VAUGHN & MELTON CONSULTING ENGINEERS, INC.
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A JMT COMPANY

Memorandum:

To: Shawn Fitzpatrick, PE, City of Knoxville, Tennessee

FROM: Patrick Gallagher, PE, Senior Bridge Engineer
SUBJECT: Urban Wilderness Gateway, South Knoxville Bridge Analysis

SUMMARY:

In accordance with Contract No. C-20-0173 and Change Order No. 1 dated June 11, 2021, Vaughn & Melton Consulting Engineers (V&M) performed a Load Rating Analysis of the South Knoxville Bridge over the Tennessee River in Knoxville, Tennessee. The load rating was conducted based upon as-built plans provided by the Tennessee Department of Transportation (TDOT) and the known condition of the bridge at the time of the analysis. It was rated for the bridge configuration in the as-built plans with the addition of a 12 foot wide sidewalk, and a concrete sidewalk and pedestrian/traffic barrier placed near the east edge of the bridge deck.

The bridge consists of two approach structures and a structure crossing the main channel. The approach structures are composed of concrete box beams skewed and with variable spacing. The main channel structure consists of variable depth steel plate girder beams with constant spacing for most of their length; flared at one end. It also has a line of steel stringers between the plate girders connected to crossframes bracing the girders.

Since this is a scoping exercise, the analysis was performed with Bentley's Leap Steel and Leap Concrete programs. The rating was otherwise performed in accordance with TDOT's Bridge Evaluation Manual dated March 31, 2021 (BEM) and the 2013 AASHTO Manual for Bridge Evaluation (MBE).

The minimum rating factors for the proposed modifications to the bridge for the design, legal, and permit trucks are 1.21, 1.47, and 0.83 respectively. V&M recommends proceeding with the final design of the addition of a sidewalk on the bridge utilizing a more sophisticated analysis program. V&M believes the final design will have minimal impact on the overall rating of the bridge.

ANALYSIS APPROACH:

This analysis was intended to determine if there is a reasonable expectation that adding the sidewalk would not overload the bridge. A Load and Resistance Factor Rating (LRFR) was performed on the primary members of the superstructure of the bridge. Bent reactions were also considered to validate the substructure capacity in the proposed condition.

Load rating analysis is divided up into a number of vehicles, depending upon the agency managing the bridge. Three vehicle loading types are considered, Design, Legal, and Permit. Load rating analysis also considers two different loading cases, Inventory and Operating. Differing axle configurations common to Tennessee roads are reflected in the specific vehicles, differing use of the bridge is reflected in the loading types, and different load frequency is distinguished in the different cases.

For each vehicle, type, and case, a Rating Factor (RF) is assigned based upon the analysis. That RF describes the adequacy of the bridge to support each vehicle for each use and frequency of loading expected. A RF at or above 1.0 is satisfactory. Any portion of the RF value above 1.0 describes how much extra load of that vehicle, type, and case can be resisted by the bridge. It's not uncommon for some RFs to be close to 1.0 and others to be well above 1.0; it depends upon the characteristics of the bridge being analyzed. For unusually heavy vehicles, such as the permit vehicles, it's not uncommon for them to be below 1.0. The MBE and TDOT's BEM lists over 20 vehicles to consider for the inventory and operating loading cases making for over 40 evaluations to be performed. All of the vehicles TDOT requires were evaluated for each type and case.

Structural modeling was done with a Leap Concrete and Leap Steel model. A grillage analysis method in Leap Steel was selected due to the complexity of the steel bridge configuration. Leap was selected as a reasonable means of determining the scope and potential success of the project. In accordance with the BEM, AASHTO Ware and CSI Bridge should be used for a full-scale load rating of this bridge in the final design analysis due to the size and configuration of this structure.

Leap steel does not precisely represent flared deck widths or the stringers between the girders. So, additional loading due to the flare and stringer system was considered as added loads to a non-flared model of the bridge with a constant deck width of 120 feet. Figures 1 through 4 describe the structural models. Leap Steel also struggles with rating for shear in structures with longitudinal stiffeners. To demonstrate adequacy in shear, the shear strength of the steel portions of the bridge was compared to the maximum demand.

To overcome the concerns with the flare in Leap Concrete, the longest concrete box beam was modeled with a straight alignment. Since the prestressed box beams are simple span, one span length was considered. This condition captured the most impacted box beams.

