Capabilities of BrR – LRFR
PT Concrete Multicell Box Girders

(Presentation Version)

August 07, 2018

Using BrR Version 6.8.2

Definitions

- MCB – Multi Cell Box Girders
- Caltrans – California Department of Transportation
- TL – Travel Lane
- LLDF – Live Load Distribution Factor
- PT – Post Tensioned
- LL – Live Load
- BrR – AASHTOWare Bridge Rating software
- LRFR – Load and Resistance Factor Rating
- LFR – Load Factor Rating
- RF – Rating Factor

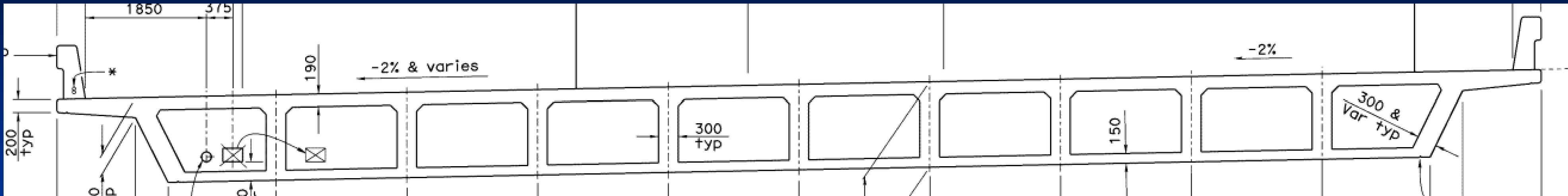
What is covered

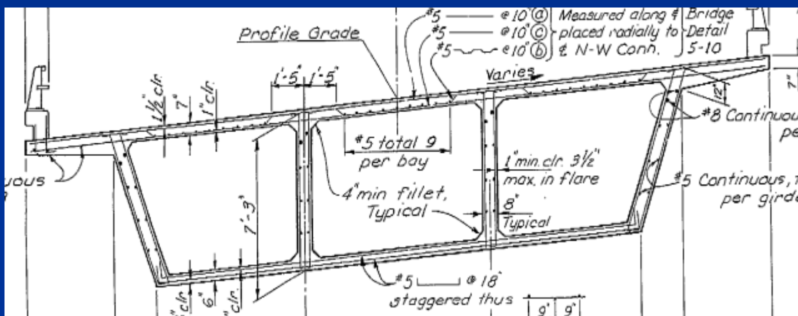
1. Analysis Approach to MCB
2. BrR Software Capabilities
3. A Few Work Arounds

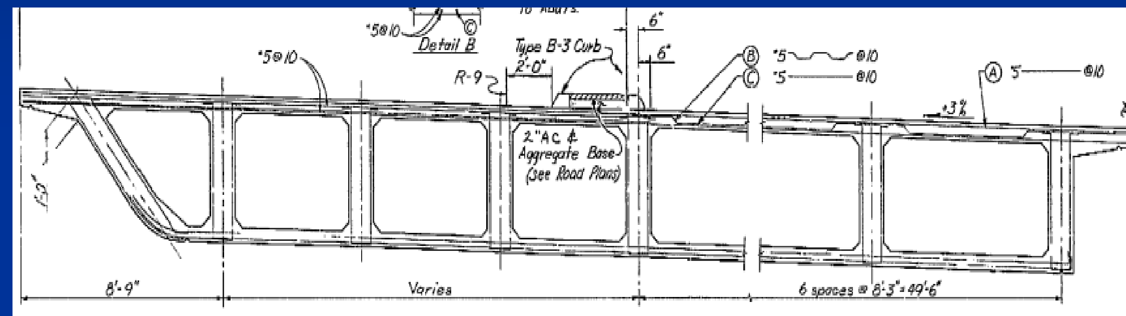
MCB example

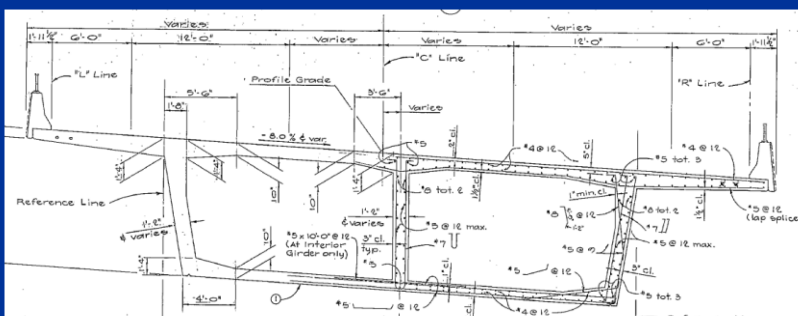
Superstructure looks like a concrete block

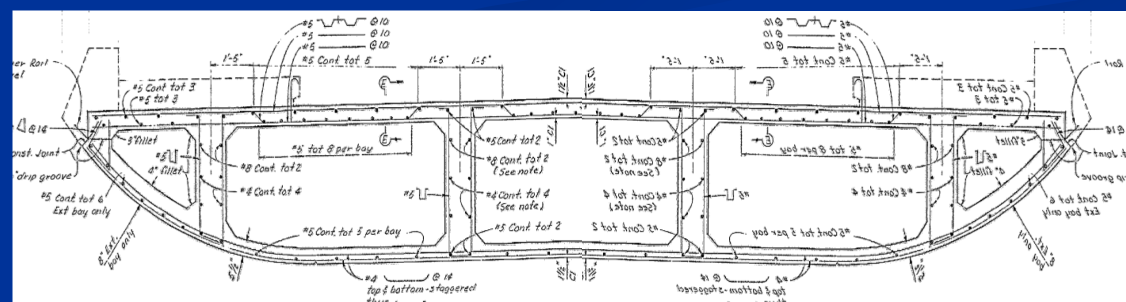
A Few MCB Girder Sections





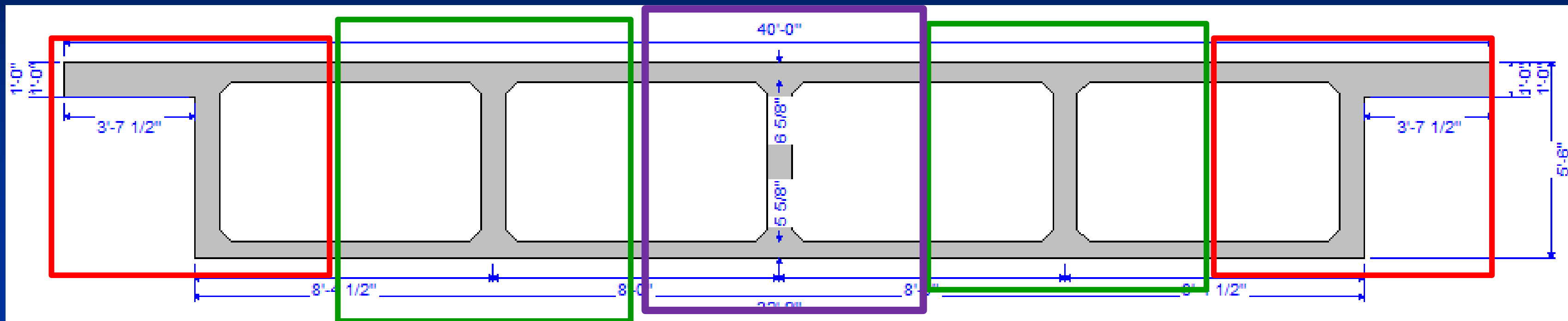






■ Varying depth (parabolic)

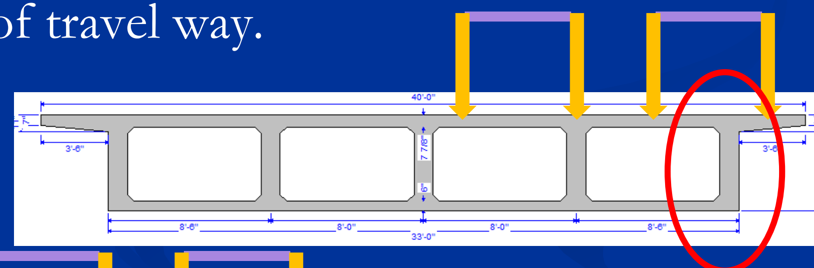
Analysis Approach of MCB



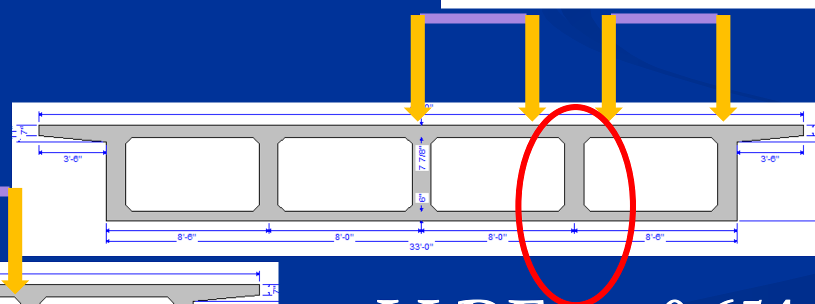
- In the early 1990s, Caltrans began designing and load rating MCB girder bridges using the "Full Box" methodology.
- In general, BrR software uses the same "Full Box" concept for load rating multi-cell box girders.

Analysis Approach of MCB

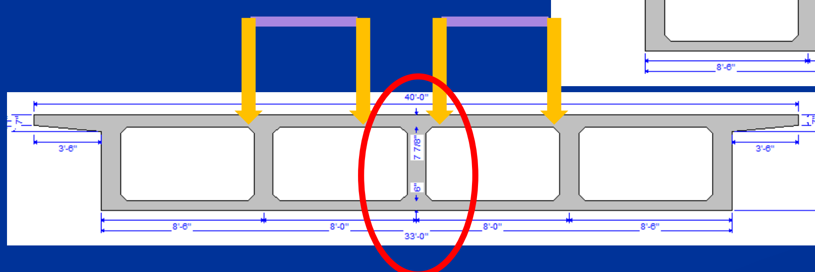
- Illustration using Moment Demand on a 40ft wide, 2 Lane Bridge. (Br. No: 52C0170)
  - Approximate locations of two side by side LL Trucks that will produce largest demand on each girder shown. Capacity of each girder will then be used to establish RF of girder.
  - Note that except for shear in exterior girders, the LLDF for MCB girder is not dependent on the location of the edge of travel way.



$LLDF_M$ = 0.572



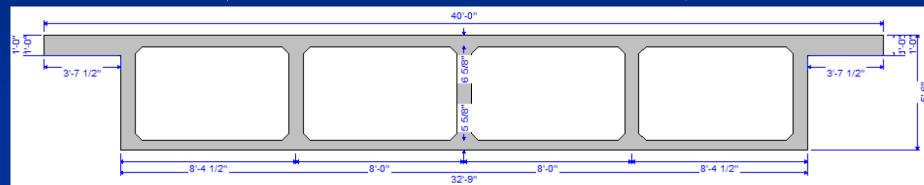
$LLDF_M$ = 0.654



$LLDF_M$ = 0.654

Full Box vs Individual Web Analysis

- Comparison of LRFR RF based on Individual Webs vs Full Box using Moment Demand (Br. No: 52C0170)

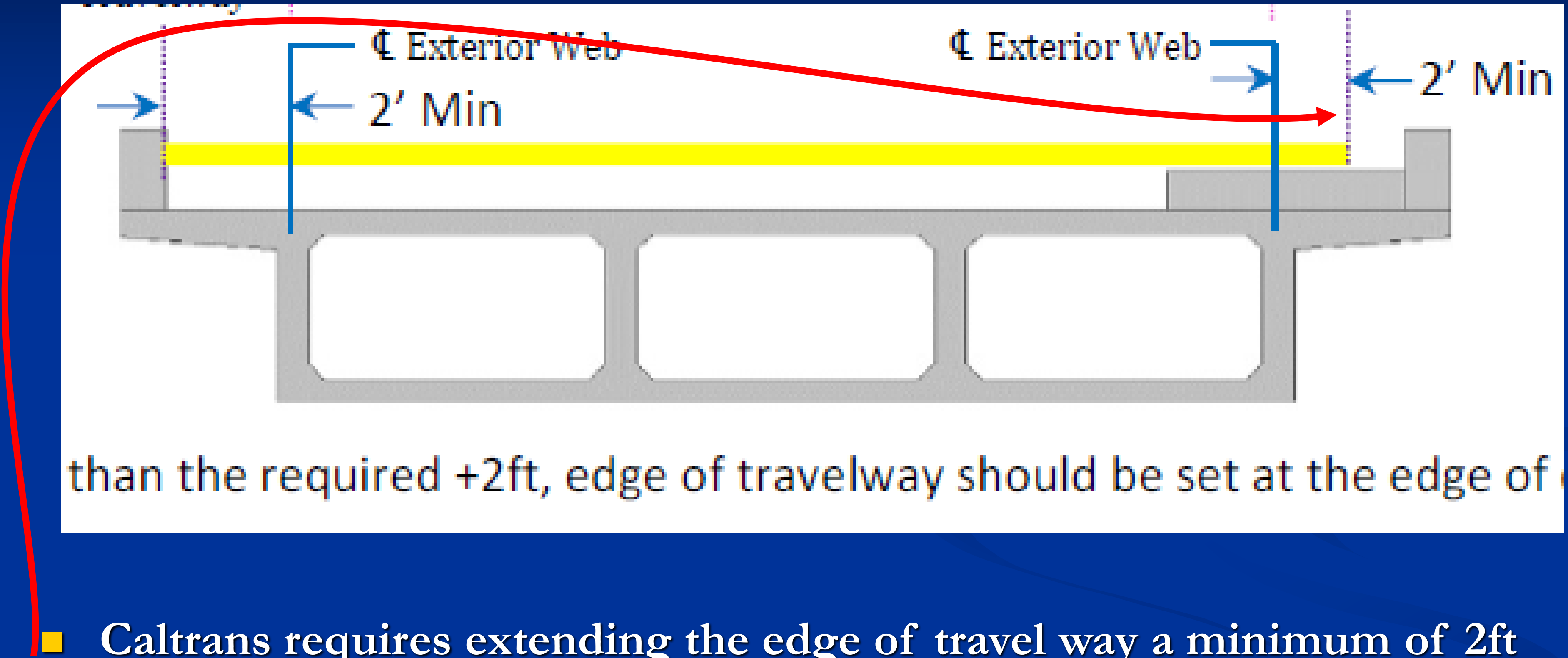


Summation of webs

	Web 1	Web 2	Web 3	Web 4	Web 5	Full Box
LLDF for Moment	0.571	0.639	0.639	0.639	0.571	3.059
Moment Capacity	5973.3	5973.3	5973.3	5973.3	5973.3	29866.4
DL Moment	1807.4	1831.7	1831.7	1831.7	1831.7	9134.2
Available Capacity for LL	3714.0	3683.7	3683.7	3683.7	3683.7	18448.7
HL93 Demand	1386.4	1551.6	1551.6	1551.6	1386.4	7427.5
Operating RF	1.98	1.76	1.76	1.76	1.97	**1.84**

  - The total LL Lanes used to design/rate the bridge (3.059) will be larger than the number of lanes that can physically fit on the bridge (3 lanes).
  - Rating Factors of Interior Girders are slightly less than the rating factors obtained from Full Box Concept.

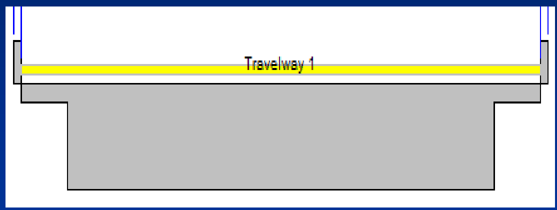
Full Box vs Individual Web Analysis



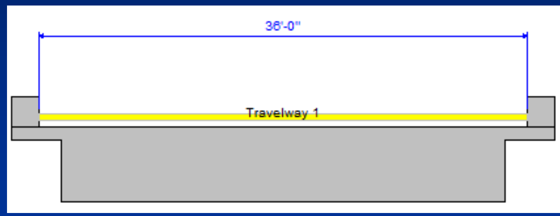
- **Caltrans requires extending the edge of travel way a minimum of 2ft beyond the CL of exterior web. If the edge of barrier is more than 2ft, actual edge of barrier will be used.**
- Note that travel way width (used for analysis referred to as **notional travel way**) is larger than "actual travel way" [the distance between the face of barrier and face of the side walk.]

Full Box vs Individual Web Analysis

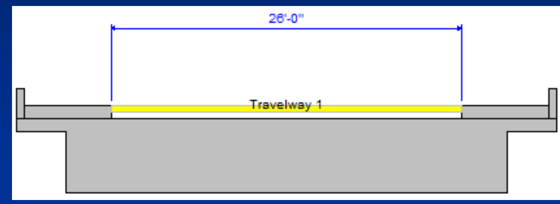
Case 1: Full width



Case 2: 2 ft wide barrier



Case 3: 7 ft wide barrier



	Web 1	Web 2	Web 3	Web 4	Web 5	Full Box Actual TL	Full Box Notional TL
Case 1 (TL: 40ft wide)	1.53	1.82	1.82	1.82	1.53	1.73	1.73
Case 2 (TL: 36ft wide)	1.73	1.82	1.82	1.82	1.74	1.85	1.85
Case 3 (TL: 26ft wide)	3.05	1.82	1.82	1.82	3.05	2.15	1.85

1. If we were to load rate the bridge using individual web analysis concept, the critical RF will be 1.82.
2. As the travel width reduces, the RF based on full box increases, but the critical RF based on interior webs remain the same. This is because:
   - the LLDF expression for shear of interior webs IS NOT dependent on the travel width
   - the LLDF expression for shear of exterior webs IS dependent on the travel width
3. RF for the full box with 2ft barrier width produces a value closer to the RF established for Interior web (girder)

Full Box Approach of MCB

- To obtain a rating factor (that is very closer to the lowest RF of all webs) by using Full Box concept, the user needs to pay attention to how the LLDF is generated.
  - Note that if the LLDF for a web uses "Lever Rule" (ex: one lane LLDF for shear), the travel width will play a significant role in "Full Box" rating.
  - When any one of the variables of an LLDF expression falls outside of range of applicability, the software defaults to Lever Rule method to establish the LLDF.
- Full box analysis assumes all girders are fully effective in carrying total demand. For cases where this may not be true, full box analysis should not be used.

