Transportation Research Division

Technical Report 14-12

Advanced Bridge Safety Initiative

Investigation of Floor Beam Performance in Three Steel Through-Truss Bridges

Task 7
The Advanced Structures and Composites Center at the University of Maine (UMaine) performed live load testing and rating adjustment factor analysis for three truss bridges. The Maine Department of Transportation (DOT) indicated that the floor beams are not sufficient for carrying the legal loads for these bridges. Each bridge is a steel through-truss bridge with floor beams, stringers and a variable depth concrete slab that was not designed to be composite with the steel framing. The bridges were all located in Maine in Brownville, Chester and T-3 Indian Purchase. Live load testing was conducted on April 8th, April 10th and April 15th, 2014 by UMaine with assistance from Maine DOT personnel to evaluate the performance of typical floor beams. Stringers were considered to be of secondary concern to the Maine DOT, and were not heavily instrumented.

The strain measurements were consistent, and the results appear reliable. Measured floor beam strains were less than expected based on a lever rule analysis for live load distribution. If the MaineDOT agrees with our assessment, a conventional, lever rule load rating of the floor beams for these three structures that accounts for the condition of the floor beams including section losses must be completed. The rating factors determined from these analyses can then be increased by the values of K reported. Any existing cracking near copes or connections and remaining fatigue life have not been considered as part of this analysis, and should also be considered given the age of these structures.
Investigation of Floor Beam Performance in
Three Steel Through-Truss Bridges

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Report Number: 15-6-979

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University of Maine’s Advanced Structures and Composites Center.

An ISO 17025 accredited testing laboratory, accredited by the International Accreditation Service.
The Advanced Structures and Composites Center at the University of Maine (UMaine) performed live load testing and rating adjustment factor analysis for three truss bridges. The Maine Department of Transportation (DOT) indicated that the floor beams are not sufficient for carrying the legal loads for these bridges. Each bridge is a steel through-truss bridge with floor beams, stringers and a variable depth concrete slab that was not designed to be composite with the steel framing. The bridges were all located in Maine in Brownville, Chester and T-3 Indian Purchase. Live load testing was conducted on April 8th, April 10th and April 15th, 2014 by UMaine with assistance from Maine DOT personnel to evaluate the performance of typical floor beams. Stringers were considered to be of secondary concern to the Maine DOT, and were not heavily instrumented.

**TEST SETUP & INSTRUMENTATION**

Each bridge was instrumented with strain gages using a semi-wireless structural testing system. These gages were generally located on the bottom flange, mid-height and under the top flange of the steel members. On each bridge, two floor beams and one stringer were instrumented. Eighteen gages were used for both the Brownville and Chester bridges each and 24 gages were installed on the Indian Purchase bridge test. Gage locations at each cross section are shown in Figure 1, Figure 2, and Figure 3.

![Diagram of bridge cross section](image)

**Figure 1 - Gage location on Brownville cross section of floor beams and stringers respectively**
Figure 2 - Gage location on Chester cross section of floor beams and stringers respectively

Figure 3 - Gage location on Indian Purchase cross section of floor beams and stringers respectively

Bridge number 3222 in Brownville had 6 cross sections with three gages each. Four cross-sections were on the floor beams and two on the centerline stringer spanning between the instrumented floor beams. The third and fourth floor beams from the south abutment were instrumented and can be seen in Figure 4. The bridges in Chester and Indian Purchase are instrumented similarly and are shown in Figure 5 and Figure 6 respectively.
Figure 4 – Gage locations for Bridge No. 3222 in Brownville, ME
Figure 5 – Gage locations for Bridge No. 3790 in Chester, ME
TEST VEHICLES

Four loaded, dual rear axle dump trucks were used to load each bridge. The weight of each set of wheels and the spacing of the axles and wheels were recorded on site prior to loading the bridge. These measurements are given in Appendix A. The average weight of the trucks is shown in Table 1 and a typical truck can be seen in Figure 7.

Table 1 – Average truck weight during bridge testing

<table>
<thead>
<tr>
<th></th>
<th>Brownville (#3222)</th>
<th>Chester (#3790)</th>
<th>T3-Indian Purchase (#3366)</th>
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<tr>
<td>Average truck weight</td>
<td>54,840 lb.</td>
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<td>60,825</td>
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Three series of tests were conducted at each bridge, each with increasing loads to the bridge members. Initially, a single truck was driven across the bridge at low speed (see Figure 7). The second test had two trucks traveling side by side at low speed across the bridge. The final series consisted of two static tests with four trucks positioned to maximize load to the floor beams of interest. Truck position was captured during the rolling tests with the AutoClicker, which records tire revolutions from a starting point on the bridge.

The load cases for the Brownville bridge are shown in Figure 8, Figure 9 and Figure 10. Similarly, the load cases for Chester are shown in Figure 11, Figure 12 and Figure 13 and Indian Purchase in Figure 14, Figure 15, and Figure 16.
Figure 8 – One truck loading of Brownville

Trucks traveled from end of span to past midspan during test

Figure 9 – Two truck loading of Brownville

Trucks traveled from end of span to past midspan during test
Figure 10 – Four truck loading of Brownville

Figure 11- One truck loading of Chester
Figure 12 – Two truck loading of Chester

Figure 13 – Four truck loading of Chester
Figure 14 – One truck loading of Indian Purchase bridge

Figure 15 – Two truck loading at Indian Purchase bridge
RESULTS

Strain data were collected with three different loadings at each bridge. Representative strain plots for key locations and peak values for all gages are detailed as follows for each structure.