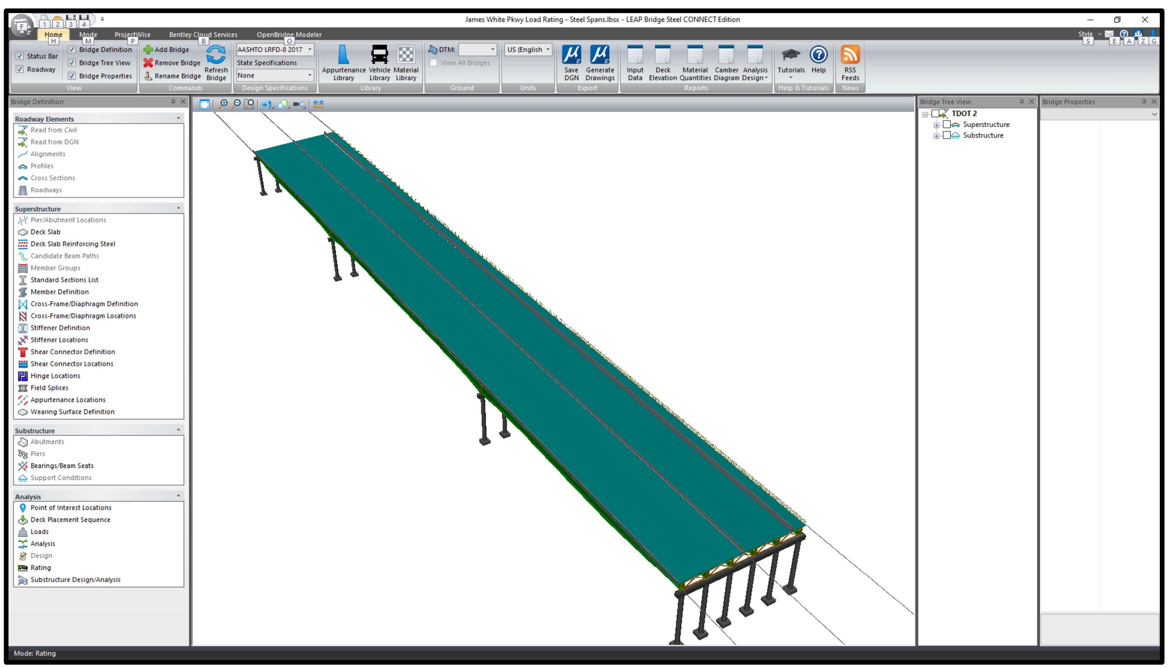

Figure 1: Structural Steel Model Rendering, Top Side

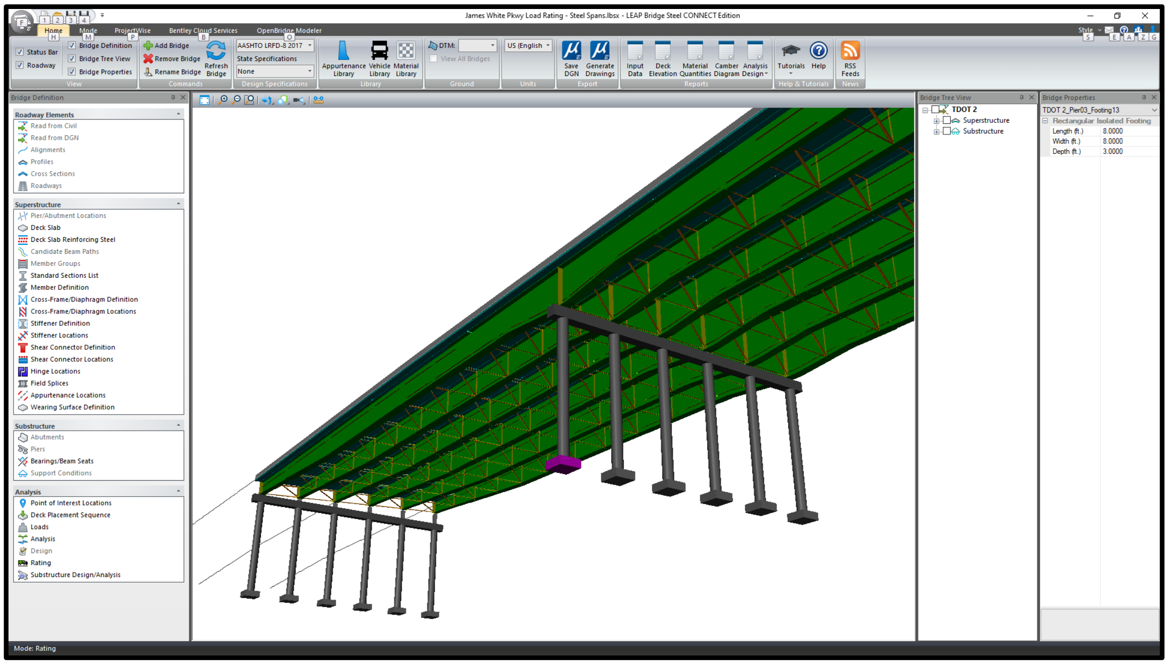

Figure 2: Structural Steel Model Rendering, Close up of Underside

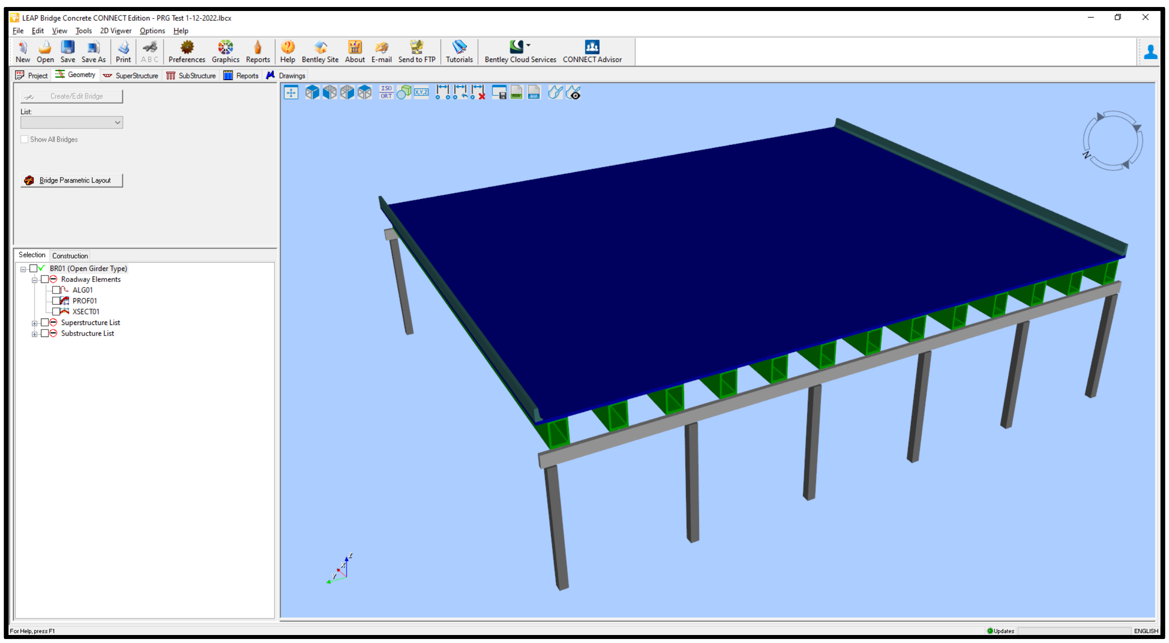

Figure 3: Structural Concrete Model Rendering, Top Side

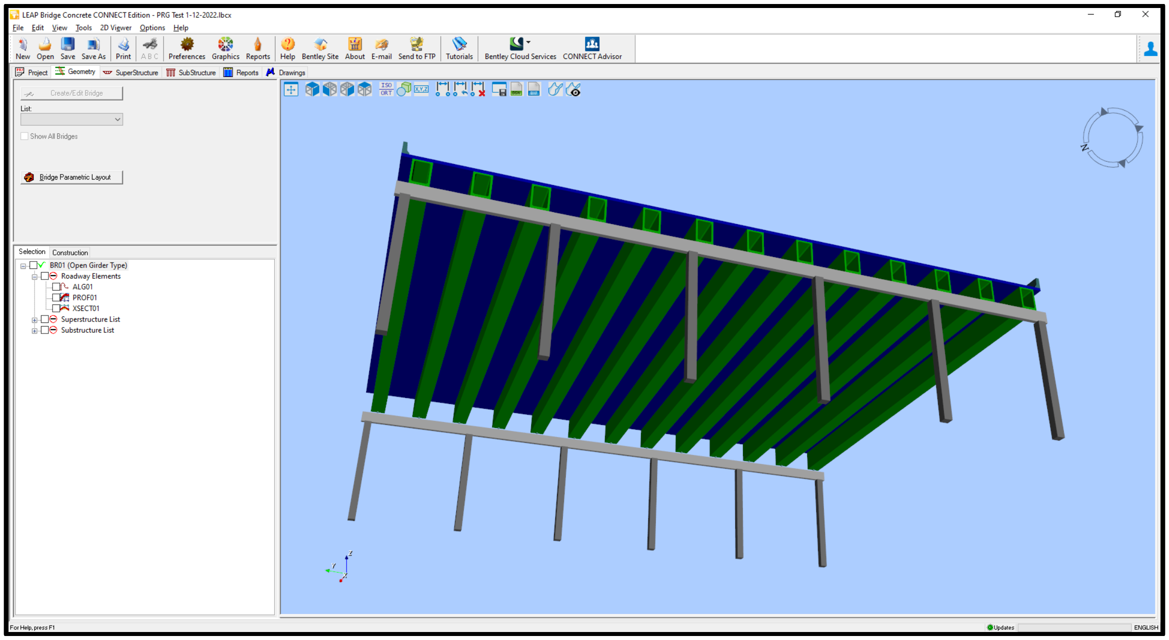

Figure 4: Structural Concrete Model Rendering, Close up of Underside

Representative cross sections of the superstructure and sidewalk are shown in Figures 5 through 7. Figures 8 through 10 display the girder and skew configuration for each span. The concrete approaches consist of pretensioned hollow concrete box girders spaced up to 17.3 feet apart and spanning up to 120 feet. The main channel girders consist of variable depth steel plate girders typically spaced at 22 feet on center and spanning up to 390 feet. Steel stringers and cross frames support the deck between the plate girders. The sidewalk is 12 feet wide and has a 6 inch thick concrete surface in the analysis. The concrete barrier between the sidewalk and traffic lanes is designed with concrete and similarly sized as typical concrete bridge rails. The bridge is very wide, yet typical design practice is to distribute loads at the edge of the deck equally to each of the girders.

Material strengths were based upon the material specifications noted in the plans. In accordance with the material specified in the as-built plans, the primary steel elements considered steel strengths of 50 ksi. Concrete strengths considered were those listed in the as-built plans for all concrete elements except the deck. The concrete strength for the deck was not specifically stated in the as-built plans. TDOT's load rating policy was applied, allowing 3 ksi be considered in the deck.