Standard BrR Capabilities for MCB

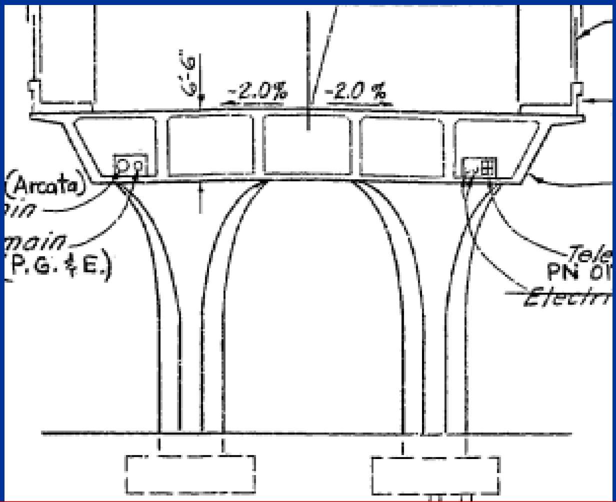
- Depth of the girder can be constant, linearly varying, or parabolically varying (concave)
- Web Flares are allowed
- Cell width can be constant or linearly varying
- No limit on number of spans
- Different skews at supports
- Superstructure with integral bents
- Web shear reinforcement Wizard
- ONE "continuous" post-tensioned profile
- Establishes the PT force losses using AASHTO expressions
- Generates LLDF for webs and then establishes the LLDF for Full Box based on defined Travel way

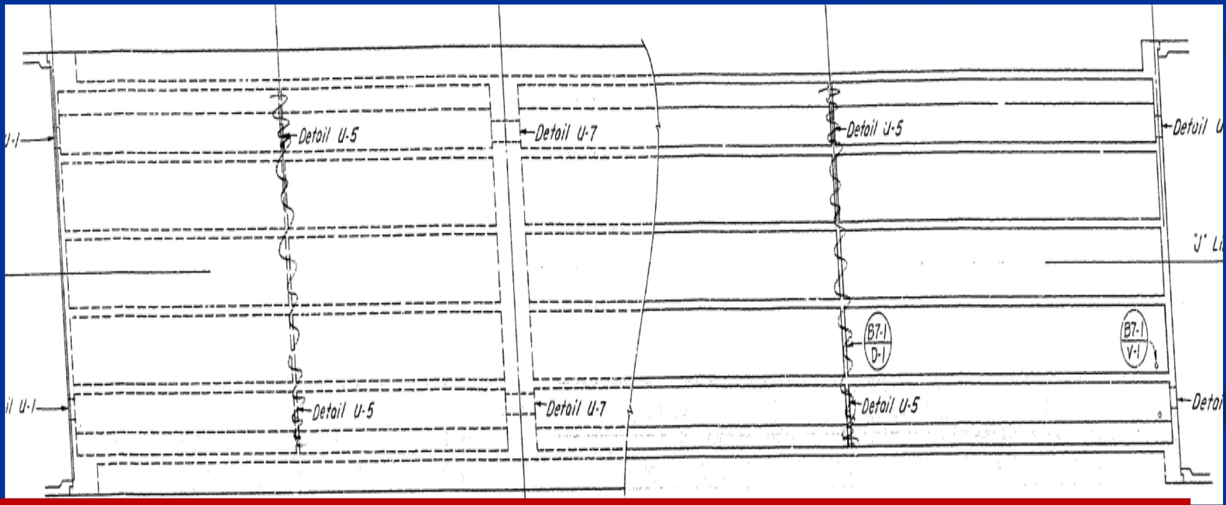
Standard Capabilities cont.

- Load rate for moment and shear demands using Full Box concept
  - If the span length of all webs are the same, software load rates each web as well
- Can load rate for shear using any of the four acceptable shear computation methods
  - General Procedure
  - General Procedure – Appendix B
  - Simplified Procedure
  - Simplified Procedure - Vci and Vcw
- Overwrite the Moment and Shear Capacity for Full box at any analysis point is allowed
- Graphically displays shear reinforcement pattern entered for each web

Standard MCB Girders

- Number of Cells remains the same for the entire length.
- Bridge width and Cell width remain the same for the entire length.
- Straight bridge with same skew at all supports.





Rate the bridge using individual webs and Full Box concept

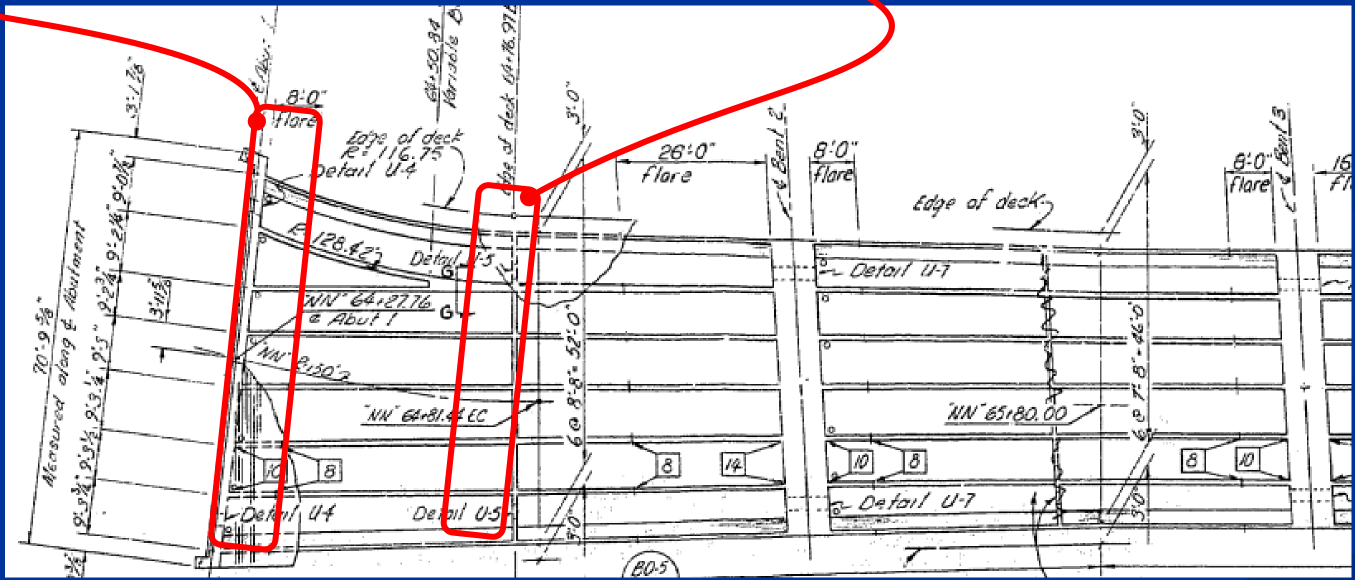
Capabilities for Standard MCB Girders

- Rates the "Full Box" using Moment and Shear demands.

- Also, Rates all webs using shear demands.
  - Note that the software assumes the same number of tendons are provided in all webs for post-tensioned box girders.
  - Since it does load rate the webs for shear, "notional travel width" need not be considered when load rating these bridges.

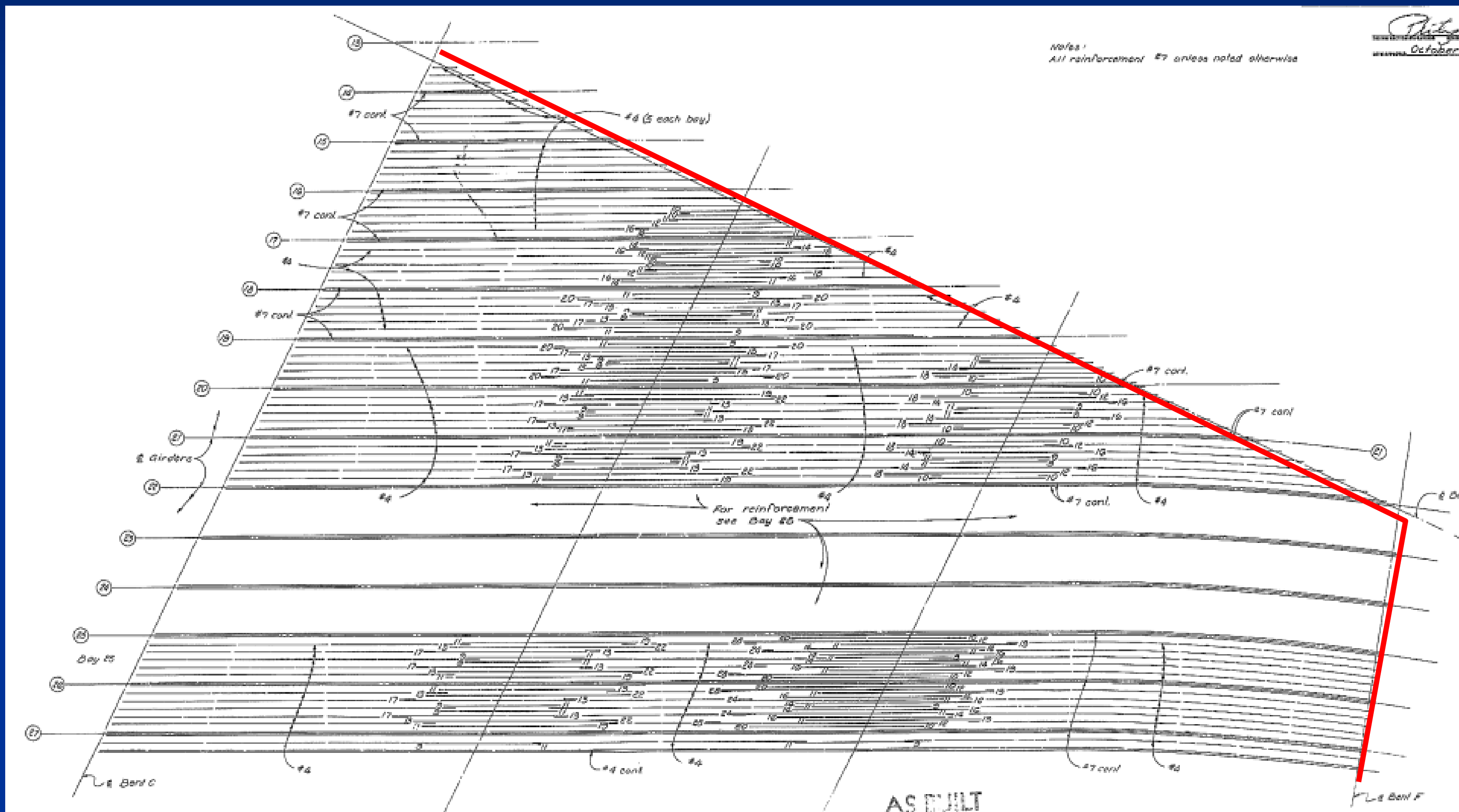
Complex MCB Girder

- Number of Cells changes intermittently
  - Number of Cells changes within a span
  - Number of Cells at Abut 1 = 7
  - Number of Cells at mid span 1 = 6



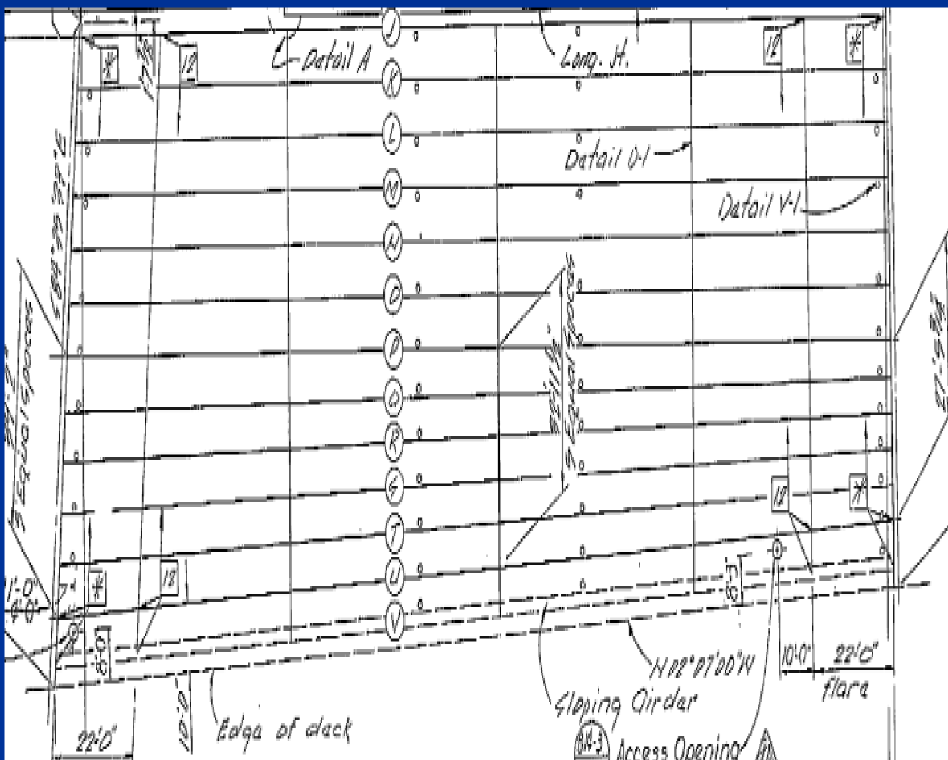
- Software canNOT rate this bridge configuration

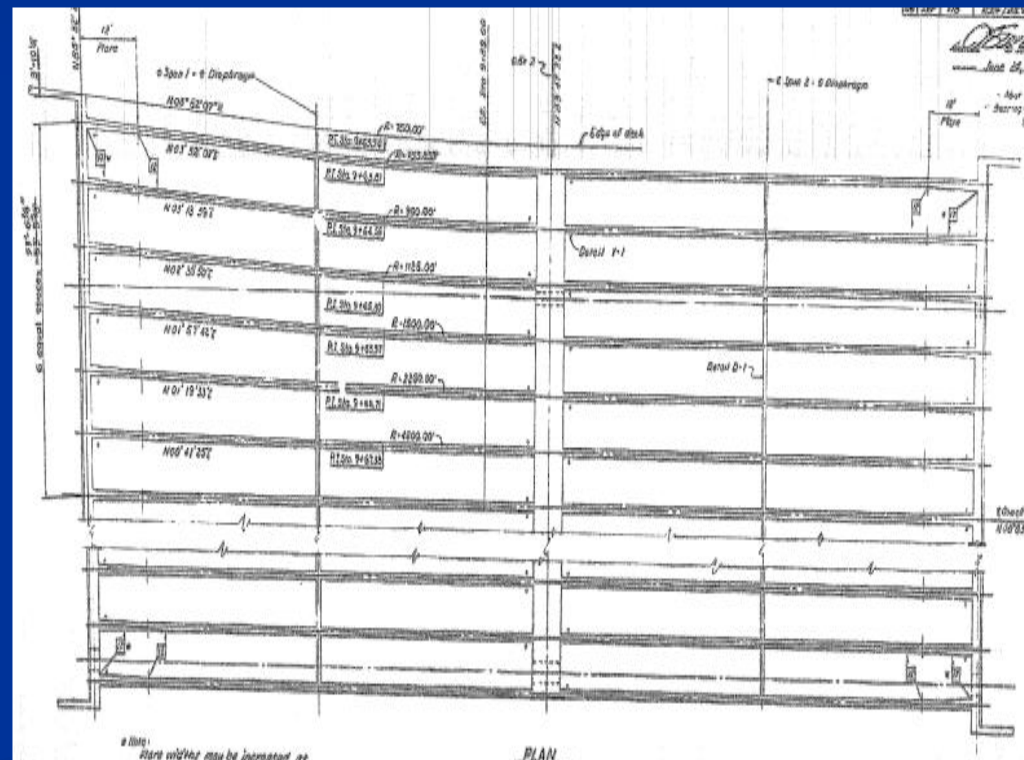
Complex MCB Girder



Complex MCB Girder

- Anything that fall between the above two extreme cases, can be done by using “Work Arounds”

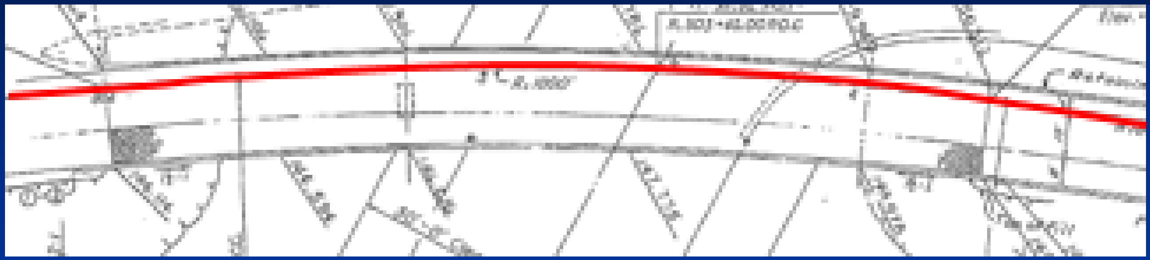


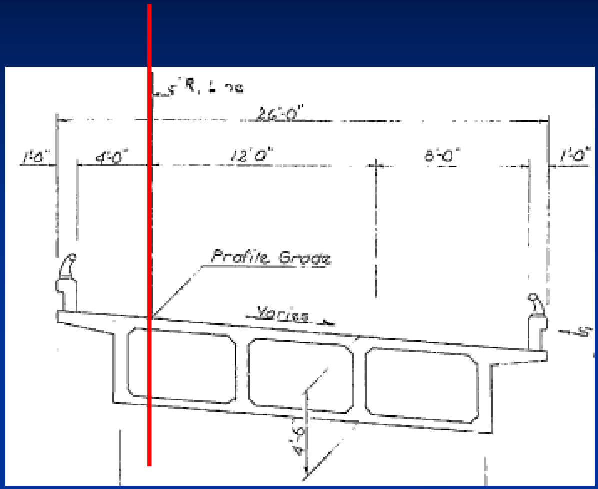


Work Arounds For a Few limitations

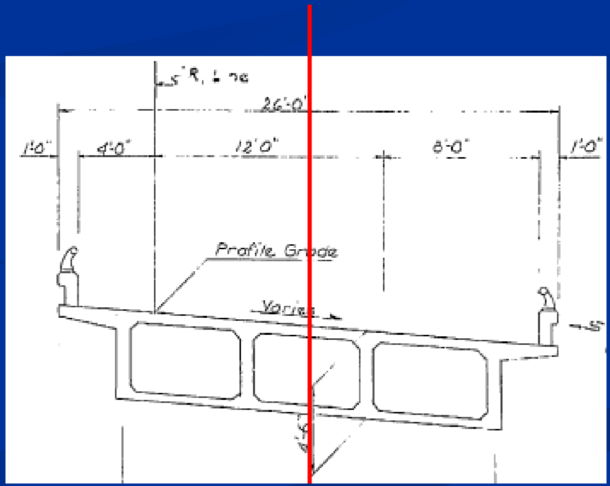
1. Location of Reference Line not coinciding with centerline of the Bridge
2. Analysis at Hinge Location
3. Modulus of Elasticity based on LFD and LRFD
4. Not meeting minimum shear reinforcement
5. Widen with One or Two Cell Box
6. Mixed Girder Types (PT and RC Box) Bridge
7. Multiple Post-Tensioning Cable Paths
8. Number of Cells is less than 3
9. Longitudinal Slope and Super Elevation slope is limited to 6%
10. Column Heights (of multi column bent) must be equal at a Bent

WA 1: Location of the Reference Line





- Note that BrR requires the user to enter the geometric dimensions of the Box girder, hinge location, tendon profile, and member load etc. along the CL of the bridge.

