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Transportation Research Division

Technical Report 18-2

Instrumentation During Live Load Testing and Load Rating of Five Slab-On-Girder Bridges

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Five slab-on-girder bridges were tested during the summer of 2016 by the University of Maine (UMaine) as part of this program for the Maine Department of Transportation (MaineDOT):

1. Steuben No. 3067 Dyer Bay Road over Dyer Creek,
2. Waltham No. 3238 Route 179 over Union River,
3. Pembroke No. 3884 Pembroke Cross Road over Pennamaquan River,
4. Windham No. 5298 Windham Center Road over Pleasant River,
5. Buckfield No. 5452 North Buckfield Road over Nezinscot River (West Branch).

Revised load ratings were computed using data collected during live load testing. Details of bridge instrumentation, load cases, and strain plots for each bridge are provided in Appendices A.1, A.3, A.3.5, A.4.5, and A.5.5. The results of the tests and analyses are summarized below and are compared with the existing ratings. Use of these revised load ratings, live load test data, and extrapolation of these results to other structures is at the sole discretion of the bridge owner.

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Instrumentation During Live Load Testing and Load Rating of Five Slab-On-Girder Bridges

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Table of Contents

Index of Figures

Index of Tables

Acronyms

Cases

Executive Summary

Five slab-on-girder bridges were tested during the summer of 2016 by the University of Maine (UMaine) as part of this program for the Maine Department of Transportation (MaineDOT):

1. Steuben No. 3067 Dyer Bay Road over Dyer Creek,
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Revised load ratings were computed using data collected during live load testing. Details of bridge instrumentation, load cases, and strain plots for each bridge are provided in Appendices A.1, A.3, A.3.5, A.4.5, and A.5.5. The results of the tests and analyses are summarized below and are compared with the existing ratings. Use of the these revised load ratings, live load test data, and extrapolation of these results to other structures is at the sole discretion of the bridge owner.

1. Steuben No. 3067: On July 21, 2016, four trucks were used to produce 78% of an HL-93 service load with impact. The rating factors based on non-composite response were 0.80 for interior and 1.04 for exterior girders, which made this span the lowest capacity bridge tested. Applied loads were near the predicted capacity. Not surprisingly, the strains measured were the highest for any of the bridges and it was among those exhibiting the least observed partial composite action, which led to the most modest rating factor increases for this set of bridges. However, using the provisions of the AASHTO *Manual for Bridge Evaluation* (AASHTO 2012), the rating factor for HL-93 was still increased to 1.09 for the interior girder and 1.13 for exterior girder bringing the rating factors above 1.0.
2. Waltham No. 3238: On July 14, 2016 87% of an HL-93 loading with impact was produced with four trucks. This was the highest loading for all bridges, but this structure also had the highest non-composite rating factors of 1.17 for the interior girder and 1.61 for the exterior girder. Full composite action was observed for this bridge, and measured strains were relatively small. Rating factors were increased for this structure to 1.68 for interior girders and 2.82 for exterior girders.
3. Pembroke No. 3884: On July 19, 2016 81% of an HL-93 loading with impact was produced for this span using four trucks. The initial non-composite rating factors were 0.86 for interior girders and 1.09 for exterior girders. Fairly high strain was produced compared to other bridges in the group, but full composite action was observed. Live load testing results allowed the rating factors to be increased to 1.33 for interior girders and 2.52 for exterior girders.
4. Windham No. 5298: On August 23, 2016 77% of an HL-93 loading with impact was achieved with four trucks. This structure had low non-composite rating factors of 0.81 for the interior and 0.99 for the exterior girders. Due to the observed full composite action, measured strains were low and rating factor increases to 1.26 and 1.29 for interior and exterior girders, respectively, were justified.

5. Buckfield No. 5452: On July 12, 2016 four trucks were used to produce 74% of an HL-93 loading with impact. Despite only partial composite action, this bridge saw the highest increase in rating factors from 0.96 and 1.18 to 1.61 and 1.76 for interior and exterior girders respectively.

1 Bridge Testing Program

Five concrete slab on steel girder bridges were tested during the summer of 2016 as part of this program:

1. Steuben No. 3067 Dyer Bay Road over Dyer Creek
2. Waltham No. 3238 Route 179 over Union River,
3. Pembroke No. 3884 Pembroke Cross Road over Pennamaquan River,
4. Windham No. 5298 Windham Center Road over Pleasant River,
5. Buckfield No. 5452 North Buckfield Road over Nezinscot River (West Branch).

All bridges were instrumented with a strain measuring system, loaded with heavy trucks, and then analyzed to determine whether it is reasonable to change the bridge rating factors based on the test results. These bridges were all constructed between 1935 and 1951, and were originally designed as non-composite with no shear studs. However, the top flanges of the girders were fully embedded in the concrete deck for all structures, which can result in significant composite action. The primary objective of this study was to assess the magnitude and significance of unintended composite action between the deck and girders. Additionally, the live load testing permitted quantification of partial support fixity, actual live load distribution, and the contribution of non-structural elements such as curbs, wearing surfaces, and partial concrete embedment of girder ends. Finally, recommendations for rating factor modifications are made based on the observed and computed response of these structures. Characteristics of the bridges tested and analyzed in this study are summarized in Table 1.

Table 1: Bridge Characteristics

Bridge	**Steuben**	**Waltham**	**Pembroke**	**Windham**	**Buckfield**
Number	3067	3238	3884	5298	5452
Year Built	1949	1935	1944	1950	1951
Span (feet)	50.00	55.00	45.25	46.00	42.50
Interior Girder Size	W30x108	W36x150	W27x98	W30x108	W27x102
Number of Girders	5	5	5	5	5
Girder Spacing (in)	64	66	69	69	69
Total depth (in)	29.83	35.85	27.00	29.83	27.09
Girder flange width (in)	10.48	11.98	10.00	10.48	10.02
Girder flange thickness (in)	0.76	0.94	0.79	0.76	0.83
Girder web thickness (in)	0.55	0.63	0.50	0.55	0.52
Haunch (in)	-6.25	2.00	-0.792	0.50	2.00
Slab Thickness (in)	6.75	11.0	6.75	9.00	9.00

1.1 Instrumentation

The strain measurement system utilized in this research is a partially Wireless Structural Testing System (STS-Wi-Fi) produced by Bridge Diagnostics Inc. (BDI). The system used for this testing utilized a mobile base station to communicate with up to 6 nodes, with up to 4 strain sensors or linear variable differential transformers (LVDTs) connected to each node. This system communicated with a dedicated laptop running BDI-specific WinSTS data acquisition software. A sample setup in the field is shown in Figure 1, with strain sensors mounted under the bridge at mid-span connected to battery operated wireless nodes. A clear diagram of the entire network is shown in Figure 2 including strain and displacement sensors, wireless nodes, the wireless base station, autoclicker, and the data recording laptop.

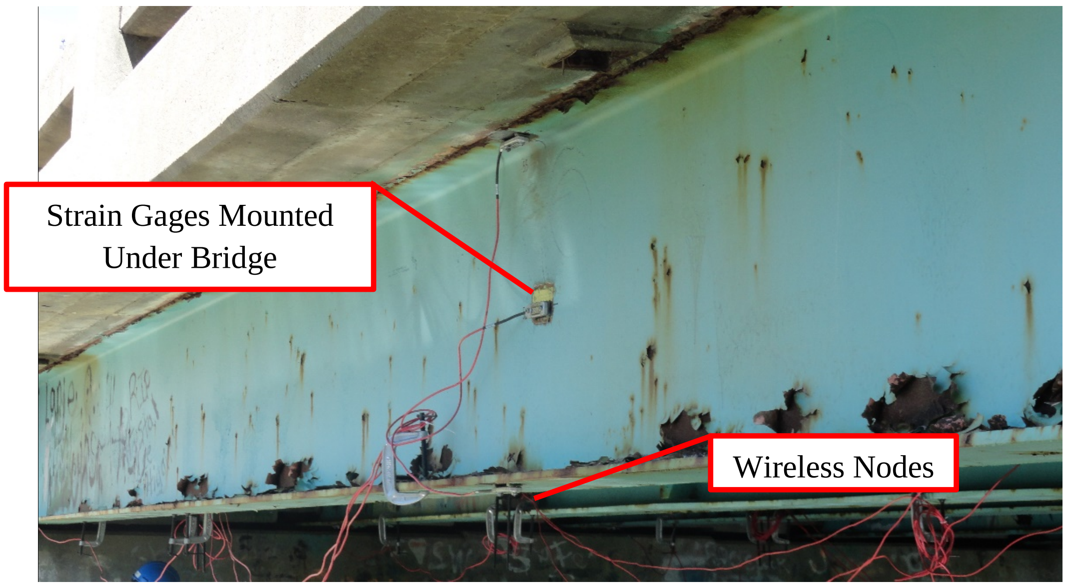


Figure 1: Typical strain sensors mounted under bridge connected to wireless nodes

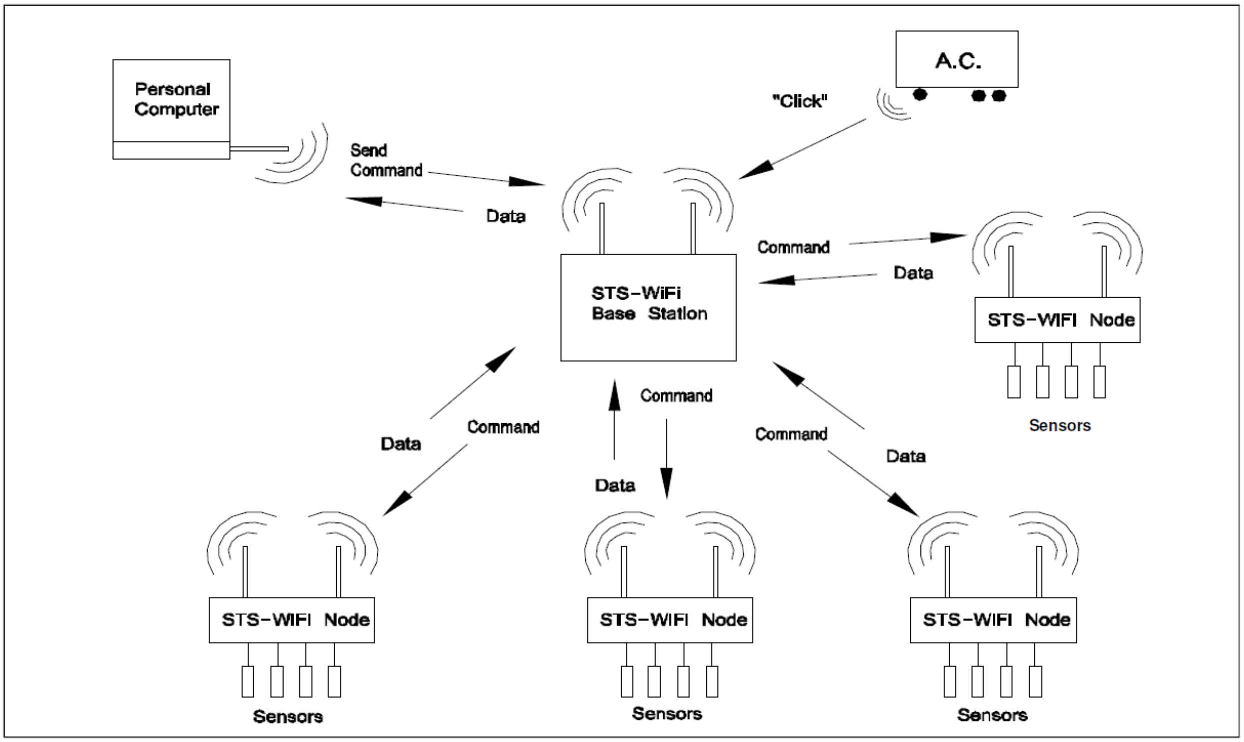


Figure 2: BDI STS-Wi-Fi network setup for bridge sensor setup.

Strain and displacement sensors were mounted under the bridges using a MaineDOT Under Bridge Inspection Truck (UBIT) as shown in Figure 3. The sensors were mounted to the girders by first grinding the steel to a fresh, unpainted surface, then using the recommended adhesive to connect the strain sensor tabs to the steel. All structures had three strain gages mounted to the top flange, mid-depth and bottom flange of at least three girders at mid-span to give a complete picture of load distribution and peak flexural strains in each girder type: center, interior non-center, and exterior. Strain gages were also installed near the ends of selected girders to assess the support rotational restraint. LVDTs were placed near the ends of selected girders with one end attached to a girder top flange and one end attached to the bottom of the slab to measure slip between the slab and girder top flange. Strain sensor layout varied slightly for each bridge, with individual sensor layouts shown in the appendices A.2.2 for Steuben, A.3.2 for Waltham, A.4.2 for Pembroke, A.5.2 for Windham, and A.6.2 for Buckfield.

Figure 3: MaineDOT UBIT utilized to install sensors

1.2 Loading

The vehicles used for this testing were Maine DOT standard three-axle dump trucks as shown in Figure 4. Each truck wheel or pair of wheels was weighed using state patrol certified portable scales as shown in Figure 5. Loading cases included one, two, and four trucks in designated lanes along loading paths. Trucks were positioned sequentially such that they produced maximum moment or significant shear in the bridge girders. In general, a set of tests included a single truck in one lane, two trucks in one lane back-to-back, two trucks side-by-side in opposite lanes, and four trucks, two back-to-back per lane, although not all bridges were subjected to all load cases.

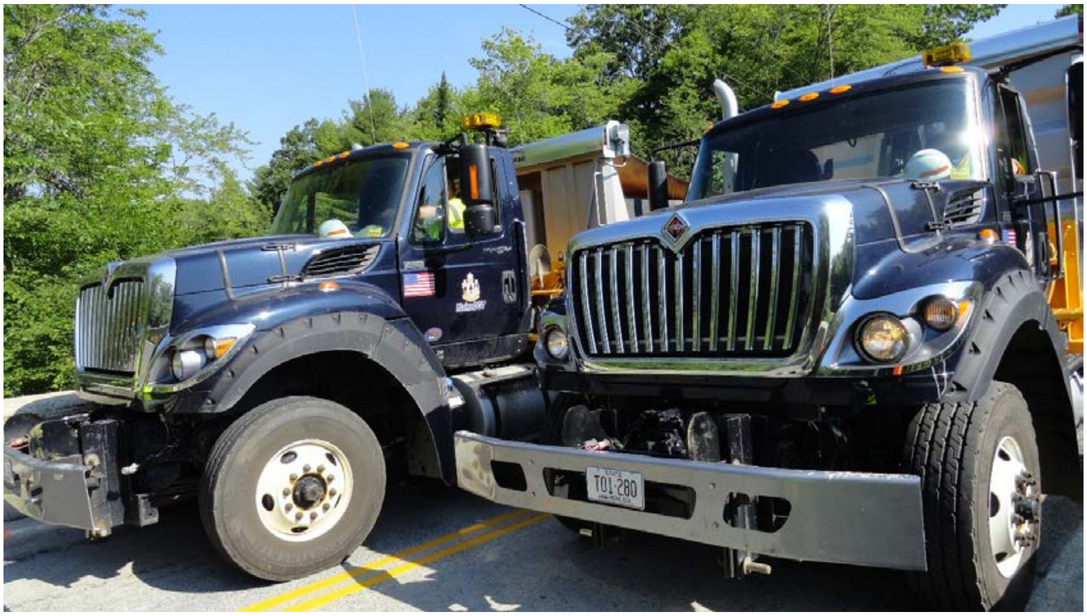


Figure 4: Maine DOT trucks used for bridge loading

Figure 5: State highway patrol certified portable crane scales used to verify vehicle weight for each test

1.3 Typical Results

Results from two bridges are presented in this section to demonstrate two distinct types of behavior in the bridges tested in this study. The first bridge, Pembroke No. 3884, is typical of bridges with observed full composite action. Figure 6 shows a time history of the strains in the center interior girder as the bridge is loaded in the four truck, two lane, second test, and Figure 7 shows the slip between the girder and the slab in inches over the same test. Positive slip indicates the girder moving toward the pinned end relative to the slab, with negative slip indicating the slab is moving toward the pinned end relative to the girder. First the trucks are positioned back to back to incrementally increase shear to a maximum value, typically producing the maximum slip shown in Figure 7, although in some instances maximum slip was seen with the trucks positioned to produce maximum moment. After shear maximization tests, the trucks were then positioned to maximize moment in the bridge where strains in the center girder are maximized as shown in Figure 6. The strains in this test are typical of those three bridges showing full composite action, in that the midspan of the center girder shows high positive strains at the bottom, near zero strains at the top of the midspan gage set, and the middle gage splits the difference. This indicates high composite action with the neutral axis near the top of the girder. The slip is small compared to bridges showing only partial composite action. One note is that this bridge is typical of all bridges with much greater slip being measured at the interior girder than the exterior girder, likely because the interior girder carried much larger live load. Another important note is that the two end gages located at the bottom of the girder recorded negative strains. This is typical of all bridges and girders, and indicates partial rotational restraint at the abutments. It is unknown if this fixity will continue to be observed at higher load levels, or if there are seasonal or local causes of this partial fixity that cannot be extrapolated to other bridges of this type. Full moment connections would yield approximately twice the strain readings as the magnitude of the midspan readings, and simply supported would yield small positive strain readings. This shows that the girder is closer to simply supported than fixed, but that the rotational restraint is still significant.

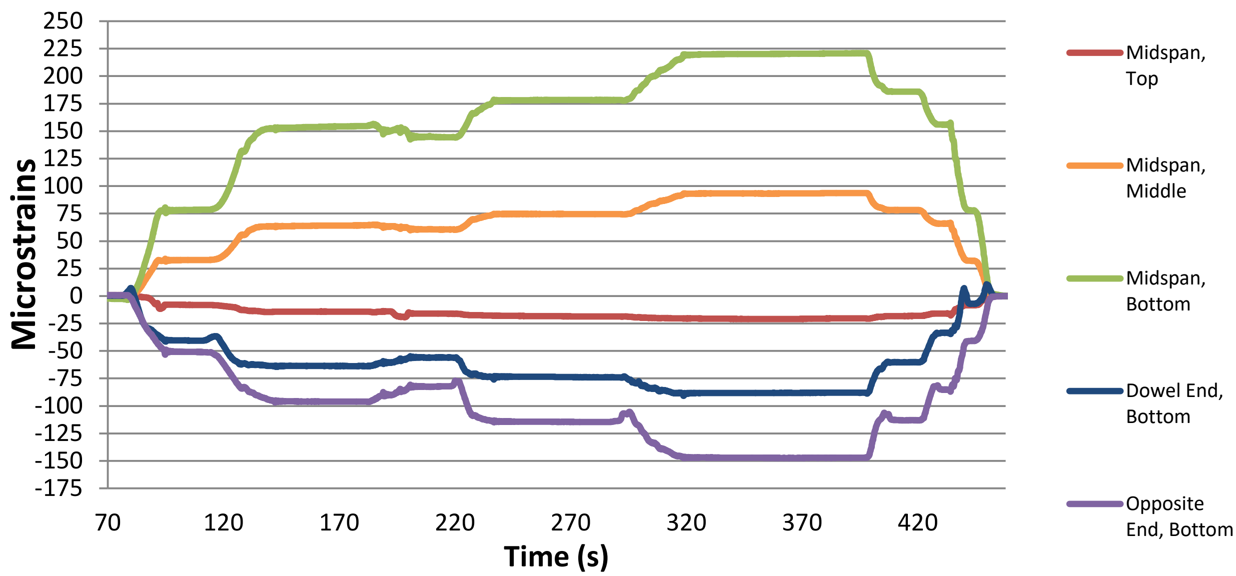


Figure 6: Pembroke No. 3884 – 4 trucks, 2 lanes, test 2, strains in center girder

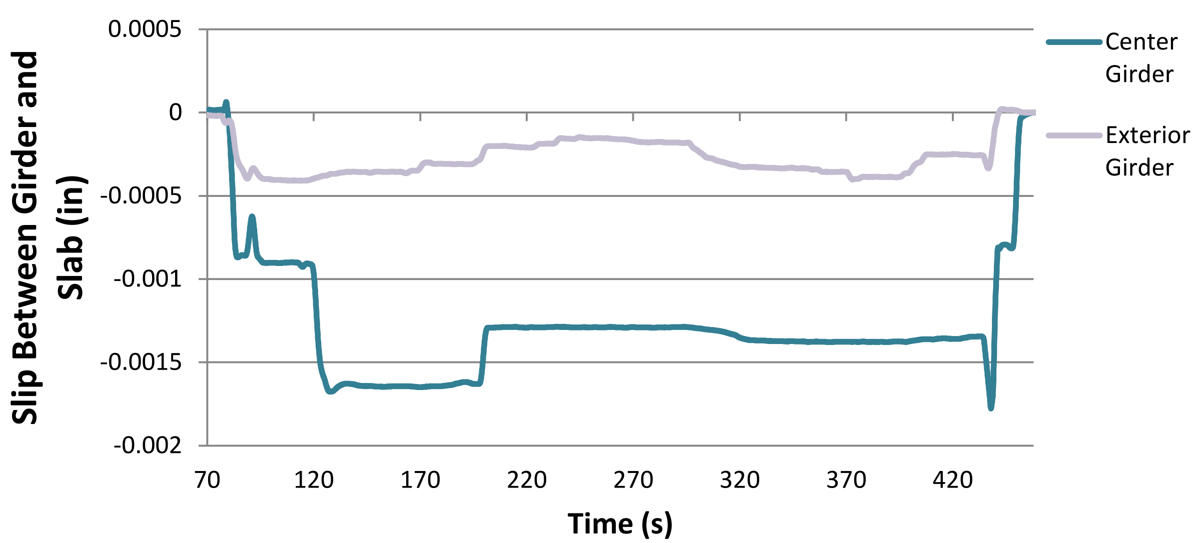


Figure 7: Pembroke No. 3884 - 4 trucks, 2 lanes, test 2, slip between girder and slab

The other bridge shown in this section is the Buckfield No. 5452 bridge undergoing four truck, two lane loading. Figure 8 shows a time series of the strains in the center interior girder and Figure 9 shows the slip between the girder and slab as the bridge is loaded in the same manner as described above for Pembroke No. 3884. This bridge is typical of the two bridges that were observed to have partial composite action. The midspan of the center interior girder shows large positive strains at the bottom, near zero strains at the middle of the girder at midspan, and large negative strains at the top of the girder at midspan. This indicates a neutral axis much closer to that of the non-composite girder than the neutral axis location predicted by fully composite action. However, this bridge is typical of all bridges tested in that negative strains were observed in the bottom flanges of the ends of the girders. This indicates that rotational restraint is provided at the abutments. Again, it is uncertain if this fixity will remain at higher loads or if it is affected by seasonal or local effects unique to these bridges. Full strain and slip plots for all bridge two and four truck tests are presented in the appendices. See section A.2.4 for Steuben No. 3067, A.3.4 for Waltham No. 3238, A.4.4 for Pembroke No. 3884, A.5.4 for Windham No. 5298, and A.6.4 for Buckfield No. 5452.

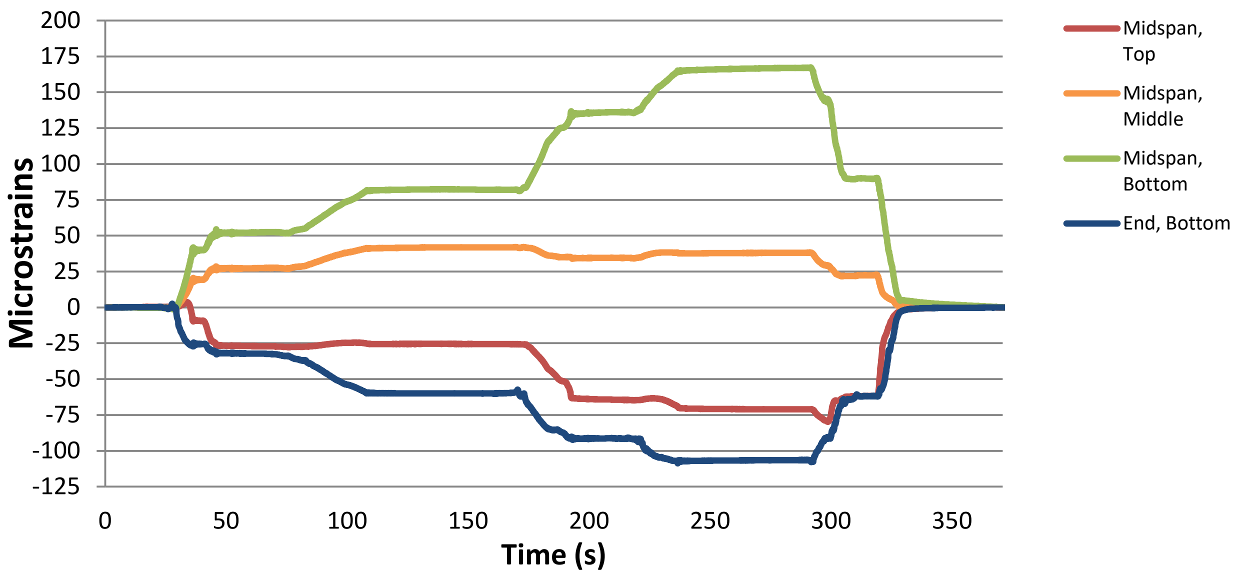


Figure 8: Buckfield No. 5452 - 4 trucks, 2 lanes, test 1, strain in center girder

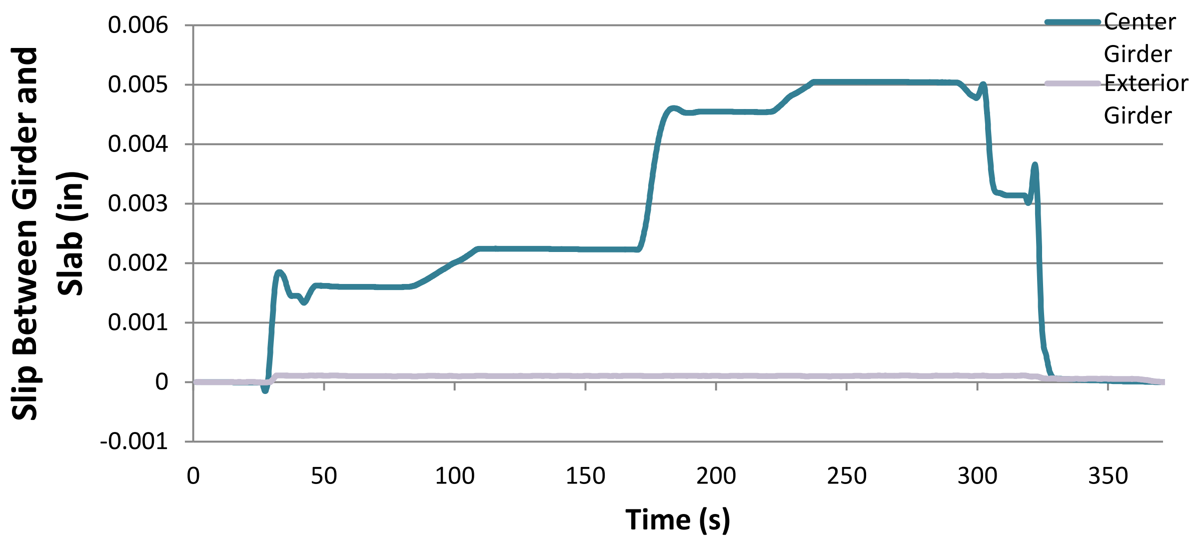


Figure 9: Buckfield No. 5452 - 4 trucks, 2 lanes, test 1, slip between girder and slab

1.4 Analysis Methodology

1.4.1 Analysis Overview

Material properties, load and resistance factors, and design live loads were taken as specified in the AASHTO *Manual For Bridge Evaluation* and used with field-measured geometry to determine original non-composite rating factors for the bridges. Bridges were then tested using heavily loaded trucks and strains were measured and correlated with these applied loads. Resulting strains from live load testing were then used to compute percent composite action, effective section properties that reflected composite action, distribution factors determined from live load testing, modified rating factors, and shear flows. These calculation sheets are included in the appendices of this report. Appendix A.2.5 contains calculations for Steuben No. 3067, A.3.5 pertains to Waltham No. 3238, A.4.5 corresponds to Pembroke No. 3884, A.5.5 is for Windham No. 5298, and A.6.5 is for Buckfield No. 5452.