The NBI bridge inspection report dated March 5, 2020 was used to establish the rating information dependent upon the condition of the bridge. The superstructure is in good condition and the deck is in satisfactory condition, coded a 6 and 7 respectively. The deck is smooth, and the bridge has approach slabs. As a result, a condition factor 1.0 was considered and impact factors were not increased beyond the minimum. The impact factor for the structure is based upon MBE Article C6A.4.4.3. The ADTT was considered to be 1000 trucks per day for the rating factor calculations.

In addition to the complex structural models, a simplified approach was considered as a means to verify the outcome of the complex analysis. The MBE does not require pedestrian live loads to be applied at the same time as vehicular loading. The expectation is that when a design level vehicular loading is applied to the bridge, it will not have a simultaneous design level pedestrian loading. This simplified check compared the reactions to the piers of the bridge as it exists today and those with a sidewalk added, both as a 6" thick overlay to the deck and with the top surface of the existing deck being used at the pathway where it currently meets ADA requirements. It included the respective barrier and lane configurations required to install the proposed pathway.

This simplified check was also considered as a means to verify the adequacy of the substructure. While substructure elements are typically not considered in a load rating according to the MBE and BEM, these specifications assume substructures are able to withstand the design loads placed on the top of the bridge. Adding a pathway modifies the design load, making a reasonable effort to verify the substructure adequacy necessary.