BROWNVILLE (No. 3222)

Data for the rolling single truck load case for Brownville is shown in Figure 17 and Table 2. The peak strain values for the rolling two truck case is given in Table 3 and the peak values for Brownville’s static four truck loading is given in Table 4. A plot of critical strain gage data during the four truck loading is also shown Figure 18.
Figure 17 – Plot of strain during first test at Brownville (Bridge No. 3222)

Table 2 - Peak Values for Single Truck Loading of the Brownville Bridge (No. 3222)

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Table 3 - Peak Values for Two Truck Loading of the Brownville Bridge (No. 3222)

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Figure 18 – Plot of peak strain during static positioning of four trucks across two floor beams for Brownville (No. 3222)
Table 4 - Peak Values for Four Truck Loading of the Brownville Bridge (No. 3222)

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CHESTER (No. 3790)

Data for the rolling single truck load case for Chester is shown in Table 5. The peak strain values for the rolling two truck case is given in Table 6 and the peak values for Chester’s static four truck loading is given in Table 7.

Table 5 - Peak Values for Single Truck Loading of the Chester bridge (No. 3790)

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<td>Min Strain (µε)</td>
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Table 6 – Peak Values for Two Truck Loading of the Chester bridge (No. 3790)

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Table 7 – Peak Values for Four Truck Loading at the Chester bridge (No. 3790)

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**INDIAN PURCHASE (NO. 3666)**

Data for the rolling single truck load case for Indian Purchase is shown in Figure 19 and Table 8. The peak strain values for the rolling two truck case is given in Table 9 and the peak values for Brownville’s static four truck loading is given in Table 10. A plot of critical strain gage data during the four truck loading is also shown Figure 20.

Table 8 – Peak strain values during 1 truck loading of Indian Purchase bridge (No. 3666)

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### Table 9 – Peak strain values during 2 truck loading of Indian Purchase bridge (No. 3666)

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<td>B3071</td>
<td>B3069</td>
<td>B3070</td>
<td>B3063</td>
</tr>
<tr>
<td>Max Strain (με)</td>
<td>1.94</td>
<td>89.27</td>
<td>0.81</td>
<td>9.37</td>
<td>163.14</td>
<td>6.81</td>
<td>31.84</td>
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<td>-138.78</td>
<td>-6.68</td>
<td>-9.82</td>
<td>-86.45</td>
<td>-7.35</td>
<td>-4.18</td>
<td>-8.95</td>
<td>-36.58</td>
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### Table 10 – Peak strain values during 4 truck loading of Indian Purchase bridge (No. 3666)

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<tr>
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<th>B3068</th>
<th>B3811</th>
<th>B3067</th>
<th>B3062</th>
<th>B3056</th>
<th>B3055</th>
<th>B3058</th>
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<tbody>
<tr>
<td>Max Strain (με)</td>
<td>168.24</td>
<td>0.57</td>
<td>7.14</td>
<td>17.53</td>
<td>195.84</td>
<td>8.01</td>
<td>4.24</td>
<td><strong>300.32</strong></td>
</tr>
<tr>
<td>Min Strain (με)</td>
<td>-3.33</td>
<td>-15.14</td>
<td>-164.21</td>
<td>-190.15</td>
<td>-6.90</td>
<td>-8.09</td>
<td>-171.33</td>
<td>-5.65</td>
</tr>
<tr>
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<td>B3075</td>
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<td>B3066</td>
<td>B3810</td>
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<td>Max Strain (με)</td>
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<td>66.58</td>
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<td>B3071</td>
<td>B3069</td>
<td>B3070</td>
<td>B3063</td>
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<tr>
<td>Max Strain (με)</td>
<td>1.18</td>
<td>166.06</td>
<td>3.89</td>
<td>1.70</td>
<td>330.49</td>
<td>9.49</td>
<td>62.88</td>
<td>33.45</td>
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<tr>
<td>Min Strain (με)</td>
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<td>-12.24</td>
<td>-162.22</td>
<td>-2.88</td>
<td>-21.26</td>
<td>-4.77</td>
<td>-33.46</td>
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Figure 19 – Chart of strain during 2 truck load case for Indian Purchase (No. 3666)

Figure 20 – Plot of strain versus time for Indian Purchase (No. 3666)
ANALYSIS OF STRAIN DATA AND CALCULATION OF THE RATING FACTOR MODIFIER

Calculations in Appendix B detail the analysis of the truss bridge floorbeams in Chester, Brownville and Indian Purchase under both the test loading and HL-93 tandem and lane loading, which would control the flexural rating of the floorbeams. Important assumptions of the analyses are detailed below:

1) The lever rule was used to distribute all loads. The deck was assumed simply supported and spanning one way between stringers, and the simply supported stringers carried live load to the floorbeams.
2) Floorbeam spans were calculated based on available drawings provided by the MaineDOT.
3) Nominal properties were assumed for all the floorbeams, and no section loss was accounted for.