1.4.2 Bridge Characteristics

First, necessary parameters were defined for use in calculations. These included material properties for each bridge, as well as general bridge geometry (i.e. span length, girder section properties, and slab section properties). These were taken from each bridge's most recent available rating report or based on minimum material properties specified by the AASHTO *Manual for Bridge Evaluation*. Dead load moments and shears were determined from the bridge geometry and typical unit weights as specified in AASHTO *Manual for Bridge Evaluation*.

1.4.3 AASHTO Distribution Factors

Distribution factors for moment and shear for interior and exterior girders are calculated based on in-situ measured bridge characteristics along with nominal values for dimensions that could not be verifie in the field in accordance with AASHTO *LRFD Bridge Design Specifications*. All distribution factors of live load per lane for moment and shear are taken as cross-section "a" from Table 4.6.2.2.1-1 and Concrete Deck on Steel. For moment on interior beams this is per Table 4.6.2.2.2b-1, with all of the ranges of applicability met. For shear in interior beams the values calculated are from Table 4.6.2.2.3a-1 with all the ranges of applicability met. For the exterior girder moment distribution factors are per Table 4.6.2.2.2d-1 and the exterior girder shear distribution factors are per Table 4.6.2.2.3b-1.

1.4.4 AASHTO Live Loads with Impact

AASHTO live loads with impact (LL + IM) are determined as the maximum load effect with HL-93 per (6A.2.3) and AASHTO LRFD Design 3.6.1.2 and 3.6.2. This includes the worst case of truck or tandem loading with lane loads and impact as applicable.

1.4.5 Non-composite Rating Factor

Non-composite flexural rating factors are computed per AASHTO Manual for Bridge Evaluation (6A.4.2.1-1) with terms as defined in that section. Values specific to the bridges in this study are as shown in Equation 1. The live load per section 1.4.4 with impact is modified by the AASHTO distribution factors as described in section 1.4.3.

$$RF = \frac{C - \gamma_{DC}DC - \gamma_{DW}DW \pm \gamma_P P}{\gamma_{LL}(LL + IM)} \qquad \text{Equation 1}$$

$C = \varphi_c \varphi_s \varphi R_n$ (6A.4.2.1-1)

$\varphi_c = 1.0$ per Table 6A.4.2.3-1

$\varphi_s = 1.0$ per Table 6A.4.2.4-1

$\varphi = 1.0$ per LRFD Design 6.5.4.2

$\gamma_{DC} = 1.25$ per Table 6A.4.2.2-1

$\gamma_{DW} = 1.50$ per Table 6A.4.2.2-1

$\gamma_{LL} = 1.75$ per Table 6A.4.2.2-1

Non-composite flexural $R_n = F_y Z$ per Table LRFD Design 6.10.7.1.2

$P = 0$ for all bridges in this study

1.4.6 Live Loads Applied during Testing

Applied moment and shear live loadings were determined based on measured truck axle weights for both the load cases of two trucks, side-by side in two lanes, and four trucks, two trucks back-to-back in each of two lanes. The average of axle loads for side-by-side trucks was used to allow live load distribution factors to be applied. The trucks were first positioned to maximize shear at distances of 2.0, 1.5, 1.0, and 0.5 times the depth from the center of the support. The trucks were then positioned to produce the maximum moment effect on the bridge. For each set of truck positions, strains were allowed to plateau and then measured before moving the trucks to the next set of truck positions.

Applied moments and shears were calculated based on simply supported beam assumptions. The percentage of AASHTO HL-93 loading achieved is the ratio of the moment produced by the live loads applied during testing and the moment produced by the AASHTO HL-93 loading as described in section 1.4.4.

1.4.7 Percent Composite Action and Measured Section Properties

For each girder, the percent composite action is calculated based on strains measured during testing. Using girder strains recorded during load testing at the top and bottom of the girders at midspan, linear strain distributions were calculated through the depth for each girder. This strain distribution was then used to calculate actual neutral axis (NA) location for each girder. This linear strain distribution is shown schematically in Figure 10.

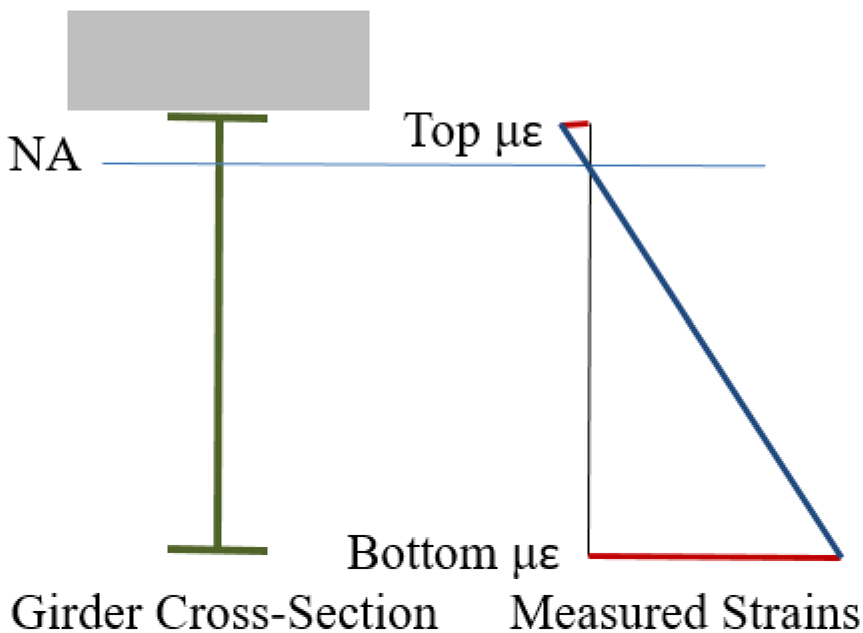


Figure 10: Typical linear strain distribution

The effective slab width – defined as the slab width that produces the NA location – was calculated. A completely non-composite girder has zero effective slab width, and a fully composite slab width is the full tributary slab width. In the case of the interior girders, the tributary slab width is the interior girder spacing. The percent composite action was then calculated as the effective slab width divided by the AASHTO-defined slab width for a fully composite girder, which is the width of slab tributary to the girder. This effective slab width is then used to calculate an effective section modulus which is used for determining distribution factors described in 1.4.8, modified rating factors described in 1.4.9, and shear stresses at the slab-girder interface as described in 1.4.10.

1.4.8 Distribution Factors Determined from Live Load Testing

Based on the neutral axis as determined by measured strains and the corresponding effective slab width, the section modulus for each girder is calculated. The moment carried by each girder is calculated as per Equation 2.

$$M_i = ES_i\varepsilon_i \qquad \text{Equation 2}$$

$M_i = Moment\ carried\ by\ girder\ i$
$E = Modulus\ of\ Elasticity\ of\ girder$
$S_i = Section\ modulus\ of\ girder\ i$
$\varepsilon_i = Strain\ measured\ in\ girder\ i$

The distribution factor for each girder was then calculated by Equation 3.

$$DF_i = \frac{M_i}{\sum_{i=1}^{5} M_i} \qquad \text{Equation 3}$$

$DF_i = Distribution\ factor\ for\ girder\ i$
$M_i = Moment\ carried\ by\ girder\ i$

1.4.9 Modified Rating Factor

In accordance with the AASHTO *Manual for Bridge Evaluation*, the ratio of computed strain ε_C (based on the measured effective section properties) to measured strain ε_T was then used to compute a rating factor modification factor as detailed below in Equation 4 to Equation 6. This analysis is based on the critical interior center girder.

$$RF_T = RF_c K \qquad \text{Equation 4}$$

In Equation 4, RF_T is the modified rating factor taking into account test results, RF_c is the rating factor based on standard calculations which assumes non-composite action, and K is an adjustment factor which incorporates the test results. K is computed per Equation 5 below.

$$K = 1 + K_a K_b \qquad \text{Equation 5}$$

K_a accounts for the difference between measured response based on load testing and expected response as shown below in Equation 6. K_b accounts for the magnitude of the applied test load and confidence in extrapolating results, and is defined in Table 8.8.2.3.1-1 in the AASHTO *Manual for Bridge Evaluation*. For all structures K_b was taken as 0.5, which reflects both the magnitude of the applied load and assumes results cannot be extrapolated to higher loads.

$$K_a = \frac{\varepsilon_c}{\varepsilon_T} - 1 \qquad \text{Equation 6}$$

1.4.10 Shear Flow

Using the maximum measured shear loading per section 1.4.6, the measured section properties from 1.4.7, and the measured distribution factors per section 1.4.8, the shear flow achieved during live load testing was calculated according to Equation 7. This value is compared to the recommended maximum shear flow of 100 psi recommended by the AASHTO *Manual for Bridge Evaluation*.

$$\tau = \frac{DF \cdot V \cdot Q}{I \cdot b} \qquad \text{Equation 7}$$

$\tau = shear\ flow$
$V = calculated\ shear\ applied\ to\ bridge$
$DF = distribution\ factor\ calculated\ from\ measured\ values$
$Q = First\ moment\ of\ area\ calculated\ from\ measured\ values$
$I = second\ moment\ of\ area\ calculated\ from\ measured\ values$
$b = shear\ area\ between\ slab\ and\ girder\ flange$

2 Live Load Test Results

2.1 Steuben No. 3067

The Steuben bridge No. 3067 over Dyer Creek is shown in Figure 11. Testing was conducted on July 21, 2016 with two trucks and with four trucks producing 53% and 78% of an HL-93 loading with impact, respectively. The rating factors based on non-composite girder behavior are 0.80 for interior and 1.04 for exterior girders, making this the lowest capacity bridge tested. The measured strains were as expected the highest for any of the bridges and partial composite action was observed. The composite action was only 47% for the two truck loading and 57% for the four truck loading. Table 2 shows the maximum measured strains and inferred neutral axis locations for this bridge. These conditions led to the most modest rating factor increases for this set of bridges. However, the rating factor for HL-93 was still able to be increased to 1.09 for the interior girder and 1.13 for exterior girder bringing the rating factors above 1.0.

The live load distribution factors determined from the measured strains and those calculated per AASHTO are shown in in Table 3, and generally indicate that the AASHTO distribution factors are somewhat conservative. This is likely due in part to the presence of integral concrete curb and guardrail visible in Figure 6 which will tend to attract load to the exterior girders. Calculated shear flows and measured slip between the girder and slab for Steuben were 69.2 psi with 1.76 mils slip for the two-truck loading and 85.6 psi with 3.43 mils slip for the four-truck loading. These shear flows were among the lowest and the slips were among the highest. This corresponds to the low degree of composite action observed in this bridge. These shear flows were below the 100 psi maximum recommended by AASHTO, and assuming a linear extrapolation gives 99.6 psi at 100% of HL-93 loading with impact. As shown in Table 2, strain measured at the ends of the girders indicates that there was rotational restraint leading to partial fixity and end moments. The strains at the girder ends for Steuben were lower as a percentage of measured midspan strain than those of other bridges in this study.

Figure 11: Steuben No. 3067 general condition

Table 2: Steuben No. 3067 Strain and Neutral Axis Data

Steuben		**Two Trucks**				**Four Trucks**			
		Midspan		***Pinned End***	***Opposite End***	***Midspan***		***Pinned End***	***Opposite End***
Girder	***Location***	***με***	***Neutral Axis (in)***	***με***	***με***	***με***	***Neutral Axis (in)***	***με***	***με***
1	**Top**	3.8	30.1	-1.36	-	5.7	30.0	-2.9	-
	Bottom	111.1		-11.8	-25.8	182.7		-16.4	-19.7
2	**Top**	-20.7	25.7	-	-	-28.0	26.0	-	-
	Bottom	157.5		-25.2	-33.1	238.4		-48.0	-41.3
3	**Top**	-86.4	19.7	46.7	-	-109.8	20.7	65.5	-
	Bottom	180.4		-30.6	-33.1	270.3		-47.9	-48.0
4	**Top**	-10.5	27.5	-	-	-18.3	27.2	-	-
	Bottom	181.6		-	-	263.4		-	-
5	**Top**	-0.9	28.9	-	-	-1.2	28.9	-	-
	Bottom	145.8		-	-	205.5		-	-

Table 3: Steuben No. 3067 distribution factors

Steuben		**Two Truck Loading**		**Four Truck Loading**	
Girder	**AASHTO DF**	**Measured DF**	**% Difference**	**Measured DF**	**% Difference**
1	0.416	0.362	-13%	0.395	-5%
2	0.468	0.366	-22%	0.368	-21%
3	0.468	0.371	-21%	0.381	-19%
4	0.468	0.422	-10%	0.407	-13%
5	0.416	0.479	15%	0.449	8%

2.2 Waltham No. 3238

The bridge in Waltham, No. 3238 over Union River, is shown in Figure 12. Testing was conducted on July 14, 2016 with two truck and four truck load cases producing 55% and 87% of an HL-93 load with impact, respectively. This is the highest percentage of HL-93 load applied among all the bridges. However, with a non-composite rating factor of 1.17 for the interior girder and 1.61 for the exterior girder, Waltham also had the highest capacity. Given that full composite action was observed for this bridge, the strains were generally lower than those observed for the other four structures as shown in Table 4. The measured composite action was more than 100% of the theoretical value for the two trucks and four trucks, giving this bridge one of the largest rating factor increases in this set to 1.68 for interior girders and 2.82 for exterior girders. The distribution factors shown in Table 5 indicate relatively stiff interior girders and less stiff exterior girders. This is surprising given the condition of the relatively new guardrail, and may be due to more restraint at the interior girder ends than the exterior ends producing lower than expected mid span maximum strains.

Shear flows and corresponding slip between the girder and slab for Waltham were calculated/measured to be 57.1 psi with 0.83 mils of slip for the two-truck loading and 109.3 psi with 1.20 mils slip for the four-truck loading. This shear flow and slip correspond to the high degree of composite action observed in this bridge. The shear flow for the four trucks exceeded the 100 psi maximum recommended by AASHTO, and assuming a linear trend the shear flow would reach 131.5 psi at 100% HL-93 loading with impact. There was partial fixity observed at the ends of the girders as measured by the negative strains at the bottom of these girders and given in Table 4. The fixity for Waltham was greater than that of Steuben as a proportion of midspan strain, but lower than that observed in Windham and Buckfield.

Figure 12: Waltham No. 3238 general condition

Table 4: Waltham No. 3238 Strain and Neutral Axis Data

Waltham		**Two Trucks**				**Four Trucks**			
		Midspan		***Pinned End***	***Opposite End***	***Midspan***		***Pinned End***	***Opposite End***
Girder	***Location***	***με***	***Neutral Axis (in)***	***με***	***με***	***με***	***Neutral Axis (in)***	***με***	***με***
1	**Top**	4.1	37.6	-	-	5.2	37.2	-	-
	Bottom	58.2		-	-	84.9		-	-
2	**Top**	11.5	41.1	-	-	23.2	43.2	-	-
	Bottom	76.8		-	-	121.3		-	-
3	**Top**	1.0	35.3	11.9	-	5.5	36.3	17.5	-
	Bottom	91.4		-41.7	-41.8	140.9		-66.5	-68.6
4	**Top**	18.5	46.6	-	-	17.1	41.1	-	-
	Bottom	74.1		-6.8	-22.7	114.1		-7.7	-31.8
5	**Top**	15.7	50.5	-2.4	-	17.7	45.1	-2.1	-
	Bottom	50.8		-33.8	-24.4	78.5		-66.9	-38.3

Table 5: Waltham No. 3238 distribution factors

Waltham		**Two Trucks**		**Four Trucks**	
Girder	**AASHTO DF**	**Measured DF**	**% Difference**	**Measured DF**	**% Difference**
1	0.38	0.319	-16%	0.304	-20%
2	0.493	0.444	-10%	0.457	-7%
3	0.493	0.529	7%	0.530	8%
4	0.493	0.429	-13%	0.429	-13%
5	0.38	0.279	-27%	0.281	-26%

2.3 Pembroke No. 3884

The bridge in Pembroke, No. 3884 over Pennamaquan River, is shown in Figure 13. Testing on July 19, 2016 with two trucks and four trucks produced 49% and 81% of HL-93 loading with impact, respectively. The non-composite rating factors were 0.86 for interior girders and 1.09 for exterior girders. Observed strains are shown in Table 6. Full composite action was observed, with more than 100% of theoretical composite action achieved for both two and four truck loadings. The rating factors were increased to 1.33 for interior girders and 2.52 for exterior girders. The distribution factors shown in Table 7 show stiffer interior girders than exterior, but in all cases the distribution factors were less than those computed per AASHTO.

Shear flows and corresponding slip between the girder and slab for Pembroke were calculated/measured to be 86.7 psi with 0.74 mils slip for the two-truck loading and 107.4 psi with 1.78 mils slip for the four-truck loading. This shear flow and slip corresponds to the high degree of composite action observed in this bridge. The shear flow for the four trucks exceeded the 100 psi maximum recommended by AASHTO, and assuming a linear trend would reach 120.1 psi at

100% HL-93 loading with impact. There was partial fixity observed in Pembroke as shown by the negative strains at the bottom of the girders given in Table 6. These negative strains were the largest in magnitude observed at the girder ends.

Figure 13: Pembroke No. 3884 General condition

Table 6: Pembroke No. 3884 Strain and Neutral Axis Data

Pembroke		**Two Trucks**				**Four Trucks**			
		Midspan		***Pinned End***	***Opposite End***	***Midspan***		***Pinned End***	***Opposite End***
Girder	***Location***	***με***	***Neutral Axis (in)***	***με***	***με***	***με***	***Neutral Axis (in)***	***με***	***με***
1	**Top**	-0.4	26.1	9.6	-	-3.9	25.2	7.1	-
	Bottom	63.6		-27.4	-20.7	99.5		-43.1	-29.9
2	**Top**	-24.0	22.0	-	-	-24.4	23.2	-	-
	Bottom	125.5		-26.4	-4.8	190.1		-55.9	-19.8
3	**Top**	-16.0	23.6	12.8	-	-20.8	24.0	9.4	-
	Bottom	144.5		-55.8	-82.3	220.4		-88.1	-147.3
4	**Top**	-41.1	18.7	-	-	-53.4	19.7	-	-
	Bottom	102.6		-	-	160.9		-	-
5	**Top**	10.3	29.9	-	-	11.0	28.9	-	-
	Bottom	82.3		-	-	118.1		-	-

Table 7: Pembroke No. 3884 distribution factors

Pembroke		**Two Trucks**		**Four Trucks**	
Girder	**AASHTO DF**	**Measured DF**	**% Difference**	**Measured DF**	**% Difference**
1	0.449	0.291	-35%	0.297	-34%
2	0.544	0.453	-17%	0.459	-16%
3	0.544	0.536	-1%	0.532	-2%
4	0.544	0.343	-37%	0.359	-34%
5	0.449	0.377	-16%	0.352	-22%

2.4 Windham No. 5298

The bridge in Windham, No. 5298 over the Pleasant River, is shown in Figure 14. On August 23, 2016 two truck and four truck loadings were applied producing 53% and 77% of an HL-93 load with impact, respectively. This bridge had low non-composite rating factors for both interior (at 0.81) and exterior (at 0.99) girders. Due to the full composite action observed during testing, with both two truck and four truck loading indicating more than 100% of theoretical composite action, the strains as shown in Table 8 were low and the rating factors can be increased to 1.26 and 1.29 for interior and exterior girders, respectively. The comparison between AASHTO-computed and measured distribution factors given in Table 9 indicate relatively stiff exterior girders.

Shear flows and corresponding slip between the girder and slab for Windham were calculated/measured to be 75.5 psi with 2.20 mils slip for the two-truck loading and 118.0 psi with 4.11 mils slip for the four-truck loading. The high shear flow coupled with high slip is an outlier for the group of bridges tested, especially given the high degree of composite action observed in this bridge. However, the slip of 4.11 mils is still quite small. The shear flow for the four trucks was 20% greater than the 100 psi capacity recommended by AASHTO, and is the highest observed in this study. Assuming a linear trend, the shear flow would reach 159.4 psi at 100% HL-93 loading with impact. Partial rotational restraint was observed at the girder ends as shown by the negative strains in the bottom of the girder ends and noted in Table 8. As with the other bridges in this study the fixity was consistent across the girders.

Figure 14: Windham No. 5298 general condition

Table 8: Windham No. 5298 Strain and Neutral Axis Data

Windham		**Two Trucks**				**Four Trucks**			
		Midspan		***Pinned End***	***Opposite End***	***Midspan***		***Pinned End***	***Opposite End***
Girder	***Location***	***με***	***Neutral Axis (in)***	***με***	***με***	***με***	***Neutral Axis (in)***	***με***	***με***
1	**Top**	-0.3	29.0	-4.1	-	-6.5	27.6	-7.3	-
	Bottom	80.1		-12.8	-21.2	126.0		-26.4	-23.9
2	**Top**	-46.6	19.1	-	-	-76.7	17.9	-	-
	Bottom	89.6		-28.2	-15.9	122.2		-55.6	-5.9
3	**Top**	7.2	28.1	31.4	-	5.8	28.1	44.3	-
	Bottom	108.1		-48.5	-64.1	154.9		-78.4	-88.1
4	**Top**	-29.7	17.9	-	-	-46.2	16.8	-	-
	Bottom	47.4		-	-	62.9		-	-
5	**Top**	15.1	33.6	-	-	17.3	33.6	-	-
	Bottom	89.2		-	-	123.1		-	-

Table 9: Windham No. 5298 distribution factors

Windham		Two Trucks		Four Trucks	
Girder	**AASHTO DF**	**Measured DF**	**% Difference**	**Measured DF**	**% Difference**
1	0.431	0.479	11%	0.518	20%
2	0.523	0.309	-41%	0.285	-46%
3	0.523	0.470	-10%	0.480	-8%
4	0.523	0.155	-70%	0.139	-74%
5	0.431	0.588	36%	0.579	34%

2.5 Buckfield No. 5452

The bridge in Buckfield, No. 5452 over the West Branch of the Nezinscot River is shown in Figure 15. On July 12, 2016 four trucks were used to produce 74% of an HL-93 loading with impact for this span, the lowest of the four truck configurations observed in this study. Despite a relatively low degree of partial composite action (35.7%), this bridge saw the highest increase in rating factors from 0.96 to 1.61 for interior and from 1.18 to 1.76 for exterior girders. Measured strains are given in Table 10, and distribution factors in Table 11.

Shear flows and corresponding slip between the girder and slab for Buckfield were calculated/measured to be 69.0 psi with 5.05 mils slip for the four-truck loading. This shear flow is the smallest observed in this study, for four trucks, and slip is the highest observed in this study. This is consistent with Buckfield exhibiting the lowest degree of partial composite action of all bridges. The partial fixity at girder ends observed in Buckfield is indicated by the strains given in Table 10.

Figure 15: Buckfield No. 5452 general condition

Table 10: Buckfield No. 5452 Strain and Neutral Axis

Buckfield		**Four Trucks**		
		Midspan		***Pinned End***
Girder	***Location***	***με***	***Neutral Axis (in)***	***με***
1	**Top**	18.2	30.0	-
	Bottom	144.9		-
2	**Top**	47.8	39.1	-
	Bottom	145.7		-
3	**Top**	-71.0	18.4	-
	Bottom	166.8		-106.6
4	**Top**	-99.5	15.1	-
	Bottom	134.5		-66.4
5	**Top**	12.1	28.1	-7.3
	Bottom	186.5		-94.3

Table 11: Buckfield No. 5452 distribution factors

Buckfield		**Four Trucks**	
Girder	**AASHTO DF**	**Measured DF**	**% Difference**
1	0.44	0.366	-17%
2	0.53	0.493	-7%
3	0.53	0.421	-20%
4	0.53	0.301	-43%
5	0.44	0.418	-5%

3 Summary of Live Load Test Data Conclusions

Analysis of the bridges tested is described in detail in Section 2. In general, calculations were based on mechanics of materials principles and AASHTO code requirements including the *Manual for Bridge Evaluation*.

Overall, a high percentage of HL-93 loading with impact was applied to the structures. For all structures, the four trucks were successful in loading the bridges to desired percentages to justify rating factor increases. While three of the five bridges showed full composite action, with slightly more than 100% of theoretical values of effective slab width computed based on measured response, significantly less composite action was observed for Steuben (56.6%) and Buckfield (35.7%).

Live load distribution factors inferred from the test data showed reasonably good agreement with AASHTO-recommended values, although the AASHTO values are conservative for four of the five bridges. The maximum percent differences are observed in Steuben and Buckfield, the two bridges that showed very little composite action compared to the other bridges in this study.

Shear stresses and slips between the girder and slab were determined for all bridges. Slip was measured directly by installing LVDTs connected to the girder and pushing against plates adhered to the slab. The shear flow was computed based on applied load and field-observed girder properties. Detailed calculations are given in Appendix A.2.5 for Steuben, A.3.5 for Waltham, A.4.5 for Pembroke, A.5.5 for Windham, and A.6.5 for Buckfield. In general, the two bridges with the least composite action, Steuben and Buckfield, not surprisingly show the largest degree of slip as well as the lowest calculated shear stress at the girder flange-slab interface. The three bridges showing full composite action had relatively little slip, except for one girder at Windham that appears to be an outlier.

One important observation was that measured strains near the girder ends for all bridges indicated some rotational restraint at each abutment. This rotational restraint was likely responsible for reductions in girder flexural strain at mid-span compared to a simple-span condition, and therefore contributed to the rating factor increases. However, the presence of this rotational restraint at higher loads and over the full range of seasonal temperature variations is not guaranteed.

The test results and analyses presented here justify significant increases in the rating factors for all the bridges according to the AASHTO *Manual for Bridge Evaluation*. Even those bridges showing partial composite action, Steuben and Buckfield, had increases in the rating factor of 36% and 23% for interior girders. The average increase in rating factors for the critical interior girders of all bridges was 43%, with minimum and maximum increases of 23% and 56%. All rating factor increases have been calculated based on the assumption that the observed results cannot be confidently extrapolated to loads 30% beyond that produced by an HL-93 load with impact, due in part to uncertainty regarding the presence of support rotational restraint and at higher loads.

4 References

1. AASHTO (2010). "The Manual for Bridge Evaluation Second Edition," American Association of State Highway and Transportation Officials Washington DC. (with 2015 Interirm Revisions).

2. AASHTO (2012). "AASHTO LRFD Bridge Design Specifications Customary U.S. Units", American Association of State Highway and Transportation Officials Washington DC. doi:978-1-56051-523-4.

A.1 Experimental Configuration and Data Collected

For each of the five bridges tested, a collection of data files is provided which contains input data, experimental configuration data, and data collected during tests. The files pertaining to each bridge are tabulated in the following appendices.

A.1.1 Input Data

Input data for each bridge includes bridge geometries, material properties, and sensor layouts. General geometry (i.e. span length, girder spacing, etc.) and material properties are tabulated in a Comma Separated Variable (.csv) file, each value listed with a description and unit. Section properties for interior and exterior girders are also listed in separate csv files, labeled and in units of inches to the appropriate power.

A .csv is also provided which gives a list of sensors in the order of collection, and another giving the layout of those sensors on each bridge. The sensor list .csv provides sensors in the order that they are used by the data acquisition system, and consequently in resulting test data. The sensor layout gives relative positions of sensors as they appeared for each bridge. Each girder is represented by three rows representing its top, middle and bottom respectively. Each collection of rows is placed in its relative position as it appears on the bridge. From left to right, columns represent the non-pinned end, mid-span, pinned end, and LVDT position on the bridge respectively. By this way, the position of each sensor can be determined. For example, a sensor in the second column of the second row would represent a sensor placed on the web of the first girder at mid-span.

A.1.2 Experimental Configuration

Experimental configuration data includes data on the loading trucks, as well as the positions of trucks at the beginning of tests. Each test includes a MATLAB variable file (a .mat file) containing information on the trucks used to test it. The truck .mat file contains structured arrays for each truck, containing its plate number, truck number in relation to each test, individual wheel weights (in pounds), lengths (center to center of wheels; side, front and back in inches), wheel bearing surface widths (front to back in inches), and wheel bearing lengths (front to back in inches). The start positions are packaged together in a single .mat file containing a structured array for each bridge. Each of those arrays contain cell arrays which show relative placements for each truck at the beginning of a test, the pinned-end of the bridge always being on the right.

A.1.3 Collected Data

Collected data includes rectified strain data (in microstrain) at critical points during each test, as well as the time index of their occurrence. For each test configuration, a Microsoft Excel file is provided which contains strain data at critical points during the test. This data has been rectified to correct for the sensors' tendency to drift its zero-point during a test, as well as to convert LVDT data to microstrain. A .csv file accompanies each Excel file, providing a description of the critical point recorded and its time of occurrence (in 1/10 seconds from the beginning of the test).

