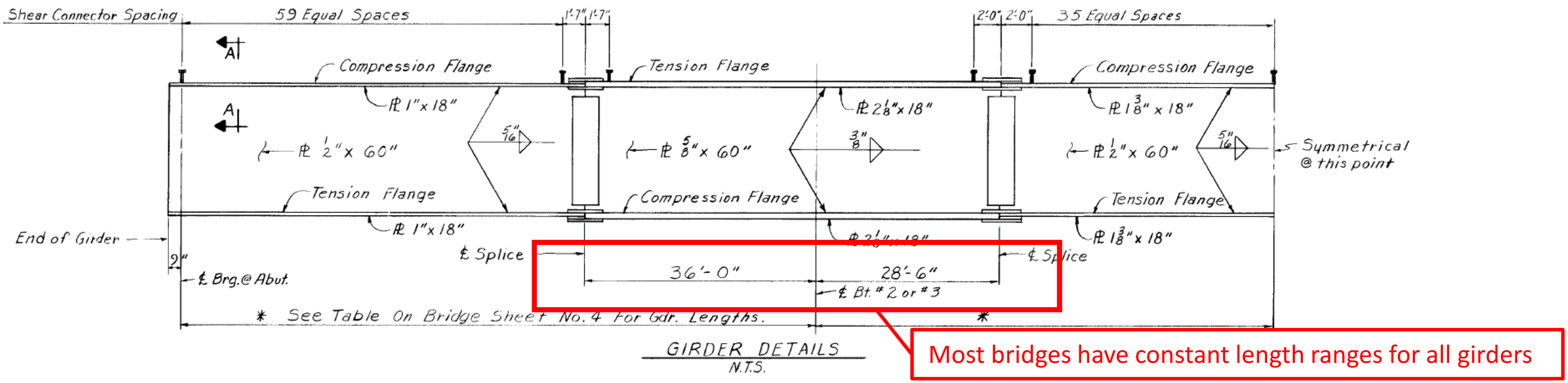
Girder Bay: 1 | Copy Bay To... | Diaphragm Wizard...

Modified by User

Note: BrR will calculate diaphragm weights if not entered.

Spacing Reference Type	Support Number	Start Distance (ft) Left Girder	Start Distance (ft) Right Girder	Left Diaphragm Spacing (ft)	Right Diaphragm Spacing (ft)	Number of Spaces	Left Length (ft)	Right Length (ft)	End Distance (ft) Left Girder	End Distance (ft) Right Girder	Load (kip)	Diaphragm
Both Gir	1	0.00	0.00	0.000	0.000	1	0.00	0.00	0.00	0.00	0.9340	Sup
Both Gir	1	0.00	0.00	16.948	16.782	4	67.79	67.13	67.79	67.13	0.6620	Int
Both Gir	1	79.90	79.12	0.000	0.000	1	0.00	0.00	79.90	79.12	0.6620	Int
Both Gir	2	0.00	0.00	0.000	0.000	1	0.00	0.00	0.00	0.00	0.9340	Sup
Both Gir	2	0.00	0.00	10.093	9.994	2	20.19	19.99	20.19	19.99	0.6620	Int
Both Gir	2	32.30	31.98	0.000	0.000	1	0.00	0.00	32.30	31.98	0.6620	Int
Both Gir	2	32.30	31.98	11.247	11.136	7	78.73	77.95	111.02	109.94	0.6620	Int
Both Gir	2	123.13	121.93	0.000	0.000	1	0.00	0.00	123.13	121.93	0.6620	Int
Both Gir	2	133.23	131.92	0.000	0.000	1	0.00	0.00	133.23	131.92	0.6620	Int
Both Gir	3	0.00	0.00	0.000	0.000	1	0.00	0.00	0.00	0.00	0.9340	Sup
Both Gir	3	10.09	9.99	0.000	0.000	1	0.00	0.00	10.09	9.99	0.6620	Int
Both Gir	3	22.20	21.99	0.000	0.000	1	0.00	0.00	22.20	21.99	0.6620	Int
Both Gir	3	22.20	21.99	16.948	16.782	3	50.84	50.35	73.05	72.33	0.6620	Int
Both Gir	3	73.05	72.33	16.948	16.782	1	16.95	16.78	90.00	89.11	0.9340	Sup