The field-measured strains indicate full composite action for the Brownville truss during the test, and no significant composite action at either Indian Purchase or Chester. These responses are consistent with details in the design drawings and visual inspection of the structures, which show significant floorbeam top flange slab embedment at Brownville and very little or no floorbeam top flange embedment in the slab for Chester or Indian Purchase. The measured strains indicate no significant rotational fixity at the floorbeam end connections for all three structures. Response for all structures remained linearly elastic, and measured strains produced by the two truck and four truck loading were approximately proportional to the increase in applied moment. The peak moments produced at Chester due to the four-truck loading were approximately 90% of the calculated moment due to an HL-93 loading with impact; at Brownville and Indian Purchase 81% and 102% of the calculated moment due to HL-93 loading with impact was applied, respectively.

Based on the calculations in Appendix B, floorbeam rating factors calculated per a conventional AASHTO lever rule analysis can be increased by the following: $K = 1.30$ for Chester; $K = 1.30$ for Brownville; $K = 1.46$ for Indian Purchase. The calculations show that composite action cannot be relied upon at Brownville at higher loads, and this is reflected in the value of 1.30. These calculated values are likely influenced by less conservative live load distribution than predicted using the lever rule. The factor of safety against yielding was calculated for Chester under full service DL + HL-93 with impact to be approximately 1.56. This calculation was performed for Chester since it has the lightest floorbeams of all three structures, and the measured floorbeam strains were significantly larger than those measured at the other two bridges. While this value of 1.56 does not account for any section loss, it does indicate that these floorbeams may have substantial residual capacity beyond that required to carry current design loads.
CONCLUSIONS

The strain measurements were consistent, and the results appear reliable. Measured floorbeam strains were less than expected based on a lever rule analysis for live load distribution. If the MaineDOT agrees with our assessment, a conventional, lever rule load rating of the floorbeams for these three structures that accounts for the condition of the floorbeams including section losses must be completed. The rating factors determined from these analyses can then be increased by the values of $K$ reported above. Any existing cracking near copes or connections and remaining fatigue life have not been considered as part of this analysis, and should also be considered given the age of these structures.

REFERENCES

4. West Branch Bridge Plans (#3666). November 1939. Provided by Maine DOT.
APPENDIX A: TRUCK MEASUREMENTS – BROWNVILLE, CHESTER, T3 INDIAN PURCHASE

Insert 3 PDFs (12 pages total)
“Brownville_Truck_Wts.pdf”
“Chester_Truck_Wts.pdf”
“T3_Indian_Purchase_Truck_Wts.pdf”
Test Vehicle Measurements

License Plate Number: T01-447
Truck Designation (4 or 2): 4

Axle Weight: 18,550
Dimensions by: CF
Axle Spacing: 50"

Axle Weight: 19,800
Axle Spacing: 177"

Axle Weight: 14,500
Wheel Spacing: 91"

Total Vehicle Weight: 51,850
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</table>

<table>
<thead>
<tr>
<th>Wheel Spacing</th>
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Total Vehicle Weight: 53,000
### Test Vehicle Measurements

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</tr>
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<tr>
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<table>
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<td>55&quot;</td>
</tr>
<tr>
<td>8,200</td>
<td>189&quot;</td>
</tr>
</tbody>
</table>

Wheel Spacing: 89"

Total Vehicle Weight: **57,900**
Test Vehicle Measurements

License Plate Number: 101-207
Truck Designation (1 or 2): 1

Axle Weight:
- 9,700
- 10,300

Axle Weight:
- 19,700
- 8,500

Axle Weight:
- 8,500
- 8,400

Axle Spacing:
- 53"
- 191"

Wheel Spacing: 91"

Total Vehicle Weight: 56,600
Test Vehicle Measurements

License Plate Number 701-129
Truck Designation (1 or 2) 2

Axle Weight 9000
Axle Spacing 95" 10300

Axle Weight 10200
Axle Spacing 22" 10400

Axle Weight 2800
Axle Spacing 11' 2 11' 2 19011

Wheel Spacing 27300 28200

Total Vehicle Weight 55500
Test Vehicle Measurements

License Plate Number: F01-228
Truck Designation (1 or 2): 1

Weighed By: CSF
Dimensions by: 12' 0"

Axle Weight:
- 9,000
- 6,000

Axle Spacing:
- 12" | 22" | 22"
- 54"

Wheel Spacing:
- 26' 0"
- 90" | 3' 0"

Total Vehicle Weight: 58,050
Test Vehicle Measurements

License Plate Number 701-225
Truck Designation (1 or 2)  

Axle Weight 12400
Axle Weight 12500
Axle Weight 7400

Weighed By: CSF
Dimensions by: CSF

Axle Spacing
Axle Spacing
Wheel Spacing

Total Vehicle Weight 70100
Test Vehicle Measurements

License Plate Number: 01-180
Truck Designation (1 or 2): 1

Axle Weight: 12,700

Weighed By: CSP
Dimensions by: CSP

Axle Spacing:

- 55 Axle Spacing
- 217 Axle Spacing
- 33400 Wheel Spacing

Total Vehicle Weight: 72,550
Test Vehicle Measurements

License Plate Number: 101-22B
Truck Designation (1 or 2): #2

Axle Weight 15,700
- 10,500
- 9,200

Axle Weight 19700
- 19,500
- 9,200

Axle Weight 15600
- 7,400
- 8,200

Axle Spacing
- 22"
- 22"

Wheel Spacing
- 90'