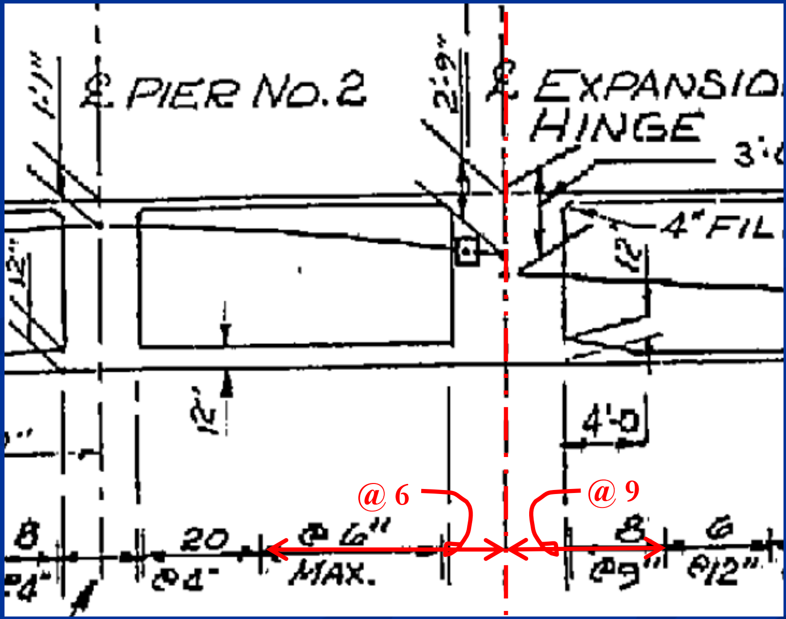


- Caltrans recommends the user to place the Reference Line along the CL of the bridge in BrR when creating the superstructure definition.

WA 2: Analysis at Hinge Location

Shear Reinforcement Ranges

★ **Hinges:** Stirrup Wizard does not consider in-span solid sections when placing reinforcement; only solid sections at ends of spans are considered. Continue stirrup spacing on either side of hinge to CL hinge.

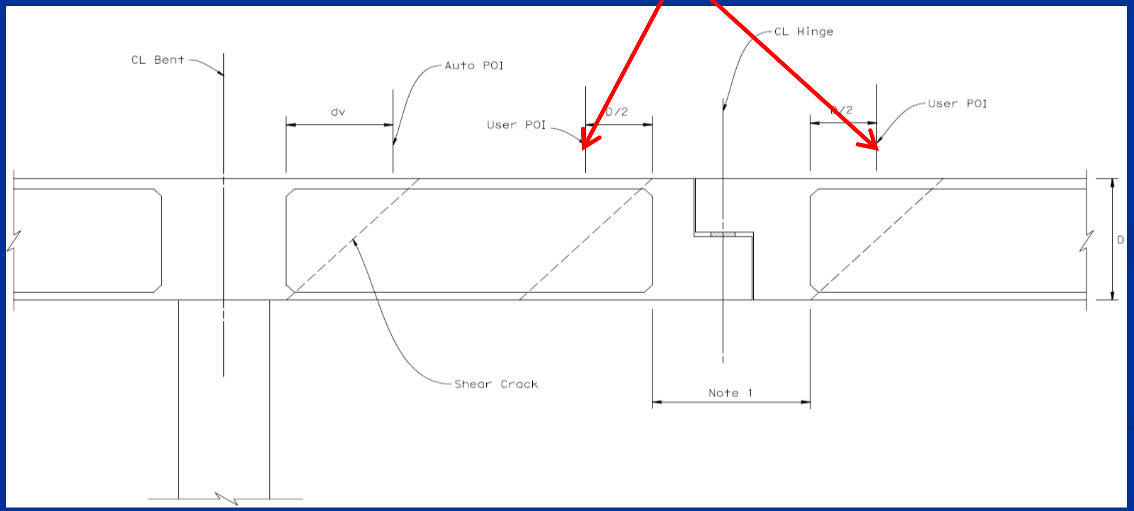


WA 2: Analysis at Hinge Location

Points of Interest

Software will NOT automatically generate analysis point at either side of hinge location.

★ **Add additional user POIs at $d_e/2$ from Hinge faces.**

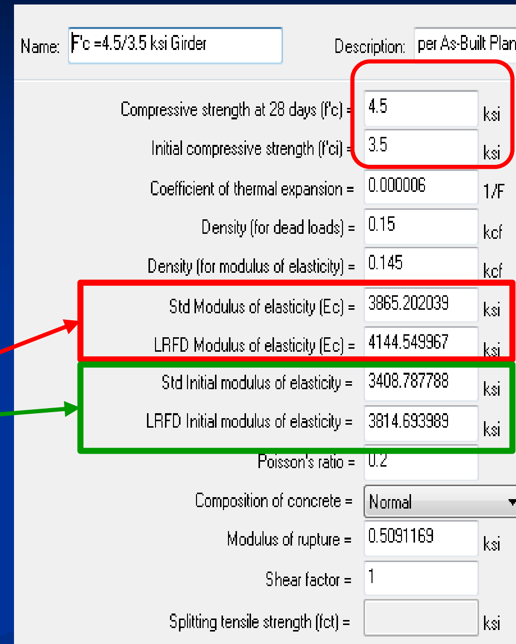


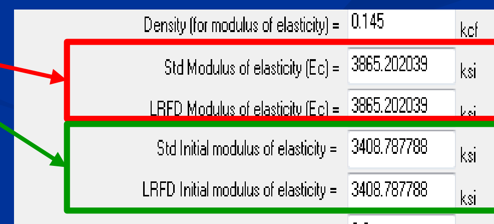
- **Also, if the hinge location falls on auto generated analysis points, user needs to create a user "defined analysis point" and overwrite the moment capacity to a larger value so that rating factor established for moment at hinge location does not control the rating.**

WA 3: Materials – Concrete

Values generated by the software for E_c and E_{ci} will be different for LFD and LRFD.

- Equation for E_c given in the 8th edition of LRFD is based on modern mix design methods.
- Caltrans requires setting both values to the values established for LFD method (Std). This is because we are dealing with older concrete.





WA 4: Not Meeting Minimum Shear reinforcement requirement

* If minimum shear reinforcement requirement AASHTO LRFD equation 5.7.2.5-1 (8th Ed.) not met, shear capacity is severely reduced. This check is more likely to fail at girder flares but may happen at any location.

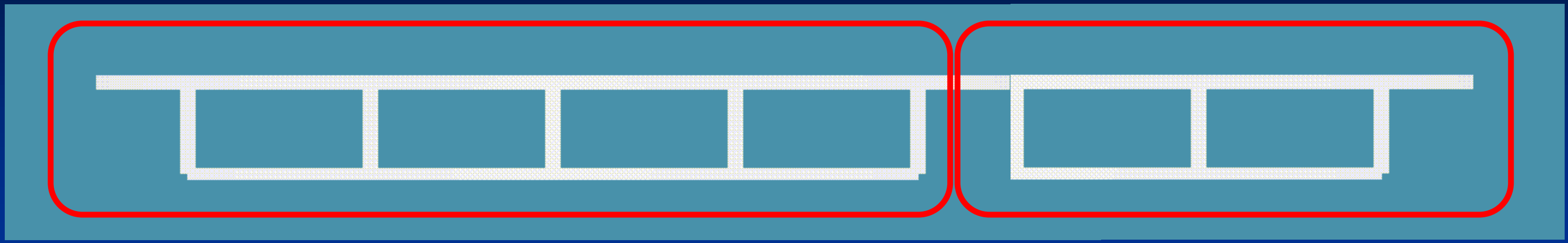
$$A_v \geq 0.0316\,\lambda\sqrt{f'_c}\,\frac{b_v s}{f_y} \qquad (5.7.2.5\text{-}1)$$

★Workaround:

1. Reduce the web width/flare to maximum which satisfies the equation.
2. Example: Difference of 0.2 inches make about 50% reduction in capacity

	Shear Rebar Size	Spacing of Rebar (in)	Rebar Fy (ksi)	F'c (ksi)	Actual bw (in)	Max. width bw (in) to meet minimum Av requirement	Vn (kip)	bw (in) if bw is set to Max width	Vn (kip)	Drop in Capacity
Web 1	#4	24.00	40	4.50	10	9.90	61.7	9.80	146	58%
Web 2	#4	24.00	40	4.50	10	9.90	80.5	9.80	164	51%

WA 5: Widened with One or Two Cell MCB



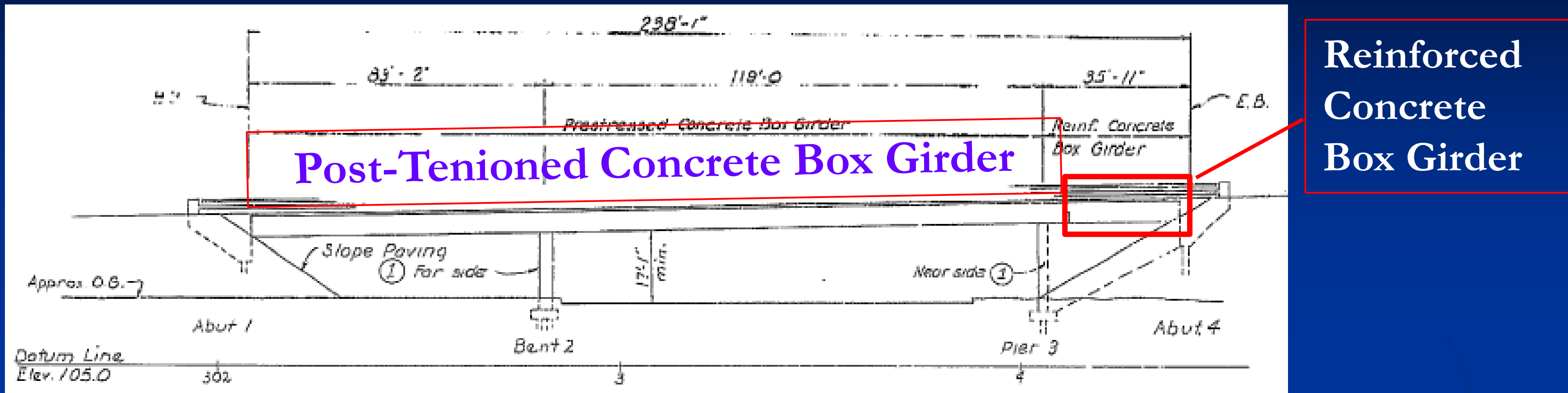
Workaround:

- ★ Create two superstructure models, (one for four cell Box and other for Two Cell box)
- ★ Manually enter the LLDF for exterior girder (next to the 2 Cell Box) and all webs of Two Cell box

Enhancement:

- ★ Modify the software to vary thickness of soffit in each cell, as it does allow the user to enter different deck thickness in cell.

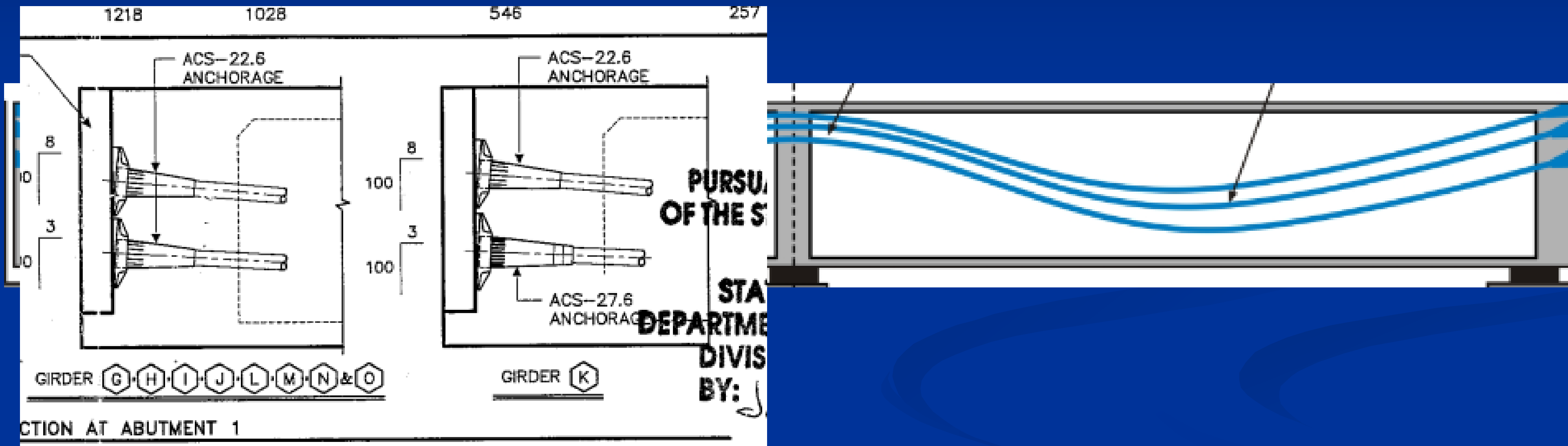
WA 6: Mixed PT and RC MCB Girder Types



- BrR software does not allow “Mixed” girder Types within a Superstructure.
- Workaround is extensive but can be done.

WA 7: Multiple Cable Paths

- Most MCB girders will have multiple ducts within each web and all have different cable paths, and BrR is limited to one



★ **Work Around:** **User determines the centroid of ALL cable paths and enters the equivalent tendon path along the CL of the bridge**

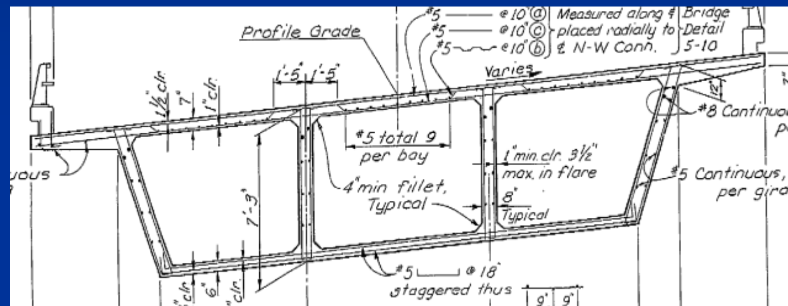
WA 8: Number of Cells is less than 3

- When the number of cells is one or two, range of applicability for the simplified LLDF expression are violated and as a result the software will revert to Lever Rule Method. This will yield very conservative ratings.

Work Around: User overwrites the LLDF created by the Lever Rule approach.

WA 9: Longitudinal Slope and Superelevation

1. Longitudinal slope (grade) should not exceed 6%.
2. Superelevation (when integral bents are used) should not exceed 6%.



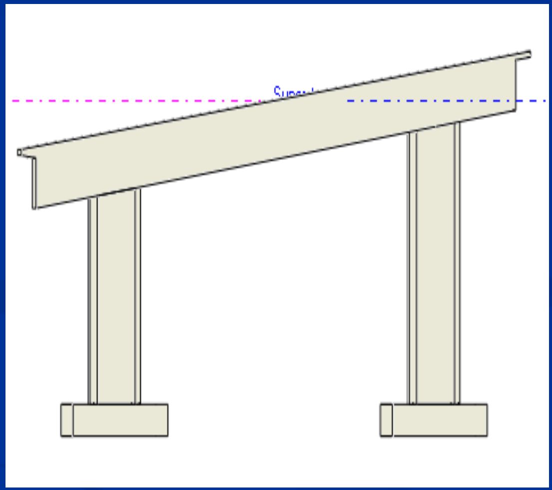
Work Around:

User uses the average elevation for all bents by entering the average elevation at both end of bent caps at all bent location.

This work around will produce a reasonable stiffness of the column, however, it may not be accurate.

WA 10: Height of Columns of Bents

- Although software allows the user to enter different height columns, it is incorrectly generating 2D elements to represent the different height columns.
- Similarly, the software is incorrectly generating 2D elements to represent multicolumn bents for bridges with superelevation.



Work Around:

- **User needs to enter the average column height (by entering the footing elevation) for all columns.**
- **For Bents with superelevation, and different column heights, the work arounds given for WA 9 and WS 10 need to be considered.**

Questions?

Capabilities of BrR – LRFR
PT Concrete Multicell Box Girders
(Full Version)

August 07, 2018
Using BrR Version 6.8.2

Definitions

- MCB – Multi Cell Box Girders
- LLDF – Live Load Distribution Factor
- PT – Post Tensioned
- LL – Live Load
- BrR – AASHTOWare BrR software
- PCA – Plan of Corrective Action
- Caltrans – California Department of Transportation
- LRFR – Load and Resistance Factor Rating
- LFR – Load Factor Rating
- RF – Rating Factor

What is covered

1. Bridge Rating in California
2. Analysis Approach to MCB
3. Possible MCB Configurations.
4. BrR Software Capabilities
5. A Few Work Arounds

1. Bridge Rating Status in California

- California is under a Plan of Corrective Action (PCA) to meet the FHWA Metric 13.
  - This is primarily due to not having load rated the bridges for shear demand.
  - Electronic models used to establish the previous rating were not archived and/or obsolete.
  - Caltrans has to update the load ratings for 13,097 bridges (out of total 23,742).

- Caltrans chose the AASHTOWare BrR software to load rate these bridges.
  - Preferred Rating method was chosen as LRFR.
  - LRFR was chosen because shear capacity demand established by the LFR method is much lower, resulting in permit rating factor drops for bridges that have been operating with permit trucks on them for the last 35 years.

