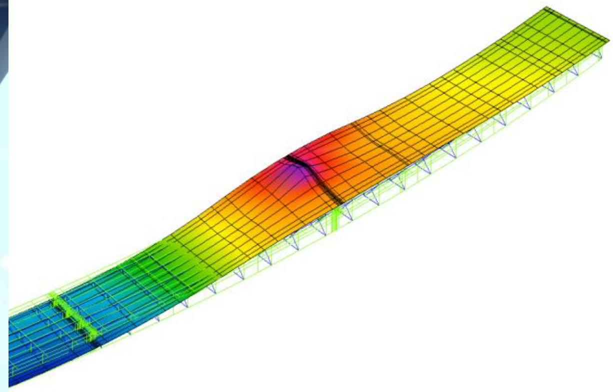

Case Study of Bridge Load Rating in KY using BrR

C.Y. Yong, P.E., S.E., ENV-SP

Outline

- Project Overview
- Choosing the Right Tool
- Validation
- Challenges
- Conclusions

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KY Bridge Load Rating

- Horizontally curved steel girder bridges
- Highly skewed pier steel girder bridges
- Multi-span pre-stressed concrete
- Complex bridges:
  - Cable stayed bridge
  - Tied arch bridge
  - Multi-span truss bridges
- Unique bridges:
  - Railroad flatcar bridges
  - Historical masonry arch bridge




Project Overview

2016-07 Statewide Load Rating Package

16 bridges including:

- Horizontally curved steel girder bridges
- Welded plate girder bridges with highly skewed piers
- Pre-stressed concrete girder bridges
- Reinforced concrete deck girder (RCDG) bridge

- Remove the number
- Variation type,

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Choosing the Right Tool

- Consideration:
  - Capable to load rate different bridge types
  - Analysis - line girder and 3D analysis
  - Specification check - compute capacity
  - Generate rating factor

We Make a Difference

Highlight curved girder
3D analysis software
Advantages of using BrR – Cabinet does not have software to do that
No 3D FEM model

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- Consideration:
  - Time and budget
  - Adaptability
    - KYTC Requirement: Rating method matches with the design method
    - FHWA mandate design load rating in LFR or LRFR
    - User defined vehicle

BrR is the ANSWER

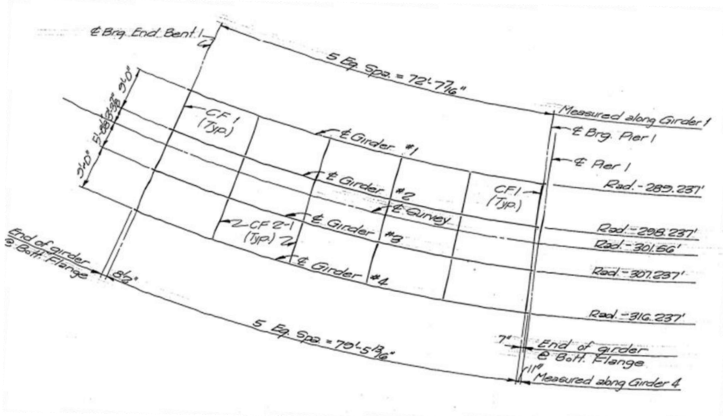
We Make a Difference

KYTC requirement
FHWA

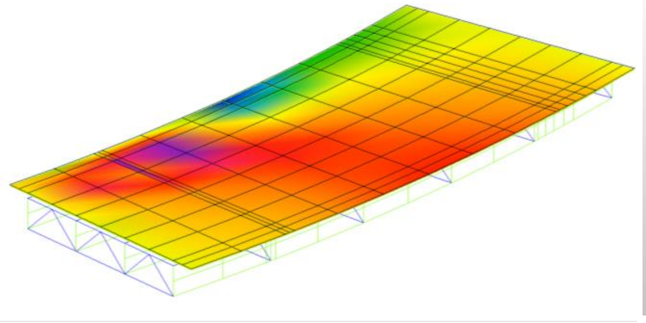
Validation

- Simple span horizontally curved steel girder bridge
  - 3D model
- Straight welded plate girder bridge
  - Line girder analysis