Define Girders

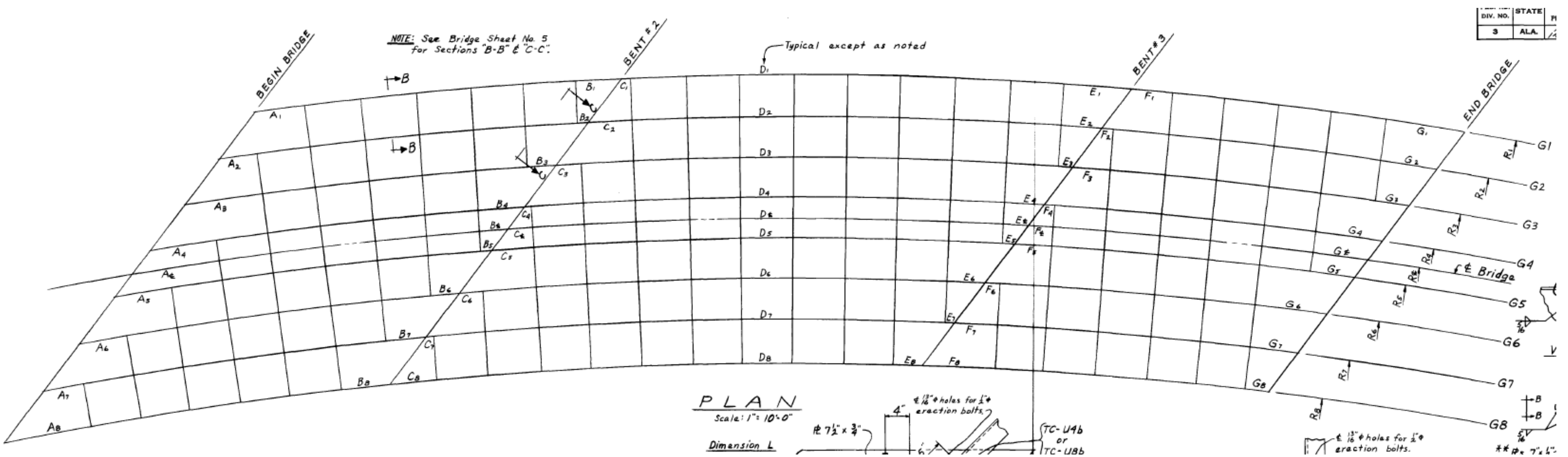


- Usually all of the flange and web sizes are the same for all girders but need to verify this before starting.
- Define the first girder “G1”.
  - Leave Live Load Distribution blank.
  - Define girder profile
  - Deck profile: Define composite ranges and use compute button to calculate effective flange widths and thicknesses
  - Define haunch profile
  - Define lateral support
  - Leave stiffener ranges blank for now
  - Verify that everything is correct.
  - Copy G1 to G2 and edit girder lengths, composite ranges and recompute deck, haunch and lateral support lengths.
  - Continue copying and editing until all girders defined.
  - Now define the stiffeners for each girder.

- Once have gone through this a few times should be relatively fast to a build model, probably about 25% to 50% longer than it takes to model a similar straight girder bridge simply because can not link the girders as you can in a straight girder bridge.

Curved Girders on Skewed Supports vs. Curved Girders on Radials

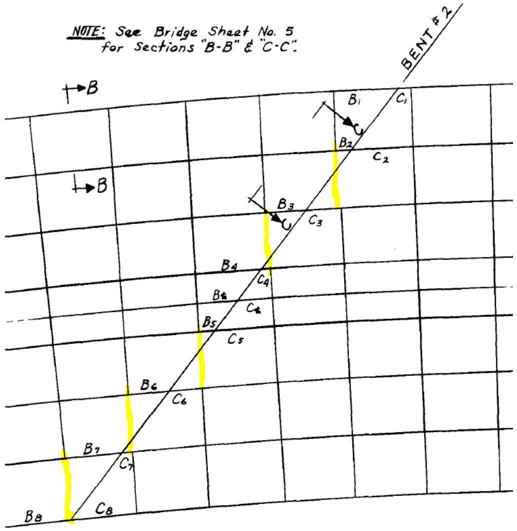
- Harder and takes much longer to model than radial type models.
- Can not use diaphragm wizard, therefore have to calculate and individually enter all diaphragms in all bays.
- More difficult to calculate girder lengths as the skew angles are different for each girder due to curvature.
  - Easier to pull girder lengths directly from BrR



Diaphragm Entry for Skewed Supports

- Enter all information for the framing plane (with the exception of the diaphragms) and the structural typical section.
- Use "Member" window to get span lengths for each girder. Note that even though greyed out can still click on and then copy and paste.
- Calculate diaphragm locations along each girder.
- Enter the diaphragms in Bay 1 (G1 & G2). Verify that locations are correct by viewing the schematics.
- Copy Bay 1 to Bay 2. Copy right girder locations and paste values to left girder locations and enter the new right girder locations. Again view schematics to verify the the locations are correct. Note; may have to add or delete some locations.
- Repeat for other Bays

Note: Girder entry will be the same as for models with supports on radials



Curved Bridges with Lateral Bracing

- Lateral bracing is difficult and tedious to enter as well.
- Use the diaphragm locations for entry.
- There is a "Bug" in BrR that need to be aware off when entering lateral bracing locations. Note: "Bug" is true for all types of bridges, not just curved.
  - BrR choses next start distance based on previous entries "Length".
  - Should choose from the previous entries "End Distance".