A.2 Steuben No. 3067

A.2.1 Input Data, Experimental Configuration, and Experimental Data Collected

Table 12: Steuben No. 3067 Bridge Input Data, Experimental Configuration, and Experimental Data Collected

File Contents	File Name	File Type
Bridge Geometry and Materials	Br3067 _Geom.csv	CSV Format
Exterior Section Data	Br3067 _Ext.csv	CSV Format
Interior Section Data	Br3067 _Int.csv	CSV Format
Sensors	Br3067 _Sensors.csv	CSV Format
Sensor Layout	Br3067 _SensorLayout.csv	CSV Format
Truck Weight and Dimensions	Br3067 _SensorLayout.mat	MATLAB Data File
Truck Starting Position	TestStart.m > Br3067 _TestStart	MATLAB Data File
Truck Position Measurements	Br3067 _Tk_Positions.mat	MATLAB Data File
Sensor Data	Br3067 _1Tks_1Lns_1.xlsx	Microsoft Excel
	Br3067 _2Tks_1Lns_1.xlsx	Microsoft Excel
	Br3067 _2Tks_2Lns_1.xlsx	Microsoft Excel
	Br3067 _4Tks_2Lns_1.xlsx	Microsoft Excel
	Br3067 _4Tks_2Lns_2.xlsx	Microsoft Excel
Data Time Indices	Br3067_1Tks_1Lns_1_Time.csv	CSV Format
	Br3067_2Tks_1Lns_1_Time.csv	CSV Format
	Br3067_2Tks_2Lns_1_Time.csv	CSV Format
	Br3067_4Tks_2Lns_1_Time.csv	CSV Format
	Br3067 _4Tks_2Lns_2_Time.csv	CSV Format