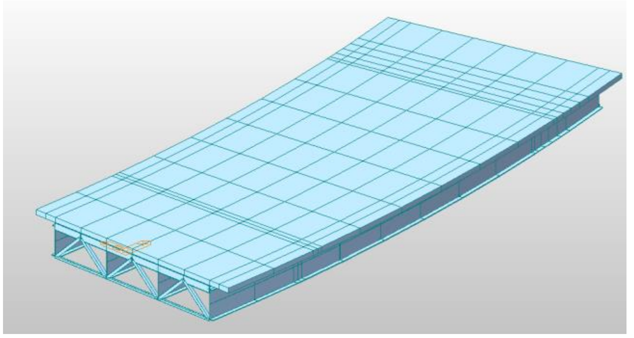
- 3D Analysis Validation
  - Compare BrR with other analysis software - MIDAS
  - Testing model - single span horizontally curved girder



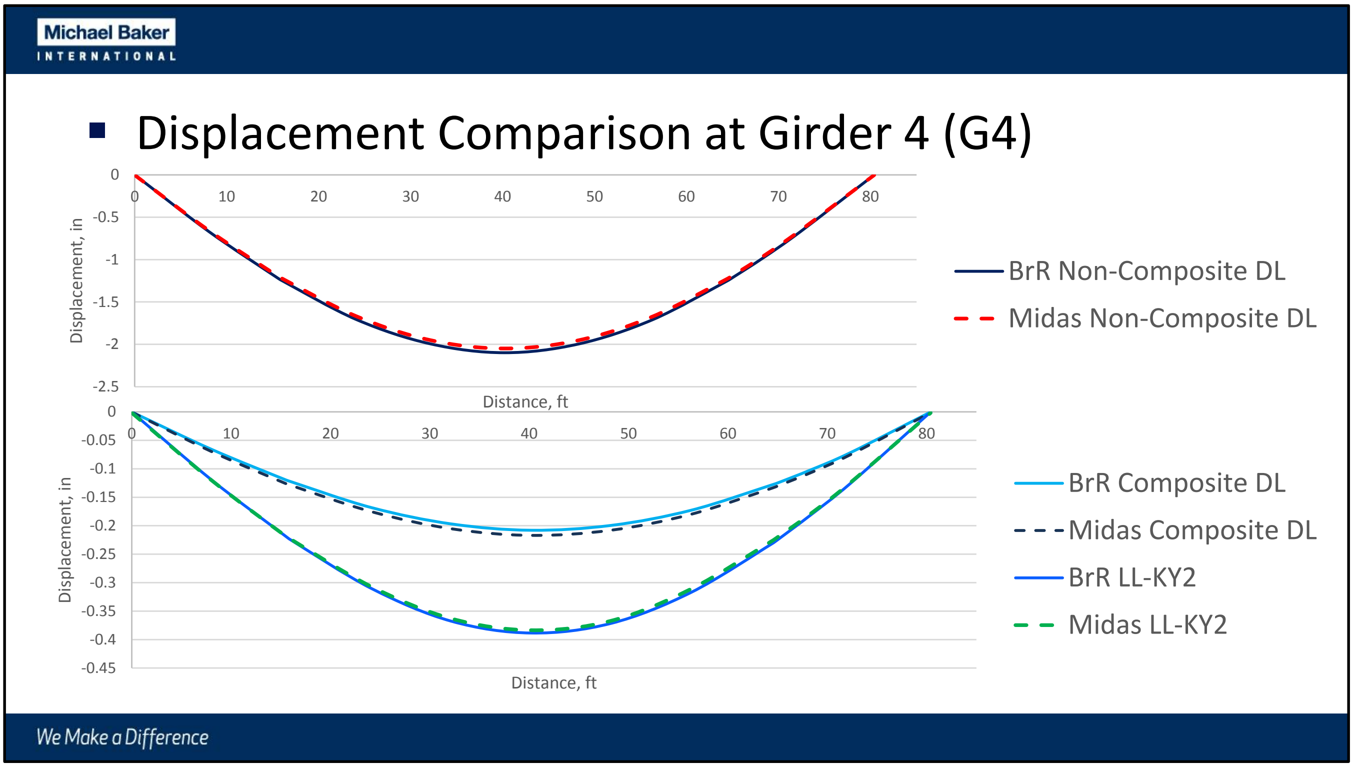
- 3D Model



BrR Model



MIDAS Civil Model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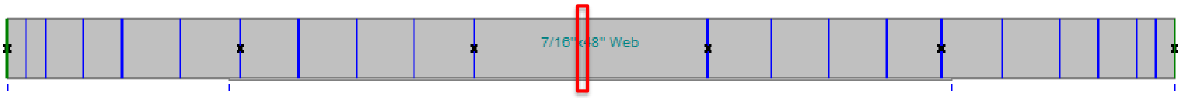
Displacement Comparison at Girder 4 (G4)
Displacement, in
Distance, ft
BrR Non-Composite DL
Midas Non-Composite DL
BrR Composite DL
Midas Composite DL
BrR LL-KY2
Midas LL-KY2
We Make a Difference