Layout | Diaphragms | Lateral Bracing Ranges

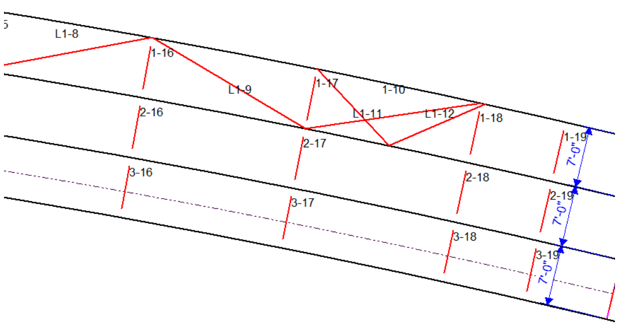
Girder Bay: 1 | Copy Bay To...

Lateral Bracing Pattern	Support Number	Start Distance (ft)		Bracing Length (ft)		Number of Braces	Lateral Bracing	Length (ft)		End Distance (ft)	
		Left Girder	Right Girder	Along Left Girder	Along Right Girder			Left	Right	Left	Right
Alter	2	0.0000		9.6716		2	LB	19.3431	0.0000	19.3431	0.0000
Alter	2	19.3431		19.3435		8	LB	154.7483	0.0000	174.0915	0.0000

Layout | Diaphragms | Lateral Bracing Ranges

Girder Bay: 1 | Copy Bay To...

Lateral Bracing Pattern	Support Number	Start Distance (ft)		Bracing Length (ft)		Number of Braces	Lateral Bracing	Length (ft)		End Distance (ft)	
		Left Girder	Right Girder	Along Left Girder	Along Right Girder			Left	Right	Left	Right
Alternating V	2	0.0000		9.6716		2	LB	19.3431	0.0000	19.3431	0.0000
Alternating V	2	19.3431		19.3435		8	LB	154.7483	0.0000	174.0915	0.0000
Alternating V	2	154.7483		9.9401		2	LB	79.5212	0.0000	234.2695	0.0000



BrR Capability Issues

Logic Issues "Bugs" in BrR and Work Arounds "Solutions"

1

Spans greater than 300'

- BrR uses the AASHTO 2003 "Horizontally Curved Steel Girder Highway Bridges" specifications.
- Specs limit span lengths to 300' due to fit up issues during construction.
- Question; why is this a limit in BrR.
  - Previous specs and LRFD spec have greater limits.
  - Construction issue only, bridges are in place making this part of the spec irrelevant.
  - Has nothing to do with structural capacity

C1.1

Although the current **AASHTO** (*1996*) is applicable to spans up to 500 feet and the **AASHTO LRFD** provisions have no span limit, these provisions are limited to 300-foot spans because of the history of construction problems associated with curved bridges with spans greater than 300 feet. Large girder self-weight may cause critical stresses and deflections during erection when the steel work is incomplete. Large lateral deflections and girder rotations associated with longer spans tend to make it difficult to fit up cross frames. Large curved bridges have been built successfully; however, these bridges deserve special considerations such as the possible need of more than one temporary support in large spans.

For old "Legacy AASHTO LFD" engine: Checks each girder individually to see if a span is > 300'

For new "AASHTO LFD" engine: Checks if span lengths along Project Grade Line "Reference Line" are > 300'

Solution: Select new engine and move the "Reference Line" such that the span lengths are < 300'.

2

Hybrid Girders:

- BrR will not rate hybrid-girders as the 2002 spec does not provide for hybrid girders even though previous specs did.
- But BrR does check web bending stresses
  - Spec bases on web yielding but check does not allow for web yielding.
  - Web bending usually controls hybrid girder ratings.

These provisions do not provide for hybrid girders. The 1993 Guide Specifications for Horizontally Curved Highway Bridges (**Guide Spec**) provided for hybrid I-girders, but not for hybrid box girders. Design of hybrid girders is based on the assumption that a portion of the web yields. There have been only incidental tests of curved hybrid girders; and there has been no study of these test results with regard to hybrid action.

- Regardless if in spec or not; need to rate all bridges or possibly loose all Federal Funds.

- New engine checks to see if all girders are hybrid or not.
- Old engine only checks 1st girder, ignores other girders.

Solution: Build model with 1st girder as non hybrid using minimum F_y (web) but model the rest of the girders as hybrid. Run model using the old "Legacy AASHTO LFD" engine. If operating rating factors > 1 for the 1st girder can stop here. If < 1, will need to build a second model, reversing the curvature and the girders.