A.2.2 Instrumentation

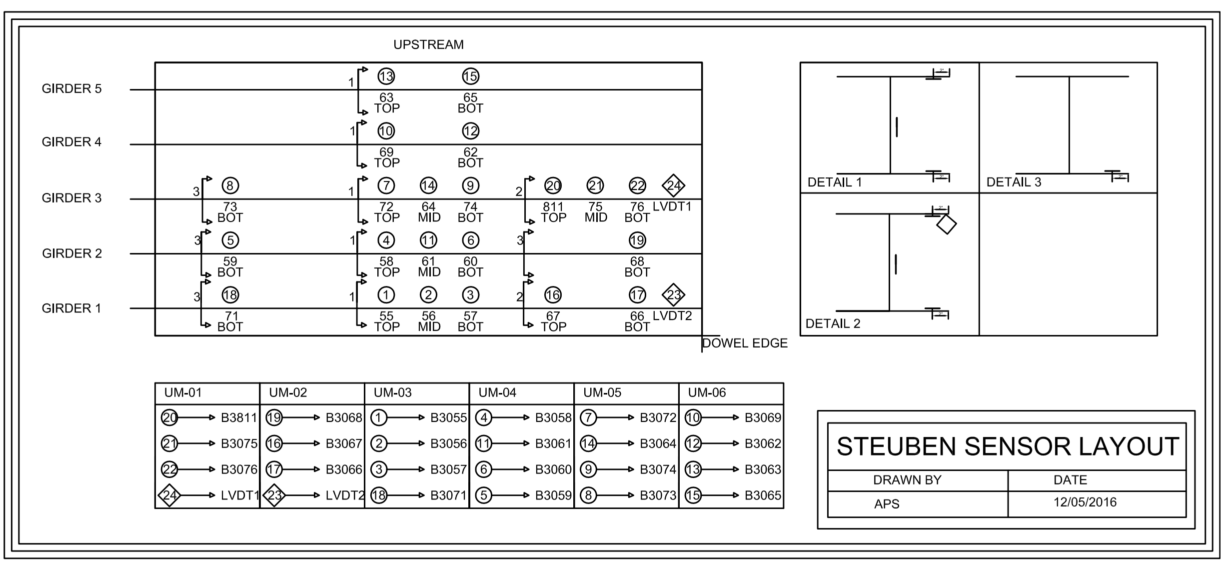


Figure 16: Steuben No. 3067 sensor layout

A.2.3 Loading

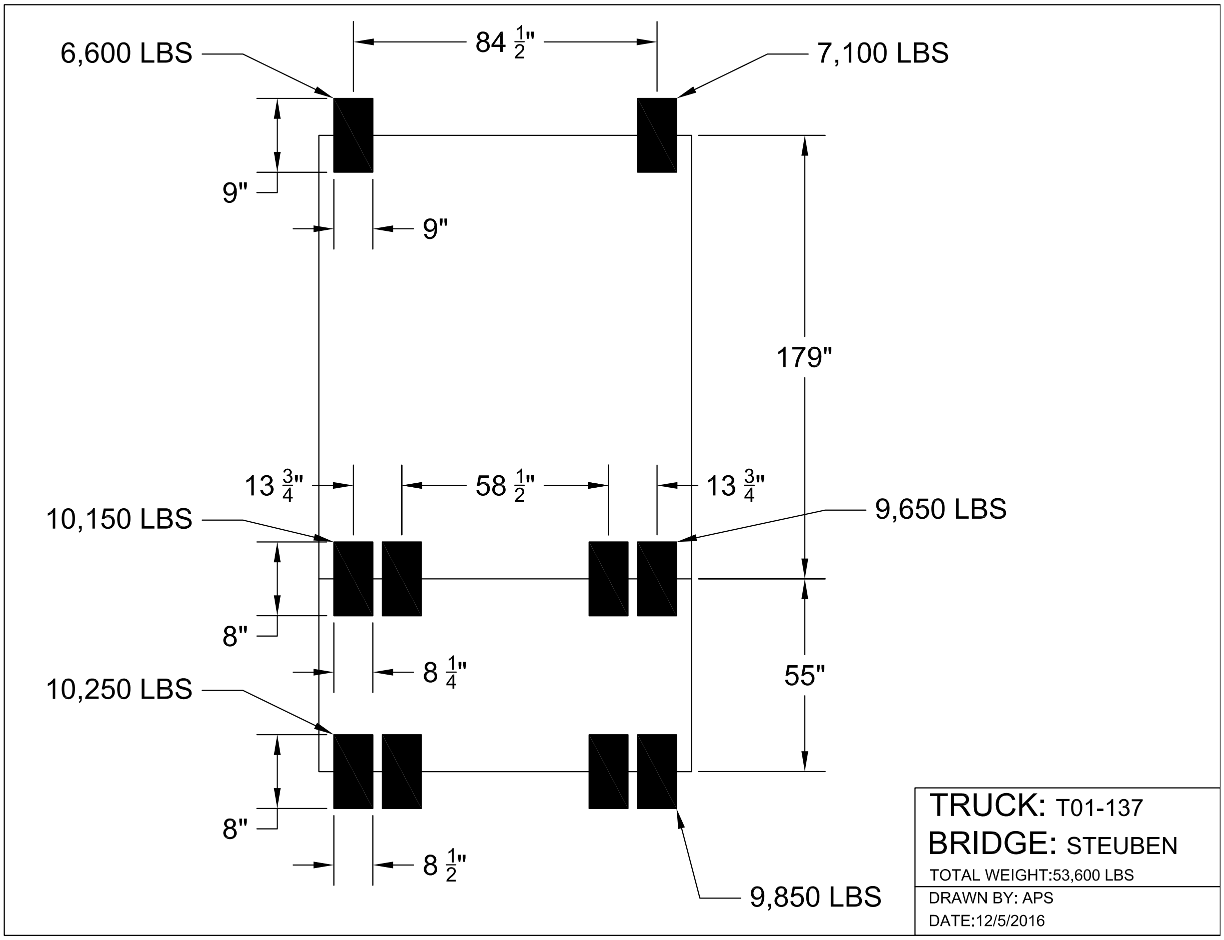


Figure 17: Steuben No. 3067 Truck T01-137 loading

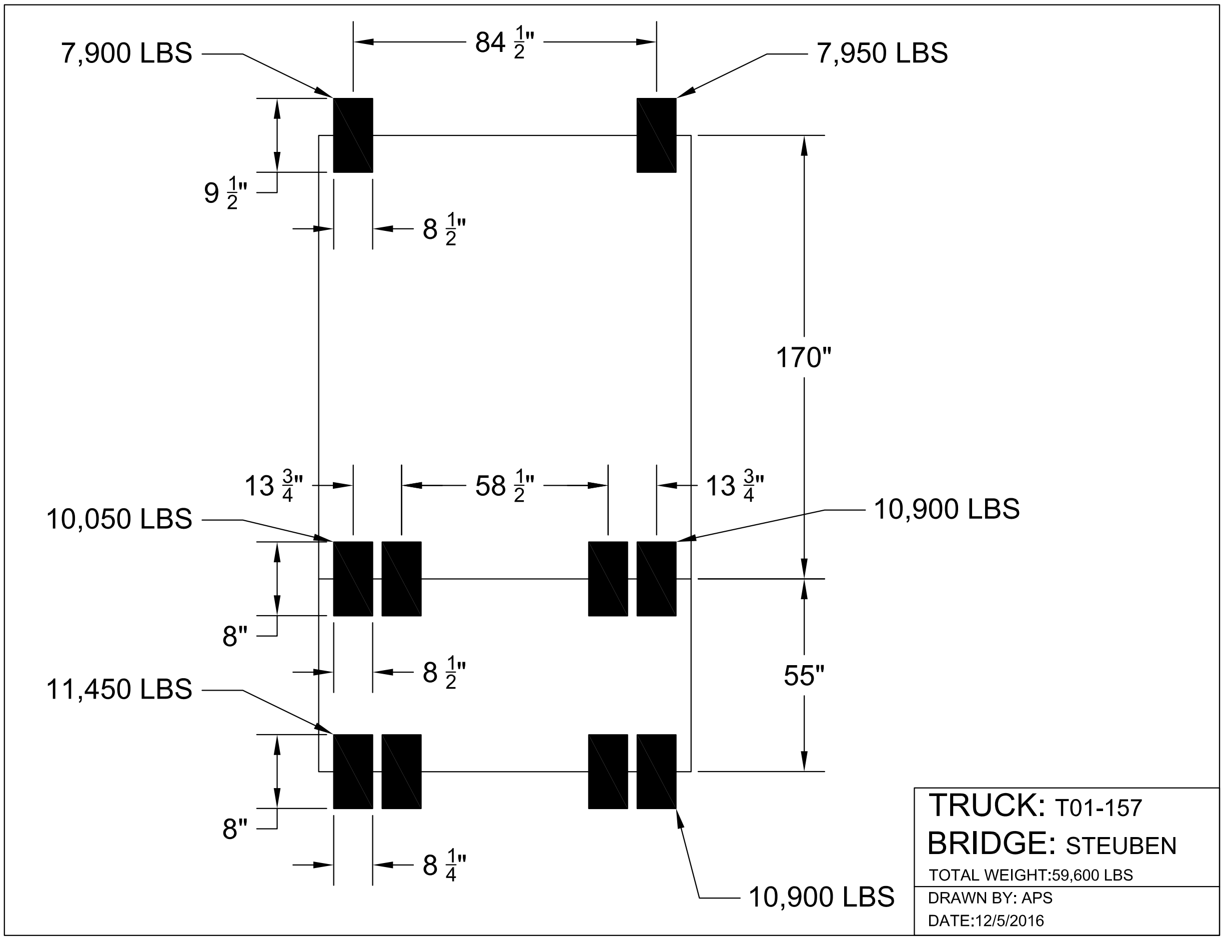


Figure 18: Steuben No. 3067 Truck T01-157 loading

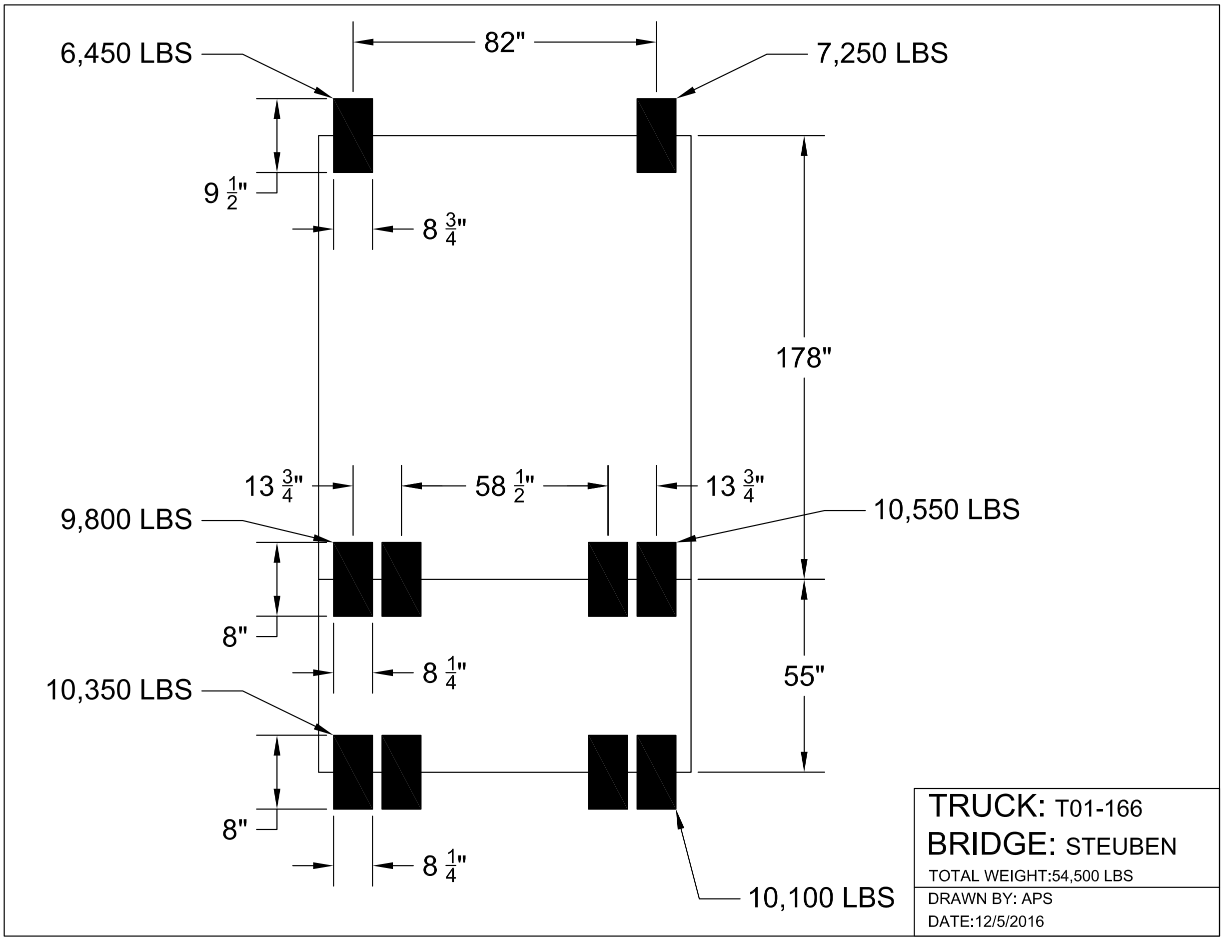


Figure 19: Steuben No. 3067 Truck T01-166 loading

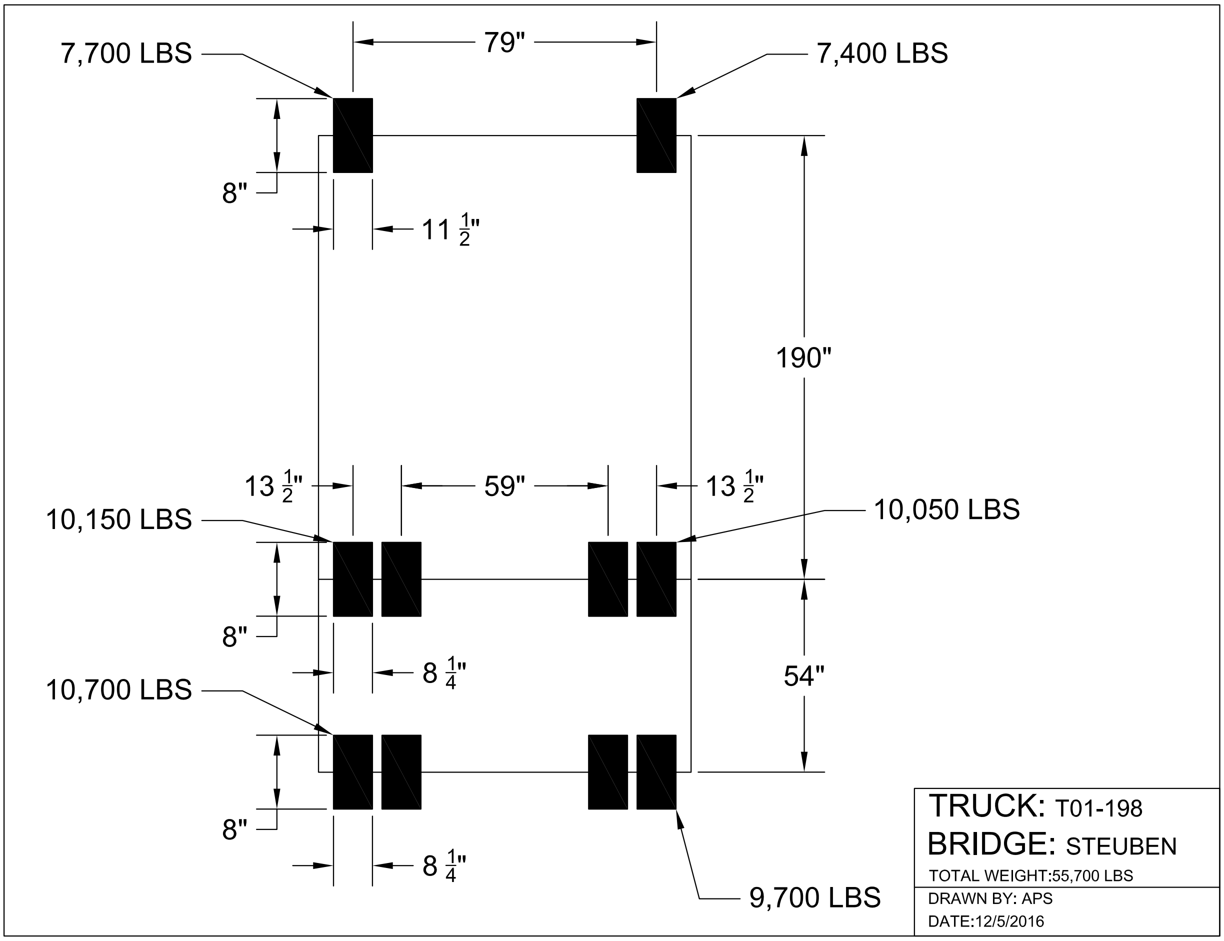


Figure 20: Steuben No. 3067 Truck T01-198 loading

A.2.4 Representative Data Plots

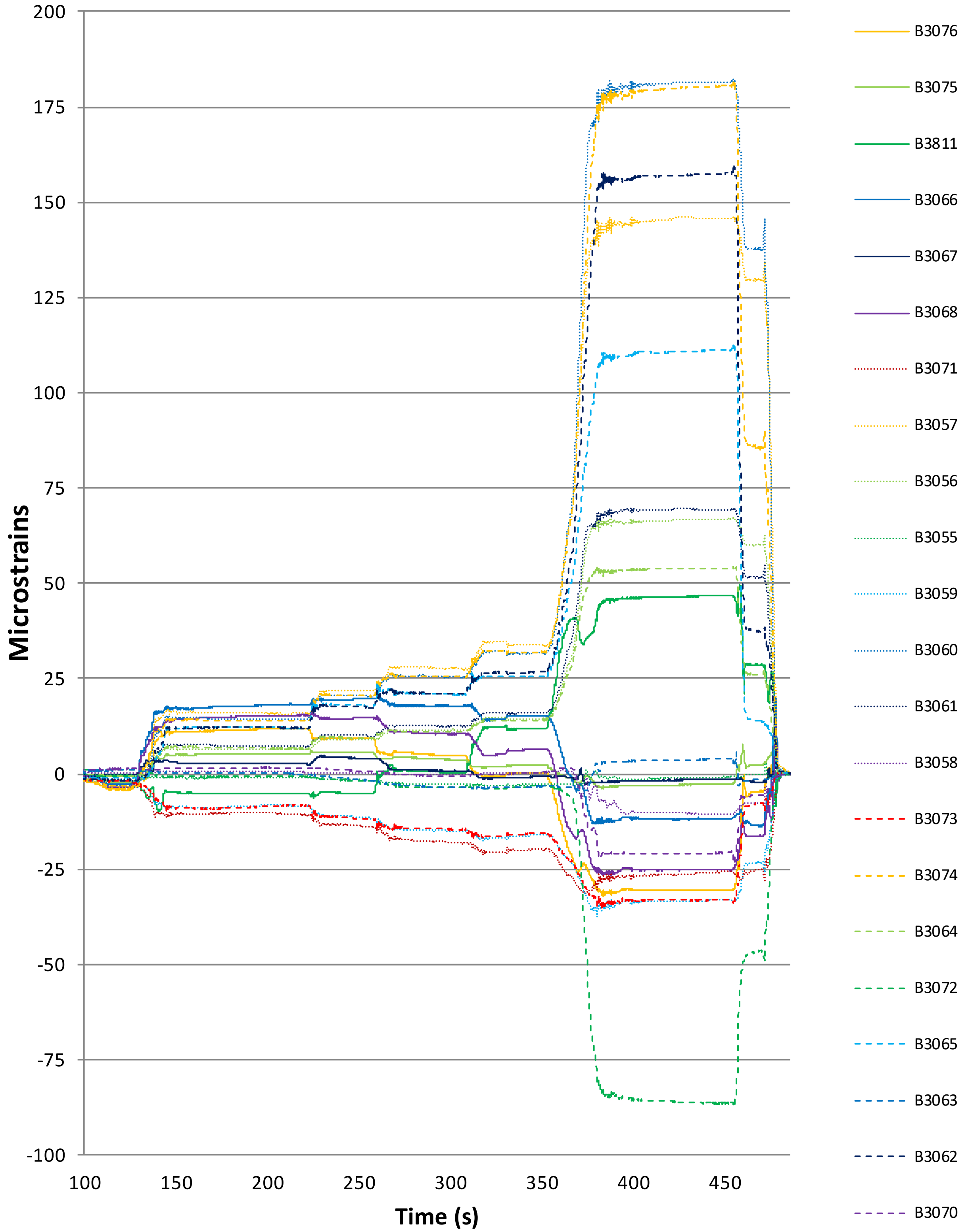


Figure 21: Steuben No. 3067- 2 trucks 2 lanes test 1 strain

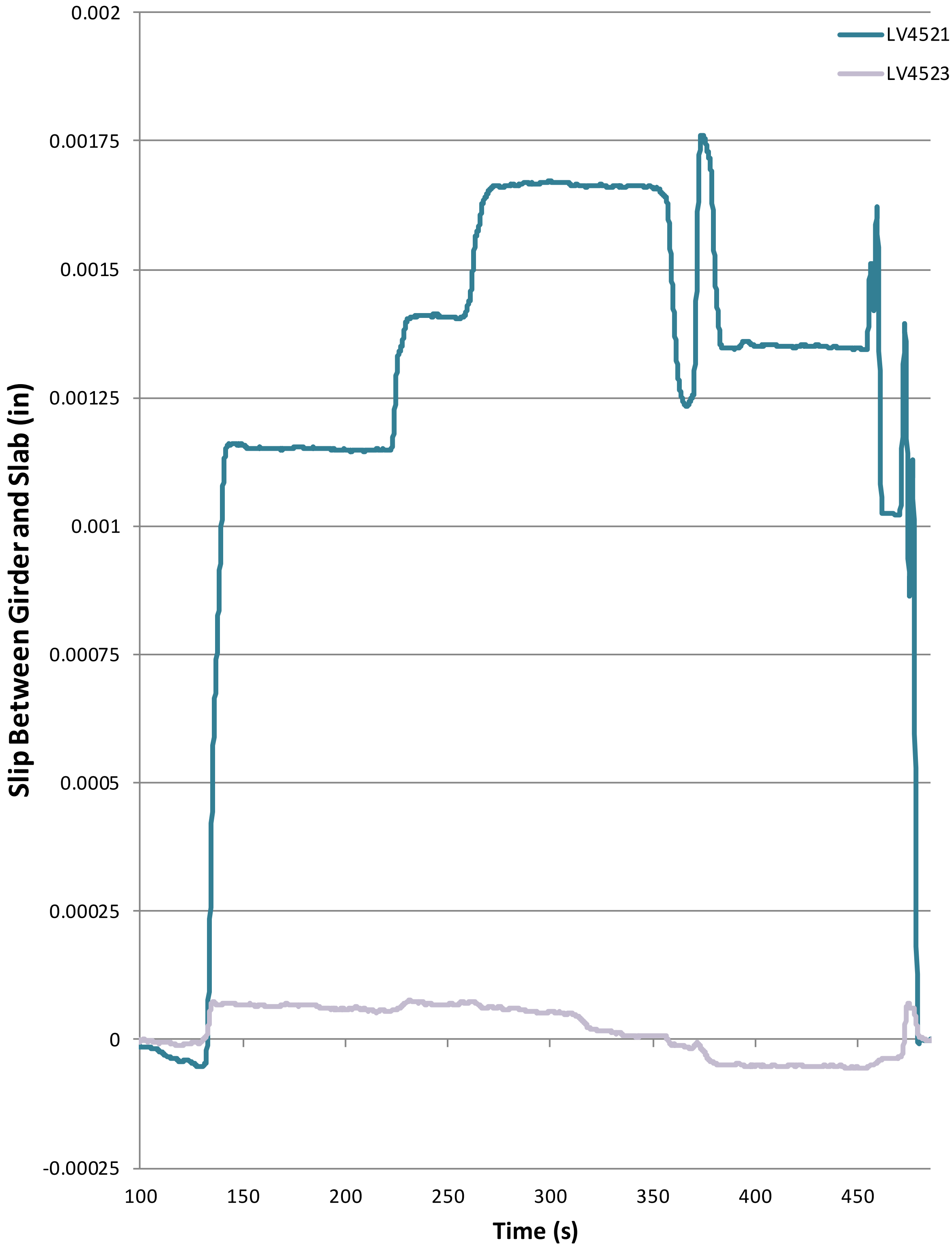


Figure 22: Steuben No. 3067- 2 trucks 2 lanes test 1 shear slip

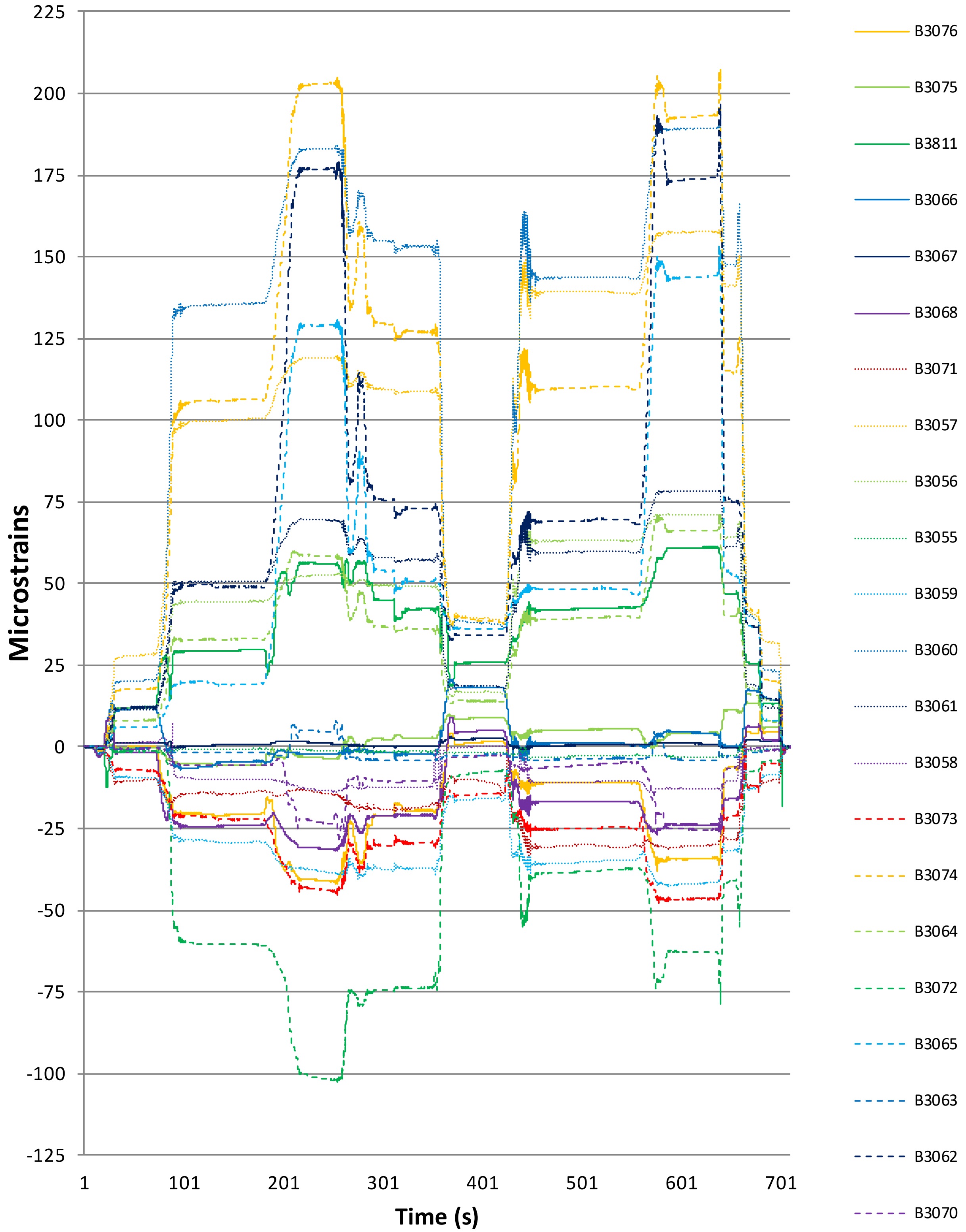


Figure 23: Steuben No. 3067- 4 trucks 2 lanes test 1 strains

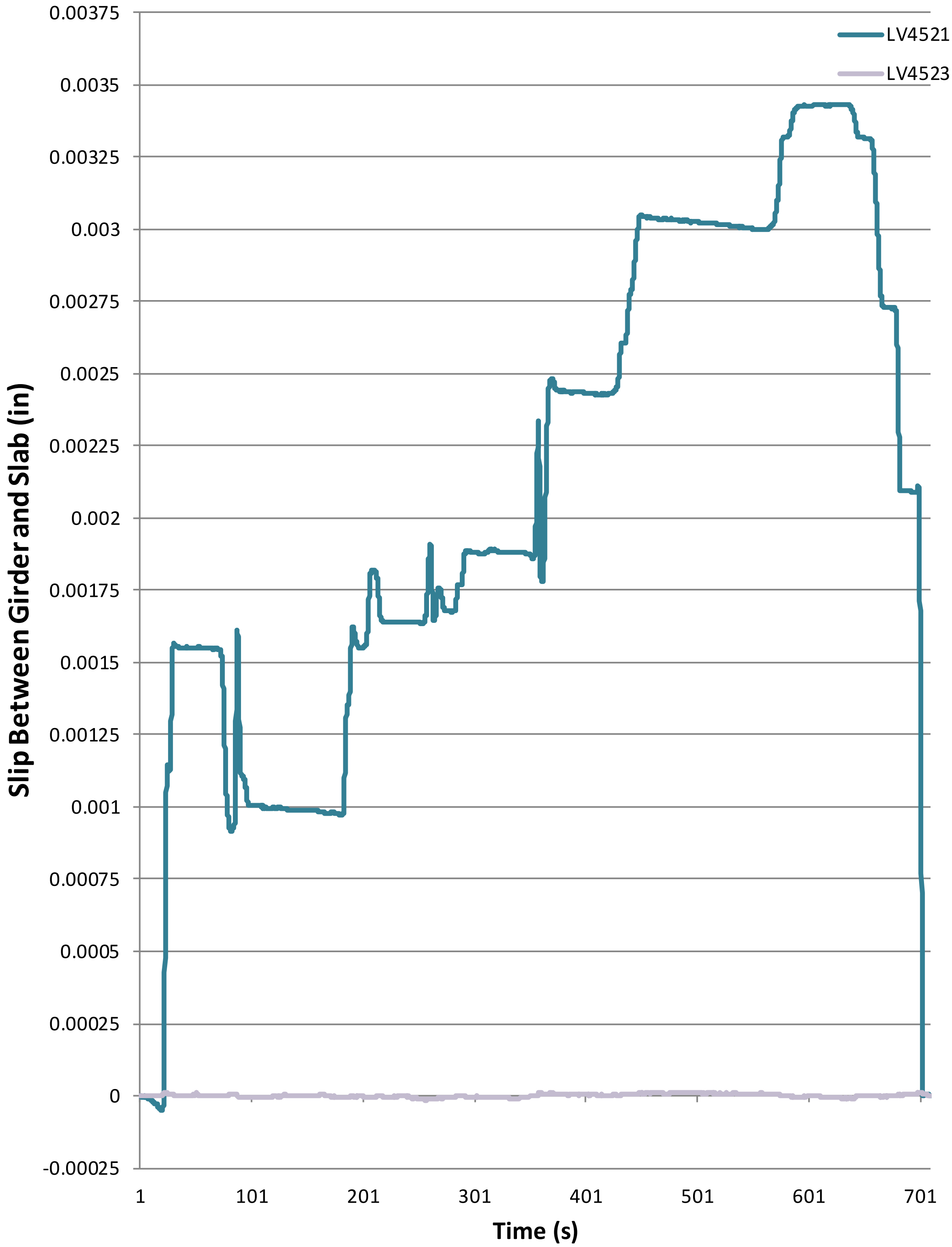


Figure 24: Steuben No. 3067- 4 trucks 2 lanes test 1 shear slip

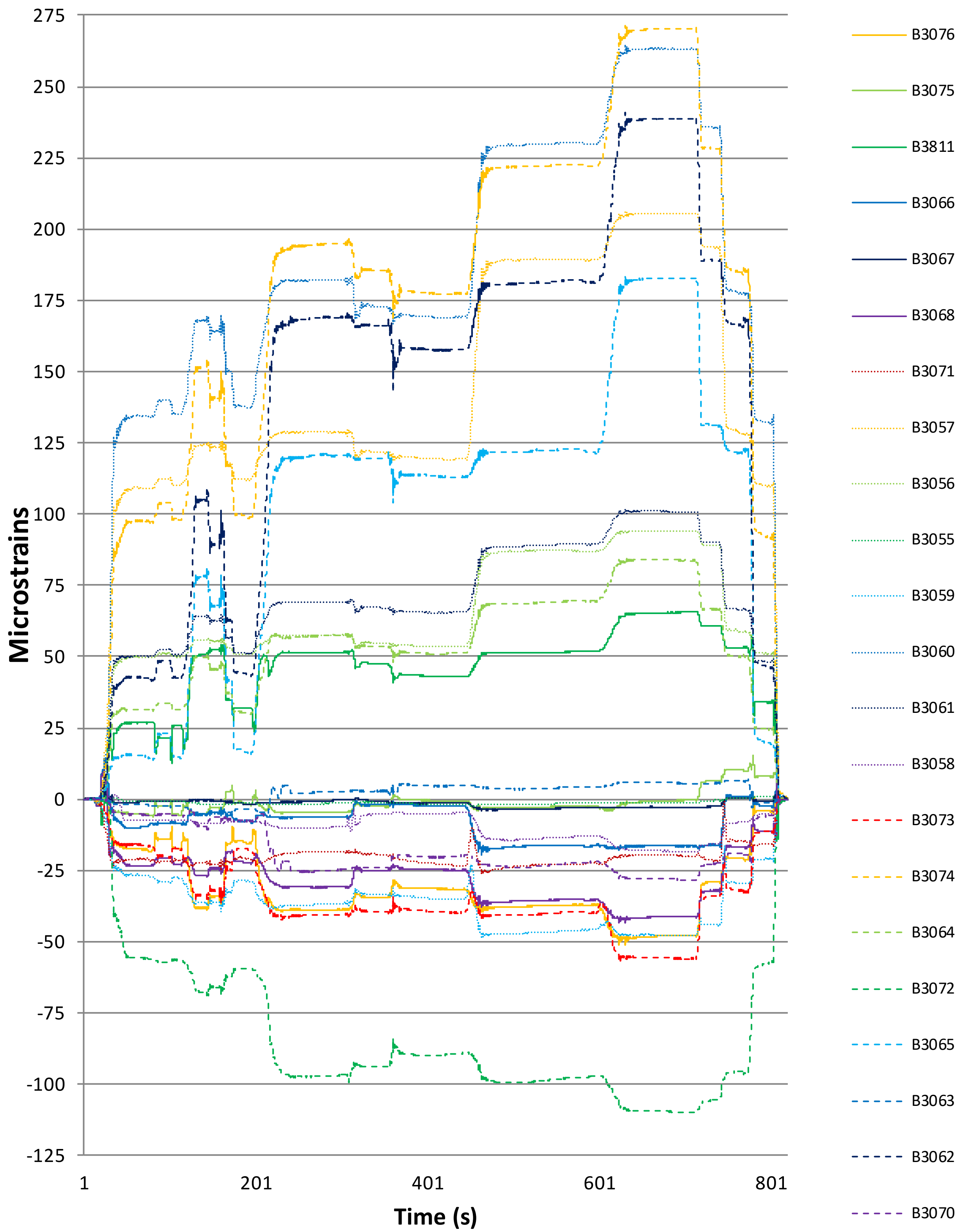


Figure 25: Steuben No. 3067- 4 trucks 2 lanes test 2 strains

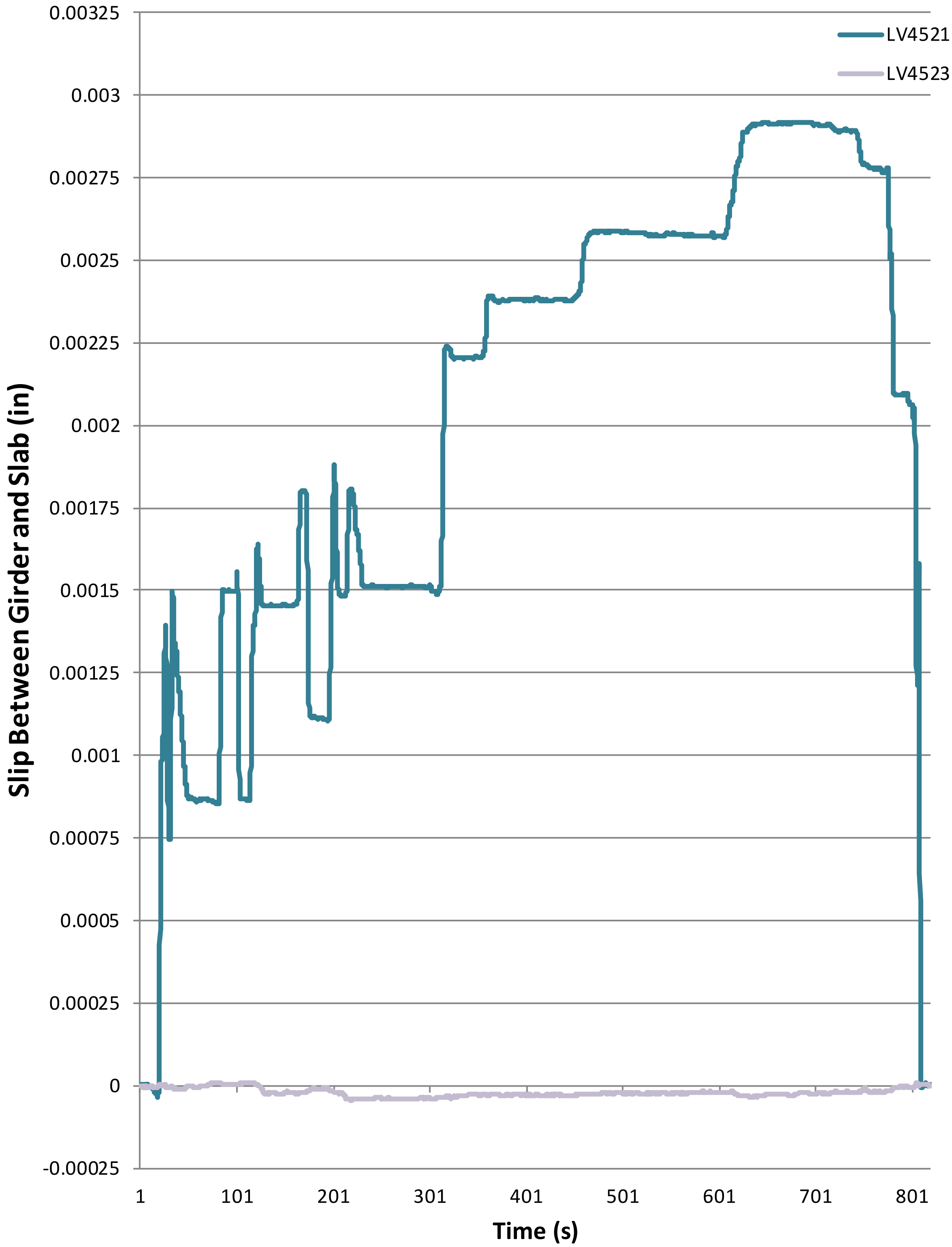


Figure 26: Steuben No. 3067- 4 trucks 2 lanes test 2 shear slip

A.2.5 Rating Factor Calculations

Figure 27: Steuben No. 3067 Calculations

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

Year Built: 1949

Table 6A.5.2.1-1—Minimum Compressive Strength of Concrete by Year of Construction

Year of Construction	Compressive Strength, f'_c, ksi
Prior to 1959	2.5
1959 and Later	3.0

$f'_c := 2.5\ ksi$

Table 6A.6.2.1-1—Minimum Mechanical Properties of Structural Steel by Year of Construction

Year of Construction	Minimum Yield Point or Minimum Yield Strength, F_y, ksi	Minimum Tensile Strength, F_u, ksi
Prior to 1905	26	52
1905 to 1936	30	60
1936 to 1963	33	66
After 1963	36	66

$fy := 33\ ksi$

$\gamma c := 150\ pcf$

$\gamma s := 490\ pcf$

$\gamma_{c\_mod} := 145\ pcf$

$Es := 29000\ ksi$

LRFD Design
Eq. 5.4.2.4-1

$$Ec := 33000 \cdot \gamma_{c\_mod}^{\ 1.5} \cdot \sqrt[2]{f'_c}$$

$$Ec := 2875.9\ ksi$$

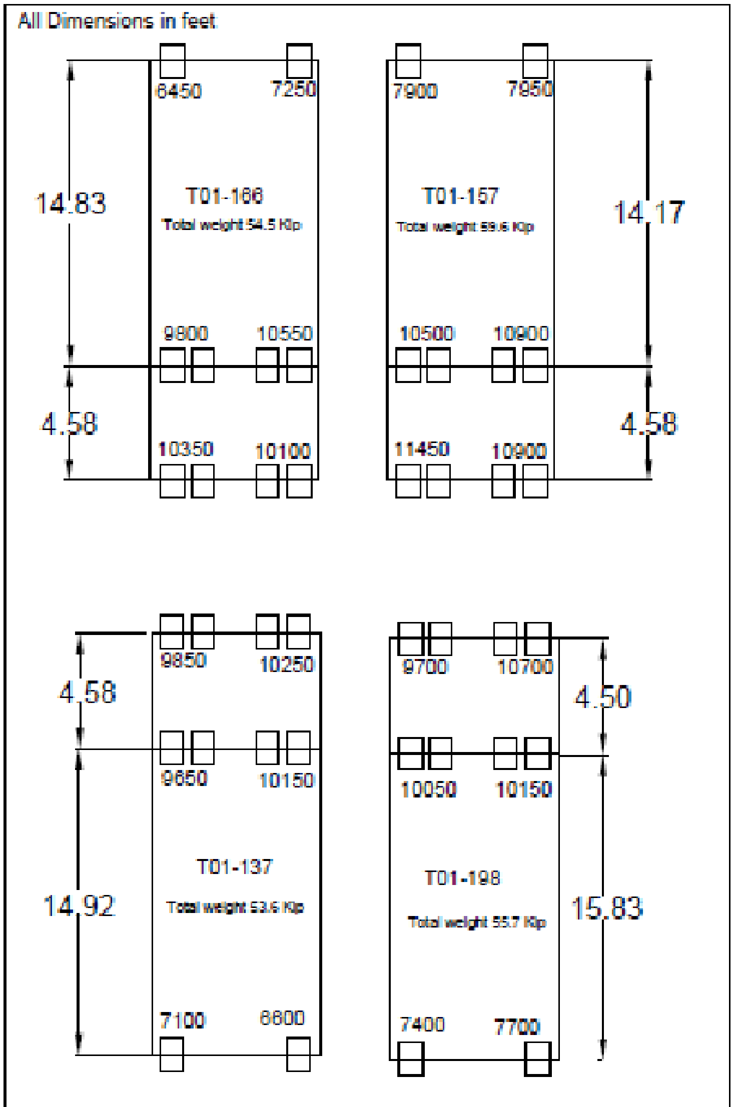
Bridge Length	$L := 50\ ft$
Spacing between Girders	$S := 5.33\ ft$
Deck thickness	$ts := 6.75\ in$
Wearing surface thickness	$t_{w.s.} := 4.5\ in$ $\gamma_{w.s.} := 140\ pcf$

Page 1 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-03

Trucks Weight & Dimensions



Trucks weights and Dimensions (Steuben)

Page 2 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-03

Loads on the Interior Girder

DeadLoad:

$M_{DC} := 328\ ft \cdot kip$ VHB report

$M_{DW} := 87\ ft \cdot kip$ VHB report

$d := 29.83\ in$ $b_f := 10.48\ in$

Live Load :

We use the average truck weight and dimensions in this calculations

				Trucks Weight
	T01-198	T01-137	T01-166	T01-157
Front wheel	15100	13700	13700	15850
front rear wheel	20200	19800	20350	21400
Last Wheel	20400	20100	20450	22350

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

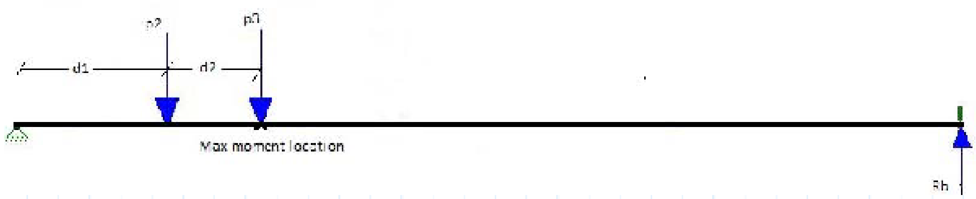
Live Load Analysis

Two trucks in two lanes

$p3 := 21.4\ kip$ $p2 := 20.9\ kip$ $p1 := 14.8\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 15\ ft$

Trucks at shear locations:



$$R_b(d1) := \frac{p2 \cdot d1 + p3 \cdot (d1 + d2)}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d2))$$

At 0.5 d from support

$d1 := 0.5 \cdot d$
$M(d1) = 139.65\ ft \cdot kip$
$M_{0.5dtwotrucks} := 139.65\ ft \cdot kip$

$R_b(d1) = 3.19\ kip$
$R_a := p2 + p3 - R_b(d1) = 39.11\ kip$
$V_{shear2t} := R_a = 39.11\ kip$

At 1.0 d from support

$d1 := 1.0 \cdot d$
$M(d1) = 180.39\ ft \cdot kip$
$M_{1.0dtwotrucks} := 180.4 \cdot ft \cdot kip$

At 1.5 d from support

$d1 := 1.5 \cdot d$
$M(d1) = 218.51\ ft \cdot kip$
$M_{1.5dtwotrucks} := 218.51 \cdot ft \cdot kip$

At 2.0 d from support

$d1 := 2.0 \cdot d$
$M(d1) = 254.02\ ft \cdot kip$
$M_{2.0dtwotrucks} := 254.02 \cdot ft \cdot kip$

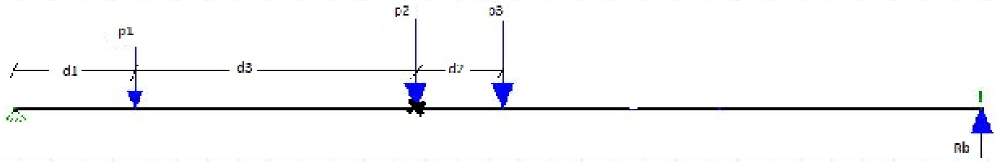
Page 4 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-03

Trucks at Maximum Moment location:

d1 distance between front wheel and the support



$$R_b(d1) := \frac{(p1 \cdot d1) + (p2 \cdot (d1 + d3)) + (p3 \cdot (d1 + d2 + d3))}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d3)) - p3 \cdot (d2)$$

$$R_b(108\ in) = 25.11\ kip$$

$$M(108\ in) = 545.808\ ft \cdot kip$$

$$M_{maxmomenttwotrucks} := 545.81 \cdot ft \cdot kip$$

Page 5 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-03

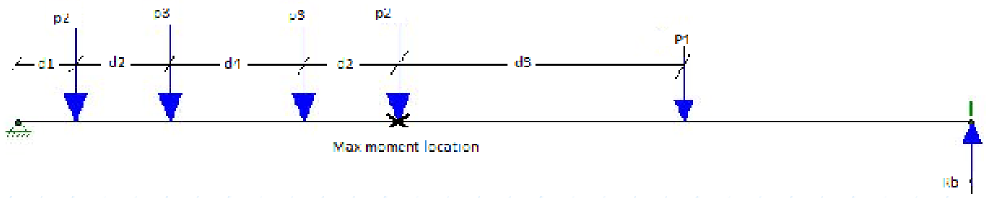
Four trucks in two lanes

$p1 := 14.6 \ kip$ $p2 := 20.4 \ kip$ $p3 := 20.8 \ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5 \ ft$
d3 distance between front wheel and front rear wheel $d3 := 15 \ ft$

Trucks at shear locations:

d1 distance between front rear wheel and the support ; d4 distance between trucks



$$R_b(d1, d4) := \frac{p2 \cdot d1 + p3 \cdot (d1 + d2) + p3 \cdot (d1 + d2 + d4) + p2 \cdot (d1 + 2 \cdot d2 + d4) + p1 \cdot (d1 + 2 \cdot d2 + d4 + d3)}{L}$$

$$M(d1, d4) := (R_b(d1, d4) \cdot (L - (d1 + d2 + d4))) - (p2 \cdot (d2)) - (p1 \cdot (d3 + d2))$$

At 2.0 d from support

$d1 := 2.0 \cdot d$ $d4 := 88 \ in$

$M(d1, d4) = 697 \ ft \cdot kip$

$M_{2.0dfourtrucks} := 697 \cdot ft \cdot kip$

$Ra := 2 \cdot p2 + 2 \cdot p3 + p1 - R_b(d1, d4) = 63.63 \ kip$

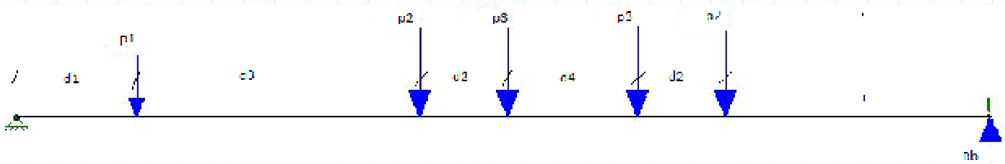
Page 6 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

Trucks at Maximum Moment location:

d1 distance between front wheel and the support ; d4 distance between trucks



At Maximum Moment:

$$R_b(d1,d4) := \frac{p1 \cdot d1 + p2 \cdot (d1+d3) + p3 \cdot (d1+d3+d2) + p3 \cdot (d1+d3+d2+d4) + p2 \cdot (d1+d3+2 \cdot d2+d4)}{L}$$

$$M(d1,d4) := (R_b(d1,d4) \cdot (L-(d1+d3+d2))) - (p2 \cdot (d2+d4)) - (p3 \cdot d4)$$

$$R_b(66\ in, 90\ in) = 49.81\ kip$$

$$M(66\ in, 90\ in) = 809.345\ ft \cdot kip$$

$$M_{maxmomentfourtrucks} := 809.35 \cdot ft \cdot kip$$

Page 7 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-03

Section Properties and Distribution Factors

Interior Girder Section Properties					
component	width	thickness	modular ratio	transf. area	y
Slab	64	6.75	10.00	43.2	32.6

Moment Distribution factors (Interior Girders)

VHB report

$DF_{onelane} = 0.419$

$DF_{twolanes} = 0.468$

Calculated Distribution factors based on actual measurements

$DF_{onelane} := 0.398$

$DF_{twolanes} := 0.516$

$DF_{shear} := 0.621$

Section Properties: Fully composite

$y' := 25.1\ in$ $\quad I := 10218 \cdot in^4$ $\quad S_{bot} := 406.9 \cdot in^3$ $\quad Q_{slab} := 305.0 \cdot in^3$

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

Maximum Live Load Moment calculation in each loadcase for the interior girder

Two trucks in two lanes

$Mt_{0.5dtwotrucks} := DF_{twolanes} \cdot M_{0.5dtwotrucks} = 72\ ft \cdot kip$

$Mt_{1.0dtwotrucks} := DF_{twolanes} \cdot M_{1.0dtwotrucks} = 93\ ft \cdot kip$

$Mt_{1.5dtwotrucks} := DF_{twolanes} \cdot M_{1.5dtwotrucks} = 113\ ft \cdot kip$

$Mt_{2.0dtwotrucks} := DF_{twolanes} \cdot M_{2.0dtwotrucks} = 131\ ft \cdot kip$

$Mt_{maxmomenttwotrucks} := DF_{twolanes} \cdot M_{maxmomenttwotrucks} = 281\ ft \cdot kip$

Four trucks in two lanes

$Mt_{2.0dfourtrucks} := DF_{twolanes} \cdot M_{2.0dfourtrucks} = 360\ ft \cdot kip$

$Mt_{maxmomentfourtrucks} := DF_{twolanes} \cdot M_{maxmomentfourtrucks} = 418\ ft \cdot kip$

Actual section Response

Four Trucks					
Position	LV4521	B3076	B3075	B3811	LV4523
4 T @ 2.0d	0.003426	-34.1729012	4.25192093	61.05499361	-6.56099E-06
Max mom	0.002915	-47.9403656	-0.545197	65.50389684	-2.12E-05
Two Trucks					

Page 9 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alhraheemi
Checked By: SMT
Date : 2016-11-03

Four Trucks

Look at the critical girder the interior girder

$y'_{2.0d} := 21.9\ in$ $S_{2.0d} := 381.8\ in^3$ $Q_{2.0d} := 209.3\ in^3$ Partial composite

$y'_{maxmoment} := 20.7\ in$ $S_{maxmoment} := 370.7\ in^3$ $Q_{maxmoment} := 174.3\ in^3$ Partial composite

$$M_{fourtrucks} := \begin{bmatrix} Mt_{2.0dfourtrucks} \\ Mt_{maxmomentfourtrucks} \end{bmatrix} ; \quad y_{fourtrucks} := \begin{bmatrix} y'_{2.0d} \\ y'_{maxmoment} \end{bmatrix} ; \quad S_{fourtrucks} := \begin{bmatrix} S_{2.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \dfrac{Mt_{2.0dfourtrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 389.79 \\ 466.17 \end{bmatrix}$$

$Kb := 0.5$

$$Ka := \frac{466.17}{270.32} - 1$$

$K := 1 + Kb \cdot Ka = 1.36$

Page 10 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-03

Two Trucks

Look at the critical girder the interior girder

$y'_{0.5d} := 30.8\ in$	$S_{0.5d} := 406.9\ in^3$	Fully composite
$y'_{1.0d} := 29.0\ in$	$S_{1.0d} := 406.9\ in^3$	Fully composite
$y'_{1.5d} := 27.6\ in$	$S_{1.5d} := 406.9\ in^3$	Fully composite
$y'_{2.0d} := 28.3\ in$	$S_{2.0d} := 406.9\ in^3$	Fully composite
$y'_{maxmoment} := 19.7\ in$	$S_{maxmoment} := 360.6\ in^3$	Partial composite

$$M_{twotrucks} := \begin{bmatrix} Mt_{0.5dtwotrucks} \\ Mt_{1.0dtwotrucks} \\ Mt_{1.5dtwotrucks} \\ Mt_{2.0dtwotrucks} \\ Mt_{maxmomenttwotrucks} \end{bmatrix} \quad y_{twotrucks} := \begin{bmatrix} y'_{0.5d} \\ y'_{1.0d} \\ y'_{1.5d} \\ y'_{2.0d} \\ y'_{maxmoment} \end{bmatrix} \quad S_{twotrucks1} := \begin{bmatrix} S_{0.5d} \\ S_{1.0d} \\ S_{1.5d} \\ S_{2.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \dfrac{Mt_{0.5dtwotrucks}}{S_{0.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.0dtwotrucks}}{S_{1.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.5dtwotrucks}}{S_{1.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{2.0dtwotrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{maxmomenttwotrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 73.28 \\ 94.66 \\ 114.66 \\ 133.29 \\ 323.18 \end{bmatrix}$$

$$Kb := 0.5$$

$$Ka := \frac{322.6}{180.41} - 1 = 0.79$$

$$K := 1 + Kb \cdot Ka = 1.39$$

Page 11 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

Shear Flow Calculation

Four Trucks maximum moment

maximum shearforce $V := 49.81\ kip$ $Q_{2.0d} = 209.3\ in^3$ $I_{2.0d} := 8361\ in^4$

$$\tau := \frac{V \cdot DF_{shear} \cdot Q_{2.0d}}{I_{2.0d} \cdot b_f} = 73.89\ psi$$ Actual shear flow

$$\tau := \frac{V \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 88.1\ psi$$ shear flow with fully composite