Total Vehicle Weight: 55,050
Test Vehicle Measurements

License Plate Number: 701-180
Truck Designation (1 or 2): 44

Axle Weight: 44,000
- 19,150
- 11,850

Axle Weight: 25,750
- 13,750
- 12,000

Axle Weight: 17,000
- 8,500
- 8,500

Axle Spacing:
- 22" from each other
- 90" from center of rear to front axle

Wheel Spacing:
- 90"

Total Vehicle Weight: 68,750
License Plate Number: 701-194

Axle Weight:
- 22,600 lbs
  - Front axle: 12,200 lbs
  - Rear axle: 10,400 lbs

Axle Weight:
- 25,500 lbs
  - Front axle: 21,500 lbs
  - Rear axle: 4,000 lbs

Axle Weight:
- 15,250 lbs
  - Front axle: 8,000 lbs
  - Rear axle: 7,250 lbs

Axle Spacing:
- 55 inches

Wheel Spacing:
- 89.2 inches

Total Vehicle Weight: 61,350 lbs
Test Vehicle Measurements

License Plate Number: 701-225
Truck Designation (1 or 2): 1

Axle Weight: 21,400
   11,300
   10,100

Axle Weight: 21,750
   11,600
   10,150
   94 1/2
   22

Axle Weight: 15,000
   11
   11

Wheel Spacing: 90

Total Vehicle Weight: 52,150
APPENDIX B: TEST CALCULATIONS

“Brownville_calcs_05_14_2014.pdf”
“Chester_FB_Analysis.pdf”
“T3_Indian_Purchase_FB_analysis_04_24_2014.pdf”
BRIDGE PROPERTIES

- STRINGERS: W21×73.5 (interim) 2 x 5-6" (5'-0" exterior) 23.21' span.
- F2: W33×180, span = 22'7"-4'-2" = 22'-0' = 22.21'
- DECK: 11" concrete (4" w/s)

MAX MEASURED FE STRAINS:

- 145 με max w/ 4 trucks
- 92.8 με max w/ 2 trucks

- Strains very low, high degree of composite action observed.
- toe flange Costa at least over flange edge in slab.

FBE MOMENTS DUE TO TRUCK LOADS:

- Computed using beam rule, field-measured wheel loads, previously verified spreadsheet

- 2 truck moment = 220.3 ft-k @ gage location.
- 4 truck moment = 368.2 ft-k

- H6 + 93 + 1/2 (tandem + lane) =

(see pp. 3 & 4)
Tandem moments computed w/ spreadsheet = 301.8 k"cu (e midspan) (two lanes, no M)

Due to Lane:

6"typ

0.064 ksf

\[
P_1 = P_5 = \left(0.064 \times 4.5 \times 4.5 \times \frac{1}{5}\right) \times 23.21 = 3.01 k"w
\]

\[
P_2 = P_4 = 0.064 \times \left(4.5 \times 2.75 + \frac{5.5}{2}\right) \times 23.21 = 7.76 k"w
\]

\[
P_3 = 0.064 \times 5.5 \times 23.21 = 8.17 k"w
\]

\[
\Sigma = 29.76 k"w
\]

\[
0.064 \times 23.21 \times 20 = 29.71 k"w
\]

\[
M_{10ne} = 8.17 \times 23.21 \frac{4}{4} \rightarrow 47.4
\]

\[
+ 15.52 \times 6.11 \times 17.11 \frac{11.61}{23.21} \rightarrow 47.4
\]

\[
+ 6.02 \times 11.11 \times 22.11 \frac{11.61}{22.11} \rightarrow 2.34
\]

\[
98.2 \text{ k"w}
\]
H L 98 + 1 m loads

\[ M_{\text{ultim}} = 1.33 \times 301.8 + 98.2 = 500 \text{in.} \]

Max 4-truck moment = 403.3 in.;
\[ \frac{M}{W} = \frac{403.3}{500} = 0.81 > 0.7 \text{ OK} \]
Assess Stain Response

- FB Flange is embedded in 11" dock, girder is exhibiting composite action.

- Assume $f' = 30,000$, $n = 10$, off flange width TED

\[
\begin{array}{c}
\text{embedment varies, put slab on} \\
0.580" \times 5.28" \\
0.855" \times 11.51" \\
& \text{Reinforced to 0.87 to save correct I for.} \\
& \text{Non-composite section}
\end{array}
\]

- Strain measurements under 4-truck load indicate

\[
\bar{\gamma} = 27.855 + 25.4 \text{in}^2/4, 29 \mu \text{in.} = 33.8" \text{ top of girder, just in slab}
\]

\[
\begin{array}{c}
\text{be} \\
60" \quad 20.5" \\
50" \quad 31.9" \\
120" \quad 73.7" \times 33.8" \Rightarrow \text{say be} = 120"
\end{array}
\]

\[
\frac{w}{be} = 120" \quad I = 22,473 \text{ in}^4, \\ S_{bod} = 662.5 \text{ in}^2; \quad W_{dock} = 654 \text{ in}^3
\]

(see next page)