Building 2nd Hybrid Girder Model (Continued)

Steps for building 2nd model:

- First copy and paste original model.
- Under Girder Superstructure Definition - Reverse direction of curvature.
- Under Framing Plan Detail - Change distance to left most girder to match distance of right most girder.
  - Will need to redo diaphragms
- Under Structure Typical Section - Change distance from left edge to the distance to that of the right edge and the distance from the right edge to that of the left edge.
  - Recompute lane position.
- Under Members - Delete all girders.
  - Copy the 1st girder in the original model to the last girder in the reversed model. Then edit material assignments so that is defined as a hybrid girder.
  - Copy the last girder in the original model to the 1st girder in the reversed model. Then edit material assignments so that is defined as a nonhybrid girder.
  - Copy the remaining girders from the original model to the reversed model reversing their position.

Logic Issues "Bugs" in BrR and Work Arounds "Solutions"

The superstructure shall have either a composite or a non-composite cast-in-place or precast concrete deck. Composite girders shall be designed to be composite along their entire length. The deck cross section may have a constant thickness or it may be vaulted (variable thickness). Longitudinal and/or transverse prestressing of the deck is permitted. These provisions do not apply to superstructures with steel orthotropic decks.

3 Composite vs. Non composite

- BrR does not handle non composite girders
  - Not a code issue.
- Also has some issues with defining composite ranges.

For continuous spans with both composite and non composite ranges.

- New engine: Ranges must be fully defined over entire length of girder.

Deck Concrete | Reinforcement | Shear Connectors

Material	Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Structural Thickness (in)	Start Effective Flange Width (Std) (in)	End Effective Flange Width (Std) (in)	Start Effective Flange Width (LRFD) (in)	End Effective Flange Width (LRFD) (in)	n
Class A (US)	1	0.00	73.60	73.60	6.7500	81.0000	81.0000	81.0000	81.0000	7.958
Class A (US)	1	73.60	75.54	149.14	6.7500	0.0000	0.0000	0.0000	0.0000	7.958
Class A (US)	2	34.15	118.27	152.42	6.7500	81.0000	81.0000	81.0000	81.0000	7.958
Class A (US)	2	152.42	87.48	239.90	6.7500	0.0000	0.0000	0.0000	0.0000	7.958
Class A (US)	3	47.27	93.26	140.53	6.7500	81.0000	81.0000	81.0000	81.0000	7.958

- Old engine: Will run majority of time if defined as above. However, occasionally will not run. If will not run, delete the "0" width ranges but note that cannot run the new engine without these ranges.

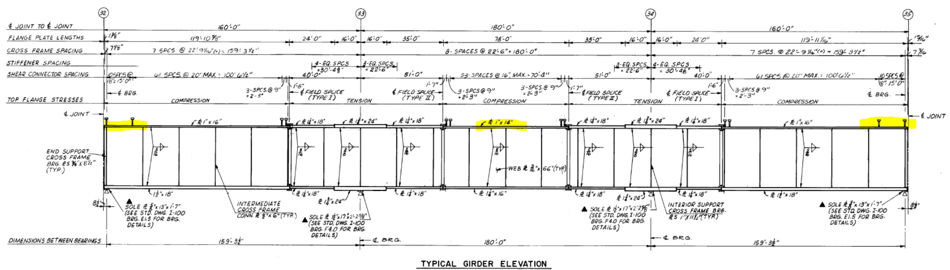
Deck Concrete | Reinforcement | Shear Connectors

Material	Support Number	Start Distance (ft)	Length (ft)	End Distance (ft)	Structural Thickness (in)	Start Effective Flange Width (Std) (in)	End Effective Flange Width (Std) (in)	Start Effective Flange Width (LRFD) (in)	End Effective Flange Width (LRFD) (in)	n
Class A (US)	1	0.00	73.60	73.60	6.7500	81.0000	81.0000	81.0000	81.0000	7.958
Class A (US)	2	34.15	118.27	152.42	6.7500	81.0000	81.0000	81.0000	81.0000	7.958
Class A (US)	3	47.27	93.26	140.53	6.7500	81.0000	81.0000	81.0000	81.0000	7.958

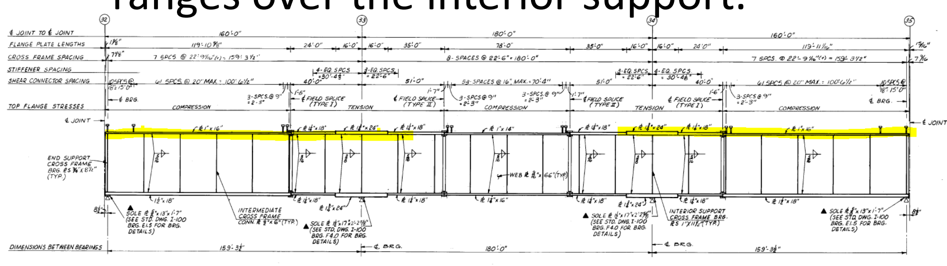
Non Composite Girders (Continued)

Solutions for modeling non composite girders:

- Make the girder ends composite for a short distance, say 25% of span length.
  - Be careful of girder transitions such as cover plate ends.
  - Should work 100% of time for simple spans and 75% of the time for continuous spans.
- For continuous spans may or may not have to build multiple models.
  - The first model should have the be defined as above but with small composite ranges at the middle of the interior spans.