Four Trucks maximum shear

maximum shearforce $V := 63.631\ kip$ $Q_{maxmoment} = 174.3\ in^3$ $I_{maxmoment} := 7679\ in^4$

$$\tau := \frac{V \cdot DF_{shear} \cdot Q_{maxmoment}}{I_{maxmoment} \cdot b_f} = 85.584\ psi$$ Actual shear flow

$$\tau := \frac{V \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 112.55\ psi$$ shear flow with fully composite

Two Trucks maximum shear

maximum shearforce $V_{shear2t} = 39.11\ kip$

$$\tau := \frac{V_{shear2t} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 69.17\ psi$$ fully composite

Page 12 of 14

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-03

Calculation of Actual Distribution Factors

Four Trucks						
Position	LV4521	B3076	B3075	B3811	LV4523	B3066
Max mom	0.0029	-47.9404	-0.5452	65.5039	0.0000	-16.4265
Two Trucks						
Position	LV4521	B3076	B3075	B3811	LV4523	B3066

Four Trucks max moment DF analysis

$Total\_moment := 1273\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.395	0.416
"girder2"	0.368	0.516
"girder3"	0.381	0.516
"girder4"	0.407	0.516
"girder5"	0.449	0.416

Two Trucks max moment DF analysis

$Total\_moment := 847\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.362	0.416
"girder2"	0.366	0.516
"girder3"	0.371	0.516
"girder4"	0.422	0.516
"girder5"	0.479	0.416

Bridge #3067 STEUBEN ME
Route DYER BAY Road
Crossing DYER CREEK

Prepared By: Mahmood J. Alhraheemi
Checked By: SMT
Date : 2016-11-03

$DF_{external} := 0.416$

Four trucks maximum moment

$M_{maxmomentfourtrucks} = 809.35\ ft \cdot kip$

$S_{4trucksexternal} := 575.1\ in^3$

$measured\_strain\_4 := 205.52$

$$\varepsilon_{4external} := \frac{M_{maxmomentfourtrucks} \cdot DF_{external}}{S_{4trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 242.25$$

$K_b := 0.5$

$$K_{a4} := \frac{\varepsilon_{4external}}{measured\_strain\_4} - 1$$

$K_4 := 1 + K_b \cdot K_{a4} = 1.09$

Two trucks maximum moment

$M_{maxmomenttwotrucks} = 545.81\ ft \cdot kip$

$S_{2trucksexternal} := 575.1\ in^3$

$measured\_strain\_2 := 145.83$

$$\varepsilon_{2external} := \frac{M_{maxmomenttwotrucks} \cdot DF_{external}}{S_{2trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 163.37$$

$$K_{a2} := \frac{\varepsilon_{2external}}{measured\_strain\_2} - 1 = 0.12$$

$K_2 := 1 + K_b \cdot K_{a2} = 1.06$

Page 14 of 14

A.3 Waltham No. 3238

A.3.1 Input Data, Experimental Configuration, and Experimental Data Collected

Table 13: Waltham No. 3238 Bridge Input Data, Experimental Configuration, and Experimental Data Collected

File Contents	File Name	File Type
Bridge Geometry and Materials	Br3238_Geom.csv	CSV Format
Exterior Section Data	Br3238_Ext.csv	CSV Format
Interior Section Data	Br3238_Int.csv	CSV Format
Sensors	Br3238_Sensors.csv	CSV Format
Sensor Layout	Br3238_SensorLayout.csv	CSV Format
Truck Weight and Dimensions	Br3238_SensorLayout.mat	MATLAB Data File
Truck Starting Position	TestStart.m > Br3238_TestStart	MATLAB Data File
Truck Position Measurements	Br3238_Tk_Positions.mat	MATLAB Data File
Sensor Data	Br3238_1Tks_1Lns_1.xlsx	Microsoft Excel
	Br3238_2Tks_1Lns_1.xlsx	Microsoft Excel
	Br3238_2Tks_2Lns_1.xlsx	Microsoft Excel
	Br3238_4Tks_2Lns_1.xlsx	Microsoft Excel
Data Time Indices	Br3238_1Tks_1Lns_1_Time.csv	CSV Format
	Br3238_2Tks_1Lns_1_Time.csv	CSV Format
	Br3238_2Tks_2Lns_1_Time.csv	CSV Format
	Br3238_4Tks_2Lns_1_Time.csv	CSV Format