- Computed strain: $\epsilon_4 = \frac{268.2 \text{ft} \times 1.2 \times 10^6}{29000 \times 662.5} = 280 \mu \epsilon$ vs $\epsilon_t = 145$

\[
\frac{\epsilon_4}{\epsilon_t} = \frac{280}{145} = 1.59
\]
Girder Section Properties -- W33x130

interior girder, slab = 8.76" at girder CL

<table>
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<th>width</th>
<th>thickness</th>
<th>modular ratio</th>
<th>transf. area</th>
<th>y</th>
<th>Area*y</th>
<th>I_bar</th>
<th>A*y^2</th>
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<td>10</td>
<td>132.00</td>
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<td>5098.1</td>
<td>1331.0</td>
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<td>0</td>
<td>1</td>
<td>0.00</td>
<td>38.62</td>
<td>0.0</td>
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<td>0.0</td>
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<td>Top Flange</td>
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<td>0.87</td>
<td>1</td>
<td>10.03</td>
<td>0.44</td>
<td>4.4</td>
<td>0.6</td>
<td>11070.2</td>
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Note: flange thicknesses increased slightly to give correct I for non-composite section

\[ y_{\text{bar}} = 33.7 \text{ in from bottom} \]

Moment of Inertia = 22473 in^4

Q_deck = 654 654 654 in^3 -- three calculations, all the same

S_bottom = 667.5
Assess strain response:

Can we extrapolate composite action to 1.32W? 
- Per NCHRP Research Results Digest 234, 100 psi bond stress can be reliably developed @ interface 
- Max FB shear from test = 63.0° 
- \[ \frac{V_0}{I_6} = \frac{63 \times 0.54 \text{ in}^2}{22473 \times 11.51}\text{in} = 159 \text{psi} > 100 \text{psi} \]

6° composite action is not reliable

- However, the ratio \( E_c/E_t = 1.59 \) is correctly (and conservatively) based on the presence of composite action.

- \( T/W > 0.7 \); results cannot be directly extrapolated to 1.32W, since composite action was observed but is not likely to be reliable

- Grid shear is clearly fully braced against LTB, and capacity calculations can be based on the section developing \( M_p \).

- A safe estimate of the RF modification is 
  \[ K = 1 + 0.5 \times (1.59 - 1) = 1.30 \]
Trucks traveled from end of span to past midspan during test.
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<tbody>
<tr>
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Total Vehicle Weight: 51,850
License Plate Number: 701-835
Truck Designation (Load): 3

Axle Weight: 18,200

Axle Weight: 19,500

Axle Weight: 5,300

Wheel Spacing: 95"

Axle Spacing: 53"

Axle Spacing: 174"

Total Vehicle Weight: 53,000
Test Vehicle Measurements

License Plate Number: 1 - 241
Truck Designation (1 or 2): 2

Axle Weight: 20,000
Axle Spacing: 55"
Wheel Spacing: 89"

Axle Weight: 10,000
Axle Spacing: 22"

Axle Weight: 10,500

Axle Weight: 16,900
Axle Spacing: 11"

Total Vehicle Weight: 57,900
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<table>
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<tr>
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<tbody>
<tr>
<td>91&quot;</td>
</tr>
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Total Vehicle Weight 56,600
BRIDGE PROPERTIES:

STRINGERS - W 18x55 (interior) @ 5'-0", 2' to FB and FBs - W 30x124, span @ 24', spaced @ 25'-0"
DECK - 5"/4" CONCRETE + 2" ARMR CL WLS.

MAX MEASURED FB STRAINS

- 410.3 με ε max w/ 4 trucks
- 279.3 με ε max w/ 2 trucks

Strains @ mid-depth ≈ 0, hence compression @ top, girders are non-composite. Consistent with construction details, moments reanalysis do not indicate fixity.

FB MOMENTS DUE TO TRUCK LOADS:

- Computed using lower rule, field-measured wheel loads, previously verified spreadsheet.
- 2 truck moment: 289.6 k-ft @ jace location, 258.0 @ mid-span
- 4 truck moment: 457.2 k-ft @ gauge location, 467.3 @ mid-span
- 1t-9t +1mA: 540' & mid-span (see p. 3)
Lane load: \[ P_1 = P_5 = 0.064 \times 2.5 \times 25 = 4'' \]
\[ P_2 = P_3 = P_4 = 0.064 \times 5 \times 25' = 8'' \]
\[ \sum B = 0.064 \times 25 \times 20 = 32' \]

\[ M_{lane} = 2 \times \frac{4 \times 22 \times 2}{24} + 2 \times \frac{8 \times 17 \times 12}{24} + \frac{8 \times 24}{4} \]
\[ = 8 \times 11 + 56 + 48 = 128'' \text{ kip} \text{ ft} \text{ (mid-span)} \]

\[ M_{tandem} = 322'' \text{ kip} \text{ ft} \text{ mid-span (10 ft)} \]

\[ M_{9.5+im} = 1.32 \times 322 + 112 = 540'' \text{ kip} \text{ ft} \text{ mid-span} \]

Our 4-truck moment = 487.2'' kip ft mid-span
\[ T/W = 487.2 / 540 = 0.90 > 0.70 \text{ - OK} \]
Assess Strain Response

2 trucks: \[ M/L = \frac{239.6 \times 12}{29000 \times 355} \times (10^6) = 279 \mu \varepsilon \text{ vs. } 229.2 \mu \varepsilon \text{ measured} \]

4 trucks: \[ M/L = \frac{457.2 \times 12}{29000 \times 355} \times 10^6 = 533 \mu \varepsilon \text{ vs. } 410.2 \mu \varepsilon \text{ measured} \]

\[
\frac{279.2}{239.6} = 1.16 \mu \varepsilon/ft/lb \]

\[
\frac{533 \mu \varepsilon}{457.2} = 1.16 \mu \varepsilon/ft/lb \]

\[
\frac{E_c}{E_t} = \frac{522}{410.2} = 1.30
\]