  - The other models should have the end spans fully composite with short ranges over the interior support.



Summary of Issues that need to be Addressed/Changed/Fixed in BrR

1 Remove 300’ span length check since is a construction issue and not a rating issue. Bridge is already built and any construction issues have been resolved.

2 Change hybrid girder flag from an error to a warning. Many of the bridges designed prior to the 2003 used hybrid girders. Allow the rating engineer to decide if valid or not.

3 Add non composite capabilities.

- Old Engine - Currently models run for hours but will not give girder ratings.
- New Engine - Analysis stops and gives error message.

Fix engine to accept both types of composite range definitions just like in a straight girder model.

Version 6.8.4:

Non composite will run if do not define composite ranges. If define with 0” width composite ranges will have spec check violation.

BrR Limitations

Limitations and Possible Enhancement Considerations

Flared Girders - Many curved bridges are bridge ramps that transition from one roadway width to a different roadway width.

Type 1 – Girder spacing varies from one end to another. Basically, one girder radius is tied to the project grade line and the other girder radii are adjusted to provide variable spacing.

Type 2 – Combination of straight and curved girders. Typically used on a mainline span that transitions to the beginning of a ramp.

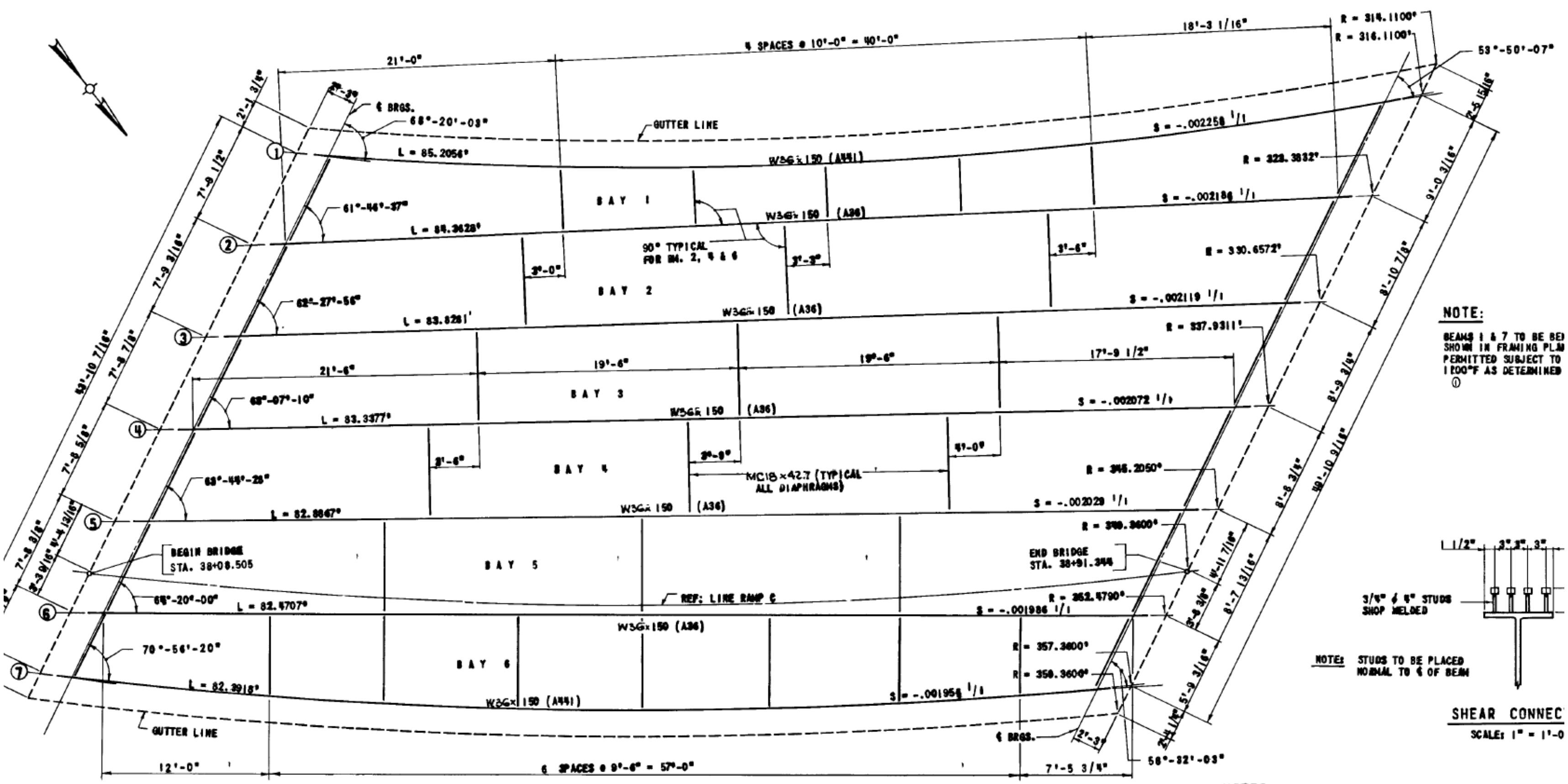
Multiple Curves - While BrR can handle multiple cases of curved – tangent combinations, it cannot handle having more that one curve in the model.