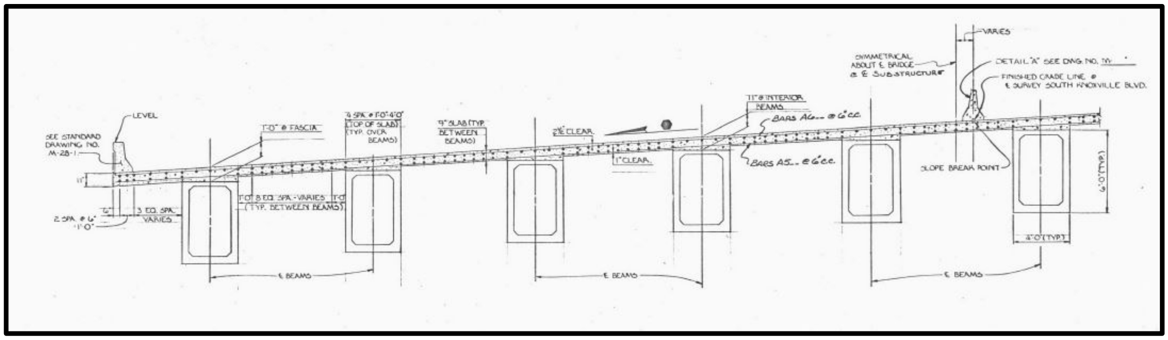

Figure 5: Concrete Approach Cross Half-Section, Current Configuration

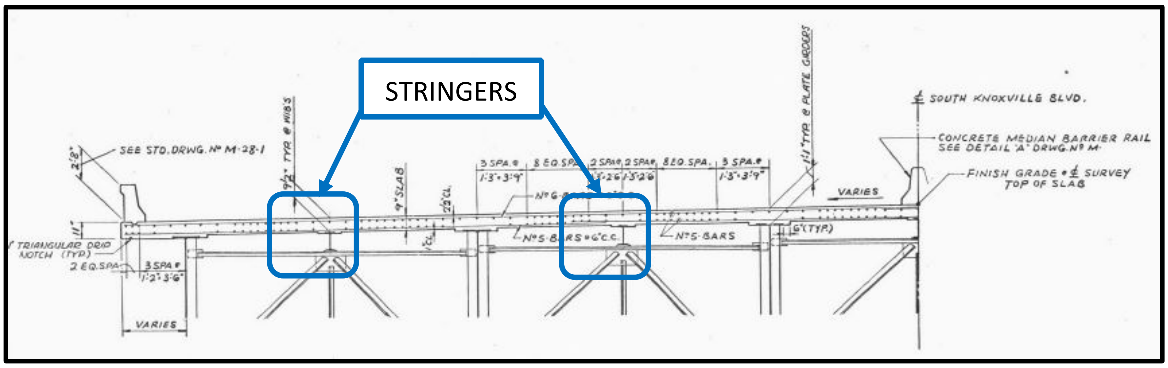

Figure 6: Steel Span & Stringer Cross Half-Section, Current Configuration

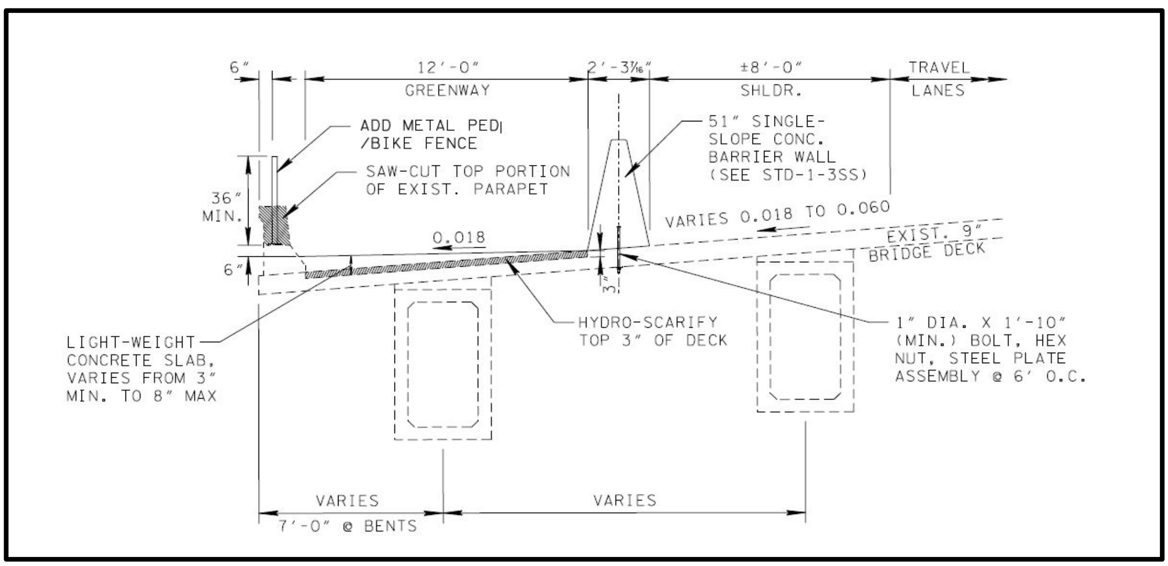

Figure 7: Proposed Sidewalk at East Edge of Deck

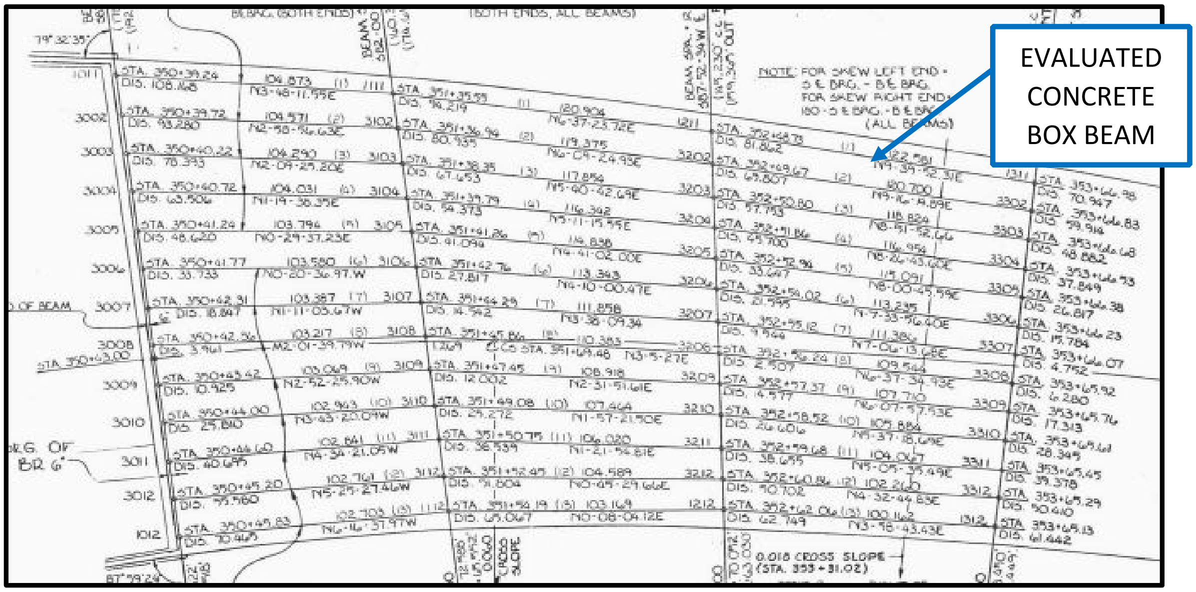

Figure 8: South Approach Spans, Current Configuration

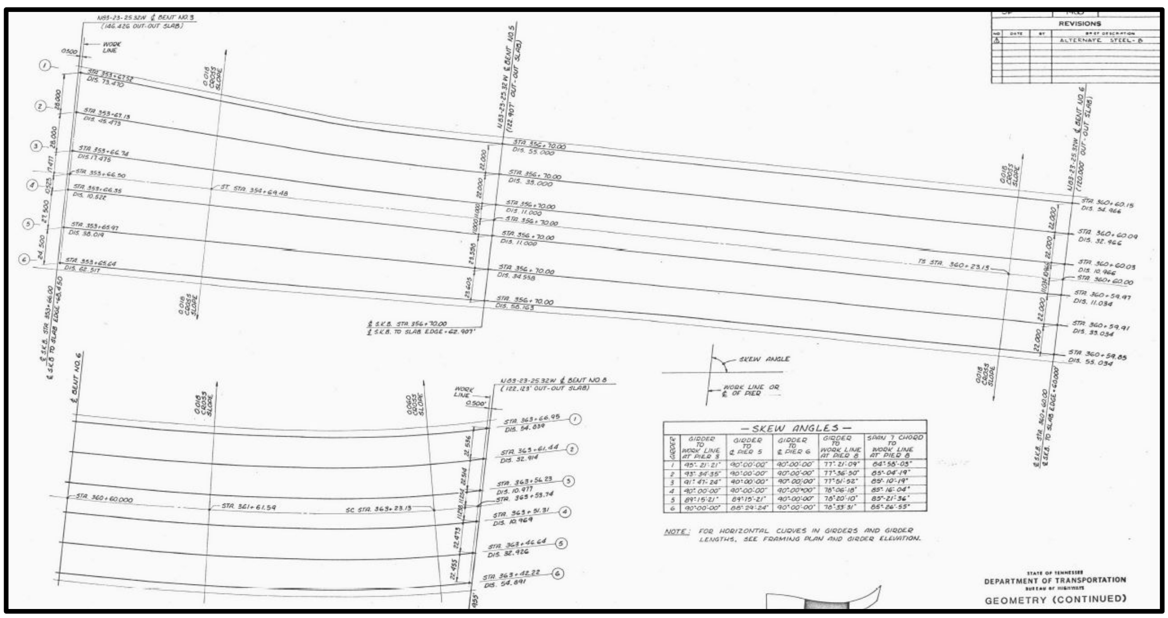

Figure 9: Steel Spans, Current Configuration

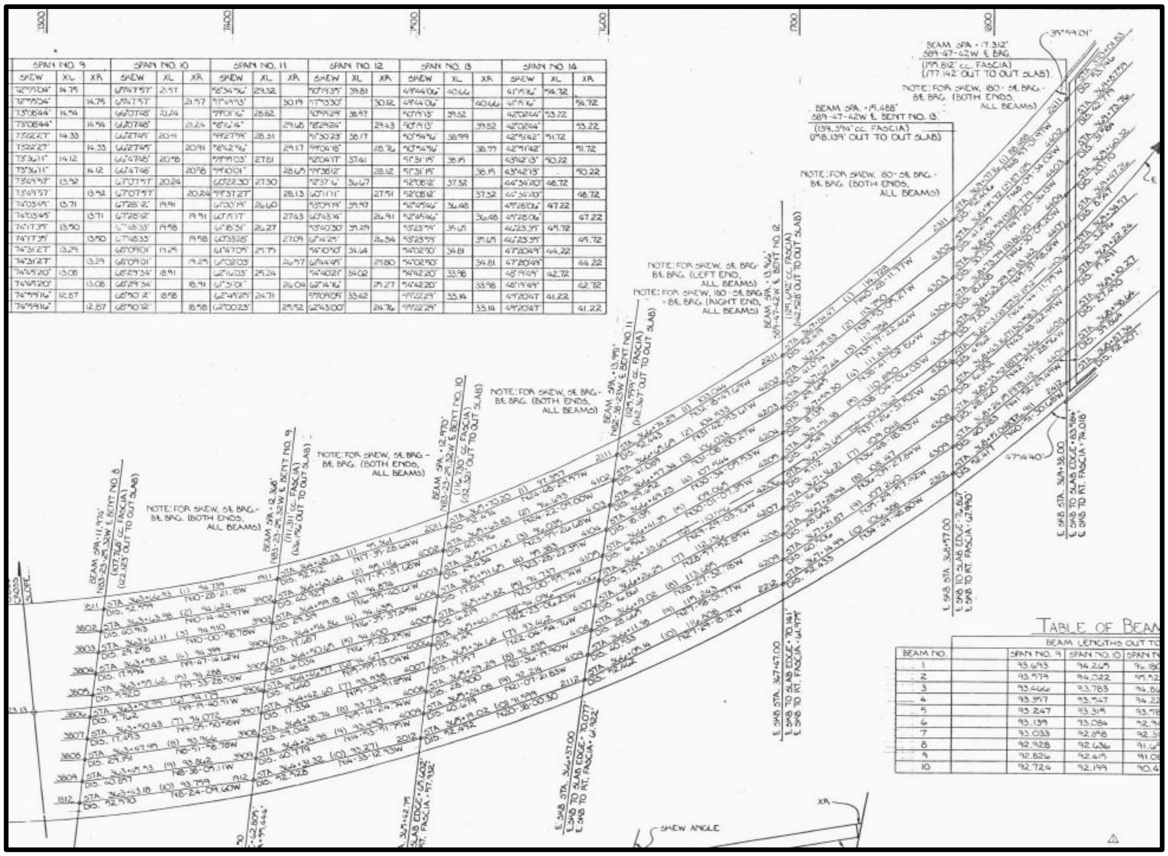

Figure 10: North Approach Spans, Current Configuration

RESULTS:

Figures 11 through 14 present moment and shear diagrams, showing the nature of the stress distribution through the steel and concrete spans respectively.

Tabulated rating factors for the proposed configuration of the bridge are listed in Appendix A and B. Rating factors for design and legal loads were above the threshold of 1.0. Permit load rating factors were most often above 1.0, but lower in one case.

Shear capacity of the steel girders is 2562 kips. The maximum shear demand is 960 kips for the Strength 1 load case, well below the capacity.

The results of the simplified approach outlined earlier is listed in Appendix C. The bent reactions for the current condition, proposed condition with a 6” thick concrete sidewalk slab, and the proposed condition without a 6” thick sidewalk slab were all very close to each other. With the addition of a pedestrian walkway and 6” thick concrete overlay, the bent reaction increased by 1.25%. When a pedestrian walkway was added without a 6” thick concrete overlay, the net bent reaction was reduced by 6.78%. This change in reaction is directly reflected in the stresses in the superstructures the bents support.

While the concrete model was based on the longest span and the exterior girder, it’s reasonable to expect that a more detailed analysis would provide consistent results.