RF modifier: \[ K = 1 + KaK_b = 1 + (1.30 - 1.0) \times 1.0 = 1.30 \]

\[ \therefore \text{ Can increase RF by 1.30} \]

Examine Residual Capacity: say 8"W5; 2"mulls + 5.5" slab

Die each FB = \[ \left( \frac{8.75 \times 150pcf \times 5'}{12} + 55 \text{ #} \right) \times 25' = 15,000 \text{ lb/stirner} \]

\[ M_{DL} = \frac{15 \times 24^2}{4} + 2 \times 15 \times \frac{7 \times 17}{24} \times \frac{12}{17} + 2 \times 15 \times \left( \frac{2 \times 22}{24} \right) \times \frac{12}{22} + \frac{0.124 \times 24^2}{8} \]

\[ = 90 + 105 + 20 + 9 = 234 \mu \varepsilon \]

Expected stress = \[ M_{DL} + 1.32 \times 410 \text{ psi} \]

\[ \frac{234 \times 12}{355} + \frac{410.2 \times 6 \times (540 \text{ in}) \times 29000}{1 \times 10^6} = \frac{7.9 \mu \varepsilon}{2 \mu \varepsilon} = 24 \mu \varepsilon \]

\[ \text{ratio up to } \frac{FS}{2 \mu \varepsilon} = \frac{36}{2} = 1.56 \]
Trucks traveled from end of span to past midspan during test

2-6" (Typ)
Test Vehicle Measurements

License Plate Number: 701-299
Truck Designation (1 or 2): 2

Weighed By: CSF
Dimensions by: KMG

Axle Weight:
- Front: 9000
- Middle: 10300
- Rear: 10400

Axle Spacing:
- Front: 91
- Middle: 11'2"
- Rear: 1901

Wheel Spacing:
- 27300

Total Vehicle Weight: 55500
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<tbody>
<tr>
<td>Wheel Spacing</td>
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</tbody>
</table>

Total Vehicle Weight 58,050
Test Vehicle Measurements

License Plate Number: J01-225
Truck Designation (1 or 2): 1

Axle Weight: 12,400
Axle Spacing: 50"
Axle Weight: 12,500
Axle Spacing: 90"

Wheel Spacing: 32300

Total Vehicle Weight: 70100
Test Vehicle Measurements

License Plate Number: 01-180
Truck Designation: KMG

Axle Weight: 12,700
Axle Weight: 7,000
Axle Weight: 3,300

Weighted By: CSP
Dimensions by: CSP

94
65,300

55
Axle Spacing

217
Axle Spacing

39150
Wheel Spacing

Total Vehicle Weight: 72,550
BRIDGE PROPERTIES:

- STANCHIONS: 4'2"x 68"x 5'-3" O/C. (Exterior smaller)
- FB: W36x150 spaced @ 20'-0", 26.16' span
- DECK: 8'-6" (Incl 3" concrete ws, Field verified)

MAX. MEASURED FB STRAINS:

- 320με tension w/ 4 truck sides
- 163με tension w/ 2 truck sides

- Strains at mid-depth = 0, significant compression top, girders are non-composite, consistent w/ construction details, which shows no flange embedment in deck.
- Strains near end indicate no fixity & FB spres.

FB MOMENTS DUE TO TRUCK LOADS:

- Computed using lever rule, field-measured wheel loads, previously verified spread sheet

- 4 truck moment = 587.4ft.k. @ gage location (21" off mid span)
- 2 truck moment = 214.5ft.k. @ gage location.
- H2-92 + 1m (tandem + lane) = 624.4ft.k. @ mid-span (See pp. 3 & 4)
35.85" ± 0.40°

-180 με (4 trucks)
-140 με (2 trucks)

35.718" ± 0.685"

36 × 150

W 36 × 150

\[ S_x = 58,740 \text{ in}^2 \]
\[ I = 9040 \text{ in}^4 \]

350.5 με (4 trucks)
162 με (2 trucks)

W 21 × 68

\[ S_x = 140 \]
\[ I = 1480 \]
Due to Tandems:

\[ P_1 = \left(1 + \frac{2b}{30}\right) \times \frac{2.75 \times 12.5}{5.25} = 17.22 = P_5 \]
\[ P_2 = 1.866 \times \left(\frac{2.75}{5.25} + \frac{2}{5.25}\right) \times 12.5 = 20.84 \text{ kN} = P_4 \]
\[ P_3 = 1.966 \times 2 \times \frac{3.25}{5.25} \times 12.5 = 58.84 \text{ kN} \]

Due to lanes:

\[ P_1 = P_5 = \left(0.064 \times 4.75 \times 4.75 \times \frac{1}{2} \times 5.25\right) \times 30' = 4.13 \text{ kN} \]
\[ P_2 = P_4 = 0.064 \times \left(4.75 \times 2.875 + 5.25 \times \frac{5.25}{2}\right) \times 30' = 10.08 \text{ kN} \]
\[ P_1 = 0.064 \times 5.25 \times 30' = 10.08 \text{ kN} \]

\[ M_{\text{tandem}} = 552 \text{ kNm} \] (spreadsheet)

\[ M_{\text{lane}} = \frac{10.08 \times 26.16}{4} + 2 \left(\frac{10.08 \times 18.33 \times 7.83}{26.16} \times \frac{12.08}{18.33} \right) \left(\frac{4.13 \times 2.58 \times 23.58}{26.16} \times \frac{13.08}{23.58}\right) = 155.1 \text{ kNm} \]
Total He-93 + 1m load:

\[ 1.33 \times 352 \text{ in} + 155.1 \text{ in} = 624.4 \text{ in} \] (peak at mid-span)