- Cannot handle curved-tangent-curved (regardless of radii).
- Cannot handle multiple (spiral) curve definitions.

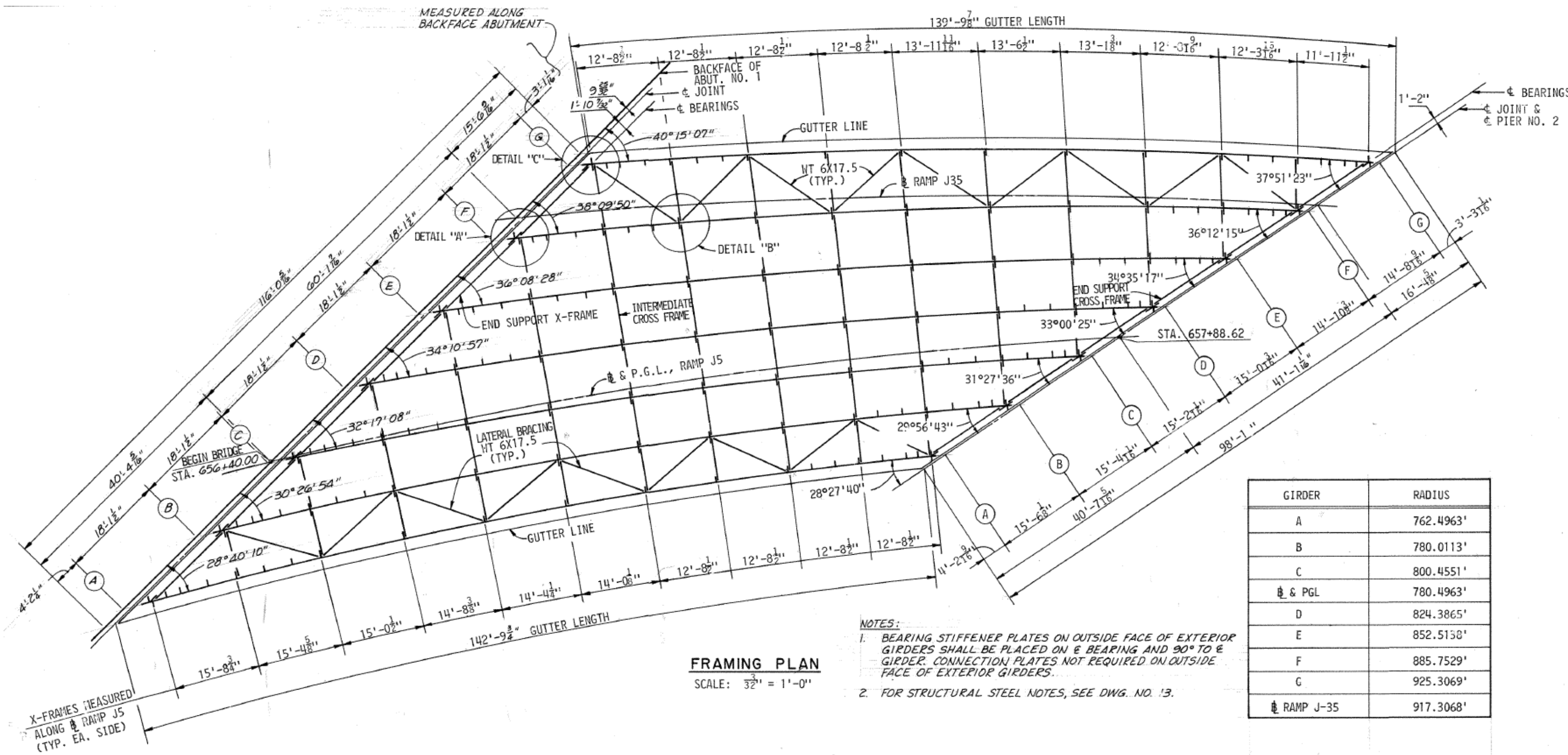
So far I have not come across a spiral curve. I have come across one curved-tangent-curved bridge. But I have come across quite a few flared girders. As owners, need to check your inventory to decide if need to add enhancements.