% difference

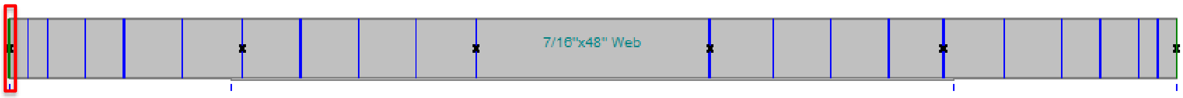
- Moment Comparison at G4-Midpoint



	BrR (kip-ft)	MIDAS (kip-ft)	% Difference
DC	1165	1074	7.8%
DW	354	349	1.5%
LL-KY2	726	676	6.9%

Put percentage

- Shear Comparison at G4-Left Support



	BrR (kips)	MIDAS (kips)	% Difference
DC	50	56	11.0%
DW	22	26	20.8%
LL-KY2	28	28	0.1%

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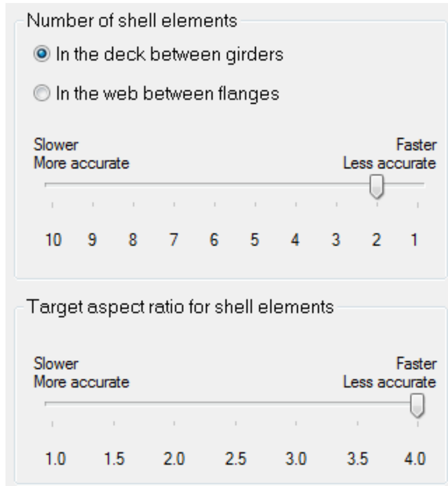
- 3D Model element size in BrR
  - Analysis time
  - Bridge complexity
  - 2 Studies:
    - Number of shell elements
    - Target aspect ratio



We Make a Difference

The importance shell element and aspect ratio, work with the budget and time – size of the problem, complex
Accurate, representative problem

Girder 4 Results Comparison

- Number of shell element in the deck between girders

	1	2	4	6	8	10
KY 2 - RF	3.26	3.42	3.46	3.61	3.62	3.63
% Difference	4.9%	**Baseline**	1.1%	5.4%	5.9%	6.1%