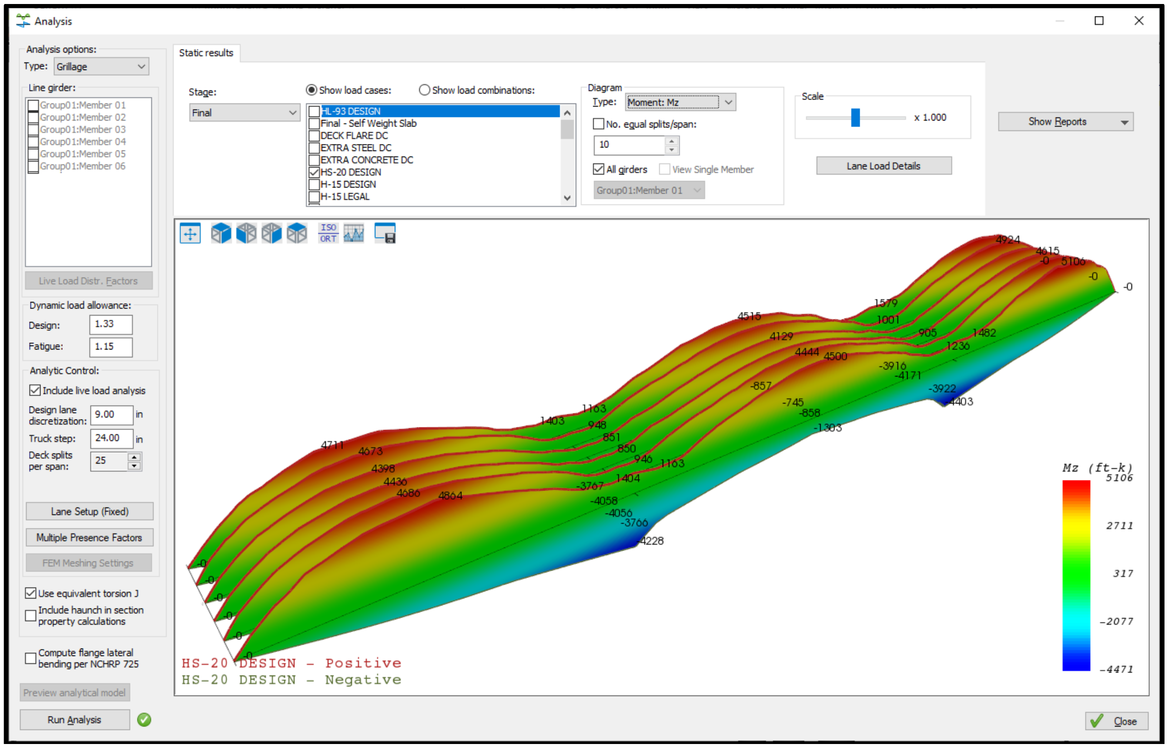

Figure 11: HS-20 Design Load Moment, Steel Spans

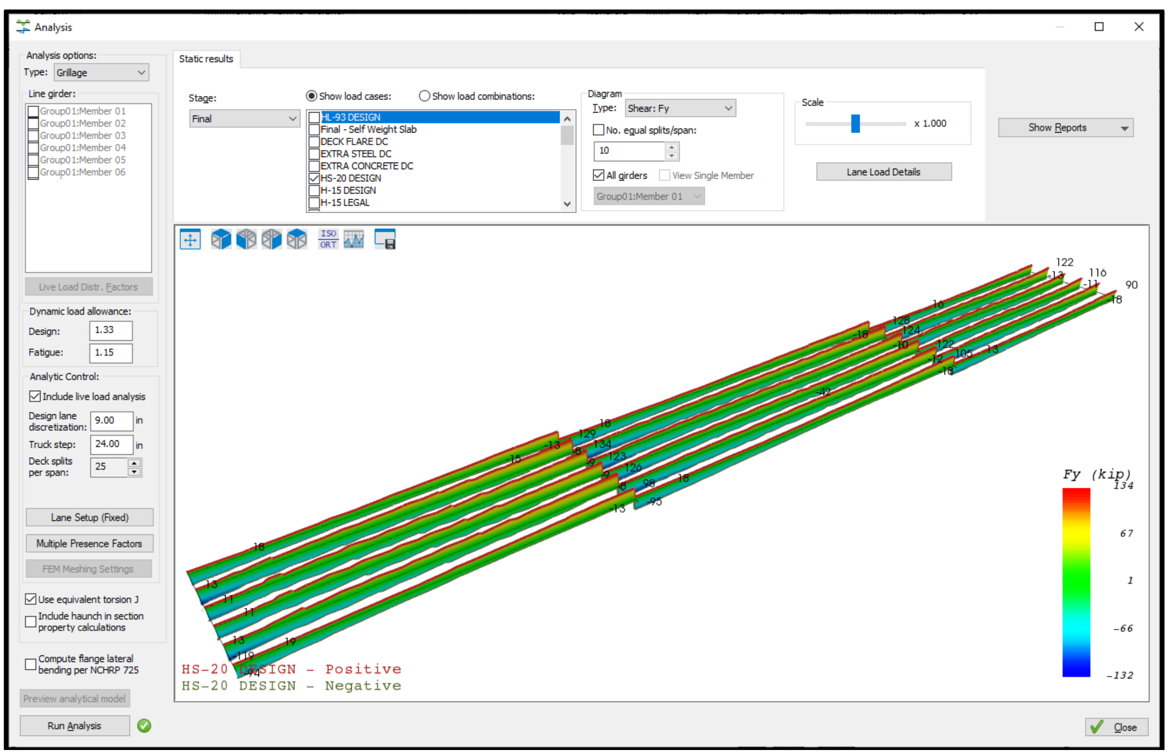

Figure 12: HS-20 Design Load Shear, Steel Spans

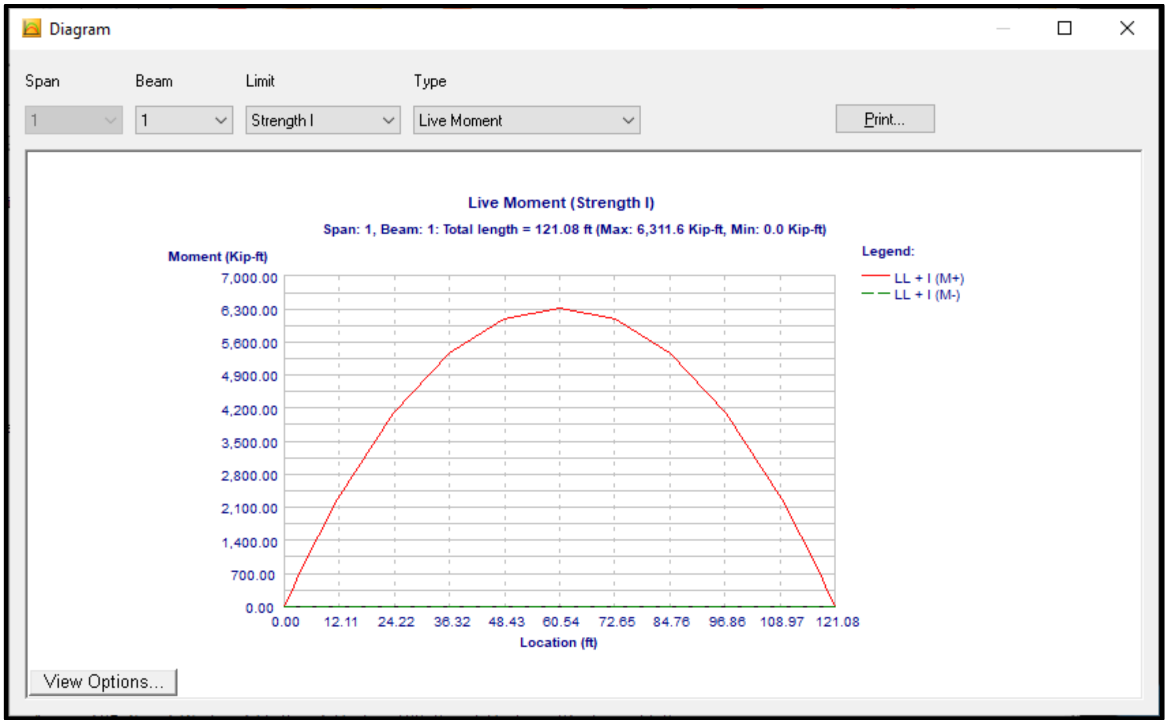

Figure 13: Strength 1 Live Load Moment, Concrete Spans

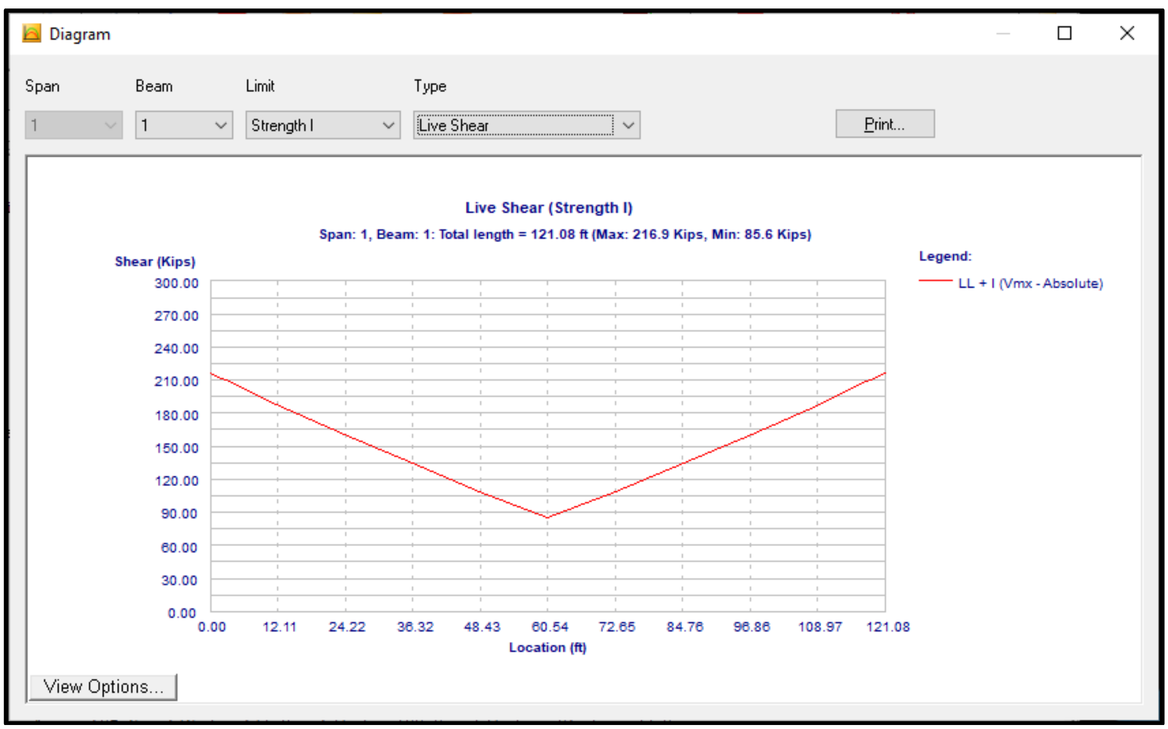

Figure 14: Strength 1 Live Load Shear, Concrete Spans

APPLICABILITY:

It's our understanding that TDOT is conducting a research study for this type of bridge. The research study is focused on live load distribution to the steel stringers and steel girders for bridges with this unique configuration. It's for this reason that the steel stringers were not evaluated.

It's advised that TDOT concludes their research on this type of bridge before commencing with construction of the proposed sidewalk. Prior to construction, the rating of this bridge should be verified with an analysis performed in conformance with the findings of that research project, and with precise representation of the flared steel portions in CSI Bridge or AASHTO Ware. If the rating of the bridge is not deemed adequate after applying those research findings to the bridge, alterations to the bridge or sidewalk should be made to assure conformance to those research findings and in a manner that preserves the bridge's capacity to TDOT's expectations.

Based upon our understanding of bridge performance for this type of structural system in Tennessee, we expect TDOT's findings to demonstrate that the stringer system is adequate. We understand that the intent of the research is to resolve the conflict between analysis results and observed results in the field. Apparently, the stringer systems typically rate poorly, yet show no signs of distress on bridges currently in service. It's for this reason we do not expect this research to hinder the development of a walkway added to this bridge. Once again, this expectation should be verified when that research is concluded.

CONCLUSION:

V&M believes the South Knoxville Bridge over the Tennessee River is able to load rate as favorably with the addition of a pedestrian walkway at the east edge of the bridge.

V&M recommends considering the lightest reasonable sidewalk configuration possible so as to minimize the addition of dead or vehicular load. We believe this can be done with the addition of a walkway placed directly on top of the existing bridge deck when the superelevation accommodates walkway requirements, and with a concrete rail installed between the walkway and vehicular traffic. We also believe adding a concrete surface up to an average of 6" thick to the deck in portions where the superelevation does not permit proper sidewalk cross slopes is feasible.

Final design and construction of the sidewalk and barriers should incorporate the elements noted within the Applicability section of this report.

If you have any questions, please contact Patrick Gallagher at (984) 500-7124 or prgallagher@vaughnmelton.com.