A.3.2 Instrumentation

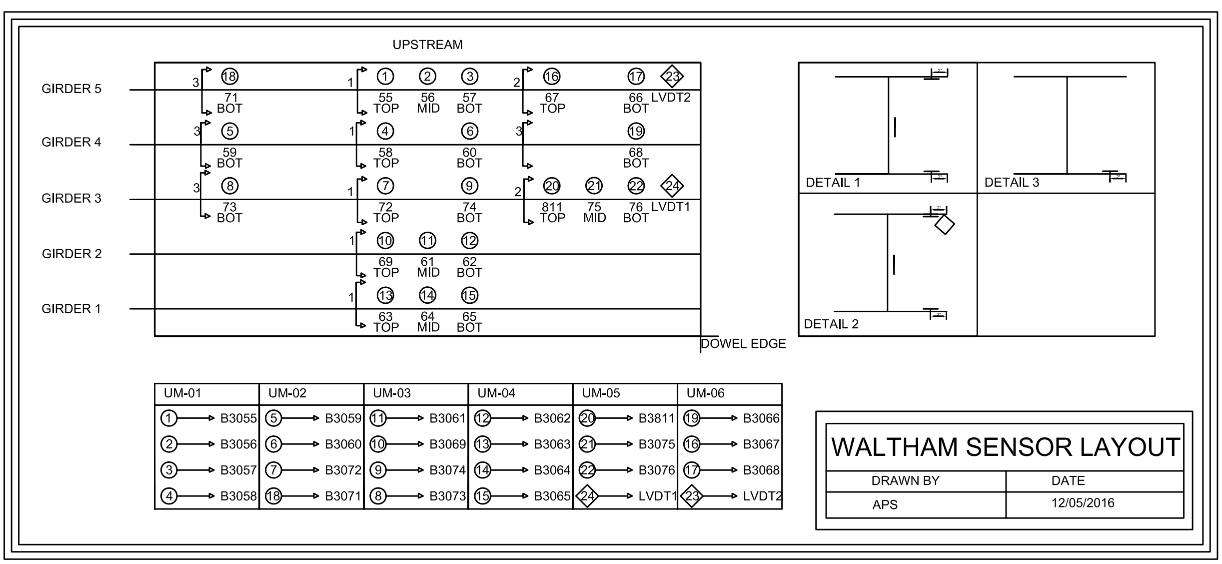


Figure 28: Waltham No. 3238 sensor layout

A.3.3 Loading

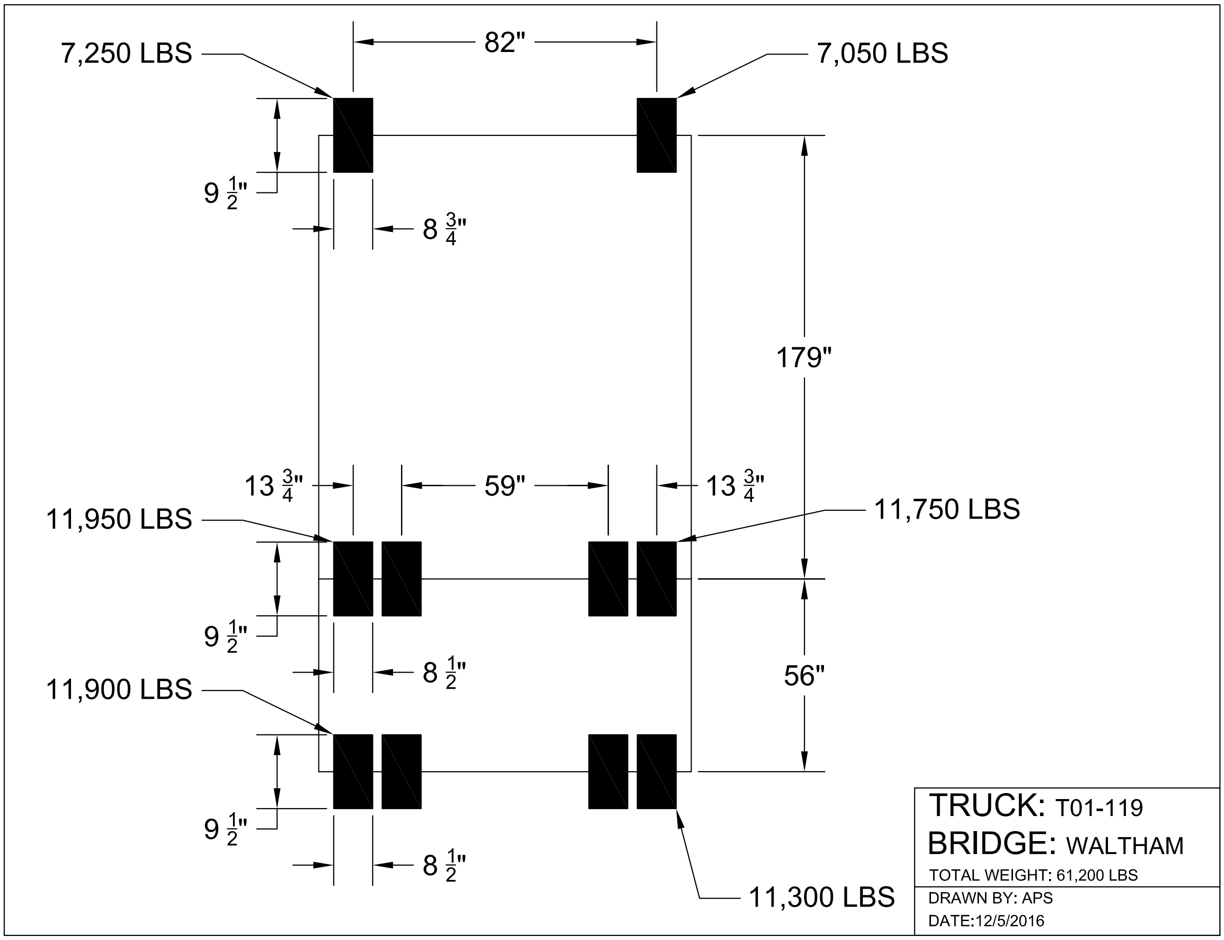


Figure 29: Waltham No. 3238 Truck T01-119 loading

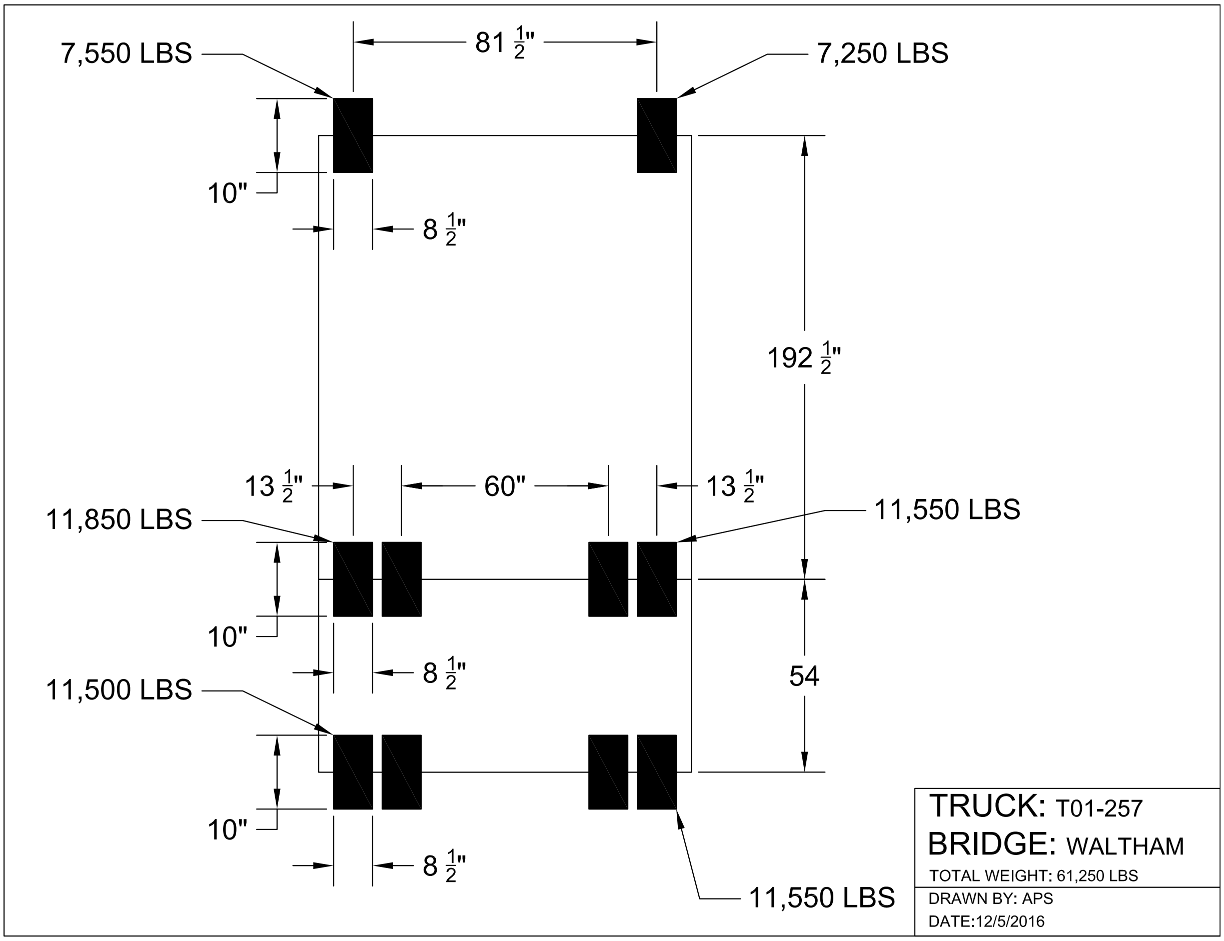


Figure 30: Waltham No. 3238 Truck T01-257 loading

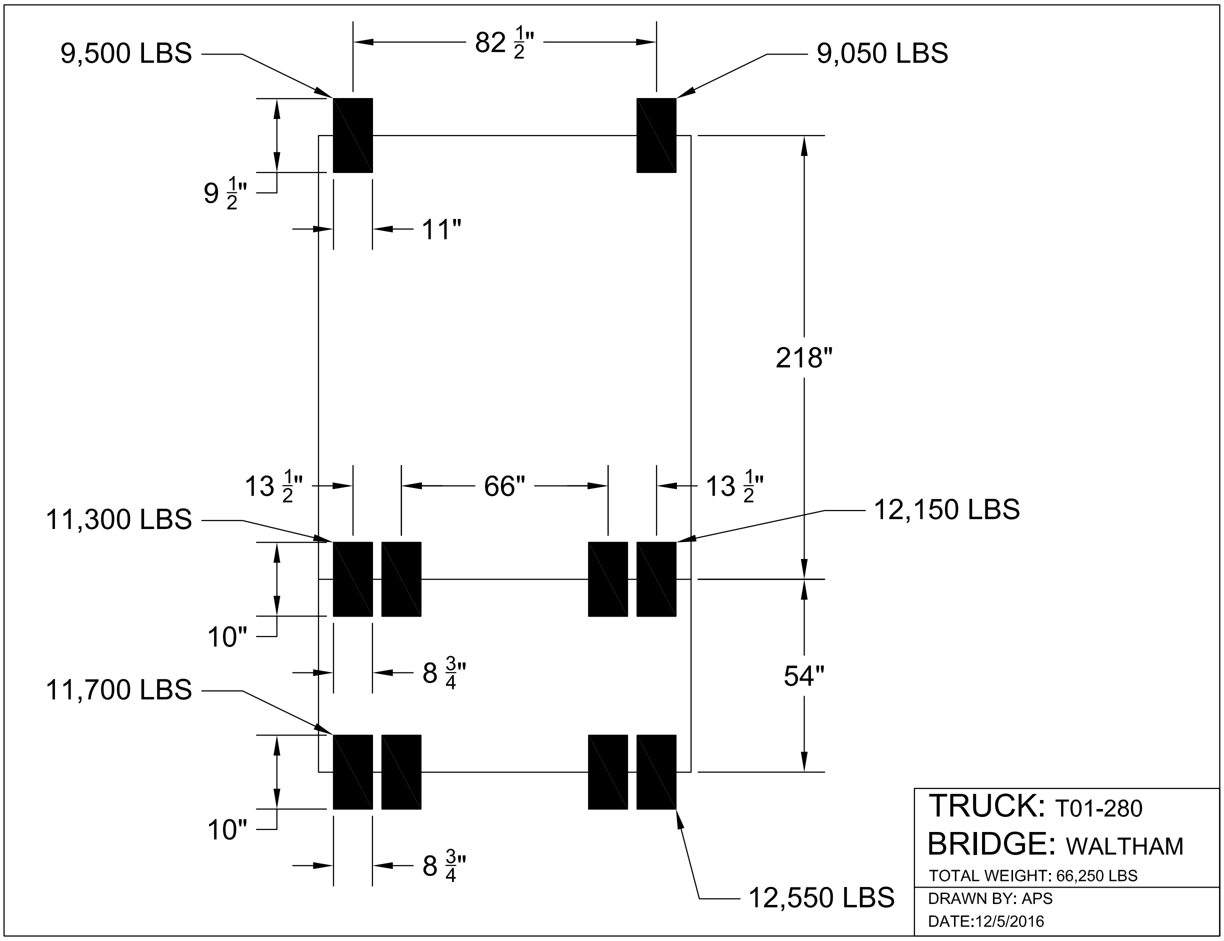


Figure 31: Waltham No. 3238 Truck T01-280 loading

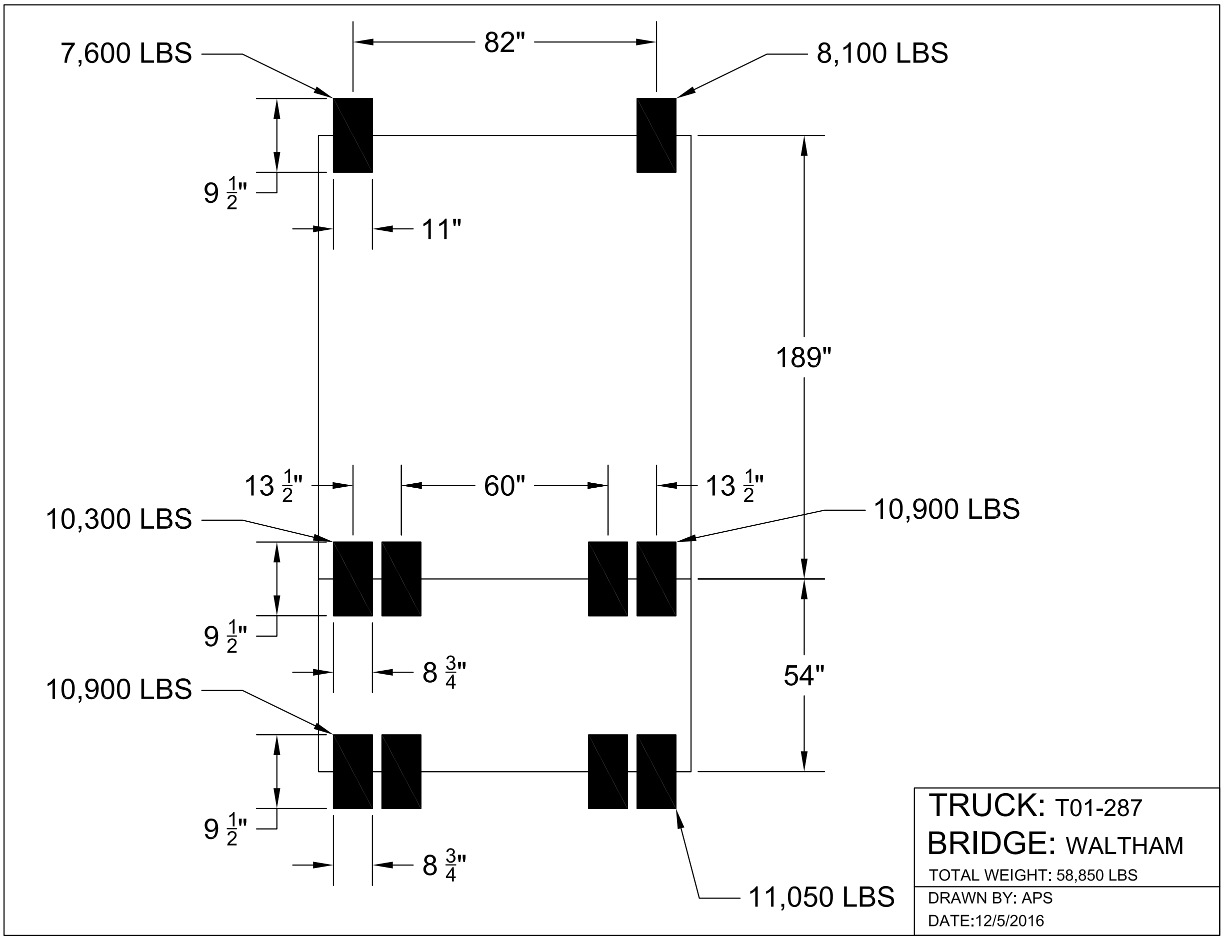


Figure 32: Waltham No. 3238 Truck T01-287 loading

A.3.4 Representative Data Plots

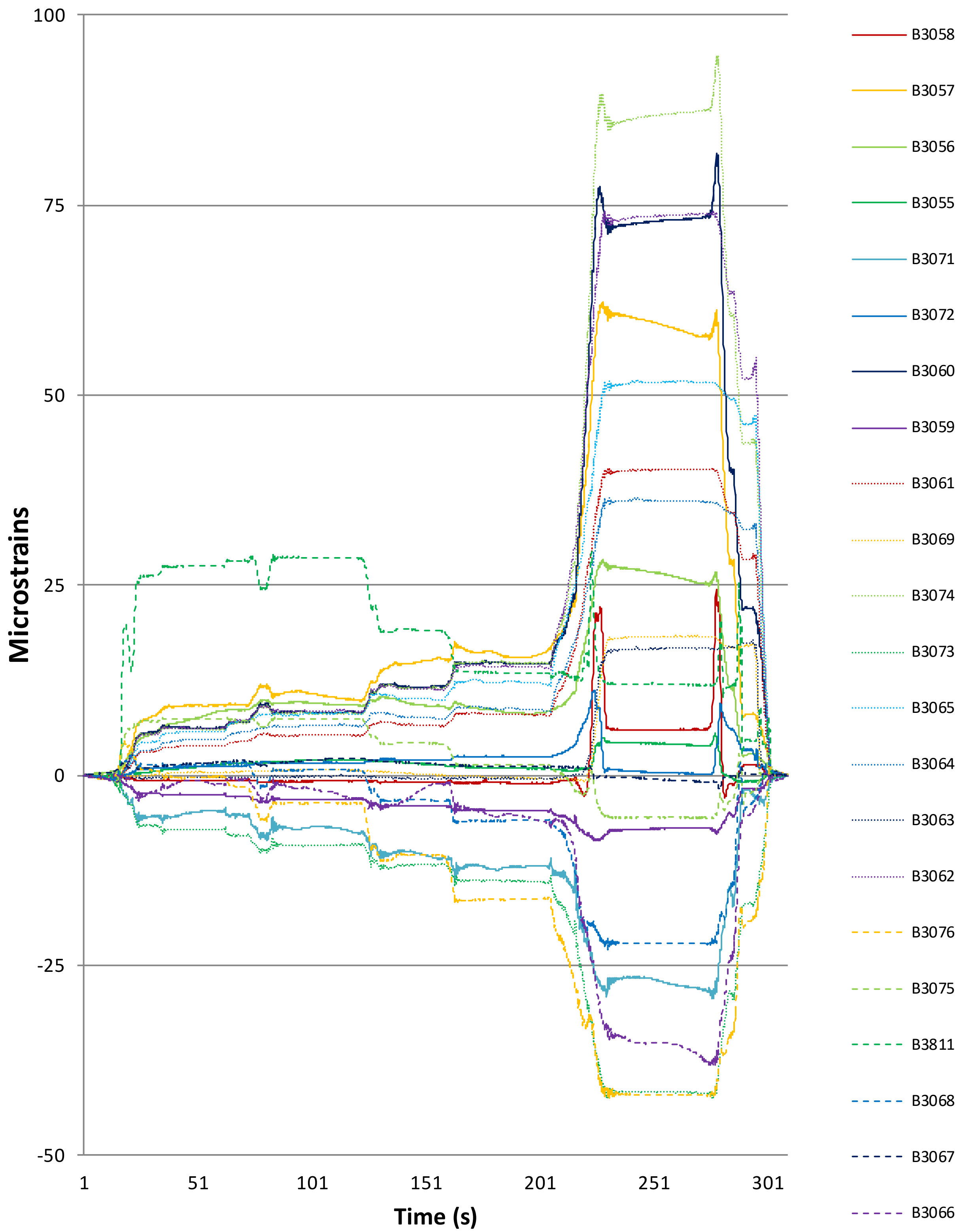


Figure 33: Waltham No. 3238 - 2 trucks 2 lanes test 2 strains

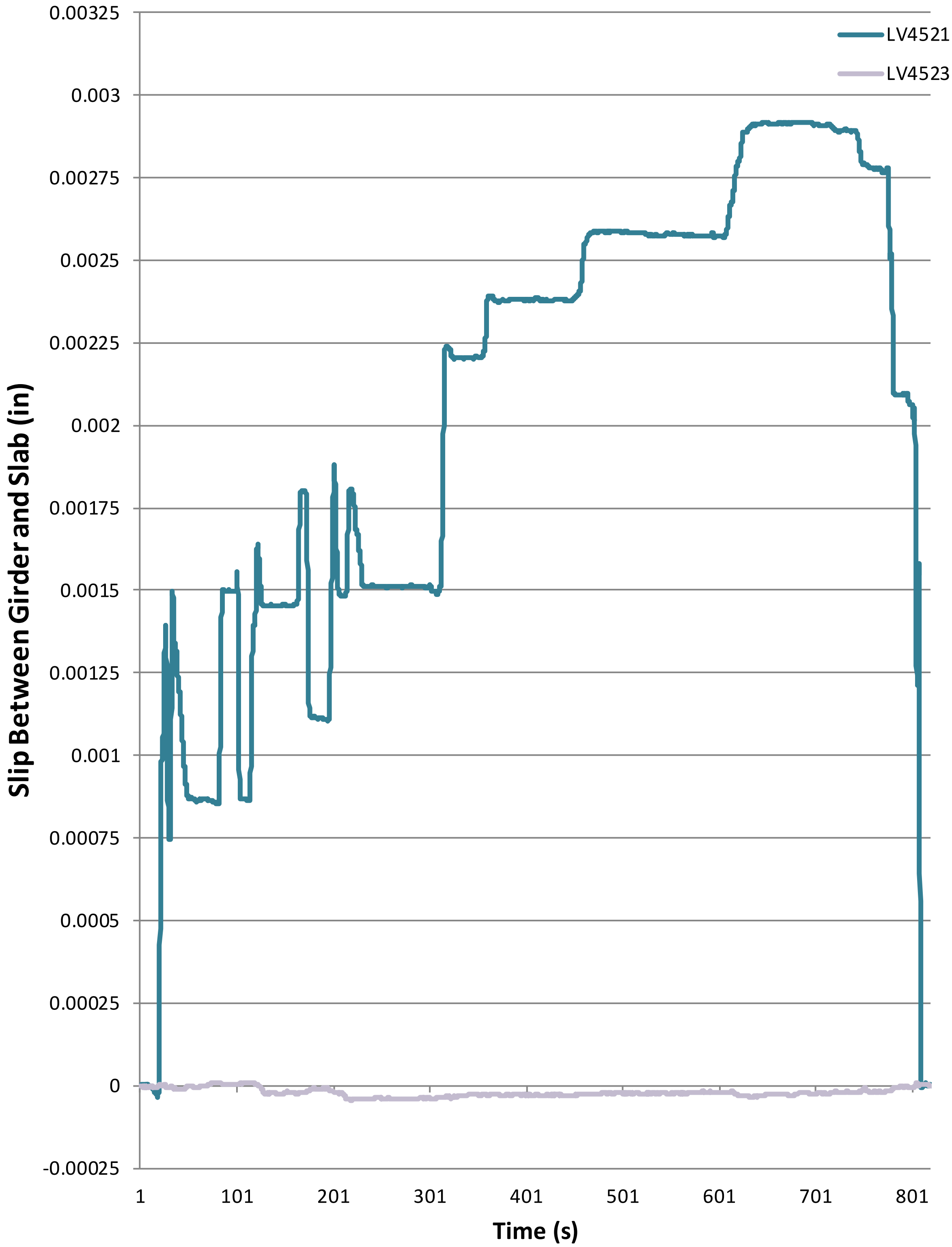


Figure 34: Waltham No. 3238 - 2 trucks 2 lanes test 2 shear slip

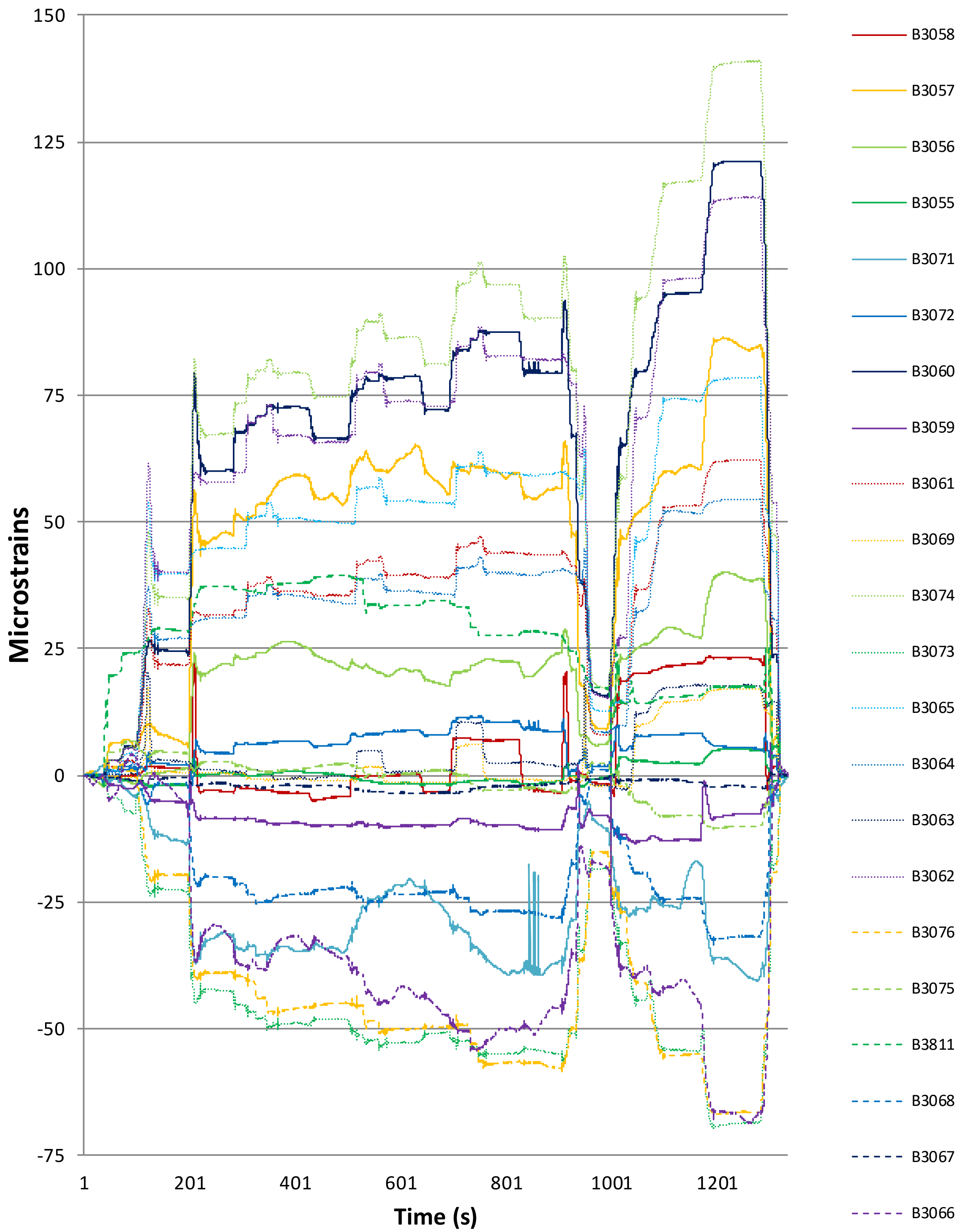


Figure 35: Waltham No. 3238 - 4 trucks 2 lanes test 1 strains

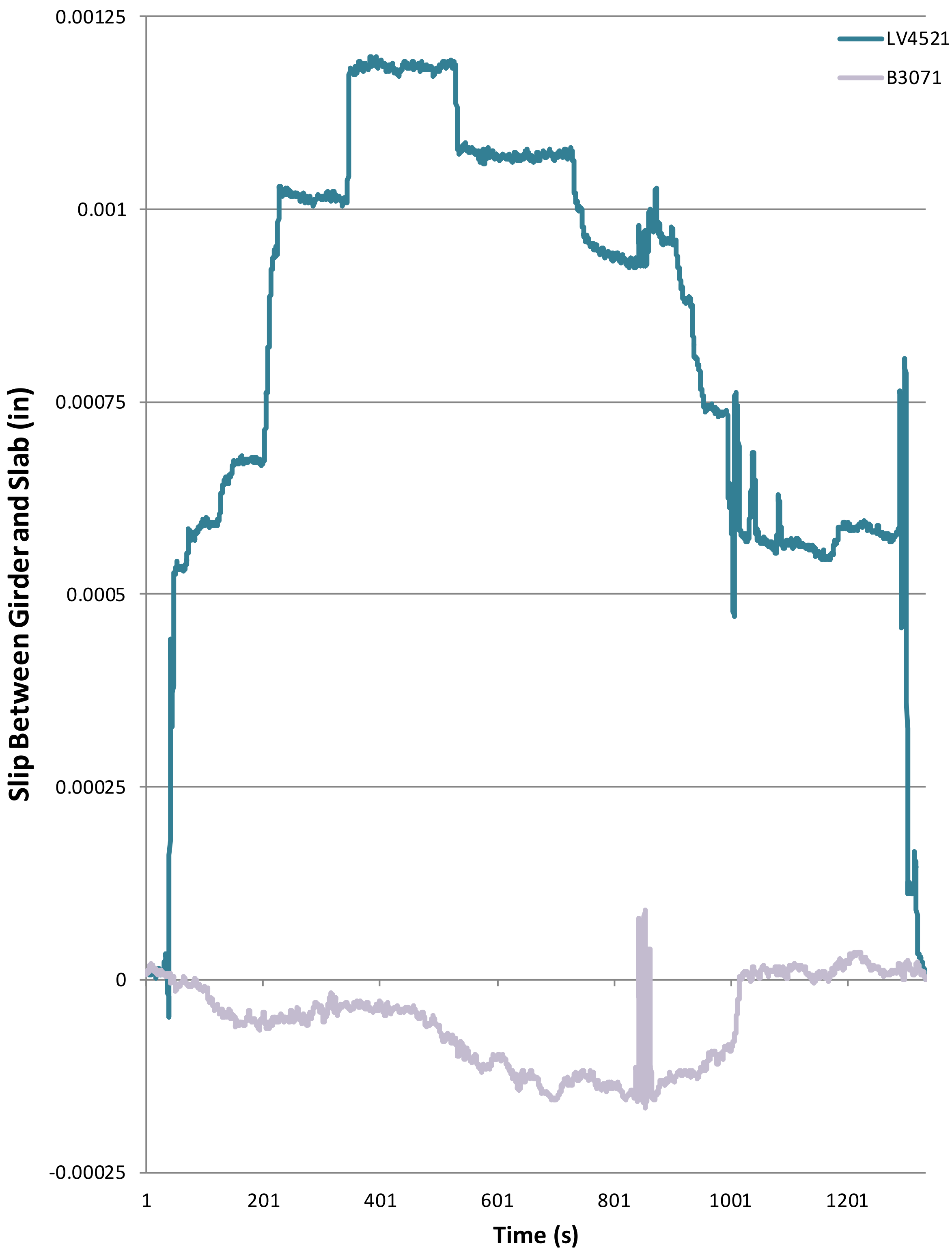


Figure 36: Waltham No. 3238 - 4 trucks 2 lanes test 1 shear slip

A.3.5 Rating Factor Calculations

Figure 37: Waltham No. 3238 Calculations

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Year Built: 1935

Table 6A.5.2.1-1—Minimum Compressive Strength of Concrete by Year of Construction

Year of Construction	Compressive Strength, f'_c, ksi
Prior to 1959	2.5
1959 and Later	3.0

$f'_c := 2.5\ ksi$

$\gamma c := 150\ pcf$

$\gamma_{c\_mod} := 145\ pcf$

LRFD Design
Eq. 5.4.2.4-1

$$Ec := 33000 \cdot \gamma_{c\_mod}{}^{1.5} \cdot \sqrt[2]{f'_c}$$

$Ec := 2880.95\ ksi$

$\gamma_{w.s.} := 156\ pcf$

Table 6A.6.2.1-1—Minimum Mechanical Properties of Structural Steel by Year of Construction

Year of Construction	Minimum Yield Point or Minimum Yield Strength, F_y, ksi	Minimum Tensile Strength, F_u, ksi
Prior to 1905	26	52
1905 to 1936	30	60
1936 to 1963	33	66
After 1963	36	66

$fy := 30\ ksi$

$\gamma s := 490\ pcf$

$Es := 29000\ ksi$

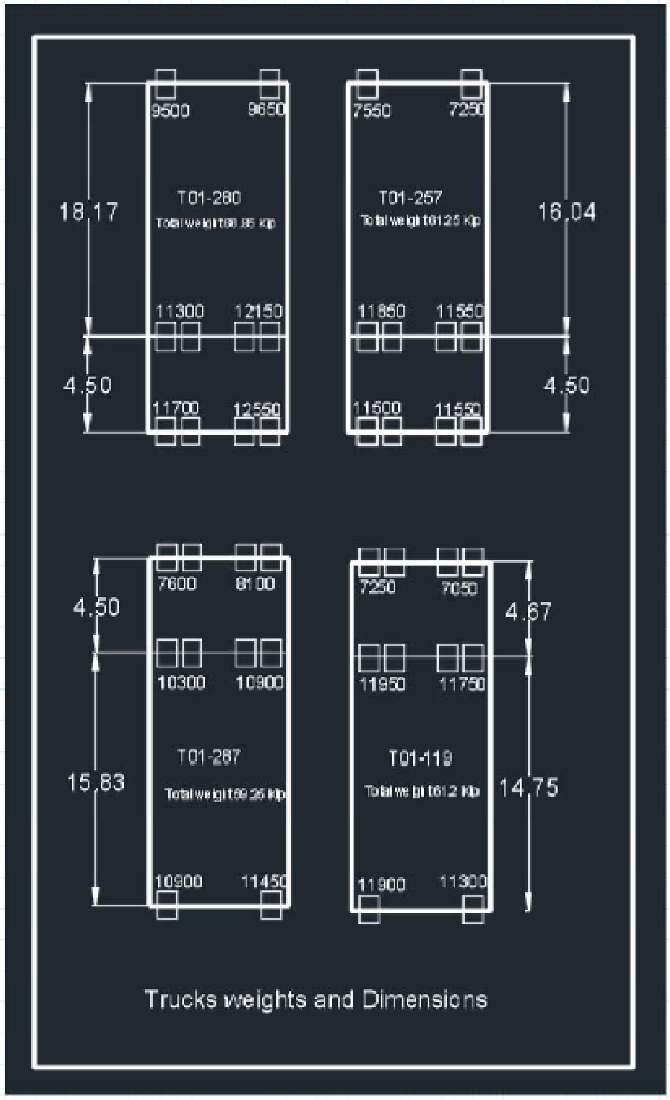
Bridge Length	$L := 55\ ft$
Deck thickness	$ts := 7\ in$
Wearing surface thickness	$t_{w.s.} := 4\ in$
Spacing between Girders	$S := 5.5\ ft$

Page 1 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alhraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Trucks Weight & dimensions



Page 2 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alabraheemi
Checked By: Scott Tomlinson PE
Date : 201611-02

Loads on the Interior Girder

DeadLoad:

$M_{DC} := 328\ ft \cdot kip$ VHB report

$M_{DW} := 87\ ft \cdot kip$ VHB report

Live Load :

We use the average truck weight and dimensions in this calculations

	T01-280	T01287	T01-257	T01119
Front wheel	19150	15700	14800	14300
front rear wheel	23450	21200	23400	23700
rear Wheel	24250	22350	23050	23200

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Live Load Analysis

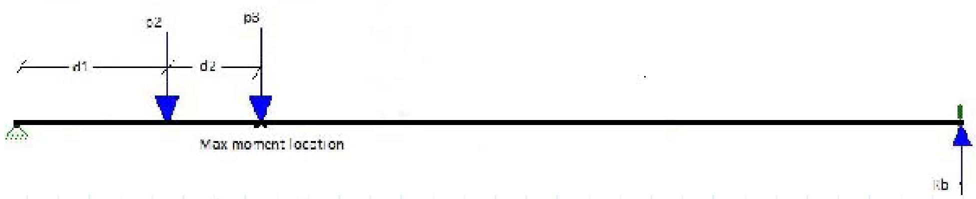
Two trucks in two lanes

$p3 := 23.3\ kip$ $p2 := 22.3\ kip$ $p1 := 17.4\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 17\ ft$

Trucks at shear locations:

d1: distance between front rear wheel and the support



$$R_b(d1) := \frac{p2 \cdot d1 + p3 \cdot (d1 + d2)}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d2))$$

At 0.5 d from support

$d1 := 1.5\ ft$

$M(1.5\ ft) = 163.048\ ft \cdot kip$

$M_{0.5dtwotrucks} := 163.048\ ft \cdot kip$

$R_b(d1) = 3.362\ kip$

$R_a(d1) := p2 + p3 - R_b(d1)$

$V_{shear2t} := R_a(d1)$

At 1.0 d from support

$d1 := 3\ ft$

$M(3\ ft) = 216.456\ ft \cdot kip$

$M_{1.0dtwotrucks} := 216.456 \cdot ft \cdot kip$

At 1.5 d from support

$d1 := 4.5\ ft$

$M(4.5\ ft) = 266.134\ ft \cdot kip$

$M_{1.5dtwotrucks} := 266.134 \cdot ft \cdot kip$

At 2.0 d from support

$d1 := 6\ ft$

$M(6\ ft) = 312.08\ ft \cdot kip$

$M_{2.0dtwotrucks} := 312.08 \cdot ft \cdot kip$

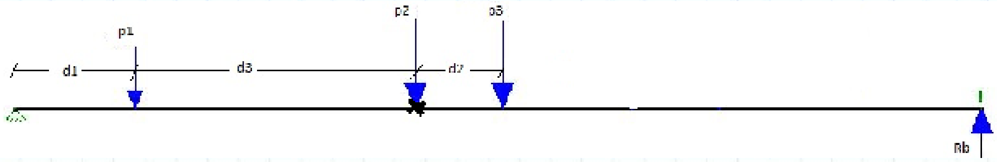
Page 4 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Trucks at Maximum Moment location:

d1 distance between front wheel and the support



$$R_b(d1) := \frac{(p1 \cdot d1) + (p2 \cdot (d1 + d3)) + (p3 \cdot (d1 + d2 + d3))}{L}$$

$M(d1) := R_b(d1) \cdot (L - (d1 + d3)) - p3 \cdot (d2)$

$R_b(11.5\ ft) = 29.385\ kip$

$M(11.5\ ft) = 662.215\ ft \cdot kip$ $\quad M_{maxmomenttwotrucks} := 662.215 \cdot ft \cdot kip$

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Four trucks in two lanes

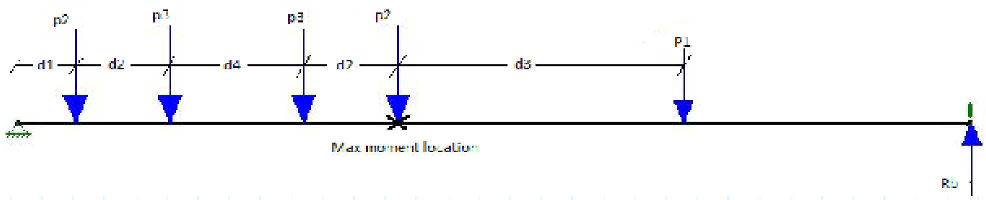
$p1 := 16\ kip$ $p2 := 22.9\ kip$ $p3 := 23.2\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5\ ft$

d3 distance between front wheel and front rear wheel $d3 := 16\ ft$

Trucks at shear locations:

d1 distance between front rear wheel and the support ; d4 distance between trucks



$$R_b(d1,d4) := \frac{p2 \cdot d1 + p3 \cdot (d1+d2) + p3 \cdot (d1+d2+d4) + p2 \cdot (d1+2 \cdot d2+d4) + p1 \cdot (d1+2 \cdot d2+d4+d3)}{L}$$

$$M(d1,d4) := (R_b(d1,d4) \cdot (L-(d1+d2+d4+d2))) - (p1 \cdot (d3))$$

At o.5 d from support

$d1 := 1.5\ ft$ $d4 := 7.5\ ft$

$M(1.5\ ft, 7.5\ ft) = 729.124\ ft \cdot kip$

$M_{0.5dfourtrucks} := 729.124\ (ft \cdot kip)$

$R_b(1.5\ ft, 7.5\ ft) = 27.365\ kip$

$R_a := 2 \cdot p2 + 2 \cdot p3 + p1 - R_b(1.5\ ft, 7.5\ ft) = ?\ kip$

At 1.0 d from support

$d1 := 3\ ft$ $d4 := 7.6\ ft$

$M(3\ ft, 7.6\ ft) = 790.736\ ft \cdot kip$

$M_{1.0dfourtrucks} := 790.736\ (ft \cdot kip)$

At 1.5 d from support

$d1 := 4.5\ ft$ $d4 := 7.4\ ft$

$M(4.5\ ft, 7.4\ ft) = 841.379\ ft \cdot kip$

$M_{1.5dfourtrucks} := 841.379\ (ft \cdot kip)$

At 2.0 d from support

$d1 := 6\ ft$ $d4 := 7.3\ ft$

$M(6\ ft, 7.3\ ft) = 884.929\ ft \cdot kip$

$M_{2.0dfourtrucks} := 884.929\ (ft \cdot kip)$

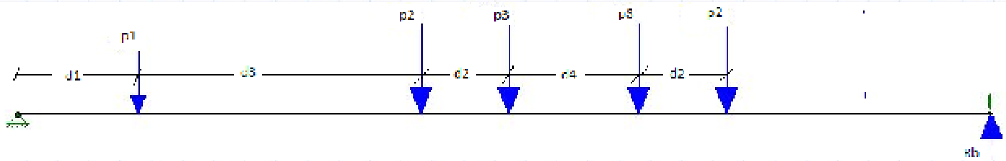
Page 6 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Trucks at Maximum Moment location:

d1 distance between front wheel and the support ; d4 distance between trucks



$$R_b(d1,d4) := \frac{p1 \cdot d1 + p2 \cdot (d1+d3) + p3 \cdot (d1+d3+d2) + p3 \cdot (d1+d3+d2+d4) + p2 \cdot (d1+d3+2 \cdot d2+d4)}{L}$$

$$M(d1,d4) := (R_b(d1,d4) \cdot (L-(d1+d3+d2))) - (p2 \cdot (d2+d4)) - (p3 \cdot d4)$$

$$R_b(6.8\ ft, 7.3\ ft) = 54.7\ kip$$

$$M(6.8\ ft, 7.3\ ft) = 1036.805\ ft \cdot kip$$

$$M_{maxmomentfourtrucks} := 1036.8 \cdot ft \cdot kip$$

Page 7 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Section Properties and Distribution Factors

Q_slab =		435.4	in^3		
External Girder Section Properties				Second assumption	
			modular	transf.	
componen	width	thickness	ratio	area	y

Moment Distribution factors (Interior Girders)

VHBreport

$DF_{onelane} = 0.375$
$DF_{twolanes} = 0.49$

Calculated Distribution factors basedon actual measurements

$DF_{onelane} := 0.377$
$DF_{twolanes} := 0.493$
$DF_{shear} := 0.634$

Section Properties:Fully composite

$y' := 33.9\ in$ $I := 27314 \cdot in^4$ $S_{bot} := 806.1 \cdot in^3$ $Q_{slab} := 698.0 \cdot in^3$

$b_f := 11.98\ in$

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Maximum Live Load Moment calculation in each loadcase for the interior girder

Two trucks in two lanes

$Mt_{0.5dtwotrucks} := DF_{twolanes} \cdot M_{0.5dtwotrucks} = 80\ ft \cdot kip$

$Mt_{1.0dtwotrucks} := DF_{twolanes} \cdot M_{1.0dtwotrucks} = 105\ ft \cdot kip$

$Mt_{1.5dtwotrucks} := DF_{twolanes} \cdot M_{1.5dtwotrucks} = 130\ ft \cdot kip$

$Mt_{2.0dtwotrucks} := DF_{twolanes} \cdot M_{2.0dtwotrucks} = 152\ ft \cdot kip$

$Mt_{maxmomenttwotrucks} := DF_{twolanes} \cdot M_{maxmomenttwotrucks} = 326\ ft \cdot kip$

Four trucks in two lanes

$Mt_{0.5dfourtrucks} := DF_{twolanes} \cdot M_{0.5dfourtrucks} = 359\ ft \cdot kip$

$Mt_{1.0dfourtrucks} := DF_{twolanes} \cdot M_{1.0dfourtrucks} = 390\ ft \cdot kip$

$Mt_{1.5dfourtrucks} := DF_{twolanes} \cdot M_{1.5dfourtrucks} = 415\ ft \cdot kip$

$Mt_{2.0dfourtrucks} := DF_{twolanes} \cdot M_{2.0dfourtrucks} = 436\ ft \cdot kip$

$Mt_{maxmomentfourtrucks} := DF_{twolanes} \cdot M_{maxmomentfourtrucks} = 511\ ft \cdot kip$

Actual section Response

1.0d	-4.329146915	55.489869	22.41063	0.288809	-34.0286	6.025945	66.6797	-9.96326
1.5d	-3.231458311	58.234414	18.40945	-1.68524	-25.1511	7.947325	72.28859	-9.93835
2.0d	-2.886442548	55.091825	20.77649	-1.60974	-39.5641	8.930679	79.44879	-10.6193
MaxMome	23.18579254	84.933748	39.37371	5.162854	-38.2792	5.548775	121.3018	-7.66561
Two Trucks 1								

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Four Trucks

$y'_{0.5d} := 37.4\ in$ $S_{0.5d} := 806.1\ in^3$ Fully composite

$y'_{1.0d} := 38.0\ in$ $S_{1.0d} := 806.1\ in^3$ Fully composite

$y'_{1.5d} := 38.7\ in$ $S_{1.5d} := 806.1\ in^3$ Fully composite

$y'_{2.0d} := 38.7\ in$ $S_{2.0d} := 806.1\ in^3$ Fully composite

$y'_{maxmoment} := 36.3\ in$ $S_{maxmoment} := 806.1\ in^3$ Fully composite

$$M_{fourtrucks} := \begin{bmatrix} M_{0.5dfourtrucks} \\ Mt_{1.0dfourtrucks} \\ Mt_{1.5dfourtrucks} \\ Mt_{2.0dfourtrucks} \\ Mt_{maxmomentfourtrucks} \end{bmatrix} \ ; \ y_{fourtrucks} := \begin{bmatrix} y'_{0.5d} \\ y'_{1.0d} \\ y'_{1.5d} \\ y'_{2.0d} \\ y'_{maxmoment} \end{bmatrix} \ ; \ S_{fourtrucks} := \begin{bmatrix} S_{0.5d} \\ S_{1.0d} \\ S_{1.5d} \\ S_{2.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \frac{Mt_{0.5dfourtrucks}}{S_{0.5d} \cdot 29000\ ksi} \\ \frac{Mt_{1.0dfourtrucks}}{S_{1.0d} \cdot 29000\ ksi} \\ \frac{Mt_{1.5dfourtrucks}}{S_{1.5d} \cdot 29000\ ksi} \\ \frac{Mt_{2.0dfourtrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \frac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 184.52 \\ 200.112 \\ 212.928 \\ 223.949 \\ 262.383 \end{bmatrix}$$

$Kb := 1.0$ $Kb := 0.5$

$Ka := \frac{259.19}{200.71} - 1 = 0.291$ $Ka := \frac{262.38}{140.87} - 1 = 0.863$

$K := 1 + Kb \cdot Ka = 1.291$ $K := 1 + Kb \cdot Ka = 1.43$

Page 10 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Two Trucks 1

$y'_{0.5d} := 41.4\ in$ $S_{0.5d} := 806.1\ in^3$ Fully composite
$y'_{1.0d} := 41.8\ in$ $S_{1.0d} := 806.1\ in^3$ Fully composite
$y'_{1.5d} := 42.6\ in$ $S_{1.5d} := 806.1\ in^3$ Fully composite
$y'_{2.0d} := 33.9\ in$ $S_{2.0d} := 806.1\ in^3$ Fully composite
$y'_{maxmoment} := 35.3\ in$ $S_{maxmoment} := 806.1\ in^3$ Fully composite

$$M_{twotrucks} := \begin{bmatrix} Mt_{0.5dtwotrucks} \\ Mt_{1.0dtwotrucks} \\ Mt_{1.5dtwotrucks} \\ Mt_{2.0dtwotrucks} \\ Mt_{maxmomenttwotrucks} \end{bmatrix} \quad y_{twotrucks} := \begin{bmatrix} y'_{0.5d} \\ y'_{1.0d} \\ y'_{1.5d} \\ y'_{2.0d} \\ y'_{maxmoment} \end{bmatrix} \quad S_{twotrucks1} := \begin{bmatrix} S_{0.5d} \\ S_{1.0d} \\ S_{1.5d} \\ S_{2.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \dfrac{Mt_{0.5dtwotrucks}}{S_{0.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.0dtwotrucks}}{S_{1.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.5dtwotrucks}}{S_{1.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{2.0dtwotrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{maxmomenttwotrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 41.263 \\ 54.779 \\ 67.351 \\ 78.978 \\ 167.587 \end{bmatrix}$$

$Kb := 1.0$ $Kb := 0.5$

$Ka := \dfrac{165.547}{133.15} - 1 = 0.243$ $Ka := \dfrac{167.587}{91.42} - 1 = 0.833$

$K := 1 + Kb \cdot Ka = 1.243$ $K := 1 + Kb \cdot Ka = 1.42$

Page 11 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

Shear Flow Calculation

Four Trucks maximum moment

maximum shearforce $V := 54.7\ kip$

$$\tau := \frac{V \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 73.98\ psi$$

Fully composite

Four Trucks maximum shear

maximum shearforce $V := 80.835\ kip$

$$\tau := \frac{V \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 109.321\ psi$$

Fully composite

Two Trucks maximum shear

maximum shearforce $V_{shear2t} = 42.238\ kip$

$$\tau := \frac{V_{shear2t} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 57.123\ psi$$

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Alraheemi
Checked By: Scott Tomlinson PE
Date : 201611-02

Calculation of Actual Distribution Factors

S_bottom =		765.6	in^3					
Mmidspar	94.04172333							
					Total I	674		

Four Trucks maxmoment DF analysis

$Total\_moment := 1035\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.304	0.38
"girder2"	0.457	0.493
"girder3"	0.530	0.493
"girder4"	0.429	0.493
"girder5"	0.281	0.38