- Target aspect ratio for the shell element

	4	2	1
KY 2 - RF	3.46	3.59	3.60
% Difference	**Baseline**	3.8%	4.0%

- Proceed with 2 shell elements and target aspect ratio of 4

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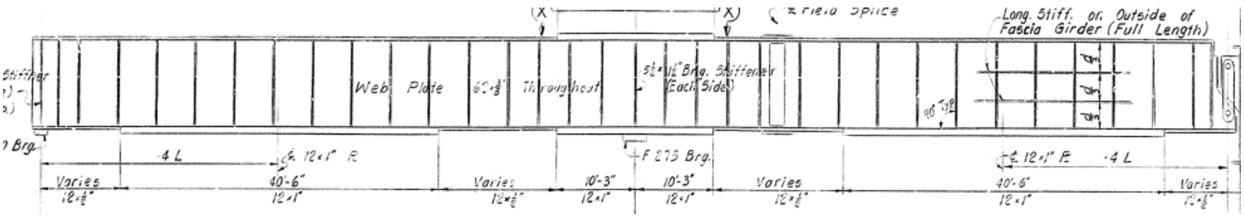
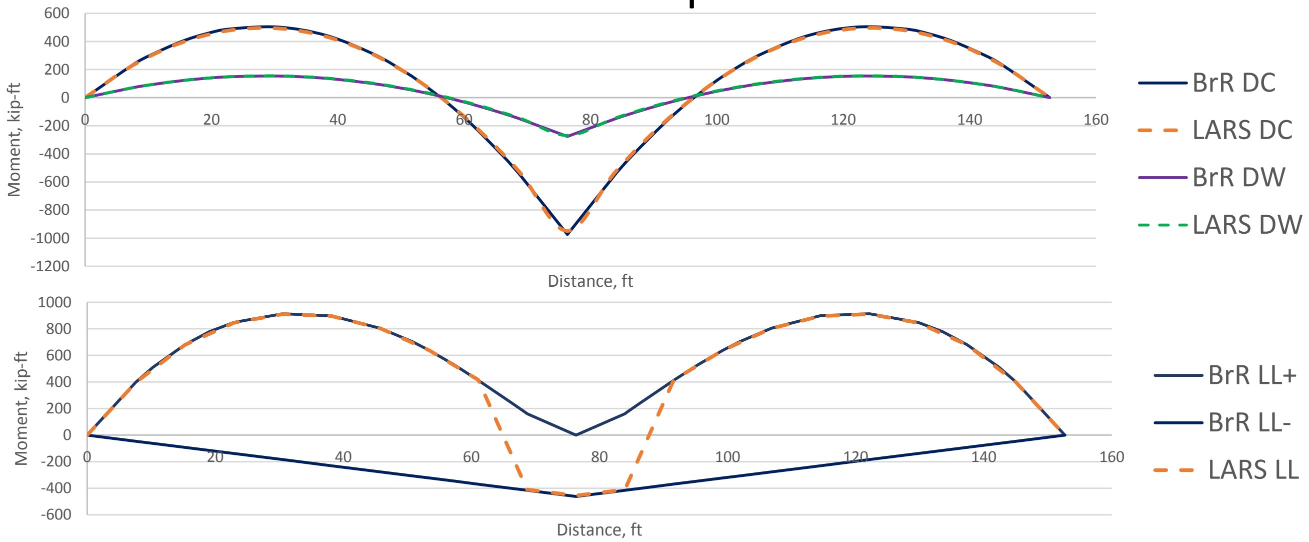
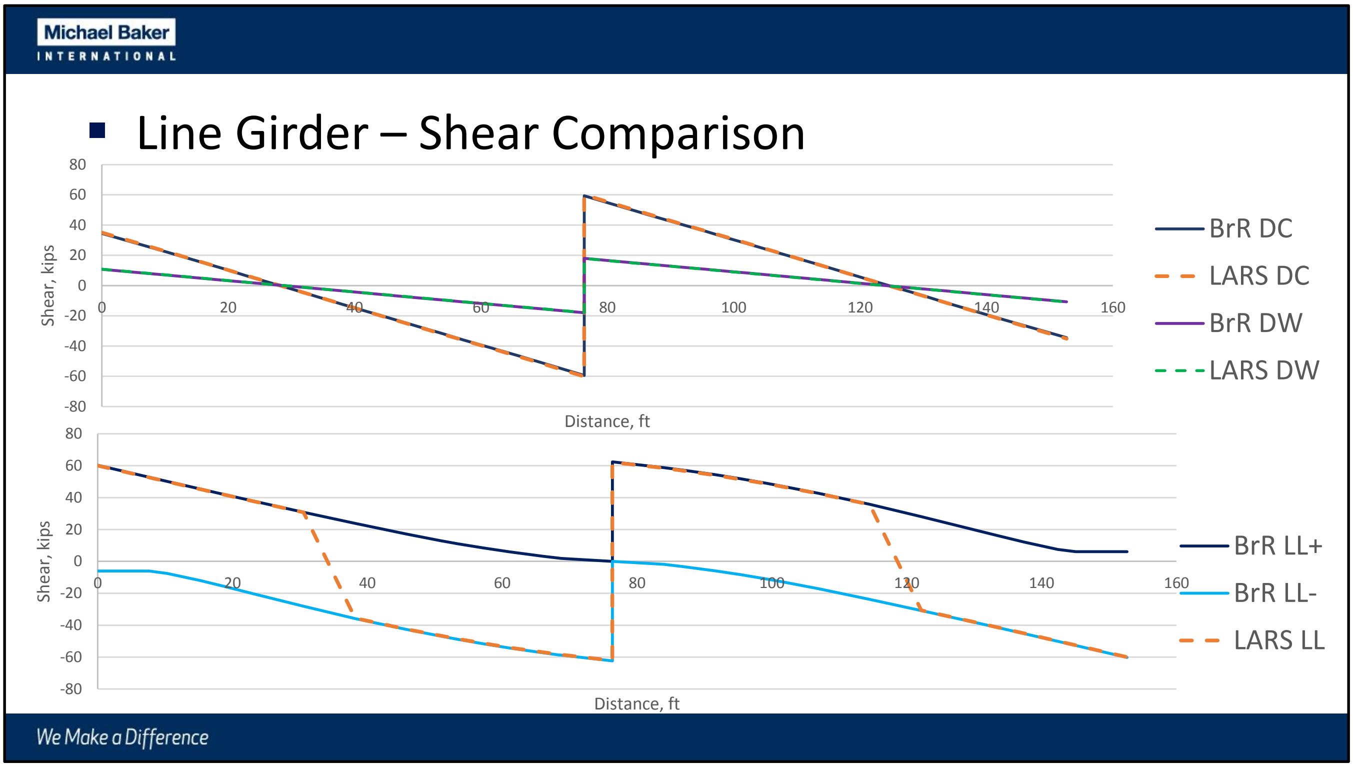
- Line Girder Validation
  - Compare BrR with LARS - used by KYTC in load rating
  - 2 span continuous straight welded steel plate girder
  - Interior girder
  - Similar live load distribution factor (LLDF) = S/5.5