In order to rate flared girders, had to build separate model for each girder. For the curved-tangent-curved bridge; had to build 2 models;
Model 1 was Curved - Tangent & Model 2 was Tangent - Curved

Examples of Flared Girders



Examples of Flared Girders

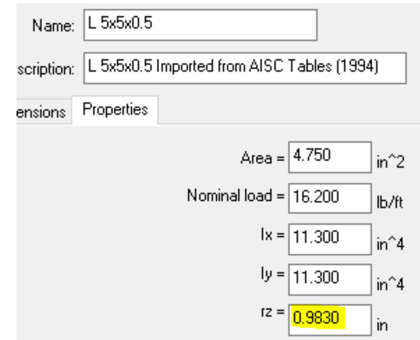


GIRDER	RADIUS
A	762.4963'
B	780.0113'
C	800.4551'
℄ & PGL	780.4963'
D	824.3865'
E	852.5158'
F	885.7529'
G	925.3069'
℄ RAMP J-35	917.3068'

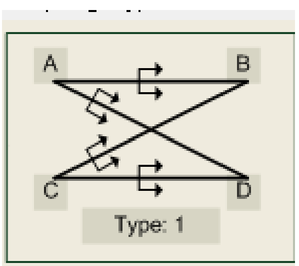
Diaphragm Issues

Diaphragms

Ratings for the angle cross-sections are incorrect. BrR bases member capacity on minimum of r_x or r_y but ignores r_z which will control.



Type 1 Diaphragms: Ratings for the diagonals (members AD & CB) are incorrect. BrR uses the full length of the diagonal even though the angles brace each other since if one is in compression the other is in tension. Causes ratings to be very low. If RF's > 1 can ignore but if < 1, have to go through pulling forces from BrR and rate by hand.



Member	Shape	Section Orientation	Section Location	Material
AB	L 6x6x0.5	Vertical	Bottom Left	ASTM A36
CD	L 6x6x0.5	Vertical	Bottom Left	ASTM A36
AD	L 6x6x0.5	Vertical	Bottom Right	ASTM A36
CB	L 6x6x0.5	Vertical	Top Left	ASTM A36

Boundary conditions for member ends should always be fixed, especially for member types other than angles. While angles are typically rated as two force members, others sections such as channels are rated using combined axial and bending.

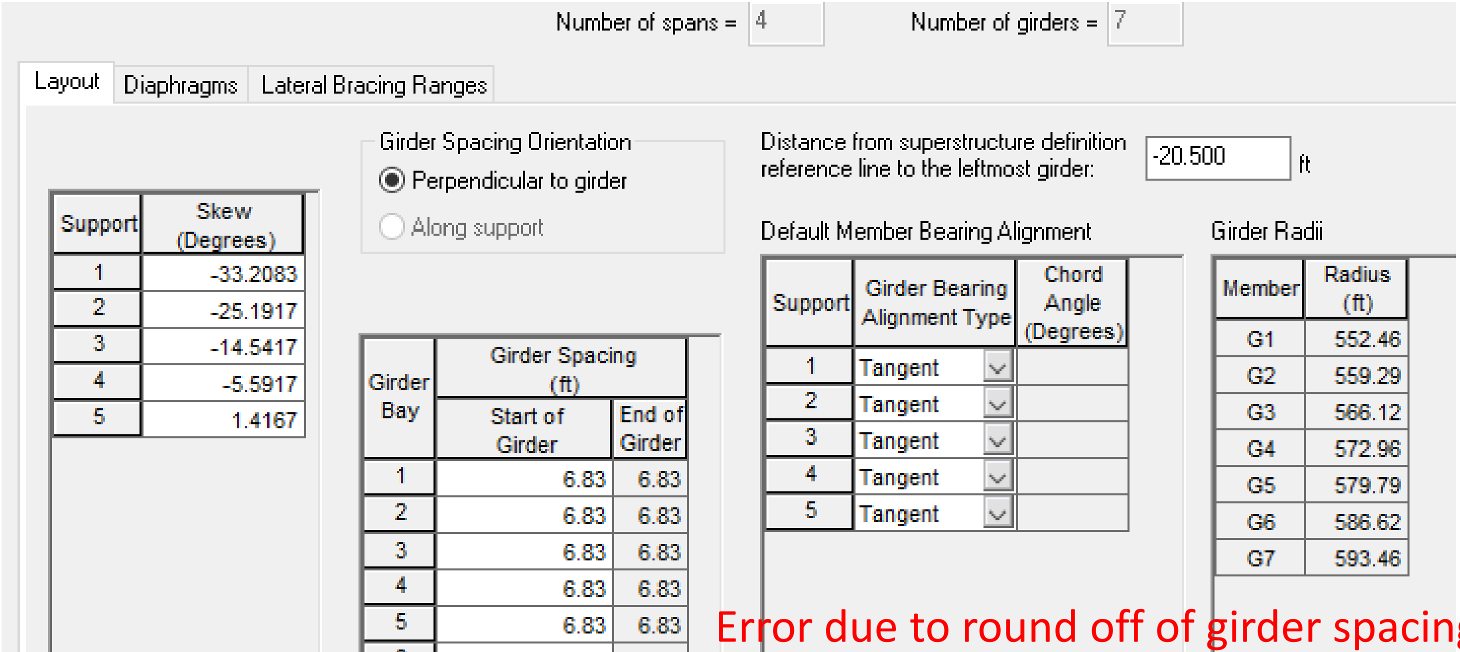
Connection	Support Type	Y (in)	Measured From
A	Fixed	7.00	Top of Web
B	Fixed	7.00	Top of Web
C	Fixed	8.25	Bottom of Web
D	Fixed	8.25	Bottom of Web
E	Fixed		

Double angles are not supported in BrR. Use a single angle definition and modify to give same section properties as the double angle.