Using lever rule calculations, test produced 634 in > He-93.
ASSESS STRAIN RESPONSE

2 trucks: \( M = 314.5 \text{ m}^3; \quad E_c = \frac{M}{ES} = \frac{314.5 \times 12 \times 1 \times 10^6}{29000 \times 504} = 258 \mu E \)

measured strain = \( E_t = 163 \mu E \); \( \frac{E_c}{E_t} = 1.58 \)

4 trucks: \( M = 587.4 \text{ m}^3; \quad E_c = \frac{587.4 \times 12 \times 1 \times 10^6}{29000 \times 504} = 482 \mu E \)

measured strain = \( E_t = 320 \mu E \); \( \frac{E_c}{E_t} = 1.46 \)

Linearity of strain response: \( \frac{587.4 \times 163}{314.5} = 304 \mu E \) vs. \( 320 \mu E \)

\( \frac{330 - 304 \times 100}{304} = 8.6\% \)

Very close to linear increase

Given that 4-truck load produced moment in excess of 1493 + 1m, the nearly linear increase in measured strain when going from 2 truck to 4 truck loading, & the lack of composite action, extrapolation to 1.28W is reasonable.

KE modifier = \( K = 1 + KaKb = 1 + (1.46 - 1) \times 1 = 1.46 \)
Trucks traveled from end of span to past midspan during test.
T01-180  T01-194
1'-4"

T01-225  T01-228

2'-4" (TYP)

72"

72"

72"

1'-4"

81"

79"

79"

79"

2'-9.5"

2'-4.5"
Test Vehicle Measurements

License Plate Number: 101-22B
Truck Designation (1 or 2): #2

Axle Weight 15,700
10,500 9,250

Axle Weight 15,700
10,500 9,200

Axle Weight 15,600
7,400 8,200

Axle Spacing
16' - 8'' = 200''

Wheel Spacing
90''

Total Vehicle Weight: 55,050
Test Vehicle Measurements

License Plate Number: 701-180
Truck Designation (1 or 2): 4

Weighed By: KMG
Dimensions by: KMG

Axle Weight 26,000
19,150
11,850

Axle Weight 25,750
13,750
12,000

Axle Weight 17,000
8,500
8,500

Wheel Spacing 90"

Total Vehicle Weight 68,750

Axle Spacing 55"
217 Ye"
Test Vehicle Measurements

License Plate Number 701-199
Truck Designation (1 or 2) 94

Weighed By: KMG
Dimensions by: CEE

Axle Weight 22,600
12,200
10,400

Axle Weight 25,500
21
21

Axle Weight 15,250
11
11

Axle Spacing 55"

Axle Spacing 10"

Wheel Spacing 89 1/2"

Total Vehicle Weight 61,350
Test Vehicle Measurements

License Plate Number: 701-225
Truck Designation (1 or 2): 1

Axle Weight:
- 24,400
  - 11,300
  - 10,100

Axle Weight: 21,750
- 11,600
- 10,150
- 94°
- 22" Axle Spacing

Axle Weight: 15,000
- 11"
- 90"
- Wheel Spacing

Total Vehicle Weight: 59,150
APPENDIX C: PRELIMINARY CALCULATIONS

“preliminary_FB_analysis.pdf”
**Brownville - Preliminary FB Analysis**

\[ FB \approx W_{33} \times 130, \quad \text{span} \approx 23' \]

**Heaviest 4-truck Loading:**

\[ P_1 = \frac{1.8}{5} \left[ 0.13(1.85) + (0.8133 + 1 + 0.677 + 0.490) \times 10 \right] = \frac{1.8}{5} \times 30.92 = 11.18' \]

\[ P_2 = \left( \frac{2.2}{5} + \frac{5.2}{5} \right) \times 30.92 = 27.1' \]

\[ P_3 = \left( \frac{4.2}{5} + \frac{4.2}{5} \right) \times 30.92 = 51.95' \]

\[ P_4 = \left( \frac{1.8}{5} + \frac{2.2}{5} \right) \times 30.92 = 27.1' \]

\[ P_5 = \frac{1.8}{5} \times 30.92 = 11.18' \]
\[ M_{\text{test}} = 472.7\text{in-lb} \Rightarrow T_{\text{test}} = \frac{472.7\times12}{406} = 14.0\text{ksi} \Rightarrow \varepsilon_{\text{test}} = \frac{483\mu e}{(k=0.05) \text{peak @ Howland}} = 2.45\mu e, \text{observed}\]

\[ \overline{T_{de}} \text{ (plans)} = \frac{335(100/1000)}{406} \approx 8.27 \]

\[ F_d \text{ against yield } = \frac{38.0}{22.3} = 1.705\text{ (1985)} \]
Typical Sections

Roadway Stringers

<table>
<thead>
<tr>
<th>INTERIOR</th>
<th>Exterior Roadway</th>
<th>Exterior Sidewalk</th>
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<tbody>
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<td>100%</td>
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<td>5 - 934 B29.55 5 - 98.7</td>
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<tr>
<td>9 - 821.59</td>
<td>5 - 101.2 B21.59 5 - 7</td>
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</tr>
</tbody>
</table>