- So far, Caltrans generated 5,680 BrR models of which 1,375 are of MCB

Breakdown of Girder Types in California

	Inventory				Plan of Corrective Action by FHWA		
NBI Bridge Type	Local Agencies	State	Grand Total		Local Agencies	State	Grand Total
00: Other	4	1	5		2	1	3
01: Slab	3662	1860	5522		1825	863	2688
02: Stringer/Multi-Beam	2161	1148	3309		577	509	1086
03: Girder & Floorbeam S	121	36	157		94	24	118
04: Tee Beam	1404	1267	2671		682	376	1058
05: Box Beam Or Gdr - Mu	1076	6759	7835		512	4100	4612
06: Box Beam Or Gdr - Sn	56	198	254		24	96	120
07: Frame (Except Frame	22	32	54		13	18	31
08: Orthotropic		3	3			2	2
09: Truss - Deck	30	8	38		17	2	19
10: Truss - Thru	166	22	188		101	4	105
11: Arch - Deck	350	105	455		270	85	355
12: Arch - Thru	8	7	15		8	5	13
13: Suspension	5	6	11		3	4	7
15: Movable - Lift	1	3	4			1	1
16: Movable - Bascule	11	6	17		8	1	9
17: Movable - Swing	10	6	16		9	4	13
19: Culvert	2210	945	3155		1964	879	2843
21: Segmental Box Girder	1	9	10			5	5
22: Channel Beam	11	12	23		7	2	9
Grand Total	11309	12433	23742		6116	6981	13097

- Significant number of bridges that are still to be load rated are of MCB Type
  - 4612 MCB bridges
  - 2843 Culverts
  - 2688 RC Slabs
  - 1058 RC Tee
  - 1086 Steel I
  - 355 Arches
  - 120 Steel Truss

Multi-Cell Box Girder Sections

- Typical Caltrans MCB girders have the following features:
  - Width of each cell at the deck level is same.
  - Overhang width is ½ of Exterior Cell width
  - Exterior girders are either vertical or sloped
  - Typical cell width is 2 times the depth for PT and 1.5 times the depth for RC

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CONCRETE GIRDER SPACING

Spacing of concrete girders should approximately be 1½ times the structure depth for all "I", "T", and reinforced box girder bridges; and 2 times the depth for prestressed box girder bridges. Following are reasons for these recommended ratios:

1. Provides effective torsional resistance and live load distribution in the superstructure.
2. Spacing of girders at a ratio of less than 1½ times the structure depth is less cost effective because of additional forming costs for CIP girders or erection costs for precast girders.
3. Provides a tension flange for conventionally reinforced bridges which is nearly 100 percent effective for steel placement.
4. Provides a sufficient number of girders for efficient prestress paths in prestressed bridges.

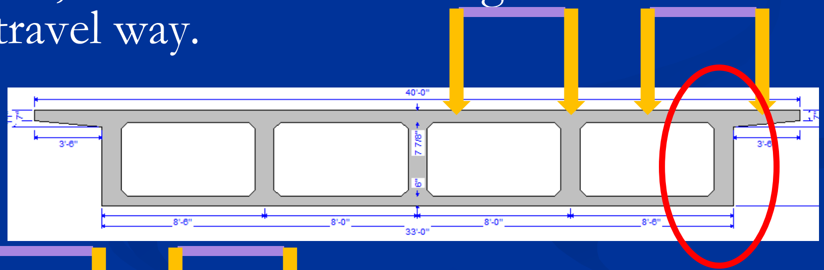
- Meeting these basic requirements allows us to use "full box" concept to design and load rate MCB Girder bridges.

Analysis Approach of MCB

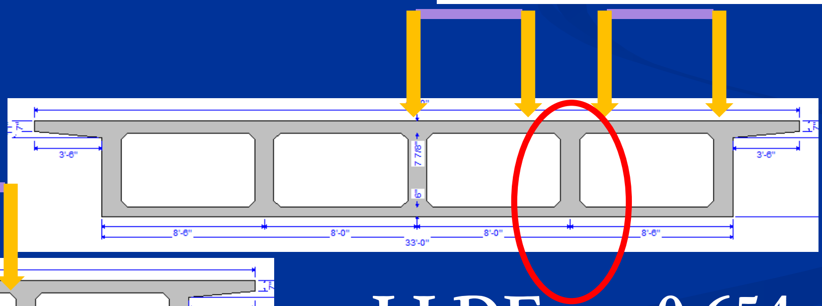
- Per AASHTO Specifications, demands on each web (or girder) needs to be established to design/rate individual webs (or girders)
- Largest possible demands must be determined when designing or rating a bridge. Maximum possible live load demand in each web (or girder) can be established by using the simplified LLDF expressions
- In the early 1990s, Caltrans started to design and load rate MCB girder bridges using "Full Box"
- In general, BrR software uses the same "Full Box" concept for load rating multi-cell box girders

Analysis Approach of MCB

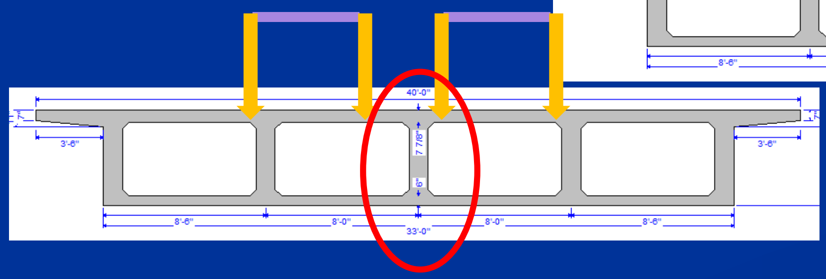
- Illustration using Moment Demand on a 40ft wide, 2 Lane Bridge.
  - (Br. No: 52C0170)
  - Approximate locations of two side by side LL Trucks that will produce largest demand on each girder is shown. Capacity of each girder will then be used to establish RF of girder.
  - Note that except for shear in exterior girders, the LLDF for MCB girder is not dependent on the location of the edge of travel way.



$LLDF_M$ = 0.572



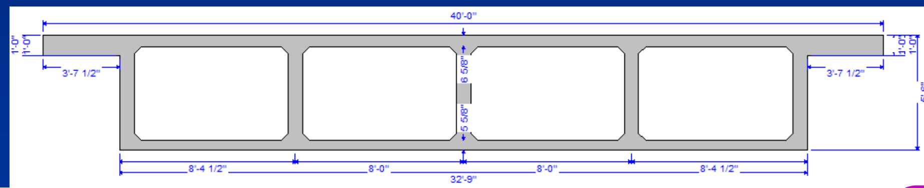
$LLDF_M$ = 0.654



$LLDF_M$ = 0.654

Full Box vs Individual Web Analysis

- Comparison of LRFR RF based on Individual Webs vs Full Box using Moment Demand (Br. No: 52C0170)



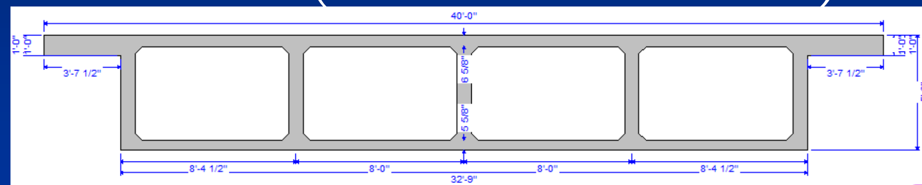
Summation of webs

	Web 1	Web 2	Web 3	Web 4	Web 5	Full Box
LLDF for Moment	0.571	0.639	0.639	0.639	0.571	3.059
Moment Capacity	5973.3	5973.3	5973.3	5973.3	5973.3	29866.4
DL Moment	1807.4	1831.7	1831.7	1831.7	1831.7	9134.2
Available Capacity for LL	3714.0	3683.7	3683.7	3683.7	3683.7	18448.7
HL93 Demand	1386.4	1551.6	1551.6	1551.6	1386.4	7427.5
Operating RF	1.98	1.76	1.76	1.76	1.97	**1.84**

  - Rating Factors of Interior Girders are slightly less than the rating factor obtained from Full Box Concept.
  - The total LL Lanes used to design/rate the bridge (3.059) will be larger than the number of lanes that can physically fit on the bridge (3 lanes).

Full Box vs Individual Web Analysis

- Comparison of LRFR RF based on Individual Webs vs Full Box using Shear Demand (Br. No: 52C0170)



Summation of webs

	Web 1	Web 2	Web 3	Web 4	Web 5	Full Box
LLDF for Shear	0.7887	0.8221	0.8221	0.8221	0.7887	4.0437
Shear Capacity	258.0	299.3	299.3	299.3	258.0	1428.2
DL Shear	70.1	70.2	70.2	70.2	70.1	350.9
Available Capacity for LL	170.3	211.5	211.5	211.5	170.3	989.6
HL93 Demand	82.5	86.1	86.0	86.1	82.5	423.1
Operating RF	1.53	1.82	1.82	1.82	1.53	**1.73**

  - Rating Factors of Exterior Girders are slightly less than the rating factor obtained from Full Box Concept.
  - The total LL Lanes used to for design/rate the bridge (4.0437) will be larger than the number of lanes that can physically fit on the bridge (3 lanes).

Full Box vs Individual Web Analysis

- A Few guidelines established by Caltrans for applying the Full Box concept to the load rating of bridges

When box girder bridges are analyzed as a "full box unit", the live load demand applied to individual webs (or girders), needs to be carefully established especially for the exterior webs and the webs adjacent to median barriers. Engineers should use best judgment in all cases.

The Lane Position tab of the Structure Typical Section GUI allows you to define the travelway location. Whenever the LLDF is established by using "Lever Rule" method (due to the range of applicability violation or due to the specification requirements), the travel width being defined plays an important role. In some cases, the "Lever Rule" method results in lower live load demand on individual webs and, consequently, produces ***un-conservative*** rating factors. To avoid this, the following guidelines for developing the travel width are provided.

General Notes:

1: It is recommended that the notional travelway used to compute LLDF values match the schematic that appears in the *Structure Typical Section View*, which may be different from the "actual/existing" travelway on the bridge.

Full Box vs Individual Web Analysis

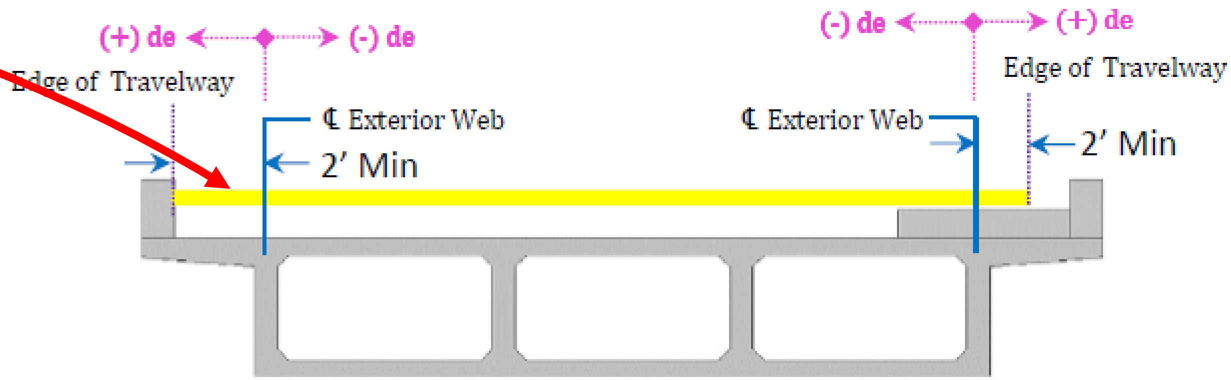
__Notional Max Travel Width__ ≥ width between the face of barriers

CASE A1 (NO. OF CELLS = 3).

de should be no less than **+2ft** *($de \geq +2'$)*

d_e	=	horizontal distance from the centerline of the exterior web of exterior beam at deck level to the interior edge of curb or traffic barrier (ft)

Example:



EXCEPTION: If overhang is less than the required +2ft, edge of travelway should be set at the edge of deck.

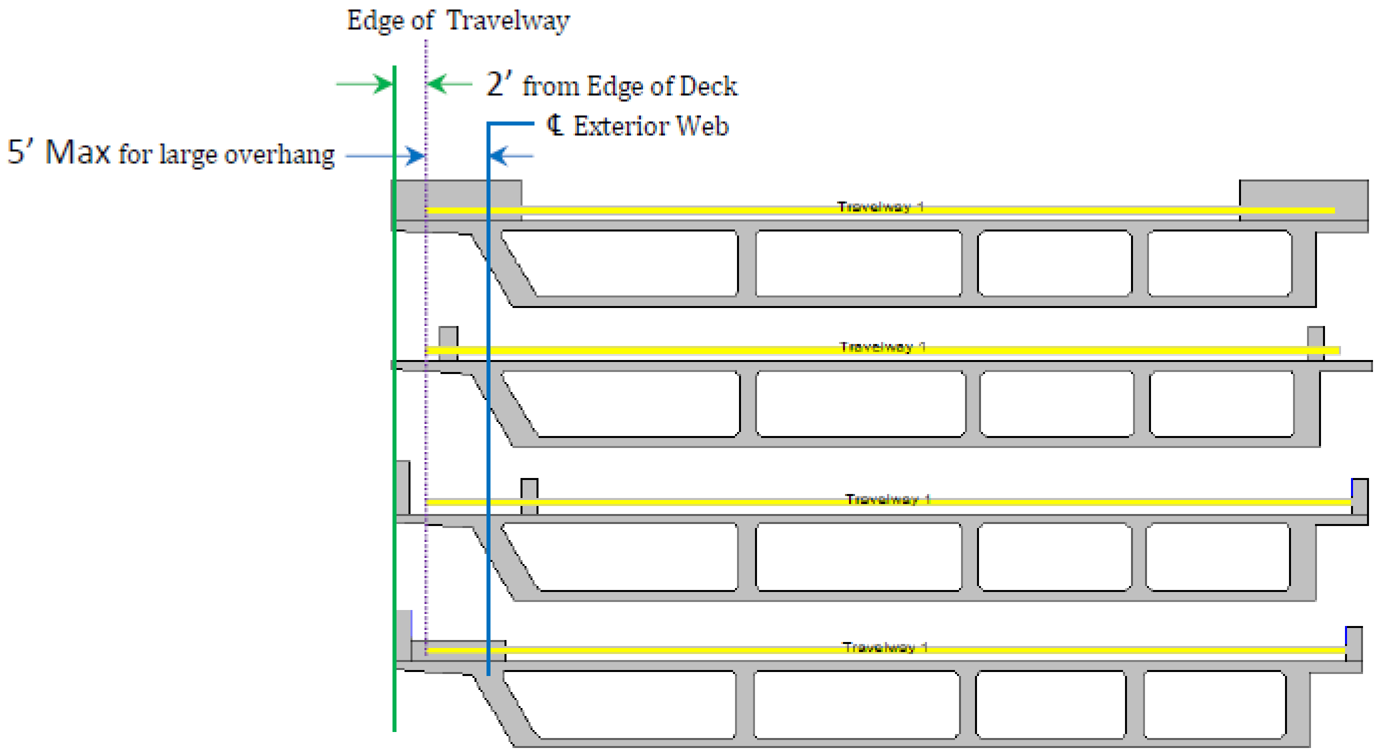
- Note that travel way width (used for analysis referred to as notional travel way) is larger than "actual travel way" [the distance between the face of barrier and face of the side walk.]

Full Box vs Individual Web Analysis

Case A2 (No. of Cells > 3).

When the barrier width, or the distance from edge of deck to interior face of barrier/sidewalk, <u>is greater than 2 feet</u>, edge of travelway is set to 2 feet from the edge of deck.

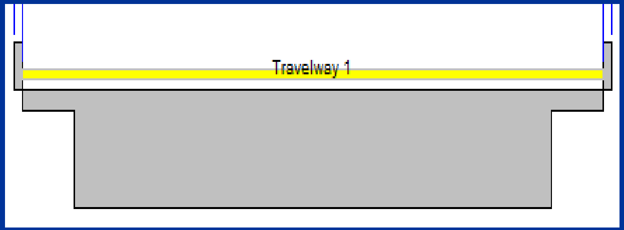
Examples:



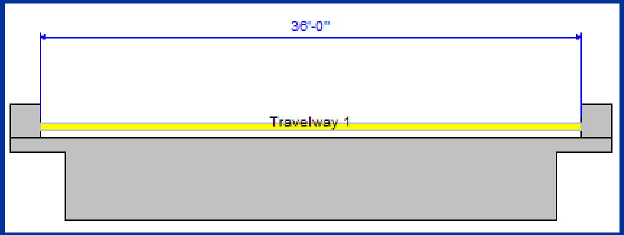
- Again, note that travel way width (used for analysis or notional travel way) is much larger than the distance between the face of barrier and side walk.

Full Box vs Individual Web Analysis

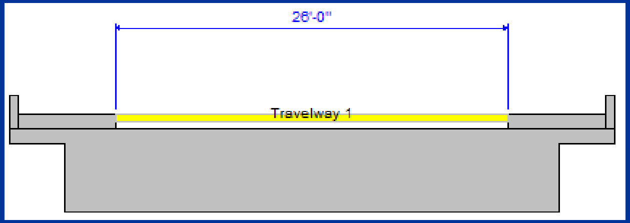
- Example: 40ft, 2 Lane, 3Cell Box Girder Bridge
- Case 1: Barrier on outside edge (40ft travel width)



- Case 2: 2 ft wide barrier (36ft travel width)

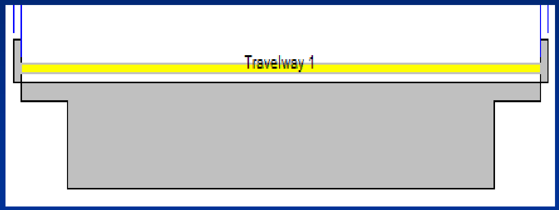


- Case 3: 7 ft wide barrier (26ft travel width)

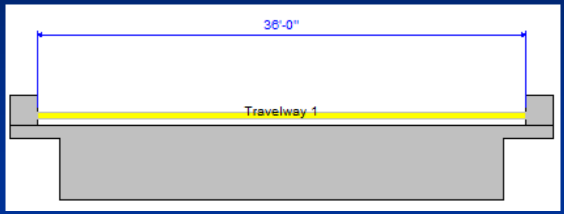


Full Box vs Individual Web Analysis

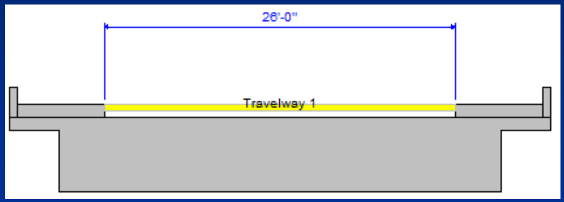
Case 1: Full width



Case 2: 2 ft wide barrier



Case 3: 7 ft wide barrier

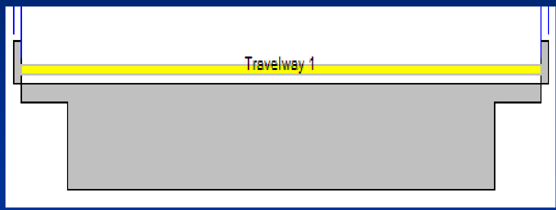


	Operating RF based on **Shear** Comparison					
	Web 1	Web 2	Web 3	Web 4	Web 5	Full Box
Case 1 (TL: 40ft wide)	1.53	1.82	1.82	1.82	1.53	**1.73**
Case 2 (TL: 36ft wide)	1.73	1.82	1.82	1.82	1.74	**1.85**
Case 3 (TL: 26ft wide)	3.05	1.82	1.82	1.82	3.05	**2.15**

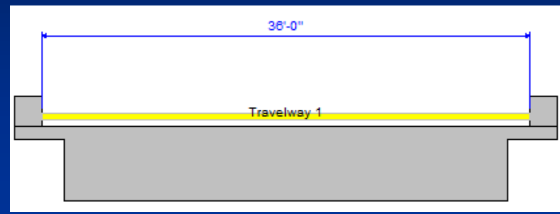
1. If we were to load rate the bridge using individual web analysis concept, the critical RF will be 1.82.
2. As the travel width reduces, the RF based on full box increases, but the critical RF based on interior webs remain the same. This is because:
   - the LLDF expression for shear of interior webs IS NOT dependent on the travel width
   - the LLDF expression for shear of exterior webs IS dependent on the travel width
3. RF for the full box with 2ft barrier width produces a value closer to the RF established for Interior web (girder)

Full Box vs Individual Web Analysis

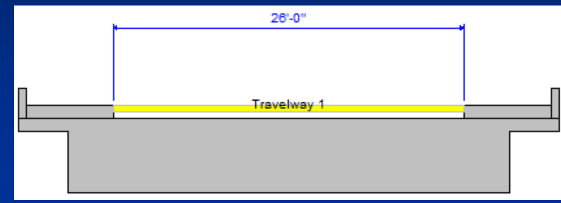
Case 1: Full width



Case 2: 2 ft wide barrier



Case 3: 7 ft wide barrier



	Operating RF based on **Moment** Comparison					
	Web 1	Web 2	Web 3	Web 4	Web 5	Full Box
Case 1 (TL: 40ft wide)	1.98	1.76	1.76	1.76	1.97	1.84
Case 2 (TL: 36ft wide)	1.98	1.76	1.76	1.76	1.97	1.84
Case 3 (TL: 26ft wide)	1.98	1.76	1.76	1.76	1.97	1.84

1. If we were to load rate the bridge using individual web analysis concept, the critical RF will be 1.76.
2. RF for moment does not vary with travel width. This is because
   - The simplified LLDF for moment does not depend on travel width
3. The RF based on Full Box is reasonable

Full Box Approach of MCB

- Summary:
  - To obtain a rating factor (that is very closer to the lowest RF of all webs) by using Full Box concept, user needs to pay attention as to how the LLDF is generated.
    - Note that if the LLDF for a web uses "Lever Rule" (ex: one lane LLDF for shear), the travel width will play a significant role in "Full Box" rating.
    - When any one of the variables of LLDF expression fall outside of range of applicability, software defaults to Lever Rule method to establish the LLDF.
  - Full box analysis assumes all girders are fully effective in carrying total demand. For cases where this may not be true, full box analysis should not be used.