Two Trucks max moment DF analysis

$Total\_moment := 674\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.319	0.38
"girder2"	0.444	0.493
"girder3"	0.529	0.493
"girder4"	0.429	0.493
"girder5"	0.279	0.38

Page 13 of 14

Bridge #3238 Waltham ME
Route 179 crossing Union River

Prepared By: Mahmood J. Abraheemi
Checked By: Scott Tomlinson PE
Date : 2016-11-02

$DF_{external} := 0.38$

Four trucks maximum moment

$M_{maxmomentfourtrucks} = \left(1.037 \cdot 10^3\right)\ ft \cdot kip$

$S_{4trucksexternal} := 765.6\ in^3$

$measured\_strain\_4 := 84.93$

$$\varepsilon_{4external} := \frac{M_{maxmomentfourtrucks} \cdot DF_{external}}{S_{4trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 212.941$$

$K_b := 0.5$

$$K_{a4} := \frac{\varepsilon_{4external}}{measured\_strain\_4} - 1$$

$K_4 := 1 + K_b \cdot K_{a4} = 1.754$

Two trucks maximum moment

$M_{maxmomenttwotrucks} = 662.215\ ft \cdot kip$

$S_{2trucksexternal} := 765.6\ in^3$

$measured\_strain\_2 := 58.19$

$$\varepsilon_{2external} := \frac{M_{maxmomenttwotrucks} \cdot DF_{external}}{S_{2trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 181.06$$

$$K_{a2} := \frac{\varepsilon_{2external}}{measured\_strain\_2} - 1 = 2.112$$

$K_2 := 1 + K_b \cdot K_{a2} = 2.056$

Page 14 of 14

A.4 Pembroke No. 3884

A.4.1 Input Data, Experimental Configuration, and Experimental Data Collected

Table 13: Pembroke No. 3884 Bridge Input Data, Experimental Configuration, and Experimental Data Collected

File Contents	File Name	File Type
Bridge Geometry and Materials	Br3884 _Geom.csv	CSV Format
Exterior Section Data	Br3884 _Ext.csv	CSV Format
Interior Section Data	Br3884 _Int.csv	CSV Format
Sensors	Br3884 _Sensors.csv	CSV Format
Sensor Layout	Br3884 _SensorLayout.csv	CSV Format
Truck Weight and Dimensions	Br3884_SensorLayout.mat	MATLAB Data File
Truck Starting Position	TestStart.m > Br3884 _TestStart	MATLAB Data File
Truck Position Measurements	Br3884 _Tk_Positions.mat	MATLAB Data File
Sensor Data	Br3884 _1Tks_1Lns_1.xlsx	Microsoft Excel
	Br3884 _2Tks_1Lns_1.xlsx	Microsoft Excel
	Br3884 _4Tks_2Lns_1.xlsx	Microsoft Excel
Data Time Indices	Br3884_1Tks_1Lns_1_Time.csv	CSV Format
	Br3884_2Tks_1Lns_1_Time.csv	CSV Format
	Br3884_4Tks_2Lns_1_Time.csv	CSV Format