Floor Beam

Dead Load

\[ R_L = \frac{1000 \times 1.61 + 1902 \times 0.51 + 13500 \times 22.67}{28.33} = 47426 \]
\[ 0.1 M \times 22826 + 12 \times 1902 \times 22.67 + 13500 \times 10.512 = 5239500 \]

Uniform Load 137.78 33.41 15 = 117200

\[ 3 \times 356700 = 1070100 \]
\[ 2430 \times 950 = 2283000 \]
\[ 709 \times 850 = 6007100 \]
\[ 3100 \times 800 = 24800000 \]
\[ 9638300 = 33567000 \]

\[ 22826 \times 120 = 2739120 \]
\[ 5 \times 401.6 \times 132 = 2895600 \]
\[ P_1 = \frac{2.7}{5} \left( 0.193 \times 8.5 + (0.827 + 1.0 + 0.72 + 0.527) \times 10 \right) = \frac{2.3}{5} \times 32.4 = 14.9 \, \text{kN} \]

\[ P_2 = \left( \frac{2.7}{5} + \frac{1.3}{5} \right) \times 32.4 = 25.9 \, \text{kN} \]

\[ P_3 = \left( \frac{2.7}{5} + \frac{2.7}{5} \right) \times 32.4 = 48.0 \, \text{kN} \]

\[ P_4 = \left( \frac{1.3}{5} + \frac{2.7}{5} \right) \times 32.4 = 25.9 \, \text{kN} \]

\[ P_5 = \frac{2.2}{5} \times 32.4 = 14.9 \, \text{kN} \]
\[ R_1 = R_2 = 4812 + 259 = 640.8^\circ \]

\[ M_{ul} = 64.8 \times 2 + 49.9 \times 5 + 24 \times 5 = 499.1 \text{ kN} \cdot \text{m} \]

\[ \sigma_{ul} = \frac{499.1 \times 12}{355 \times \frac{7}{12}} = 16.9 \text{ ksi} \Rightarrow \varepsilon_{text} = 587 \mu \varepsilon \]

\[ D_L = \frac{(8.75 \times 150 \times 5 + 55) \times 251}{7000} = 15^\circ / \text{strmgr} \]

\[ M_{dl} = 45 \times 24 + 2 \times 15 \times \left( \frac{7 \times 17 \times 12}{24 \times 17} \right) + 2 \times 15 \times \left( \frac{2 \times 22 \times 12}{24 \times 22} \right) + \frac{0.124 \times 24}{8} \]

\[ = 90 + 105 + 30 + 8.98 = 224 \text{ kN} \cdot \text{m} \]

\[ \sigma_{dl} = \frac{224 \times 12}{355} = 7.91 \text{ ksi} \Rightarrow F_S = \frac{33}{16.9 + 7.91} = 1.33 \]
Refer to p.4 - Simpson spacing = 5'-0" & FB Sp. = 30'

Coefficient top to bottom = \[
\frac{30 - 15.83' - 4.33'}{30} = 0.328
\]
\[
\frac{30 - 4.33'}{30} = 0.856
\]
\[
\frac{30 - 7.5}{30} = 0.75
\]
\[
\frac{30 - 7.5 - 4.33'}{30} = 0.606
\]
\[
\frac{30 - 7.5 - 15.83'}{30} = 0.178 \text{ (stem angle in lower truck contributes)}
\]

\[
P_1 = \frac{2.05}{5.25} \times 5.25 = 7.212 \times 10 = 72.12
\]
\[
P_2 = \left(\frac{3.22}{5.25} + \frac{1.3}{5.25}\right) \times 75.6 = 30.5 \text{ k}
\]
\[
P_3 = \left(\frac{3.95}{5.25} + \frac{3.95}{5.25}\right) \times 75.6 = 53.6 \text{ k}
\]
\[
P_4 = \left(\frac{1.2}{5.25} + \frac{3.2}{5.25}\right) \times 25.6 = 30.5 \text{ k}
\]
\[
P_5 = \frac{2.05}{5.25} \times 25.6 = 13.9 \text{ k}
\]
\[ R_1 = R_2 = 12.9 + 30.5 + \frac{53.6}{2} = 71.2 \text{ kN} \]

\[ \tau_{ul} = \frac{625.2 \times 12}{504 \times 10^{-3}} = 14.9 \text{ ksi } \Rightarrow \varepsilon \approx 514 \text{ microstrain} \]

\[ DU_{strain} = \frac{(8.75 \times 5.25 \times 150 + 68) \times 30'}{1000} = 19.3 \text{ kN} \]

\[ M_{DL} = \frac{19.3 \times 26.2}{4} + \left( \frac{19.3 \times 7.25 \times 18.35}{26.2} \times 13.1 \right) \times 2 + \frac{19.3 \times 26 \times 23.6 \times 121.2}{23.6} \]

\[ + \frac{0.150 \times 26.2^2}{2} = 126.4 + 141.1 + 50.2 + 12.9 = 331 \text{ in-lb} \]

\[ N_{DC} = \frac{331 \times 12}{504} = 7.9 \text{ ksi} \]

\[ F_s = \frac{33}{14.9 + 7.9} = 1.45 \text{ ksi} \]