MCB Girder Configurations

Based on the complexity that exists, seven configurations have been used to categorize them:

1. Standard MCB Girder
2. Complex MCB Girder - I
3. Complex MCB Girder – II
4. Complex MCB Girders – III
5. Complex MCB Girders – IV
6. Curved MCB Girders I
7. Curved MCB Girders II

Standard BrR Capabilities of MCB

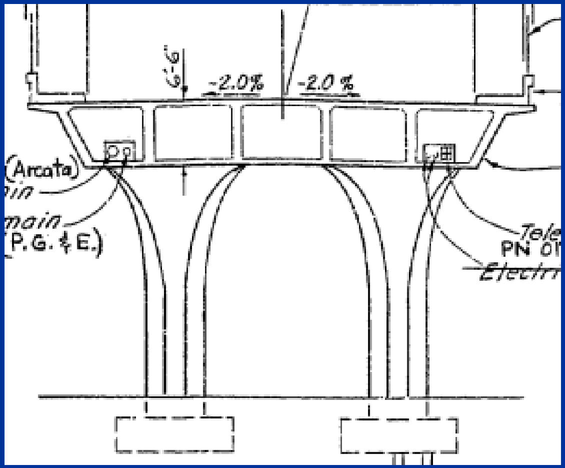
- Software has, in general, the following capabilities
  - Depth of the girder can be constant, linearly varying, or parabolically varying (concave)
  - Web Flare is allowed
  - No limit on number of spans
  - Different skews at supports
  - Superstructure with integral bents
  - Only ONE "continuous" post-tensioned profile
  - Establishes the post-tensioned force losses using AASHTO expressions.

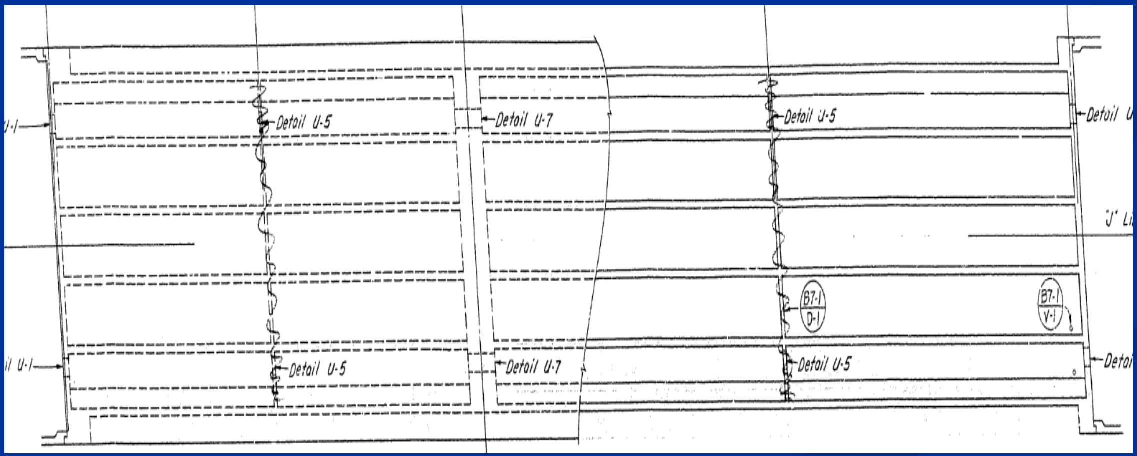
Standard BrR Capabilities of MCB

- Software has, in general, the following capabilities cont.
  - Load rate for moment and shear demands
  - Can load rate for shear using any of the four possible shear computation methods
    - General Procedure
    - General Procedure – Appendix B
    - Simplified Procedure
    - Simplified Procedure - Vci and Vcw
  - Overwrite of the Moment and Shear Capacity for Full box at any analysis point is allowed
  - Graphically displays shear reinforcement pattern entered for each web

1. Standard MCB Girders

- Number of Cells remains the same for the entire length
- Bridge width and Cell width remain the same for the entire length
- Straight bridge with same skew at all supports





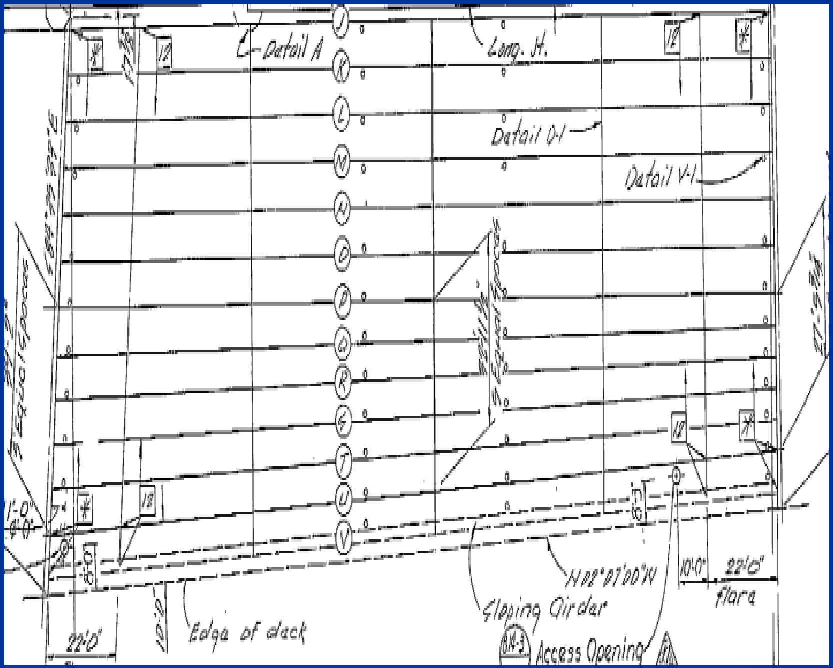
1. Capabilities for Standard MCB Girders

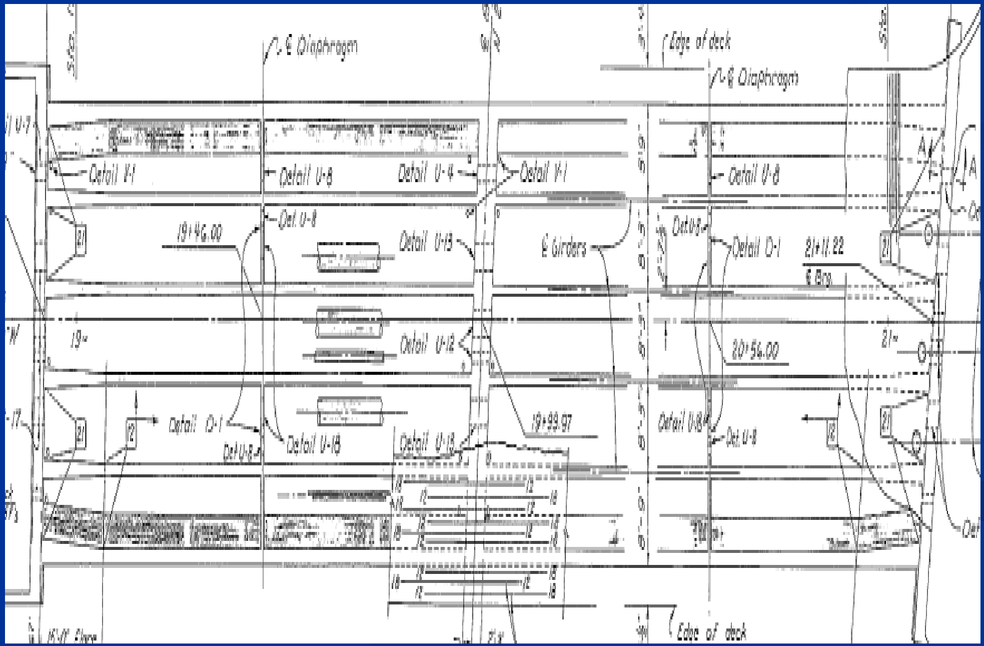
- Rate the "Full Box" using Moment and Shear demands

- Also, Rate all webs using shear demand
  - Note that the software assumes the same number of tendons are provided in all webs for post-tensioned box girders.
  - Since it does load rate the webs for shear, "notional travel width" need not be considered when load rating these bridges.

2. Complex MCB Girder – I

- Number of cells remains the same for the entire length
- Straight bridge with Linearly varying cell and bridge width for entire length of the bridge
- Have different skew at supports





2. Capabilities For Complex MCB Girders - I

- LLDF
  - Establishes the LLDF for each web based on its actual length (not based on the length along the CL of the bridge)
  - The LLDF for "Full Box" is obtained by adding the LLDF established for each web.
    - Software adds the values at 10^{th} points of each web to establish the LLDF for the full box
  - Considers shear skew adjustment factors for the obtuse ends
  - Considers moment reduction factor for skewed bridges.
  - Whenever range of applicability given for the simplified LLDF is violated, software defaults to "Lever Rule"
- Load Demands
  - However, load demands (DL and LL) are determined using the span length defined along the CL of the bridge.

2. Capabilities For Complex MCB Girders - I

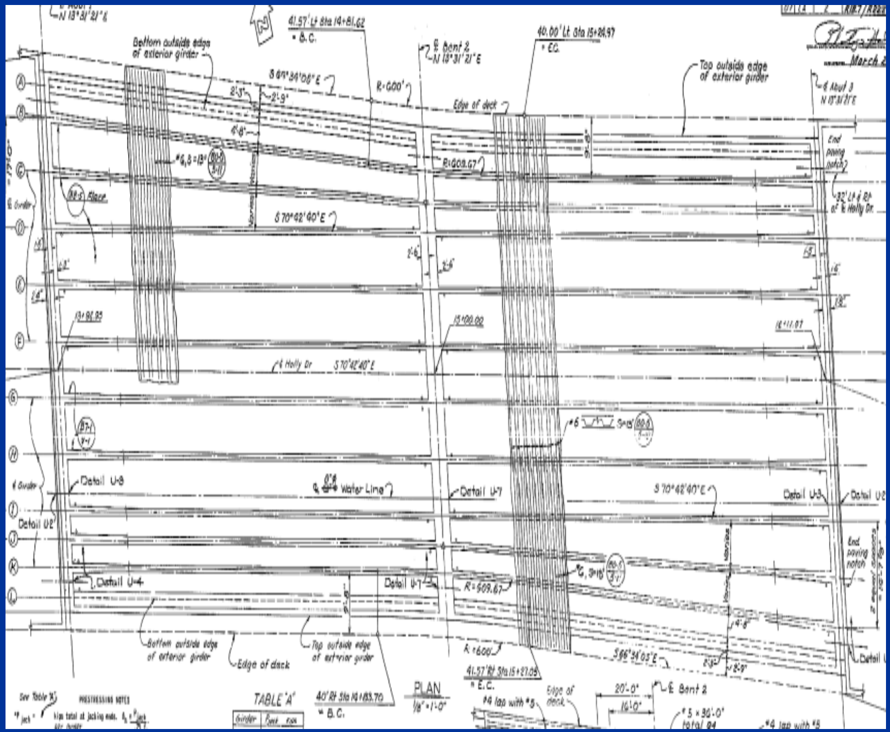
- Will NOT rate the individual webs
  - As a result, "notional travel way" needs to be considered to obtain reasonable rating factors.

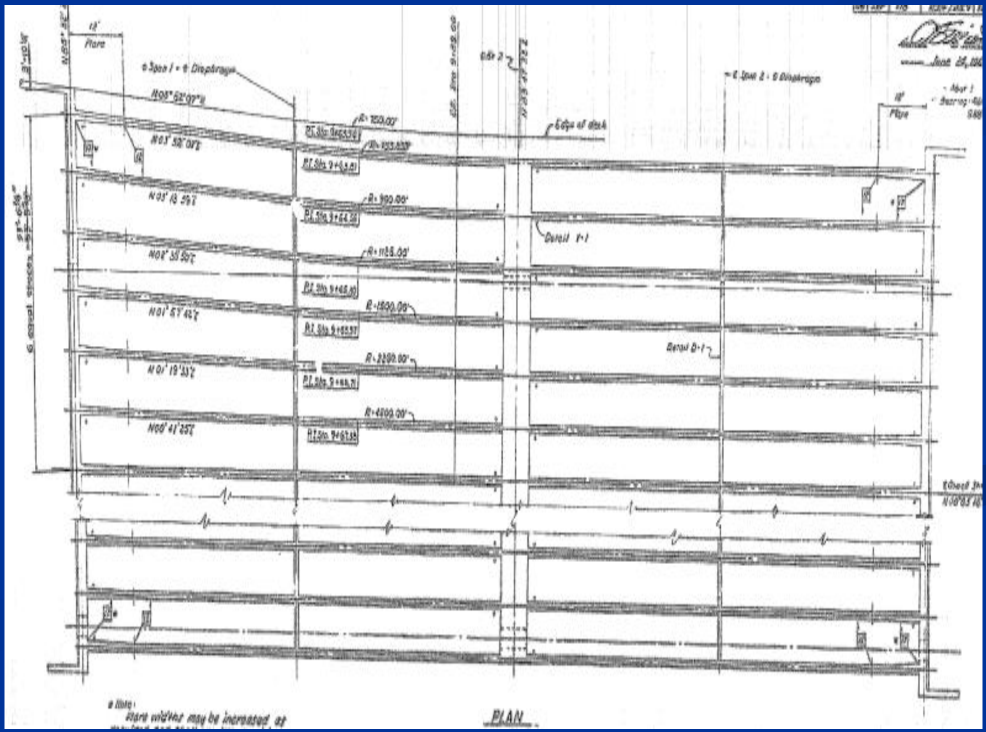
- Will rate the "Full Box" using Moment and Shear demands.
  - Since the "Full Box" concept is used, the effect of "increased" shear demand on the obtuse corner will be averaged out to all webs

  - This approach produces a higher rating factor than that established by performing an individual web analysis.