KYTC – use LARS in house

Line Girder – Moment Comparison





Legend – Label

Challenges

- Steel curved girder bridge -specification check using LFD
  - Flexure non-compact flange
  - Web bend buckling
  - Shear check

Part of our issue – owner required the load rating done same as the design method

Flexure Non-Compact Flanges

AASHTO Guide Specification for Horizontally Curved Steel Girder Section 5.2.2 Non-Compact Flanges

- Equation 5-8 is not valid at the low stress region

$$F_{cr1} = F_{bs} * \rho_b * \rho_w \quad (5\text{-}8)$$

$$\rho w1 = \frac{1}{1 - \frac{fl}{fb}\left(1 - \frac{12l}{75bf}\right)} \qquad \rho w2 = \frac{\frac{12l}{bf}}{\frac{30 + 8{,}000\left(0.1 - \frac{l}{R}\right)^2}{1 + 0.6\left(\frac{fl}{fb}\right)}}$$

- Output unreasonable rating factor

Within this section the critical average stress is calculated from Eq. 5-8 or 5-9. However, in equation 5-8 the term "ρ_w" is a function of two calculations both of which have the ratio of lateral flange bending stress (warping stress) to the major axis bending stress (f_l/f_b) in the denominator. When this ratio becomes very large the critical flange stress approaches zero. However, it is our understanding that this was outside the limits of the equation development. Going back to the 1993 version of the Guide Spec the limit on the applicability of the ratio (f_l/f_b) was set to a maximum of 0.5. This limit appears to go back to the development of the equations during the CURT (Consortium of University Research Team) which perform the original research and developed the equations in the 1960s and 1970s. In an older US Steel (USS) LRD design example the commentary states, ". . . its absolute value f_l/f_b must not exceed 0.5, except under low stress conditions not governing the design of the section." Another consideration for an understanding of the equation development is that when the equations were developed the most common method for determining the lateral flange bend (f_l) was the use of the V-Load Method. The V-Load method derives the lateral flange bending forces from the strong-axis bending and thus the ratio could not balloon to unreasonable values. Thus the implication is such that the equations are not valid for (f_l/f_b) greater than 0.5

Flexure Non-Compact Flanges

- **Resolution:**

Apply $F_{cr1} = F_{bs} * \rho_B * \rho_w$

if $|f_l / f_b| > 0.5$ and $|f_b| < \min(0.33 F_y, 17)$; then $\rho_w = 1.0$

Web Bend Buckling

- 2 span curved girder bridge – web bend buckling controls
- LFD: 2003 Curved Girder Specification
  - Strength check
  - LFR = 1.3DL + 2.17LL (Inv.) and 1.3DL + 1.3LL (Oper.)
  - Capacity: $Fcr = 0.9Ek/ (D/tw)^2 \leq Fy$
- LRFD: AASHTO LRFD Bridge Design Specification
  - Constructability and service limit state check
  - LRFR Service II = 1.0 DC+ 1.0 DW+ 1.3LL
  - Capacity: $Fcr = 0.9Ek/ (D/tw)^2 \leq Fy$

Web Bend Buckling

- Newer spec. (LRFD) addresses this behavior correctly
- At **service-level** loads, web buckles out of plane and can fatigue the weld between the web and the flange.
- At the **strength limits**, the web can buckle and we account for that as part of the flexural strength of the member. Acceptable mode of failure.
- **Resolution:** Load rate this particular bridge in LRFD