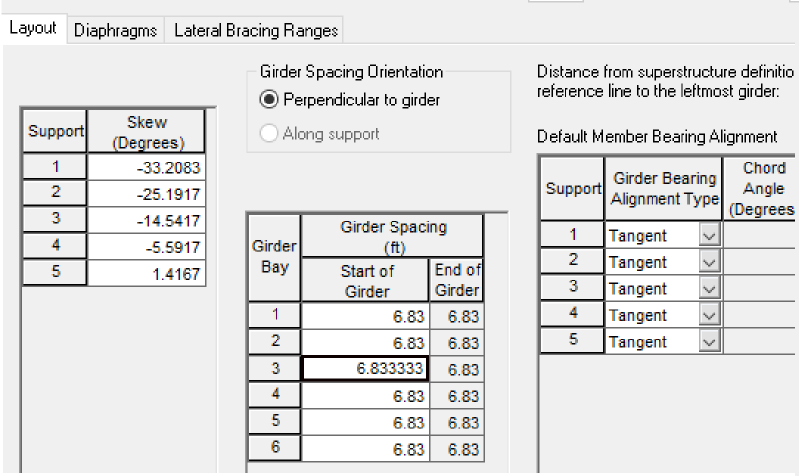
Note: Do not try and model as a T – section as ratings will be completely wrong.

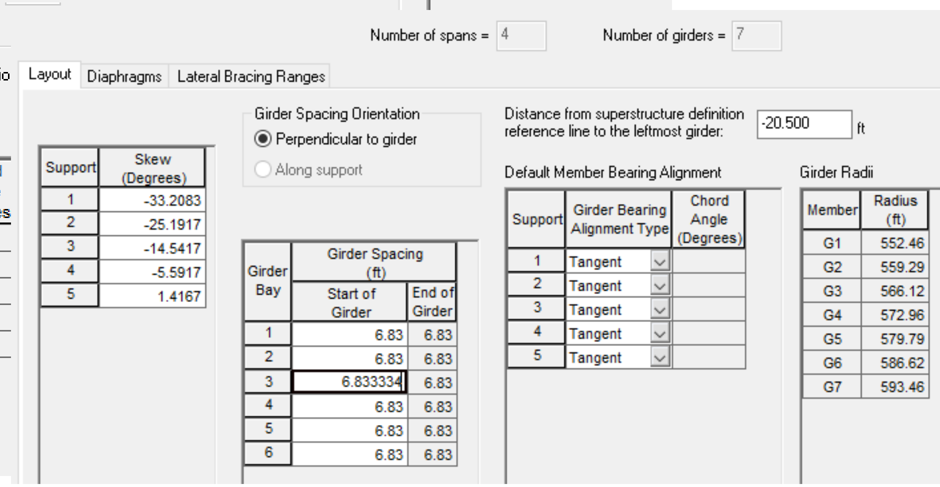
Other Tips for Curved Girder Modeling

Round Off Error



Error due to round off of girder spacings (.000001 ft).





Settings and Tips:

Tolerance: Set to maximum when building model as appears to affect the accuracy of BrR generated locations. Then reduce tolerance before running model as roundoff error can cause model to crash.

Analysis Settings: Default values are best for most cases. Do not change unless have to in order to get very large models to run that under these settings will crash due to lack of memory.

Pre-Modeling: I typically use Mathcad to calculate all of my span and transition lengths, diaphragm spacing and locations, and weights, loads etc. I then copy values directly from the Mathcad sheet to BrR. This not only helps eliminate typo type errors but speeds up the BrR modeling. Don't necessarily have to use Mathcad, could also do this in other software packages such as Excel. Only problem is that if you have an error in calc's, it will translate into model.

Run Time: Small models take anywhere from an hour or two to run. Large models can take a couple of days to run. Majority of models take anywhere from 2 to 10 hours to run. Suggest running models overnight so that you do not tie up your computer during work hours.

Memory: BrR leaves very large temporary files that will eat up disk space on your computer.

Before running a new model, delete all files with SUR, FEM and FER extensions under; C:\Users*UserName*\AppData\Local\Temp.

Note: If rerunning a model; do not delete files so that BrR can reuse the previous FE results. Will save time if rerunning a model.

QUESTIONS?

Michael Baker

INTERNATIONAL

We Make a Difference