3. Complex MCB Girder – II

- Number of cells remains the same for the entire length
- Varying Bridge and Cell Widths for partial length of bridge
- Have different skew at supports



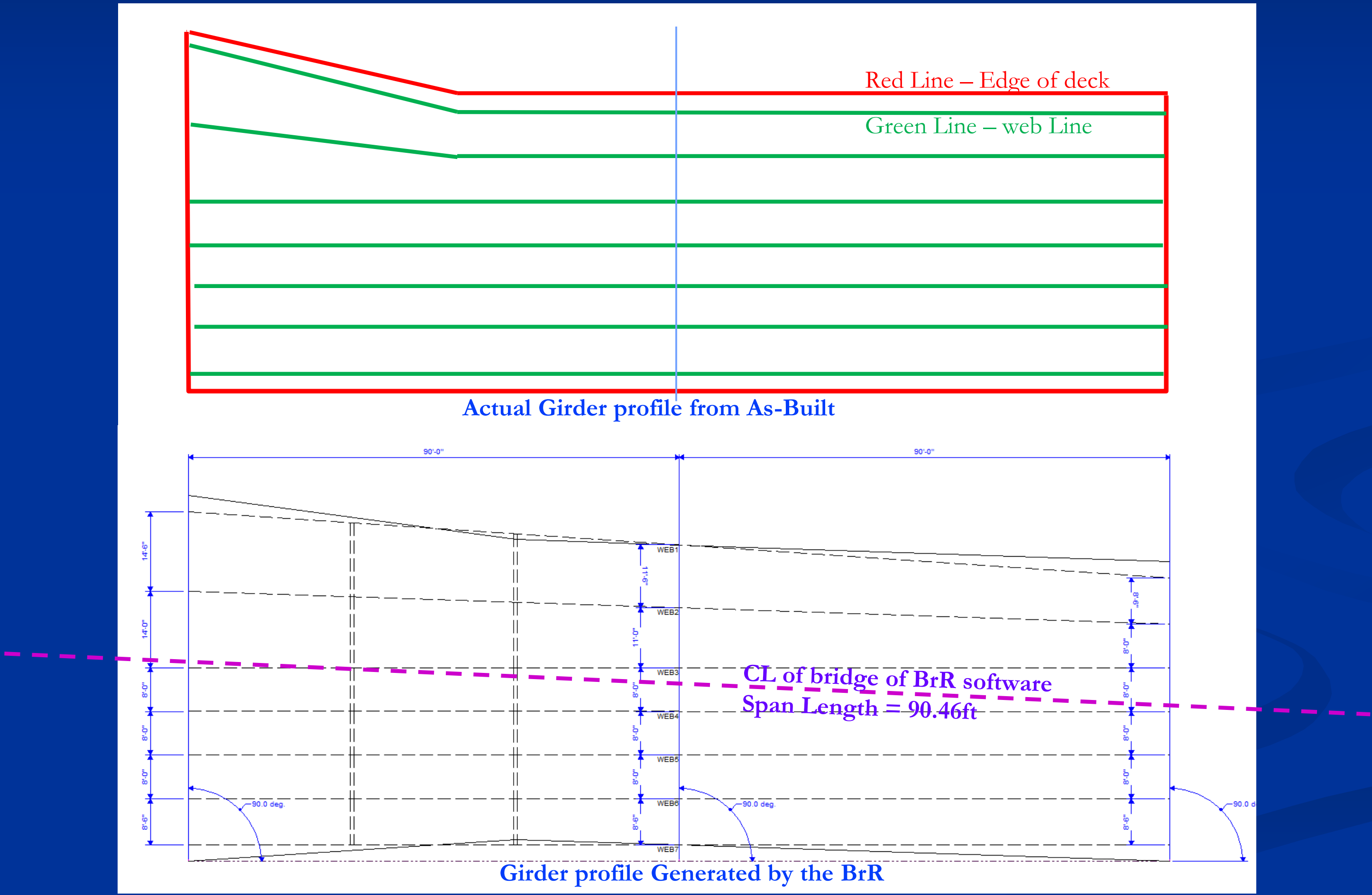


3. Capabilities For Complex MCB Girder - II

- User cannot accurately model this complex MCB girder
  - However, an approximate model can be created.
    - Length of the webs established by the software will not be equal to the actual length of webs.
      - Shear reinforcement pattern and flexural reinforcement cannot be accurately entered since the web length of the “model” does not match the actual web length.
      - Software generated LLDF will be wrong, since the length established by the software will not be correct and the overhang width is incorrectly established within the software. However, by entering the LLDF manually, user may be able to generate a reasonable rating factor for Full box analysis

3. Capabilities For Complex MCB Girder - II

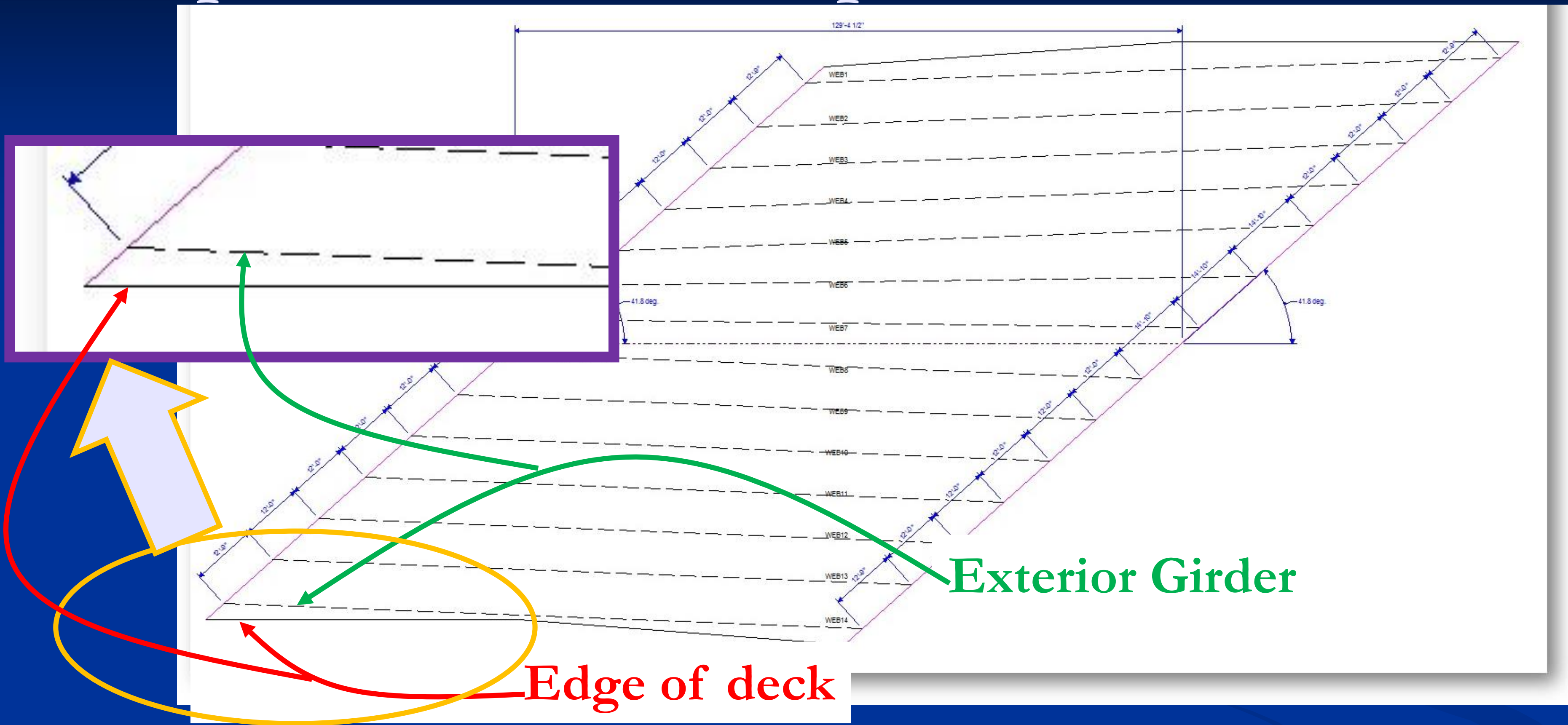
- Following figure shows the model created by BrR vs Actual web layout.



Actual Girder profile from As-Built

Girder profile Generated by the BrR

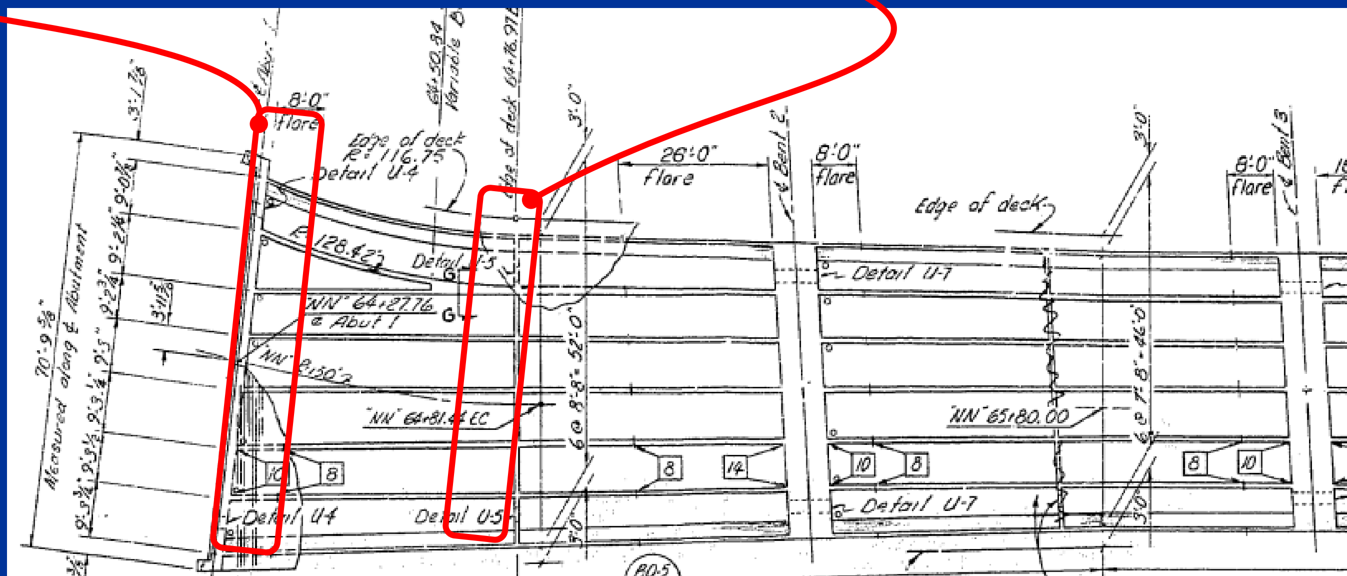
3. Capabilities For Complex MCB Girder - II



- Exterior girder falls outside of the edge, as a result, software established lower LLDF for shear at mid span region for right exterior girder

4. Complex MCB Girder – III

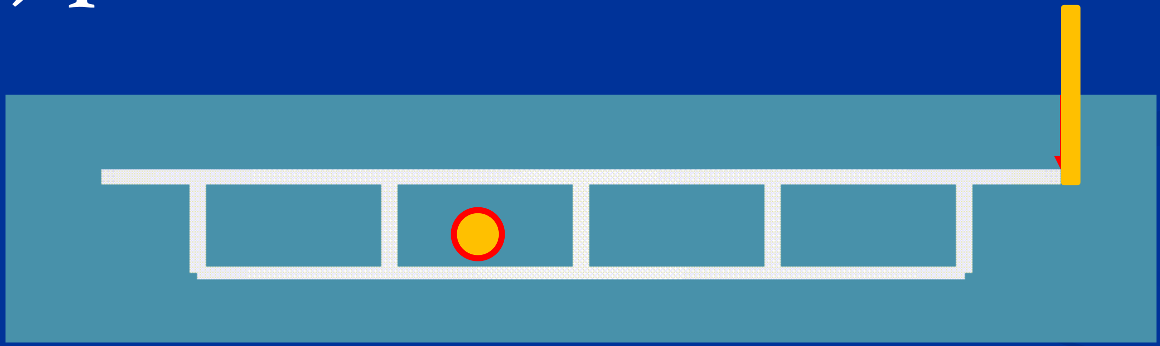
- Number of Cells changes intermittently
  - Number of Cells changes within a span
  - Number of Cells at Abut 1 = 7
  - Number of Cells at mid span 1 = 6



- Software will **NOT** rate this bridge configuration

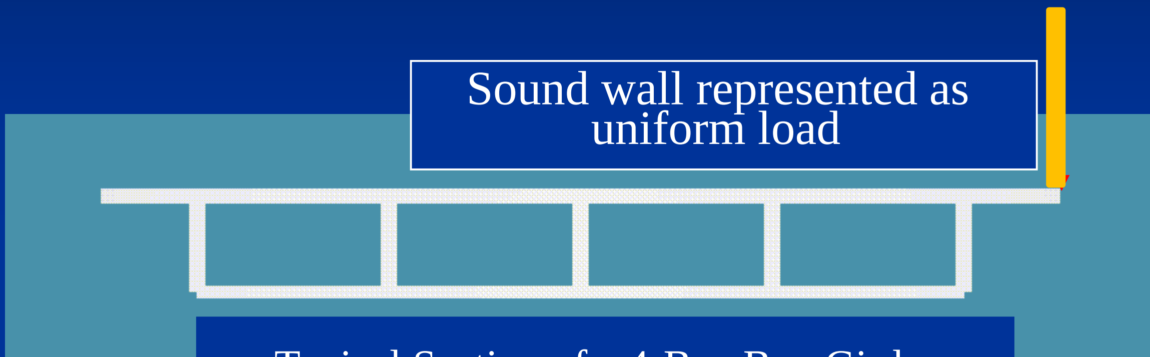
5. Complex MCB Girder – IV

- Sound Walls placed on top of Barrier Rails
- Significantly large dead load (ex: large utility pipes) placed within one of the cells

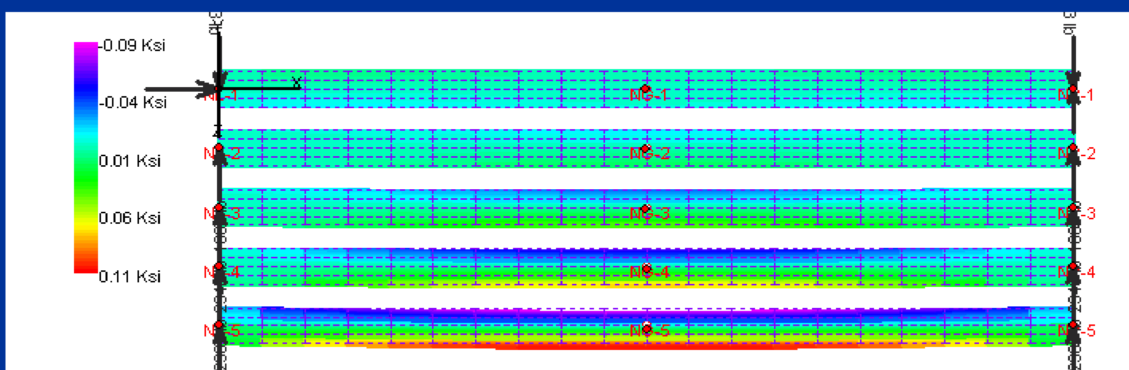


5. Complex MCB Girder – IV

- **Summary of the Study on Sound Walls placed on top of Barrier**



Typical Section of a 4-Bay Box Girder



Stresses on Girders

Girder shown at the bottom is closer to the sound wall.

Study showed that almost all (70 to 90%) of the wall weight is carried by the exterior web (or girder)

Equally distributing the sound wall load (method used by the BrR software) to all webs will underestimate the demand on exterior webs.

5. Complex MCB Girder – IV

- **Summary of the Study on Sound Walls placed on top of Barrier**

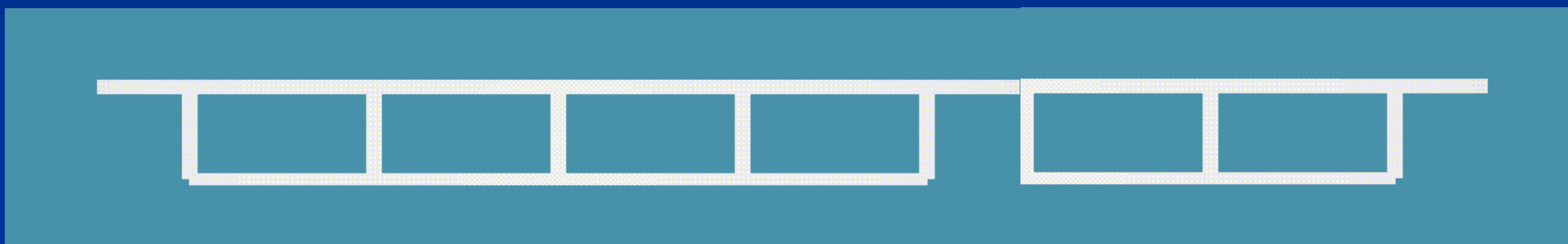
Typical Section of a 4-Bay Box Girder

Caltrans has developed a work around for this scenario. However, it is a very time consuming procedure.

As a result, Caltrans is funding an enhancement to create "Girder Line" approach by utilizing RC/PT I Section analysis. This will be implemented in version 7.1.

5. Complex MCB Girder – IV

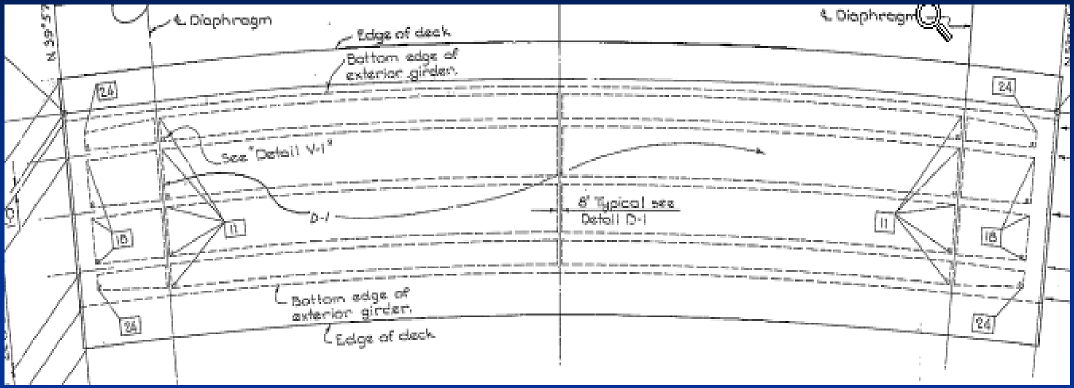
- **Bridges widened with another One or Two Cell MCB**



Software allows the user to change the deck thickness of individual cells within Advance Option. However, it does not allow the user to change the soffit thickness of individual cells.