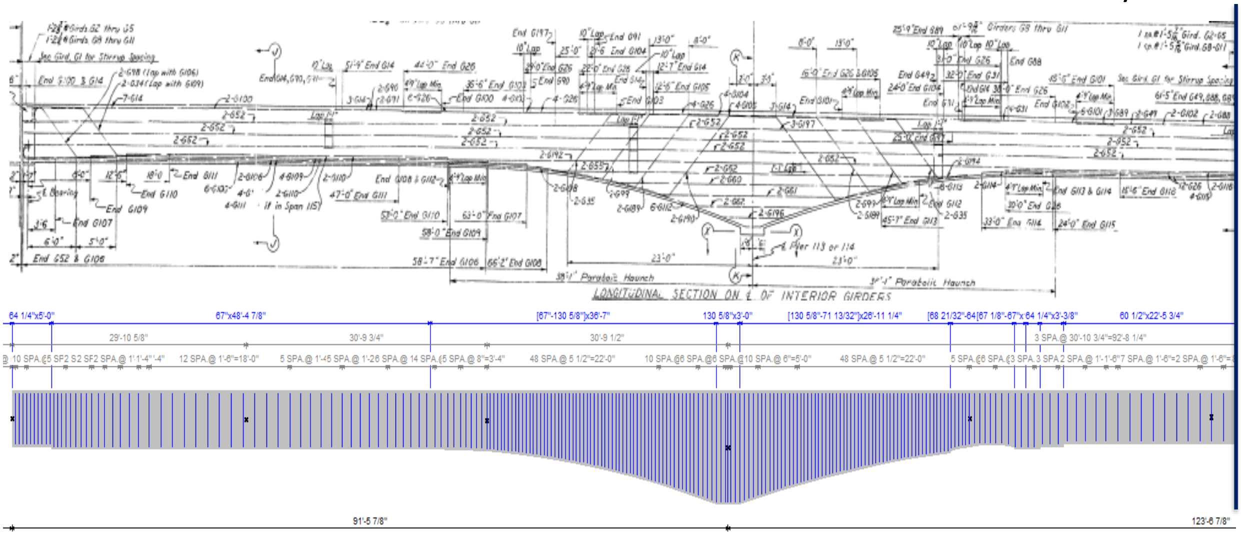
Resolution

Shear Check

- AASHTO Guide Spec. for Horizontally Curved Steel Girder Highway Bridges 2003 (LFD):
  - Overly conservative on the shear design
  - Trans. stiffener spacing > D (girder depth) = Unstiffened
  - No tension field action in the shear capacity
- LRFD: AASHTO LRFD Bridge Design Specification
  - Interior: Trans. stiffener spacing > 3D (girder depth) = Unstiffened
  - End: Trans. stiffener spacing > 1.5D (girder depth) = Unstiffened
- **Resolution**: Perform shear load rating in spreadsheet