Sincerely,

DocuSigned by:
Patrick R. Gallagher
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Patrick R. Gallagher, PE
Senior Bridge Engineer
Vaughn & Melton Consulting Engineers

4/4/2022

Appendix A:

MOMENT RATING ~ STEEL SPANS						
LOAD CASE	GIRDER 1	GIRDER 2	GIRDER 3	GIRDER 4	GIRDER 5	GIRDER 6
HL-93 DES INV SERV 2	1.24	1.78	2.59	2.60	1.83	1.52
HL-93 DESIGN OPER SERV 2	1.90	3.23	3.37	3.38	3.24	1.98
HS-20 DES INV SERV 2	6.00	5.79	6.15	6.09	5.70	5.71
HS-20 DESIGN OPER SERV 2	7.80	7.52	8.00	7.92	7.41	7.43
H-15 DES INV SERV 2	14.02	13.33	14.87	15.15	12.95	12.97
H-15 DESIGN OPER SERV 2	21.05	21.83	23.09	23.29	21.71	20.81
H-15 LEGAL INV SERV 2	14.02	13.33	14.87	15.15	12.95	12.97
H-15 LEGAL OPER SERV 2	21.05	21.83	23.09	23.29	21.71	20.81
GRAVEL LEGAL INV SERV 2	5.82	5.56	5.91	5.88	5.47	5.61
GRAVEL LEGAL OPER SERV 2	7.56	7.23	7.69	7.65	7.10	7.30
SCHOOL BUS LEGAL INV SERV 2	11.91	11.54	12.56	12.10	11.32	11.24
SCHOOL BUS LEGAL OPER SERV2	16.40	15.48	19.78	19.76	15.57	14.96
EV2 LEGAL INV SERV 2	7.44	7.06	7.57	7.50	7.00	6.95
EV2 LEGAL OPER SERV 2	9.67	9.18	9.85	9.75	9.11	9.03
EV3 LEGAL INV SERV 2	4.99	4.80	5.07	5.03	4.69	4.77
EV3 LEGAL OPER SERV 2	6.49	6.24	6.59	6.54	6.10	6.21
TYPE 3 LEGAL INV SERV 2	8.60	8.29	8.73	8.68	8.11	8.26
TYPE 3 LEGALOPER SERV 2	11.18	10.78	11.35	11.29	10.55	10.73
TYPE 3-S2 LEGAL INV SERV 2	6.27	6.31	6.50	6.51	6.24	6.10
TYPE 3-S2 LEGAL OPER SERV 2	8.16	8.20	8.44	8.47	8.11	7.94
TYPE 3-3 LEGALINV SERV 2	5.82	5.96	6.08	6.05	5.89	5.68
TYPE 3-3 LEGALOPER SERV 2	7.56	7.75	7.91	7.86	7.65	7.38
SU4 LEGAL INV SERV 2	7.92	7.45	8.04	7.91	7.35	7.56
SU4 LEGAL OPER SERV 2	10.30	9.68	10.45	10.29	9.56	9.83
SU5 LEGAL INV SERV 2	6.96	6.72	7.08	7.08	6.59	6.68
SU5 LEGAL OPER SERV 2	9.05	8.73	9.20	9.21	8.56	8.69
SU6 LEGAL INV SERV 2	6.27	5.98	6.37	6.33	5.92	6.05
SU6 LEGAL OPER SERV 2	8.16	7.78	8.28	8.23	7.70	7.86
SU7 LEGAL INV SERV 2	5.65	5.42	5.76	5.69	5.35	5.45
SU7 LEGAL OPER SERV 2	7.35	7.04	7.48	7.40	6.95	7.08
LL AASHTO 1 LEGAL INV SERV 2	7.76	7.95	8.11	8.06	7.85	7.57
LL AASHTO 1 LEGAL OPER SERV2	10.08	10.33	10.55	10.48	10.21	9.84
LL AASHTO 2 LEGAL INV SERV 2	3.64	5.50	5.32	5.29	5.43	3.64
LL AASHTO 2 LEGAL OPER SERV 2	5.84	7.15	6.92	6.88	7.05	5.88
LL GRAVEL 1 LEGAL INV SERV 2	5.82	5.56	5.91	5.88	5.47	5.61
LL GRAVEL 1 LEGAL OPER SERV2	7.56	7.23	7.69	7.65	7.10	7.30
LL GRAVEL 2 LEGAL INV SERV 2	2.77	3.29	3.33	3.33	3.29	2.05
LL GRAVEL 2 LEGAL OPER SERV 2	3.61	4.63	4.61	4.61	4.54	3.62
OW PERMIT INV SERV 2	**0.87**	1.09	1.45	1.46	1.06	**0.83**
OW PERMIT OPER SERV 2	1.25	2.57	2.60	2.60	1.89	1.61
AP1 PERMIT INV SERV 2	1.75	2.92	2.96	2.96	2.93	1.82
AP1 PERMIT OPER SERV 2	3.20	3.80	4.06	4.05	3.80	3.21
AP2 PERMIT INV SERV 2	1.72	2.75	2.85	2.84	2.71	1.79
AP2 PERMIT OPER SERV 2	3.15	3.57	3.70	3.69	3.53	3.16

Appendix B:

MOMENT RATING ~ CONCRETE SPANS	
LOAD CASE	GIRDER 1
HL-93 DESIGN INV	1.21
HS-20 DESIGN INV	1.77
H-15 DESIGN INV	3.88
HL-93 DESIGN OPER	1.73
HS-20 DESIGN OPER	2.54
H-15 DESIGN OPER	5.56
H-15 LEGAL	3.75
GRAVEL LEGAL	1.61
SCHOOL BUS LEGAL	3.35
EV2 LEGAL	2.08
EV3 LEGAL	1.47
TYPE 3 LEGAL	2.39
TYPE 3-S2 LEGAL	1.84
TYPE 3-3 LEGAL	1.91
SU4 LEGAL	2.16
SU5 LEGAL	1.93
SU6 LEGAL	1.72
SU7 LEGAL	1.56
OW PERMIT	1.60
AP1 PERMIT	1.59
AP2 PERMIT	1.27

SHEAR RATING ~ CONCRETE SPANS	
LOAD CASE	GIRDER 1
HL-93 DESIGN INV	1.64
HS-20 DESIGN INV	2.37
H-15 DESIGN INV	5.48
HL-93 DESIGN OPER	2.15
HS-20 DESIGN OPER	3.10
H-15 DESIGN OPER	7.13
H-15 LEGAL INV	8.31
GRAVEL LEGAL INV	3.46
SCHOOL BUS LEGAL INV	7.14
EV2 LEGAL INV	4.41
EV3 LEGAL INV	3.12
TYPE 3 LEGAL INV	4.35
TYPE 3-S2 LEGAL INV	3.18
TYPE 3-3 LEGAL INV	3.35
SU4 LEGAL INV	4.72
SU5 LEGAL INV	4.15
SU6 LEGAL INV	3.78
SU7 LEGAL INV	3.47
OW PERMIT	1.67
AP1 PERMIT	1.72
AP2 PERMIT	1.46

Appendix C:

BENT REACTION COMPARISONS.		
LOADING CASE	BENT REACTION	% DIFFERENCE FROM CURRENT
Current Condition	3361 kips	NA
Proposed with a sidewalk overlay	3403 kips	1.25
Proposed without a sidewalk overlay	3133 kips	-6.78