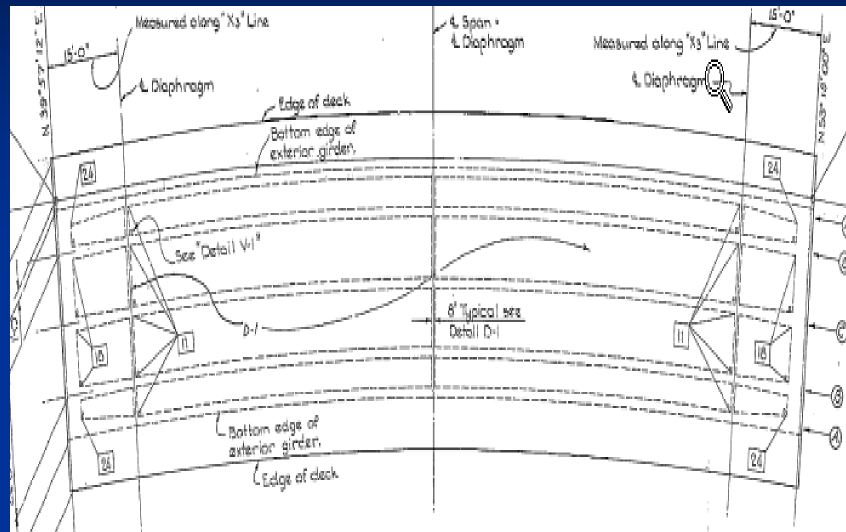
Caltrans is considering an enhancement to modify the soffit thickness

6. Curved MCB Girder – I



- Span Length / Radius of Curved Box Girder <= 0.21 or 12 degree central angle (Article 4.6.1.2.3)
- For central angles less than 12 degrees, effect of curve can be ignored and MCB girder can be modeled as straight girder
- Even for bridges with zero skew, the length of webs will be different. When modeled as straight, variable web length will not be captured in the BrR software
- The torsional load demand will not be considered in the analysis as well

6. Curved MCB Girder – II



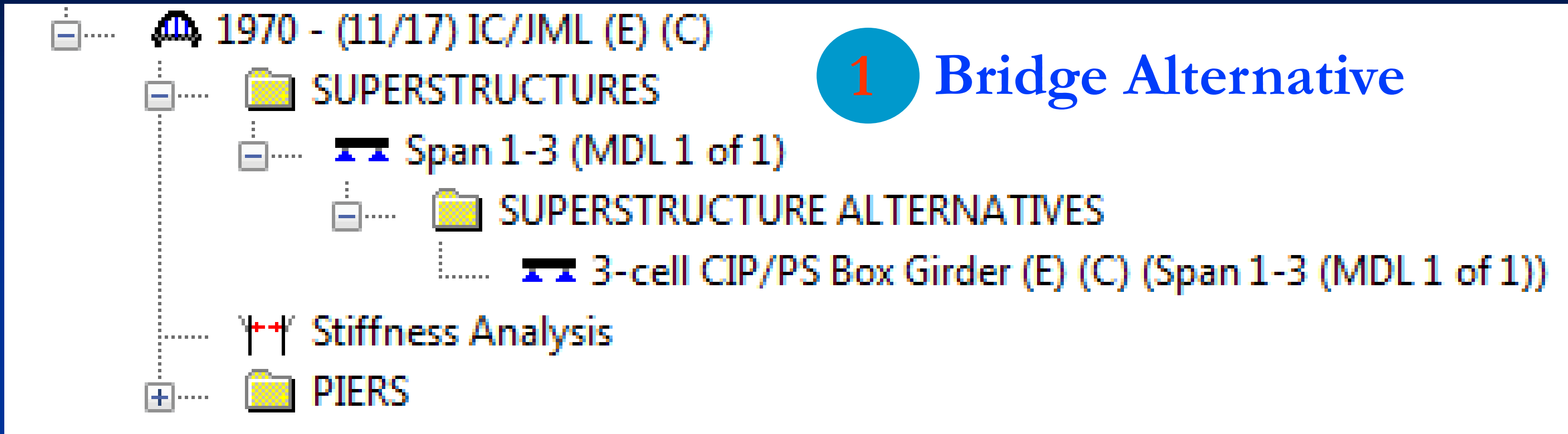
- Span Length / Radius of Curved Box Girder > 0.21 = 12 degrees central angle (Article 4.6.1.2.3)
- Torsional demand must be considered for central angles greater than 12 degrees
- **These girders cannot be analyzed by the BrR software**

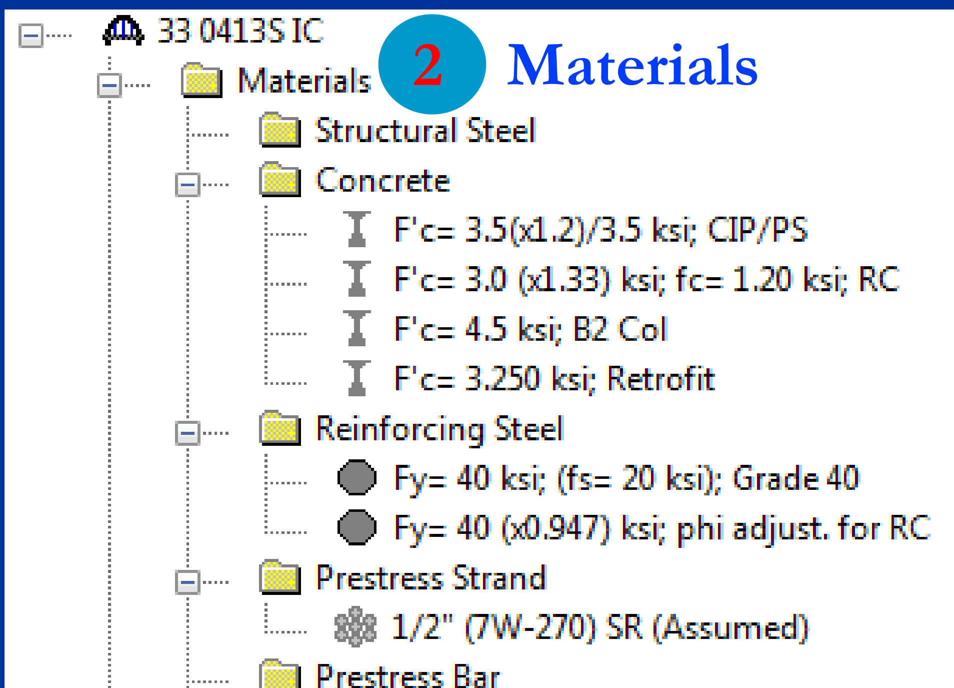
MCB Data Entry Sequence

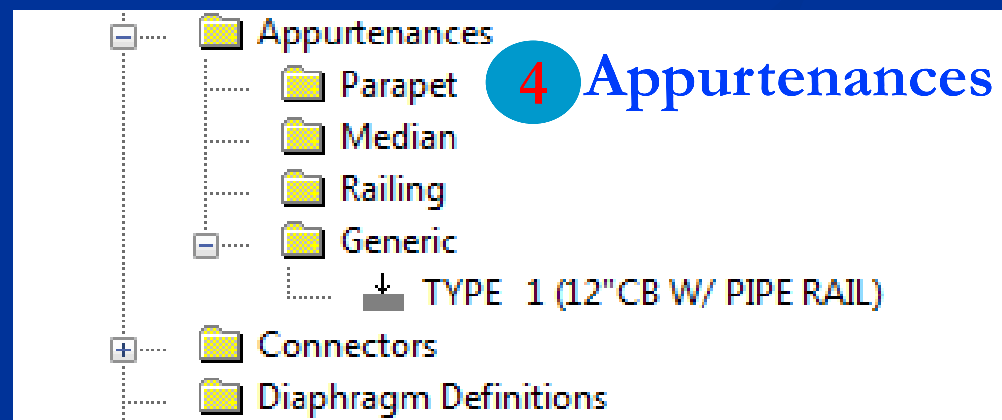
- Sequence of data entry is very similar to other girder types.
- Please note that Bridge Alternative needs additional data whenever structure is integral with Bents.

1. **Bridge Alternative**
2. **Materials**
3. **Beam Shapes**
4. **Appurtenances**
5. **Superstructure Definition**
6. **Link Super to Sub structure**
7. **Substructure Definition**

MCB Data Entry Sequence







MCB Data Entry Sequence

5 Superstructure Definition

- SUPERSTRUCTURE DEFINITIONS
  - Span 1-3 (MDL 1 of 1)
    - Impact / Dynamic Load Allowance
    - Load Case Description
    - Hinge Locations
    - Concrete Stress Limits
      - SL F'C=3.5/3.5 ksi Girder
      - SL Dummy for RC
    - Post Tension Losses
      - PT Losses
    - Structure Cross Sections
      - A1-26x4.5x(12,2x12,12)x6x6
      - A2-26x4.5x(18,2x18,18)x6x6
      - A3-26x4.5x(12,2x12,12)x6x12
      - B-26x4.5x(8,2x8,8)x6x6
    - Tendon Profile Definitions
      - FB Profile Span 1-2
      - Span 3 Fictional
    - Cross Section Range Properties
    - Structure Typical Section
    - Framing Plan Detail
    - Superstructure Loads

In general, Data Entry Sequence follows from top to bottom

- Superstructure Loads
- Shrinkage/Time
- Supports
- Slab Reinforcement
- Live Load Distribution
- Points of Interest
- Vertical Shear Reinforcement Definitions
  - #5-2Leg-40ksi
- WEBS
  - WEB1
    - Live Load Distribution
    - Shear Reinforcement Ranges
  - WEB2
    - Live Load Distribution
    - Shear Reinforcement Ranges
  - WEB3
    - Live Load Distribution
    - Shear Reinforcement Ranges
  - WEB4
    - Live Load Distribution
    - Shear Reinforcement Ranges

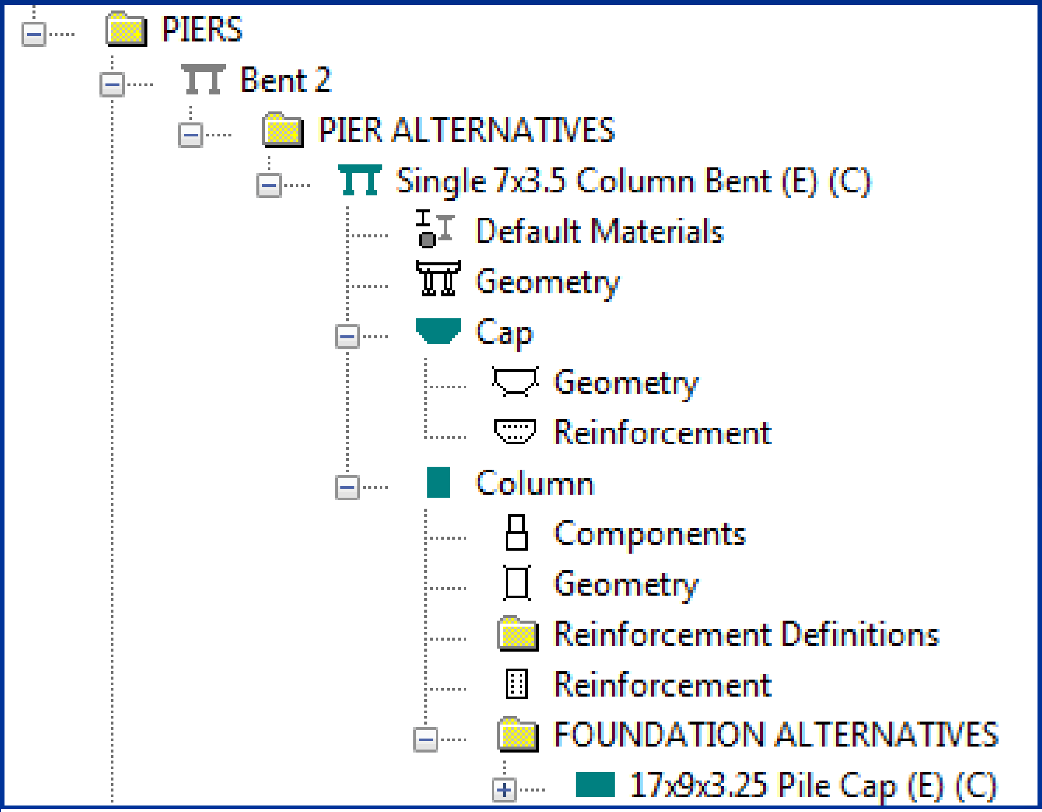
In general, Data Entry Sequence follows from top to bottom

However, LLDF should be generated only after all the required data (including substructure details of Integral bents) for the entire bridge is completed

MCB Data Entry Sequence

6 **Link the Super to Substructure (For Integral Bents)**

7 **Substructure Definition of ALL Bents**

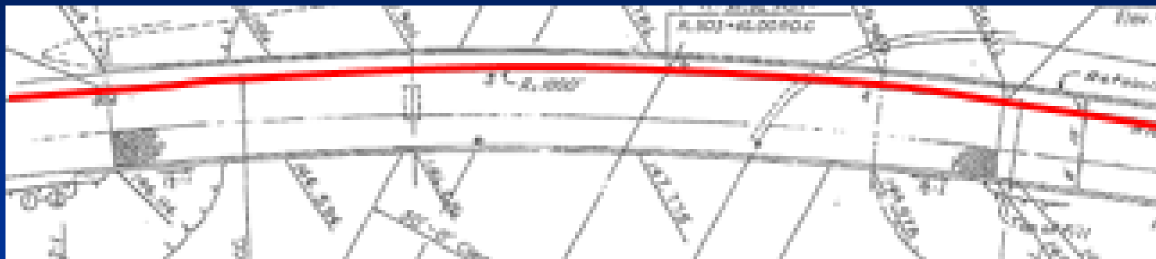


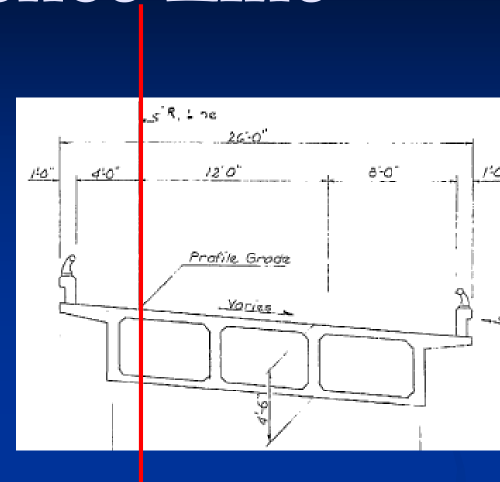
User is advised to revisit GUIs that generate the LLDF after all the required data (including substructure details of Integral bents) to insure software generated LLDF are correct.

Work Arounds For a Few limitations

1. Location of Reference Line not coinciding with centerline of the Bridge
2. Analysis at Hinge Location
3. Modulus of Elasticity based on LFD and LRFD
4. Not meeting minimum shear reinforcement
5. Widen with One or Two Cell Box
6. Mixed Girder Types (PT and RC Box) Bridge
7. Multiple Post-Tensioning Cable Paths
8. Number of Cells is less than 3
9. Longitudinal Slope and Super Elevation slope is limited to 6%
10. Column Heights (of multi column bent) must be equal at a Bent

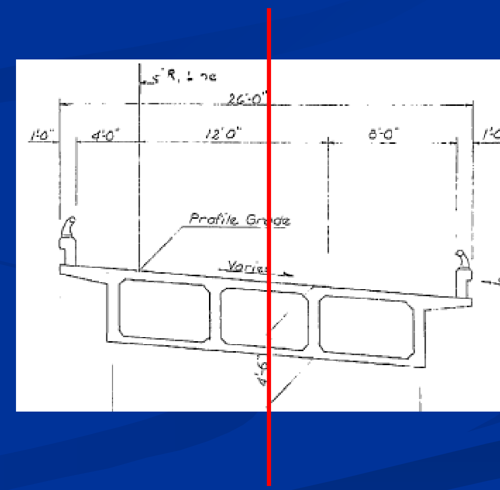
WA 1: Location of the Reference Line





- Note that the BrR requires the <u>user to enter the geometric dimensions of the Box girder, Hinge location, tendon profile, and member load etc. along the CL of the bridge.</u>

- As a result, the user has to establish the exact length along the CL of the bridge before entering data, if the data in the as-built plans given along the reference / alignment line.



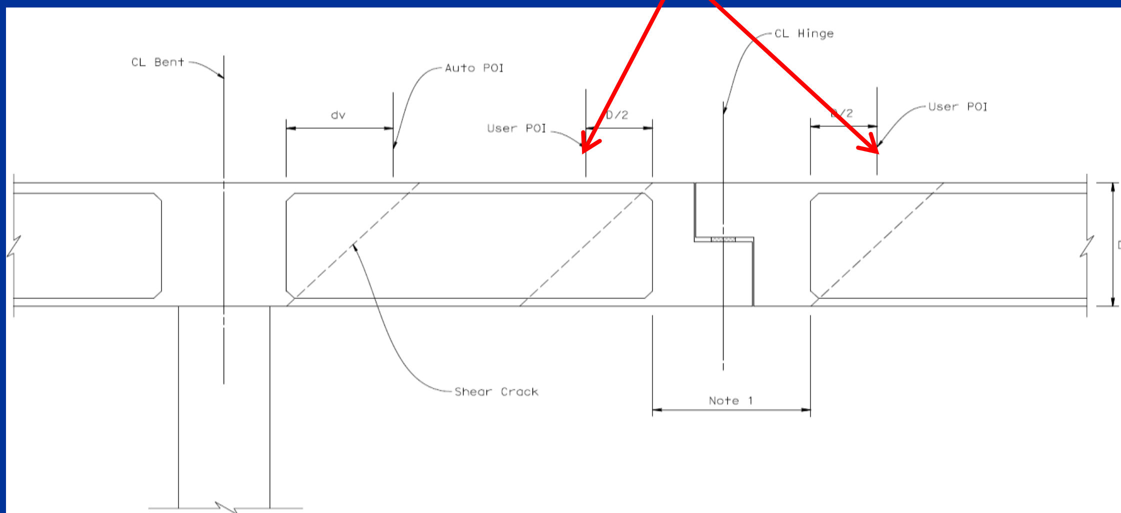
- Caltrans recommends the user to place the Reference Line along the CL of the bridge in BrR when creating the superstructure definition.

WA 2: Analysis at Hinge Location

Points of Interest

Software will NOT automatically generated analysis point at either side of hinge location.

★ **Add additional user POIs at $d_e/2$ from Hinge faces.**

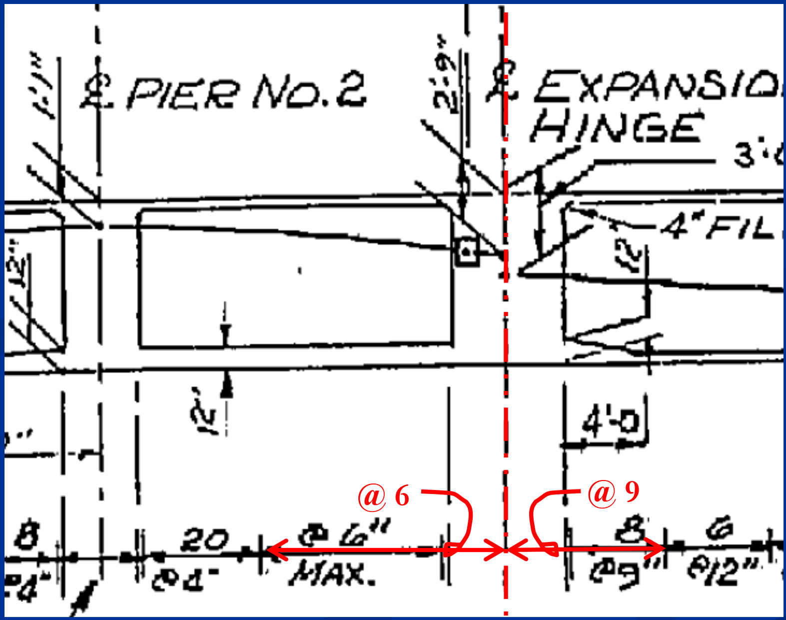


- **Also, if the hinge location falls on auto generated analysis points, user needs to create a user "defined analysis point" and overwrite the moment capacity to a larger value so that rating factor established for moment at hinge location does not control the rating.**

WA 4: Analysis at Hinge Location

Shear Reinforcement Ranges

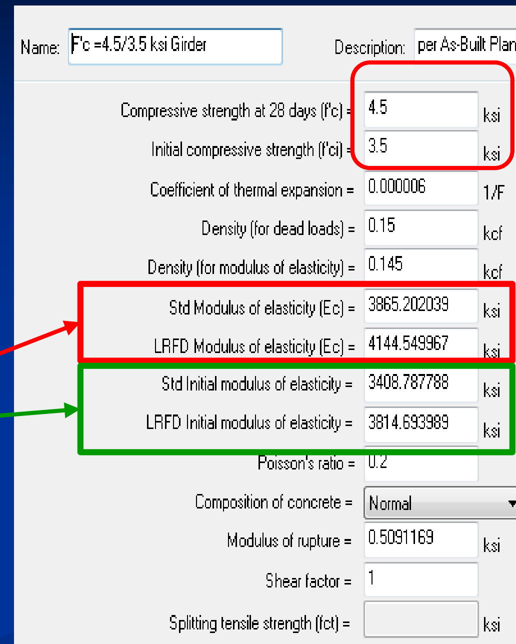
- ★ **Hinges:** Stirrup Wizard does not consider in-span solid section when placing reinforcement; only solid sections at ends of span are considered. Continue stirrup spacing on either side of hinge to CL hinge.