3 span RCDG Bridge

CL Symmetrical



Show the cross section


F
E
D
C

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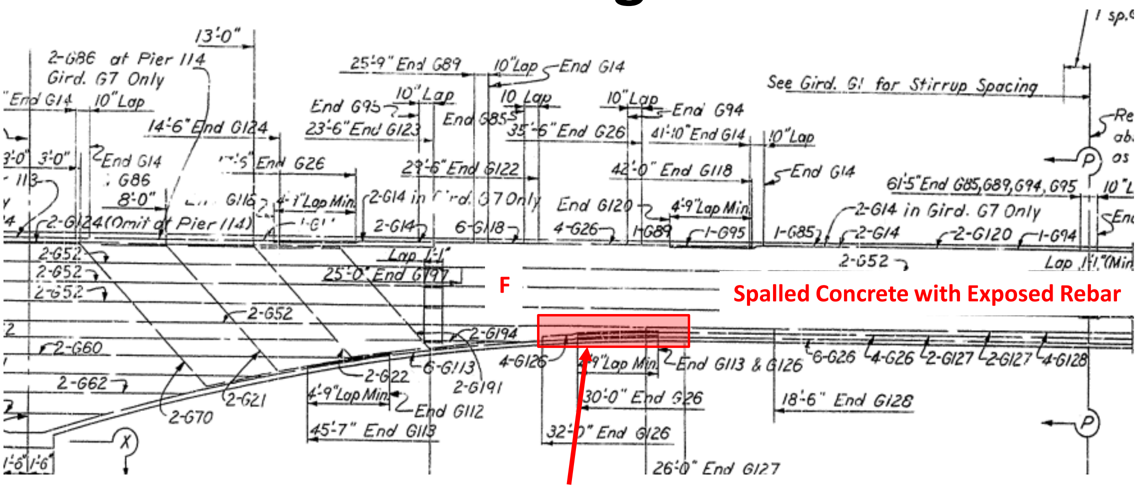
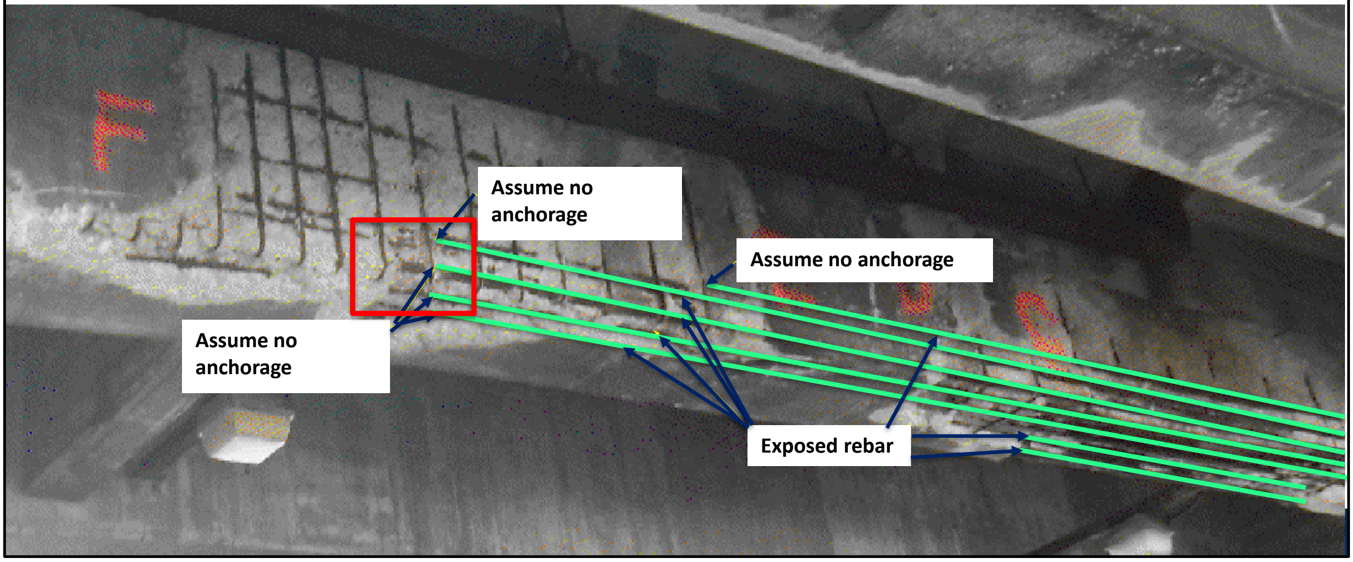
Critical Region



Exposed Rebar

- Exposed lap spliced, discounted rebar



Highlight the lap splice location

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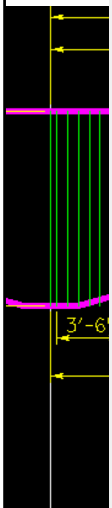
Broken Stirrups