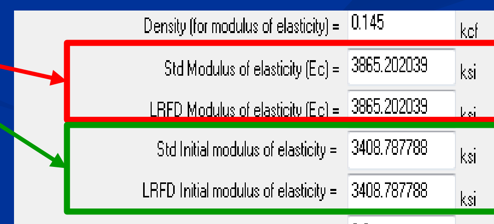


WA 3: Materials – Concrete

Values generated by the software for E_c and E_{ci} will be different for LFD and LRFD.

- Equation for E_c given in the 8th edition of LRFD is based on modern mix design methods.
- Caltrans requires to set both values to the values established for <u>LFD</u> method (Std). This is because we are dealing with older concrete.





WA 4: Not Meeting Minimum Shear reinforcement requirement

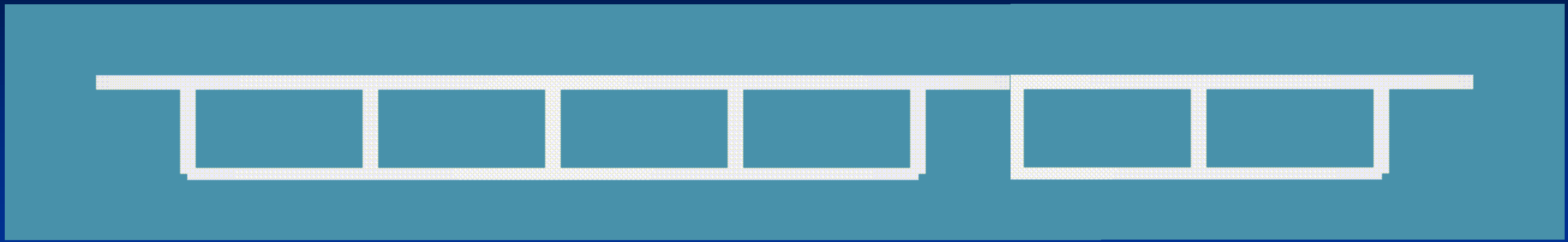
* If minimum shear reinforcement requirement AASHTO LRFD equation 5.7.2.5-1 (8th Ed.) is not met, shear capacity is severely reduced. This check is more likely to fail at girder flares but may happen at any location.

$$A_v \geq 0.0316\,\lambda\sqrt{f'_c}\,\frac{b_v s}{f_y} \qquad (5.7.2.5\text{-}1)$$

★ **Workaround:**

1. Reduce the web width/flare to the maximum value that will satisfy the equation.

WA 5: Widened with One or Two Cell MCB



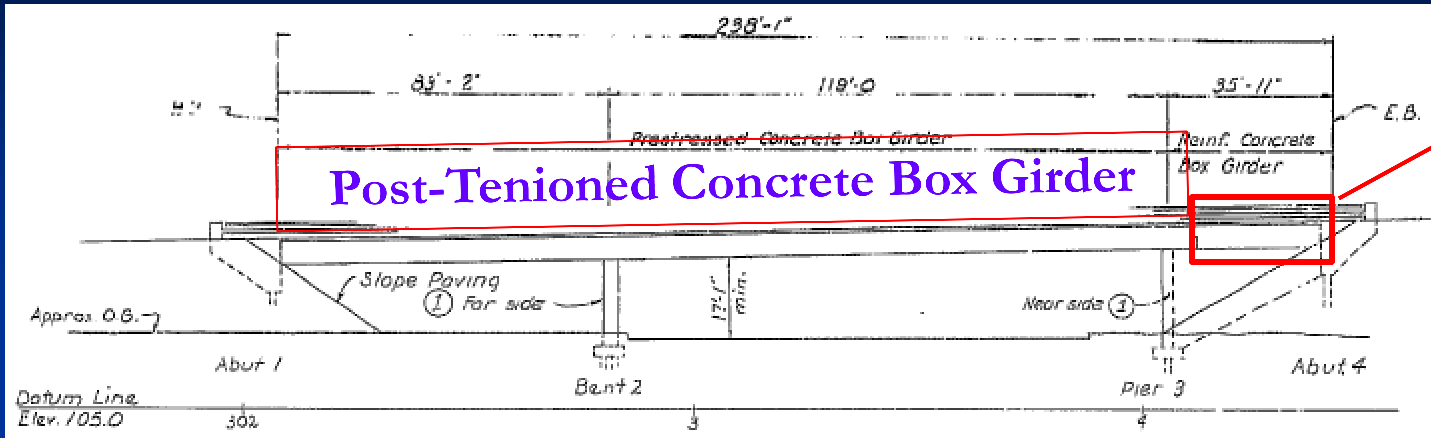
Workaround

- ★ Create two superstructure models, (one for four cell Box and other for Two Cell box)
- ★ Manually enter the LLDF for exterior girder (next to the 2 Cell Box) and all webs of Two Cell box

Enhancement:

- ★ Modify the software to vary thickness of soffit in each cell, as it does allow the user to enter different deck thickness in cell.

WA 6: Mixed PT and RC MCB Girder Types



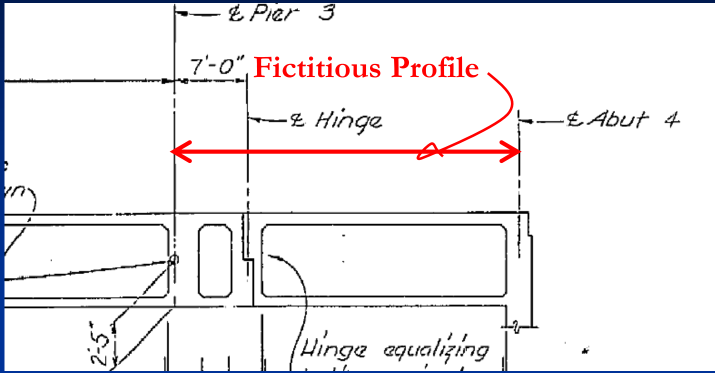
Reinforced Concrete Box Girder

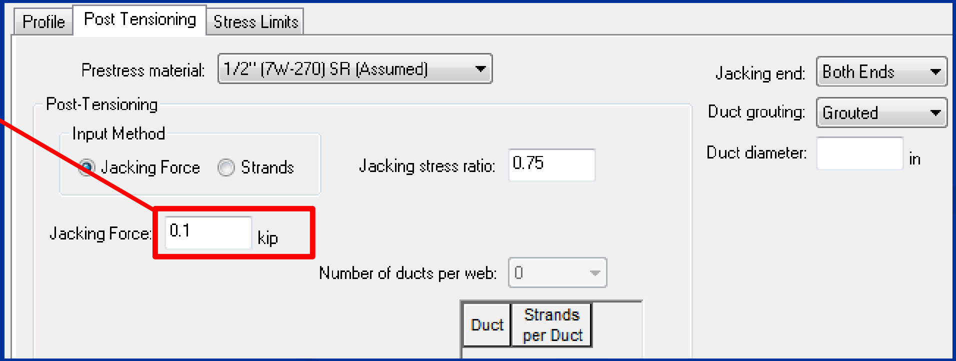
- BrR software does not allow "Mixed" girder Types within a Supestructure.
  - Consider the entire bridge as PT MCB Girder bridge
  - Place fictitious tendon profile along the mid depth of RC Box Girder Segment
  - Use 0.1 kip Jacking force within the RC Box Girder segment
  - Create a fictitious concrete stress limit so that "serviceability" check within RC Segment will not be controlling the overall rating
  - Create a rebar material with yield strength of 0.9Fy
    - This is to account for the difference in phi for moment. Phi (ϕ) for RC Box girder is 0.9, but phi (ϕ) for PT box is 1.00.
  - When entering flexural rebar within RC Box segment, use the "0.9Fy" strength rebars

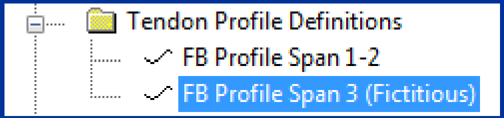
WA 6: Mixed PT and RC MCB Girder Types

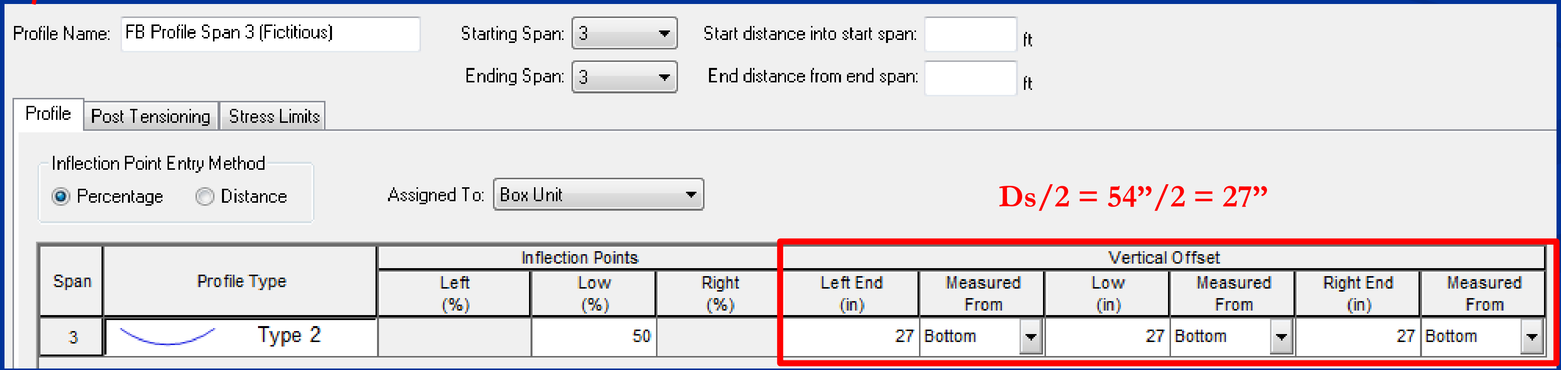
Fictitious Tendon Profile for RC portion

- Place at mid-depth of superstructure
- Use Pjack = 0.1 kips







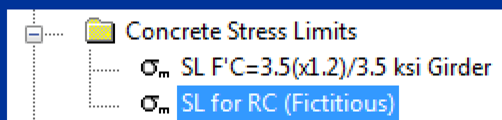


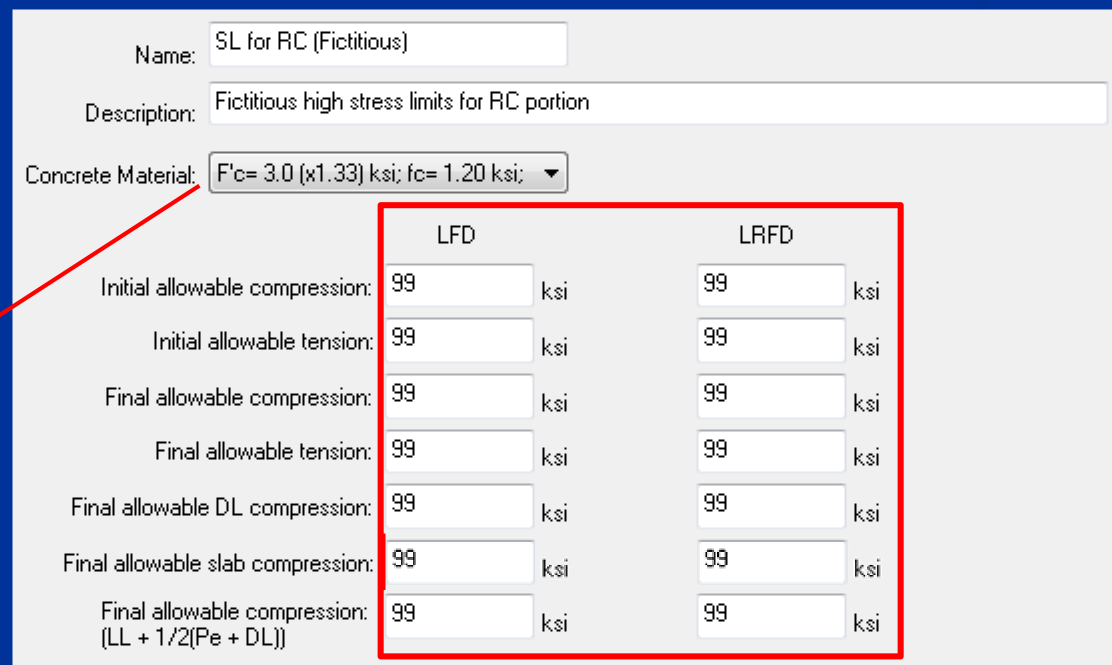
WA 6: Mixed PT and RC MCB Girder Types

Fictitious Concrete Stress Limits

Service III load combination <u>not</u> applicable to RC and to prevent this from controlling rating:

- Create a fictitious Concrete Stress Limit with value '99 ksi' for all stress limits. This stress limit will be assigned to RC span.





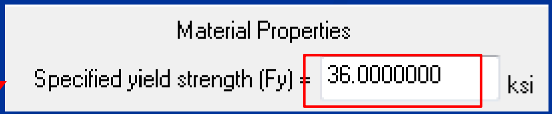
Select material that will be used for RC box girder portion.

WA 6: Mixed PT and RC MCB Girder Types

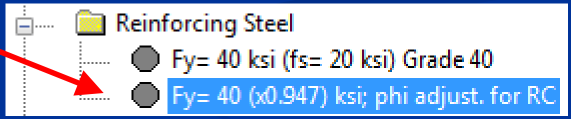
Phi Adjusted Reinforcing Steel

1. This bridge has CIP/PS and RC girders, need the following workaround to account for difference in resistance factor (ϕ), ϕRC = 0.90 and ϕCIP/PS = 1.00

2. Adjust specified yield strength



Fy(adjust)= Fy(as-built) x (FRC/FCIP/PS)= Fy(as-built) x 0.90



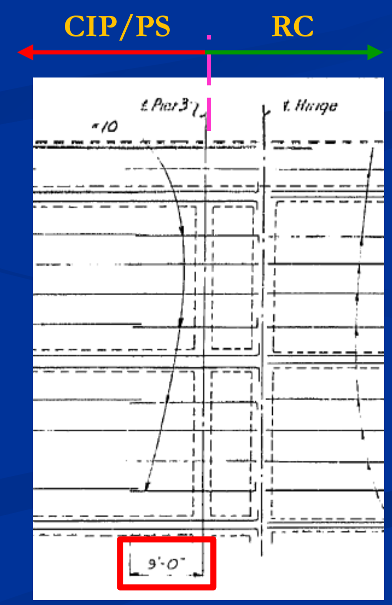
This material will be assigned to all Slab Reinforcement in RC Span.

Note: Reducing Fy also reduces development length ℓ_d (~5%), which yields higher effective As and moment capacity if POI is within development length region of rebar.

WA 6: Mixed PT and RC MCB Girder Types

Transverse Reference Lines | Cells - Top Slab | Cells - Bottom Slab | Overhangs

Cell	Material	Reference Point	Direction	Start Distance (ft)	Length (ft)	End Distance (ft)	Number of Bars	Number Bars for Left Web	Bar Size	Clear Cover (in)	Measured From	Bar Spacing (in)	Side Cover (in)	Start Fully Developed	End Fully Developed
All Cells	Fy= 40 ksi (fs= 20 ksi) Grade 40	Support 3	Left	9	9	0	2	1	10	2.19	Top of Slab	3		☐	☑
All Cells	Fy= 40 (x0.947) ksi; phi adjust. for RC	Support 3	Left	0	6.5	6.5	2	1	10	2.19	Top of Slab	3		☑	☑



For any rebar that is continuous through CIP/PS portion and RC portion,

    split rebar into CIP/PS portion and RC portion and set to proper material.

★ Check 'Fully Developed' at the split ends.

WA 7: Multiple Cable Paths

- Most MCB girders will have multiple ducts within each web and all have different cable paths.
- Unfortunately, BrR software does not allow the user to define multiple cable path.

★ **Work Around : User determines the centroid of ALL cable paths and enters the equivalent tendon path along the CL of the bridge**

★ Unfortunately, effect of prestress losses cannot be considered when establishing the "equivalent" tendon path.

WA 8: Number of Cells is less than 3

- When the number of cells is one or two, range of applicability for the simplified LLDF expression are violated and as a result the software will revert to Lever Rule Method. This will yield very conservative ratings.

Work Around: User overwrites the LLDF created by the Lever Rule approach

WA 9: Longitudinal Slope and Super Elevation

1. Longitudinal slope (grade) should not exceed 6%
2. Superelevation (when integral bents are used) should not exceed 6%

Work Around:

User uses the average elevation for all bents by entering the average elevation at both end of bent caps at all bent location.
This work around will produce a reasonable stiffness of the column, however, it may not be accurate.

WA 10: Height of Columns of Bents

- Although software allows the user to enter different height columns, it is incorrectly generating 2D elements to represent the different height columns.
- Similarly, the software is incorrectly generating 2D elements to represent multicolumn bents for bridges with superelevation.

Work Around

- **User needs to enter the average column height (by entering the footing elevation) for all columns.**
- **For Bents with superelevation, and different column heights, the work arounds given for WA 9 and WS 10 need to be considered.**

A Few More Limitations of the Software

1. Software does not allow varying fixity between the columns and superstructure at bents.
2. Cannot load rate Integral Bent Caps.
3. Exterior curved girders without shear reinforcement
4. Number of cells cannot change
5. Cannot correctly model bridges with Hinges where support & hinges have different skews

A Few More Limitations of the Software

6. Individual web (girder) analysis for moment is not possible
7. For Parabolic soffit sections, structure depth is not accurately accounted for in calculating LLDF.
8. Cannot model convex shaped parabolic soffit; need to discretize with multiple sections
9. Cannot model bridges that have constant width for a portion of the structure and transition to varying width. (Complex MCB –III)

Questions?

Typical Box Sections