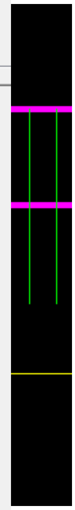
Load Rating in BrR



Type: Reinforced Concrete Tee

Section | Web Depth | Web Width | Reinforcement

Set	Bar Mark	Invert	Measured From	Distance (in)	Std Number	LRFD Number	Bar Spacing (in)	Side Cover (in)	Support Number	Direction	Start Distance (ft)	Straight Length (ft)	End Distance (ft)	Start Fully Developed	End Fully Developed
1	G106-112-1	☐	Bottom of Girder	2.7500	3.00	3.00			1	Right	0.000	112.44	112.443	☐	☐
2	G119	☐	Bottom of Girder	6.5000	4.00	4.00			1	Right	3.000	58.000	61.000	☐	☐
3	G42	☐	Bottom of Girder	6.5000	2.00	2.00			1	Right	8.500	46.000	54.500	☐	☐
4	G42	☐	Bottom of Girder	10.2500	2.00	2.00			1	Right	8.500	46.000	54.500	☐	☐
5	G125	☐	Bottom of Girder	10.2500	4.00	4.00			1	Right	15.500	32.000	47.500	☐	☐
6	LV1-G26-3#11	☐	Bottom of Girder	2.7500	3.00	3.00			2	Right	31.787	8.073	39.860	☐	☑
7	LV1-G26-3#10 EQV-1	☐	Bottom of Girder	2.7500	3.00	3.00			2	Right	39.859	3.031	42.891	☑	☑
8	LV1-G26-3#10 EQV-2	☐	Bottom of Girder	2.7500	3.00	3.00			2	Right	42.891	6.141	49.031	☑	☑
9	LV1-G26-3#9 EQV	☐	Bottom of Girder	2.7500	3.00	3.00			2	Right	49.031	16.339	65.370	☑	☑
10	LV1-G26-3#11-2	☐	Bottom of Girder	2.7500	3.00	3.00			2	Right	65.365	28.208	93.573	☑	☐
11	G106-112-1	☐	Bottom of Girder	2.7500	6.00	6.00			3	Left	20.953	112.44	91.489	☐	☐
12	G119	☐	Bottom of Girder	6.5000	4.00	4.00			3	Right	30.490	58.000	88.490	☐	☐
13	G42	☐	Bottom of Girder	6.5000	2.00	2.00			3	Right	36.990	46.000	82.990	☐	☐
14	G42	☐	Bottom of Girder	10.2500	2.00	2.00			3	Right	36.990	46.000	82.990	☐	☐
15	LV2-G26-3#11-1	☐	Bottom of Girder	6.5000	3.00	3.00			2	Right	29.792	13.094	42.885	☐	☑
16	LV2-G26-3#10 EQV	☐	Bottom of Girder	6.5000	3.00	3.00			2	Right	42.885	6.141	49.026	☑	☑
17	LV2-G26-3#11-2	☐	Bottom of Girder	6.5000	3.00	3.00			2	Right	49.026	44.766	93.792	☑	☐
18	LV2-G127-2#11-1	☐	Bottom of Girder	6.5000	2.00	2.00			2	Right	35.792	7.094	42.885	☐	☑
19	LV2-G127-2#9 EQV	☐	Bottom of Girder	6.5000	2.00	2.00			2	Right	42.885	6.141	49.026	☑	☑
20	LV2-G127-2#11-2	☐	Bottom of Girder	6.5000	2.00	2.00			2	Right	49.026	38.766	87.792	☑	☐
21	LV3-G127-1#11	☐	Bottom of Girder	10.2500	1.00	1.00			2	Right	35.792	52.000	87.792	☐	☐
22	LV3-G128-4#11	☐	Bottom of Girder	10.2500	4.00	4.00			2	Right	43.292	37.000	80.292	☐	☐



Final Rating

- Existing design - conservative
- Legal load rating is > 1.0, no posting
- Suggested for repair

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Emergency Vehicles (EV) Load Rating

- Load rate EV vehicles based on FHWA FAST Act's Memo dated November 3, 2016:

    1. Multiple presence: If necessary, when combined with other unrestricted legal loads for rating purposes, the emergency vehicle needs only to be considered in a single lane of one direction of a bridge.

We Make a Difference

KYTC – addendum
LARS – no mix traffic – line girder analysis using LLDF
MDX – no mix traffic, only design load

Emergency Vehicles (EV) Load Rating

- BrR allows load rating vehicle combined with different vehicle type on the adjacent lanes
- 3D model – LL distribution using FEM analysis
- Line girder model – Based on LRFD Article 4.6.2.2.5

$$G = G_p\left(\frac{g_1}{Z}\right) + G_D\left(g_m - \frac{g_1}{Z}\right) \quad (4.6.2.2.5\text{-}1)$$

where:

G = final force effect applied to a girder (kip or kip-ft)
G_p = force effect due to overload truck (kip or kip-ft)
g_1 = single lane live load distribution factor
G_D = force effect due to design loads (kip or kip-ft)
g_m = multiple lane live load distribution factor
Z = a factor taken as 1.20 where the lever rule was not utilized, and 1.0 where the lever rule was used for a single lane live load distribution factor

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Conclusions

- BrR capable to load rate variety of bridge types
- Great features in BrR
- BrR has potential to load rate other bridge types
- Completed the task within budget

We Make a Difference

Able to do wide variety of bridges
Added seven bridges into initial contract
Flexibility

Acknowledgement

- Kentucky Transportation Cabinet (KYTC)
- Michael Baker Project Team
- BrR Technical Support Team

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We Make a Difference

Questions?