A.4.2 Instrumentation

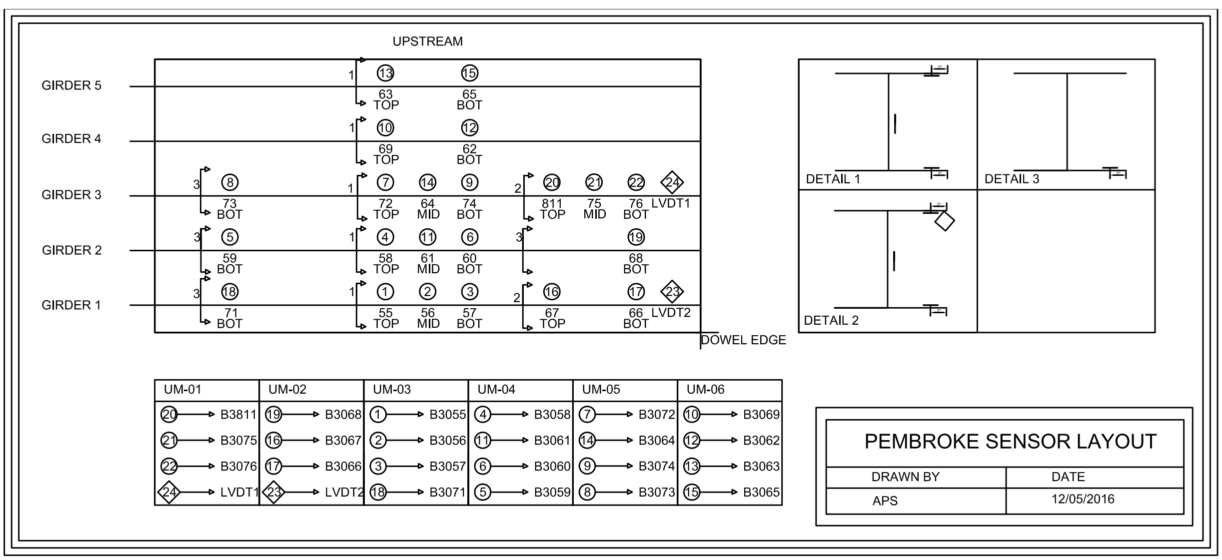


Figure 38: Pembroke No. 3884 sensor layout

A.4.3 Loading

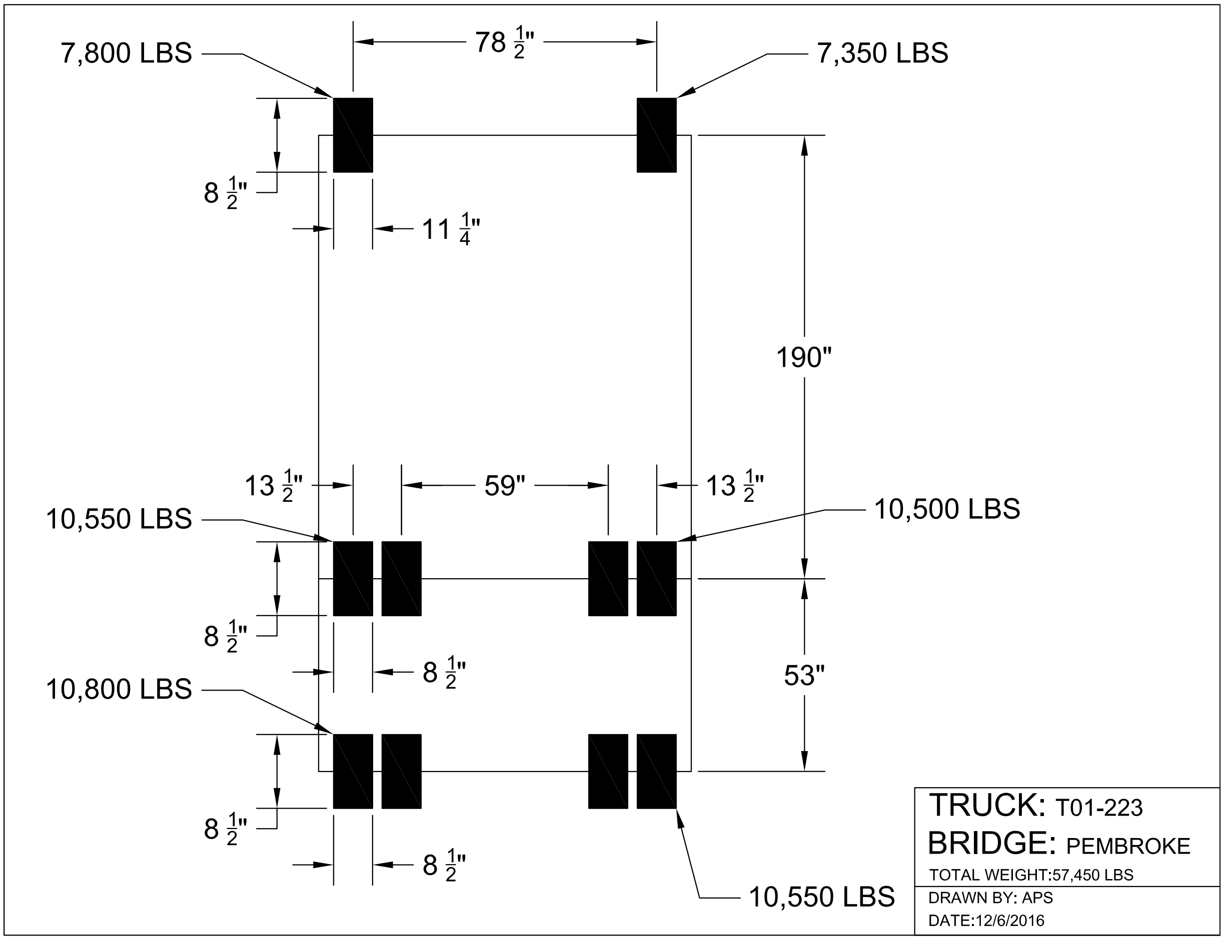


Figure 39: Pembroke No. 3884 Truck T01-223 loading

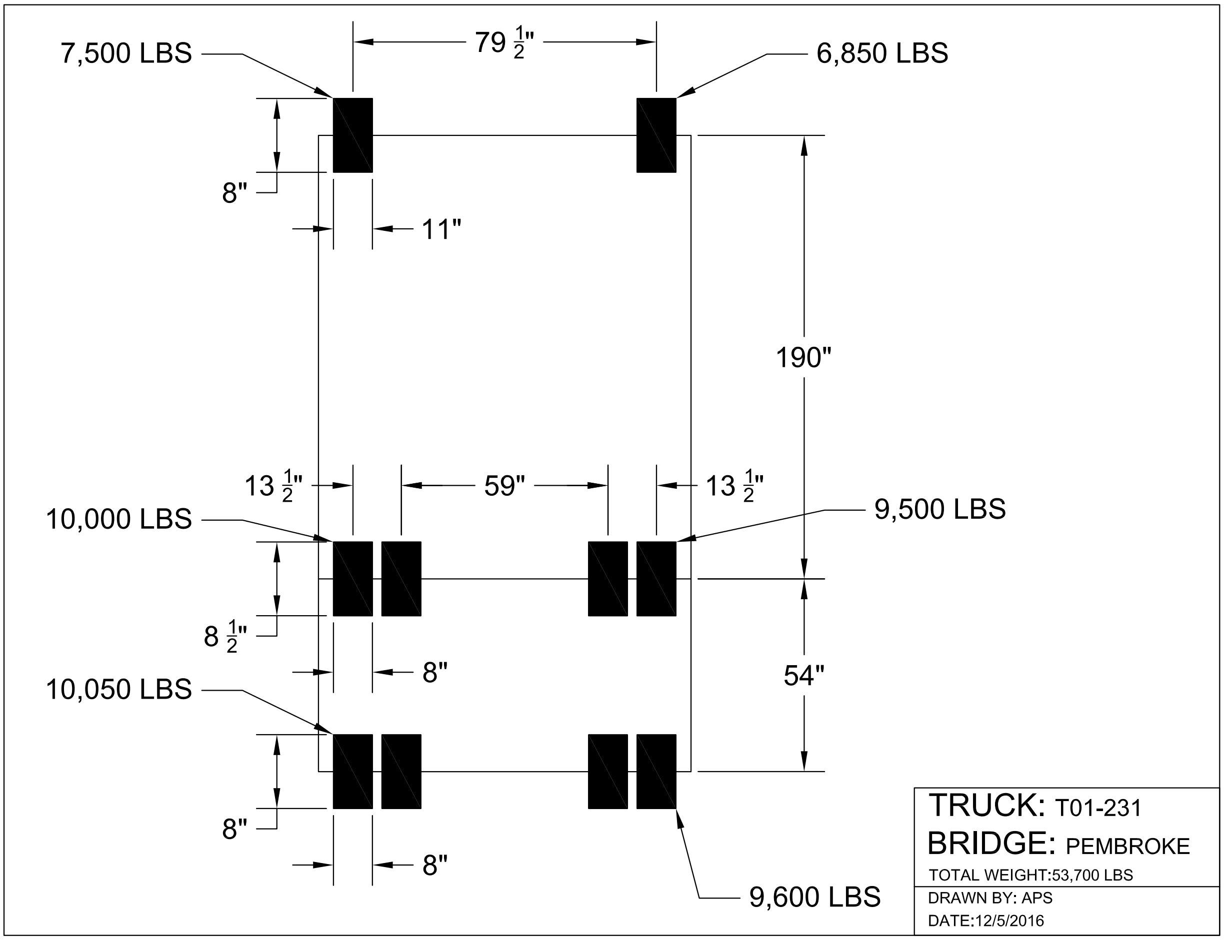


Figure 40: Pembroke No. 3884 Truck T01-231 loading

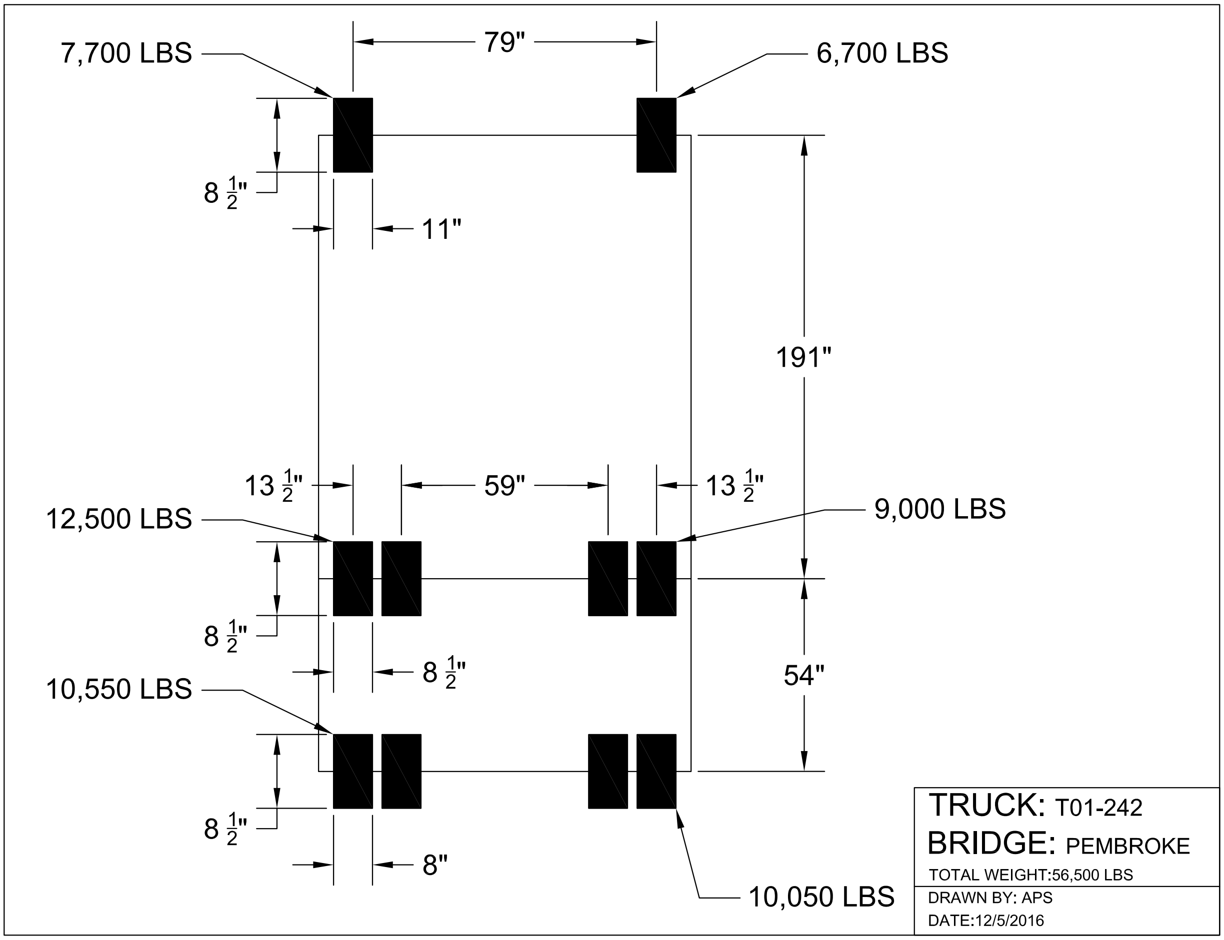


Figure 41: Pembroke No. 3884 Truck T01-242 loading

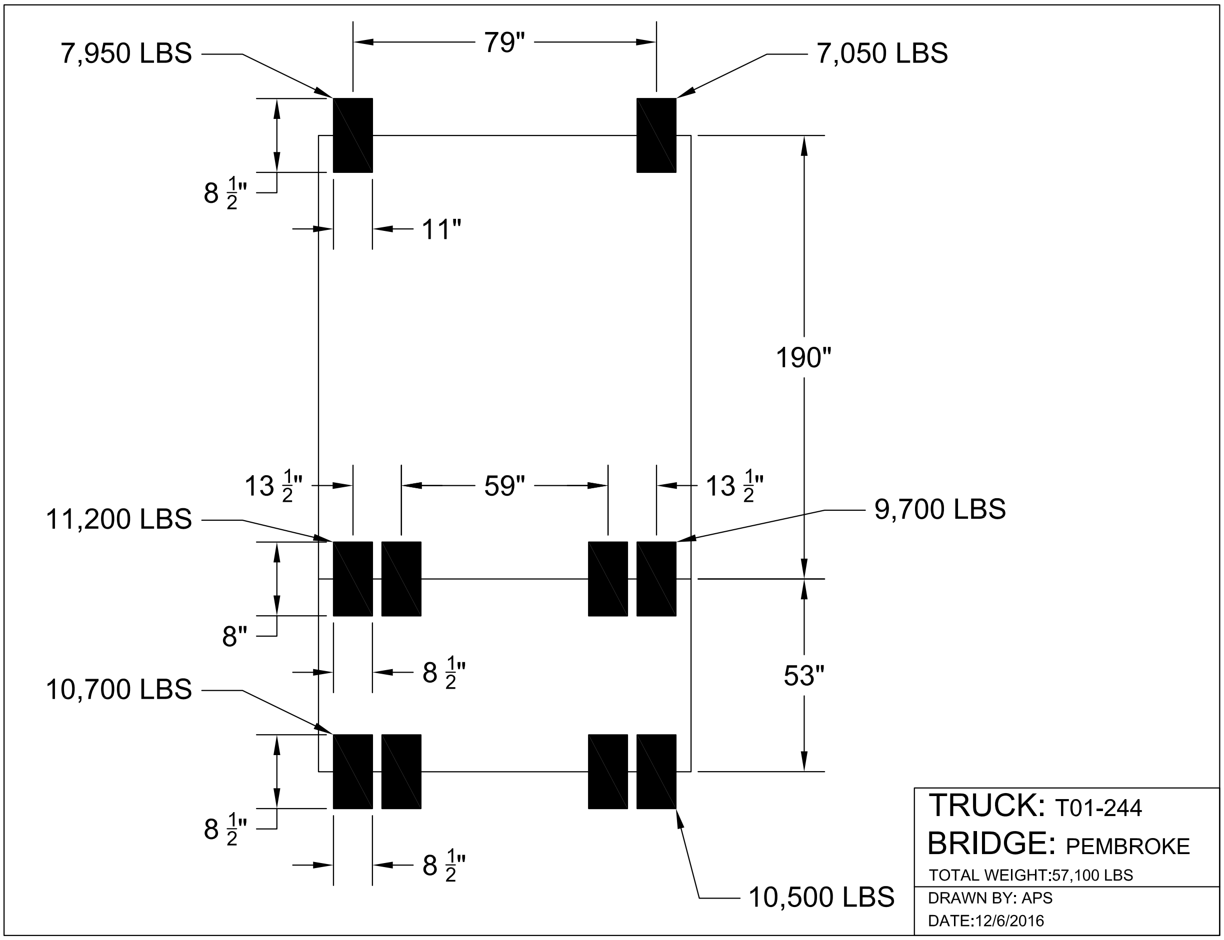


Figure 42: Pembroke No. 3884 Truck T01-244 loading

A.4.4 Representative Data Plots

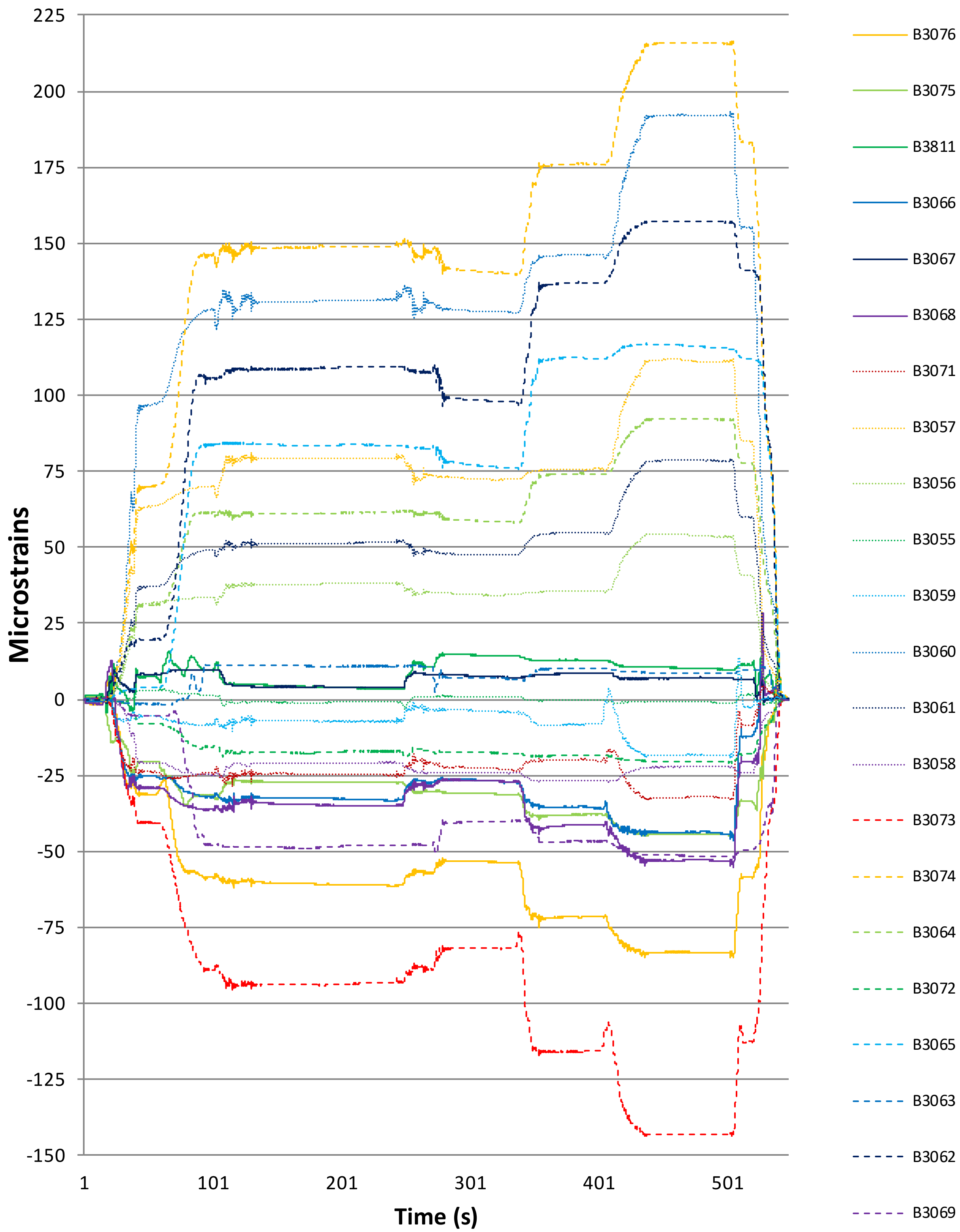


Figure 43: Pembroke No. 3884 - 4 trucks 2 lanes test 1 strains

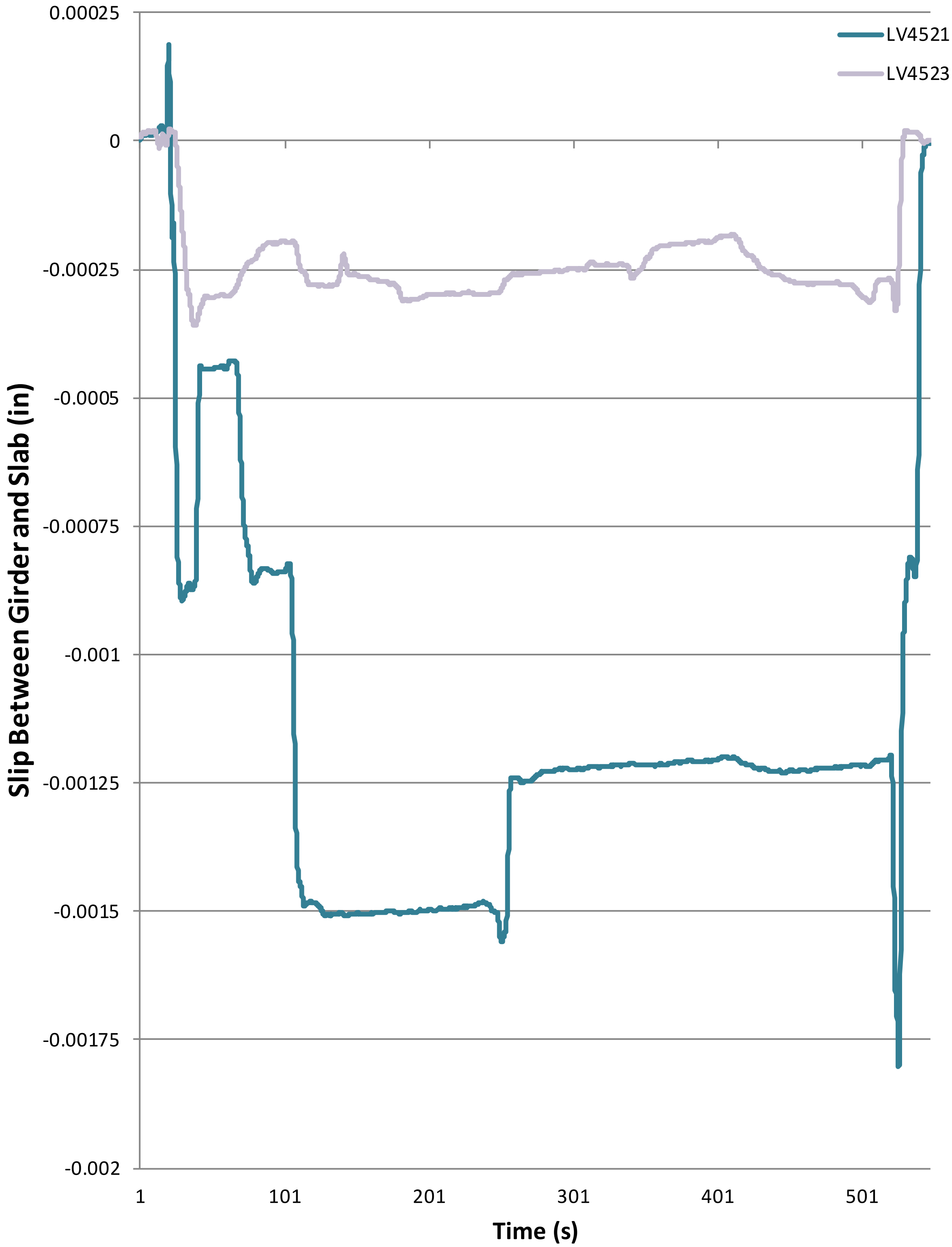


Figure 44: Pembroke No. 3884 - 4 trucks 2 lanes test 1 shear slip

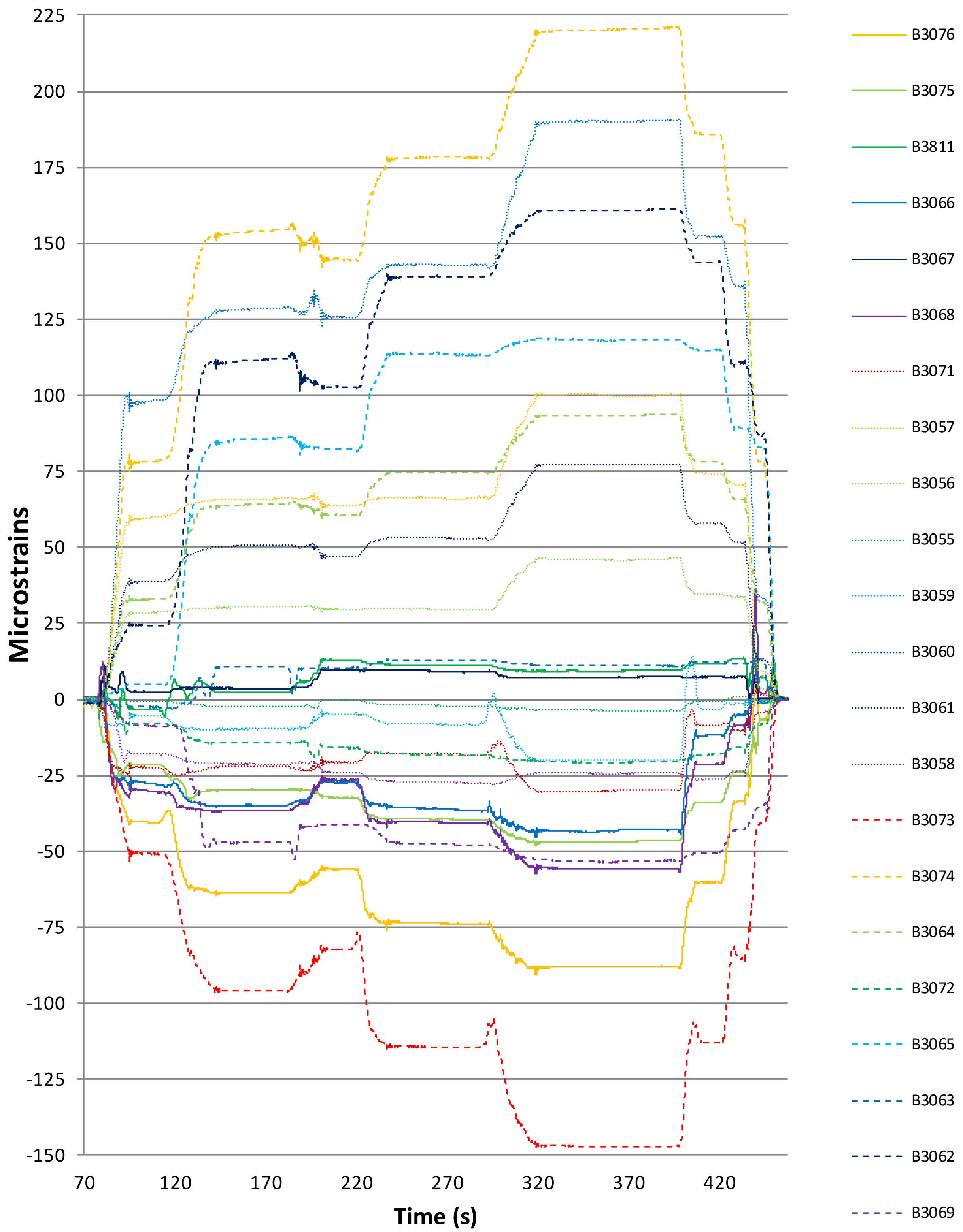


Figure 45: Pembroke No. 3884 - 4 trucks 2 lanes test 2 strains

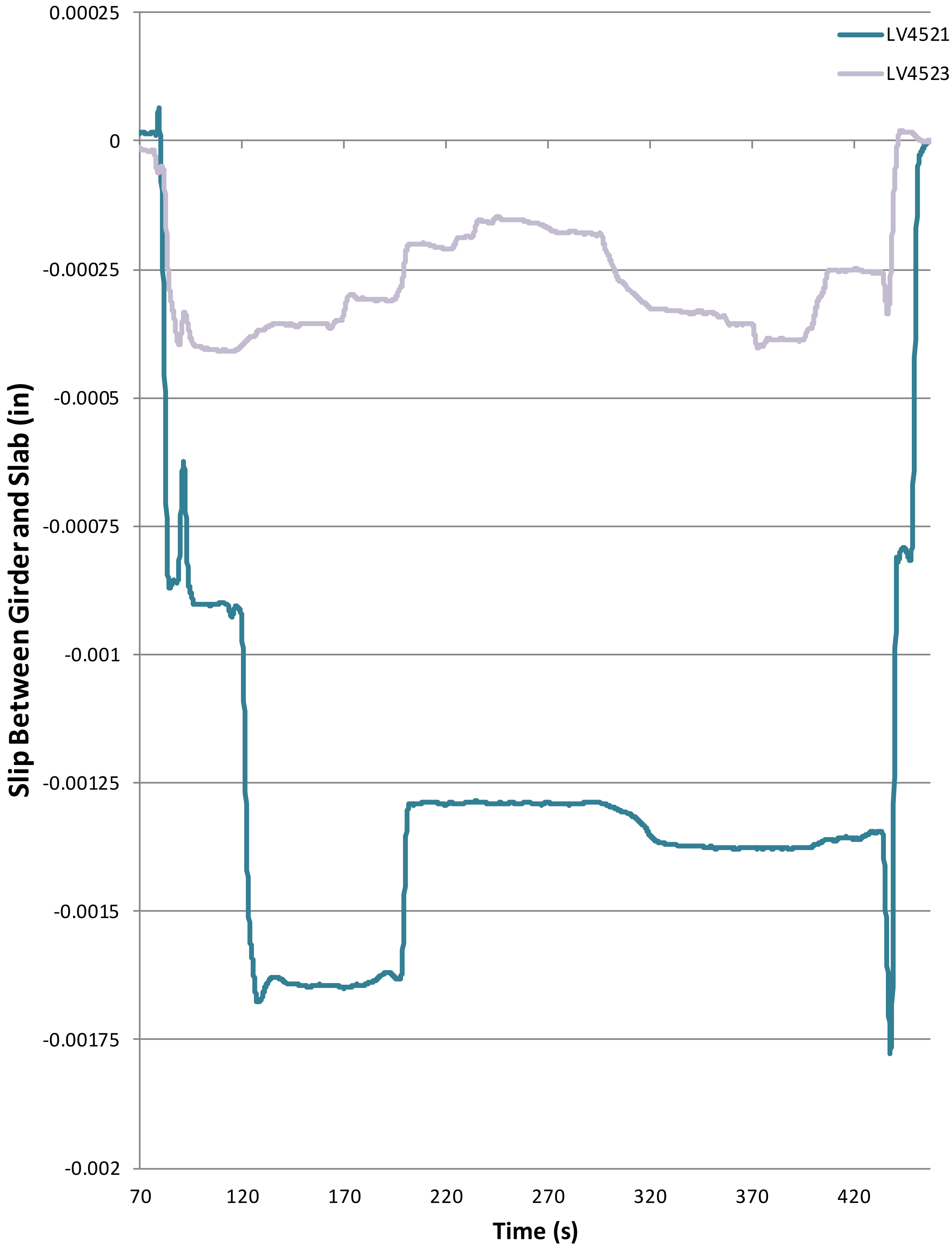


Figure 46: Pembroke No. 3884 - 4 trucks 2 lanes test 2 shear slip

A.4.5 Rating Factor Calculations

Figure 47: Pembroke No. 3884 Calculations

Bridge#3884 Pembroke ME
Pembroke Cross Road
Over PENNAMAQUAN River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-16

Year Built: 1944

Table 6A.5.2.1-1—Minimum Compressive Strength of Concrete by Year of Construction

Year of Construction	Compressive Strength, f'_c, ksi
Prior to 1959	2.5
1959 and Later	3.0

$f'_c := 2.5\ ksi$

Table 6A.6.2.1-1—Minimum Mechanical Properties of Structural Steel by Year of Construction

Year of Construction	Minimum Yield Point or Minimum Yield Strength, F_y, ksi	Minimum Tensile Strength, F_u, ksi
Prior to 1905	26	52
1905 to 1936	30	60
1936 to 1963	33	66
After 1963	36	66

$fy := 33\ ksi$

$\gamma c := 150\ pcf$

$\gamma s := 490\ pcf$

$\gamma_{c\_mod} := 145\ pcf$

$Es := 29000\ ksi$

LRFD Design
Eq. 5.4.2.4-1

$$Ec := 33000 \cdot \gamma_{c\_mod}^{1.5} \cdot \sqrt[2]{f'_c}$$

$Ec := 2875.9\ ksi$

Bridge Length $L := 45.25\ ft$

Spacing between Girders $S := 5.75\ ft$

Deck thickness $ts := 6.75\ in$

Wearing surface thickness $t_{w.s.} := 0\ in$ $\gamma_{w.s.} := 140\ pcf$

Page 1 of 12

Bridge#3884 Pembroke ME
Pembroke Cross Road
Over PENNAMAQUAN River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-16

Trucks Weight & Dimensions

Page 2 of 12

Bridge#3884 Pembroke ME
Pembroke Cross Road
Over PENNAMAQUAN River

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-16

Loads on the Interior Girder

Dead Load:

$M_{DC} := 188\ ft \cdot kip$ VHB report

$d := 27.0\ in$ $b_f := 10.0\ in$

Live Load :

We use the average truck weight and dimensions in this calculations

				Trucks Weight
	T01-231	T01-242	T01-223	T01-157244
Front wheel	14350	14400	15150	15000
front rear wheel	19500	20250	20850	20900
Last Wheel	19650	20600	21450	21200

Page 3 of 12

Bridge#3884 Pembroke ME
Pembroke Cross Road
Over PENNAMAQUAN River

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-16

Live Load Analysis

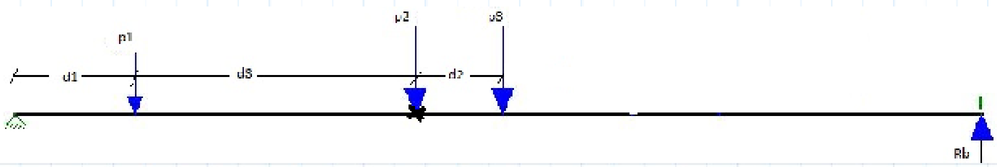
Two trucks in two lanes

$p3 := 21.3\ kip$ $p2 := 20.9\ kip$ $p1 := 15.1\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 4.5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 15.3\ ft$

Trucks at Maximum Moment location:

d1 distance between front wheel and the support



$$R_b(d1) := \frac{(p1 \cdot d1) + (p2 \cdot (d1 + d3)) + (p3 \cdot (d1 + d2 + d3))}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d3)) - p3 \cdot (d2)$$

$$R_b(2.125\ ft) = 19.08\ kip$$

$M(2.125\ ft) = 435\ ft \cdot kip$ $M_{maxmomenttwotrucks} := 435 \cdot ft \cdot kip$

$p2 + p3 + p1 - R_b(2.125\ ft) = 38.22\ kip$ $V_{shear2t} := 38.22\ kip$

Page 4 of 12

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

Prepared By: Mahmood J. Alhraheemi
Checked By: SMT
Date : 201611-16

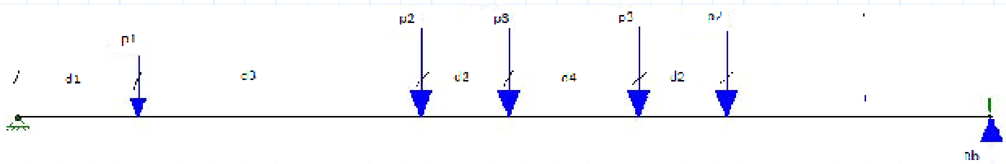
Four trucksin two lanes

$p1 := 14.7\ kip$ $p2 := 20.4\ kip$ $p3 := 20.7\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 4.5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 15.6\ ft$

Trucks at Maximum Moment location:

d1 distance between front wheel and the support ; d4 distance between trucks



At Maximum Moment:

$$R_b(d1, d4) := \frac{p1 \cdot d1 + p2 \cdot (d1 + d3) + p3 \cdot (d1 + d3 + d2) + p3 \cdot (d1 + d3 + d2 + d4) + p2 \cdot (d1 + d3 + 2 \cdot d2 + d4)}{L}$$

$$M(d1, d4) := (R_b(d1, d4) \cdot (L - (d1 + d3 + d2))) - (p2 \cdot (d2 + d4)) - (p3 \cdot d4)$$

$$R_b(2.125\ ft, 83\ in) = 47.35\ kip$$

$$M(2.125\ ft, 83\ in) = 714.067\ ft \cdot kip$$

$$M_{maxmomentfourtrucks} := 714.1 \cdot ft \cdot kip$$

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 201611-16

Section Properties and Distribution Factors

Exterior Girder Section Properties				second assumption	
			modular	transf.	

Moment Distribution factors (Interior Girders)

VHB report

$DF_{onelane} = 0.375$

$DF_{twolanes} = 0.484$

Calculated Distribution factors basedon actual measurements

$DF_{onelane} := 0.421$

$DF_{twolanes} := 0.544$

$DF_{shear} := 0.652$

Section Properties:Fully composite

$y' := 23.4\ in$ $I := 8152 \cdot in^4$ $S_{bot} := 347.8 \cdot in^3$ $Q_{slab} := 283.7 \cdot in^3$

Page 6 of12

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-16

Maximum Live Load Moment calculation in each load case for the interior girder

Two trucks in two lanes

$Mt_{maxmomenttwotrucks} := DF_{twolanes} \cdot M_{maxmomenttwotrucks} = 237\ ft \cdot kip$

Four trucks in two lanes

$Mt_{maxmomentfourtrucks} := DF_{twolanes} \cdot M_{maxmomentfourtrucks} = 388\ ft \cdot kip$

Actual section Response

Mid	B3056	29.458648		B3061	46.8835476
bot.	B3057	63.5795879		B3060	125.5109165
	y'	26.0514948		y'	22.0061647
				modular	transf.
	component	width	thickness	ratio	area

Page 7 of 12

Bridge#3884 Pembroke ME
Pembroke Cross Road
Over PENNAMAQUAN River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-16

Four Trucks

Look at the critical girder the interior girder

$y'_{maxmoment} := 24.0\ in$ $S_{maxmoment} := 347.8\ in^3$ Fully composite

Strain based on actual response

$$\varepsilon_{computed} := \frac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \cdot 10^6 = 462.18$$

$$Kb := 0.5$$

$$Ka := \frac{462.18}{220.4} - 1$$

$$K := 1 + Kb \cdot Ka = 1.55$$

Page 8 of 12

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 201611-16

Two Trucks

Look at the critical girder the interior girder

$y'_{maxmoment} := 23.6\ in$ $S_{maxmoment} := 347.8\ in^3$ Fully composite

Strain based on actual response

$$\varepsilon_{computed} := \frac{Mt_{maxmomenttwotrucks}}{S_{maxmoment} \cdot 29000\ ksi} \cdot 10^6 = 281.54$$

$Kb := 0.5$

$$Ka := \frac{281.54}{144.48} - 1$$

$K := 1 + Kb \cdot Ka = 1.47$

Page 9 of12

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-16

Shear Flow Calculation

Four Trucks maximum shear

maximum shearforce $V:=47.35\ kip$

$$\tau:=\frac{V\cdot DF_{shear}\cdot Q_{slab}}{I\cdot b_f}=107.439\ psi$$

Fully composite

Two Trucks maximum shear

maximum shear force $V_{shear2t}=38.22\ kip$

$$\tau:=\frac{V_{shear2t}\cdot DF_{shear}\cdot Q_{slab}}{I\cdot b_f}=86.72\ psi$$

Page 10 of 12

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

Prepared By: Mahmood J. Albraheemi
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Date : 201611-16

Calculation of Actual Distribution Factors

				97		2.56E+03
	y_bar =	26.4	in from bottom			
Moment of Inertia		1.131E+04	in^4			
S_bottom =		428.9	in^3			
Mmidspan	122.45					

Four Trucks maxmoment DF analysis

$Total\_moment := 696\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.297	0.449
"girder2"	0.459	0.544
"girder3"	0.532	0.544
"girder4"	0.359	0.544
"girder5"	0.353	0.449

Two Trucks max moment DF analysis

$Total\_moment := 453.1\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.291	0.449
"girder2"	0.453	0.544
"girder3"	0.536	0.544
"girder4"	0.343	0.544
"girder5"	0.377	0.449

Bridge#3884PembrokeME
Pembroke CrossRoad
Over PENNAMAQUAN River

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Date : 201611-16

$DF_{external} := 0.449$

Fourtrucksmaximummoment

$M_{maxmomentfourtrucks} = 714.1\ ft \cdot kip$

$S_{4trucksexternal} := 428.9\ in^3$

$measured\_strain\_4 := 118.14$

$$\varepsilon_{4external} := \frac{M_{maxmomentfourtrucks} \cdot DF_{external}}{S_{4trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 309.34$$

$K_b := 0.5$

$$K_{a4} := \frac{\varepsilon_{4external}}{measured\_strain\_4} - 1$$

$K_4 := 1 + K_b \cdot K_{a4} = 2.32$

Two trucksmaximummoment

$M_{maxmomenttwotrucks} = 435\ ft \cdot kip$

$S_{2trucksexternal} := 428.9\ in^3$

$measured\_strain\_2 := 82.34$

$$\varepsilon_{2external} := \frac{M_{maxmomenttwotrucks} \cdot DF_{external}}{S_{2trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 188.44$$

$$K_{a2} := \frac{\varepsilon_{2external}}{measured\_strain\_2} - 1 = 1.29$$

$K_2 := 1 + K_b \cdot K_{a2} = 1.64$

A.5 Windham No. 5298

A.5.1 Input Data, Experimental Configuration, and Experimental Data Collected

Table 144: Windham No. 5298 Bridge Input Data, Experimental Configuration, and Experimental Data Collected

File Contents	***File Name***	***File Type***
Bridge Geometry and Materials	Br5298_Geom.csv	CSV Format
Exterior Section Data	Br5298_Ext.csv	CSV Format
Interior Section Data	Br5298_Int.csv	CSV Format
Sensors	Br5298_Sensors.csv	CSV Format
Sensor Layout	Br5298_SensorLayout.csv	CSV Format
Truck Weight and Dimensions	Br5298_SensorLayout.mat	MATLAB Data File
Truck Starting Position	TestStart.m > Br5298_TestStart	MATLAB Data File
Truck Position Measurements	Br5298_Tk_Positions.mat	MATLAB Data File
Sensor Data	Br5298_1Tks_1Lns_1.xlsx	Microsoft Excel
	Br5298_2Tks_1Lns_1.xlsx	Microsoft Excel
	Br5298_2Tks_1Lns_3.xlsx	Microsoft Excel
	Br5298_2Tks_2Lns_1.xlsx	Microsoft Excel
	Br5298_4Tks_2Lns_2.xlsx	Microsoft Excel
Data Time Indices	Br3057_1Tks_1Lns_1_Time.csv	CSV Format
	Br3057_1UBT_1Lns_1_Time.csv	CSV Format
	Br3057_2Tks_1Lns_1_Time.csv	CSV Format
	Br3057_2Tks_1Lns_2_Time.csv	CSV Format
	Br3057_2Tks_2Lns_1_Time.csv	CSV Format
	Br3057_4Tks_2Lns_1_Time.csv	CSV Format

A.5.2 Instrumentation

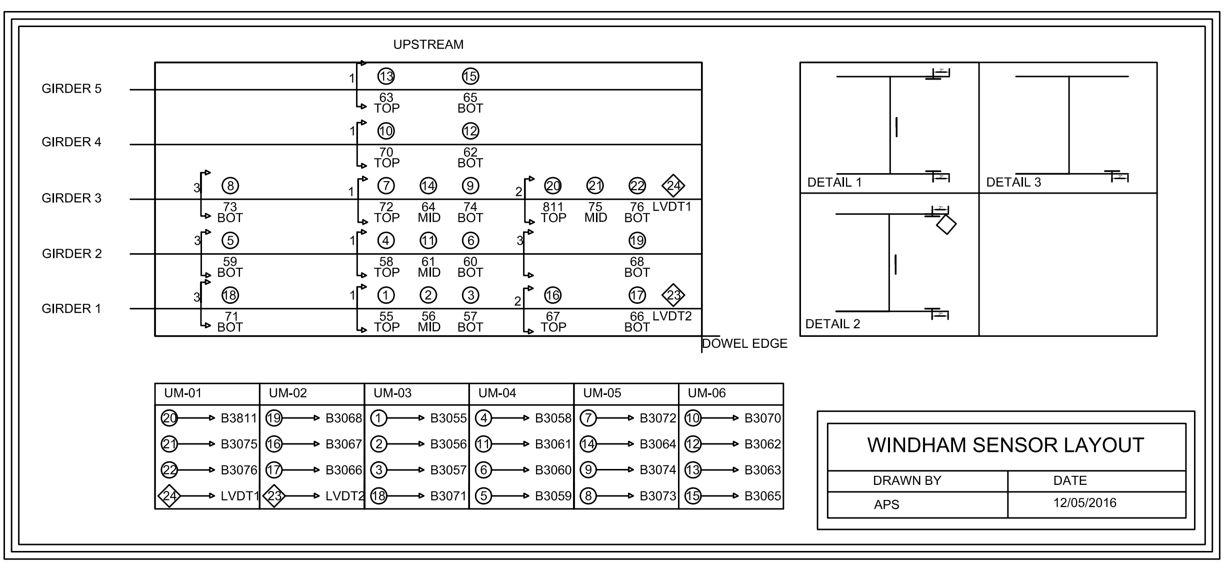


Figure 48: Windham No. 5298 sensor layout

A.5.3 Loading

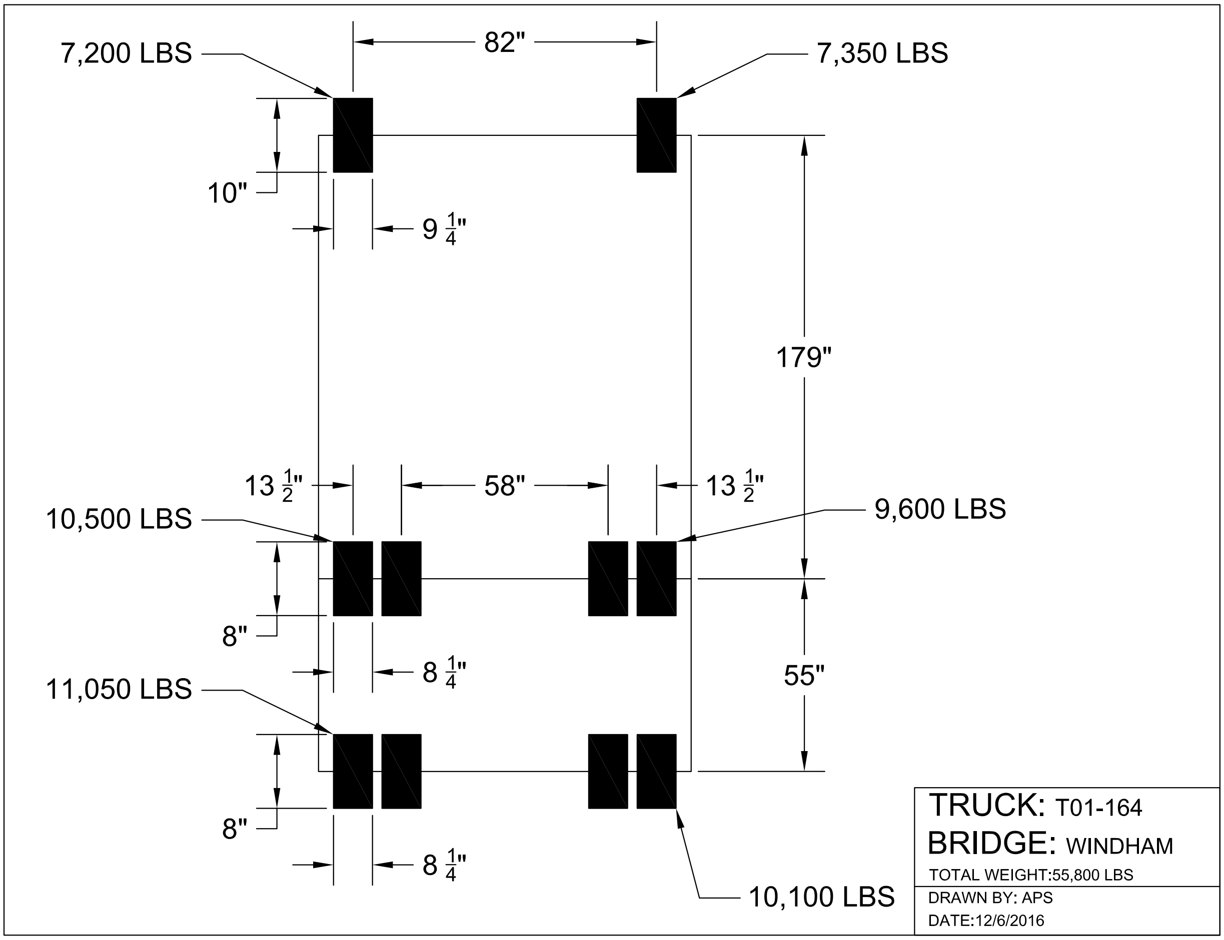


Figure 49: Windham No. 5298 Truck T01-164 loading

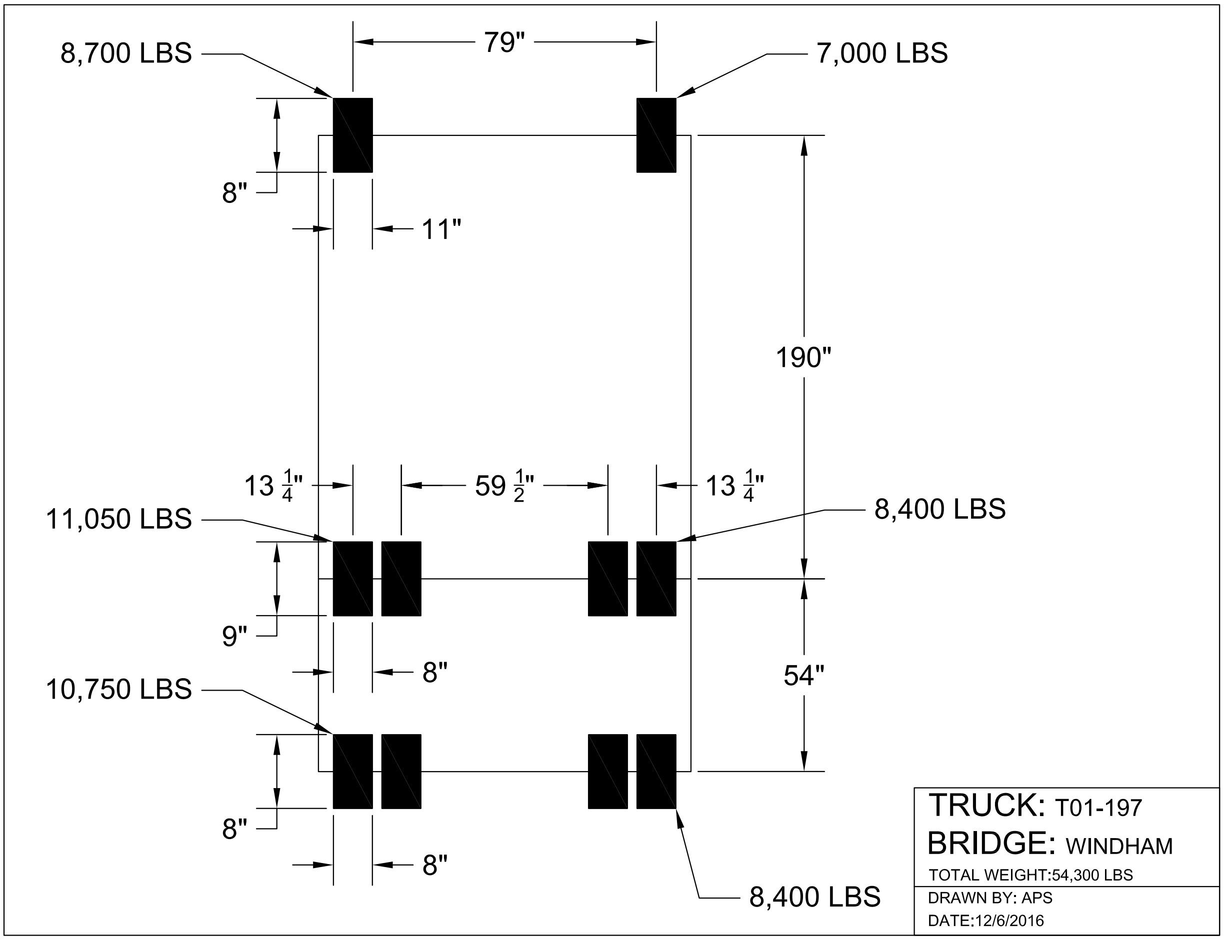


Figure 50: Windham No. 5298 Truck T01-197 loading

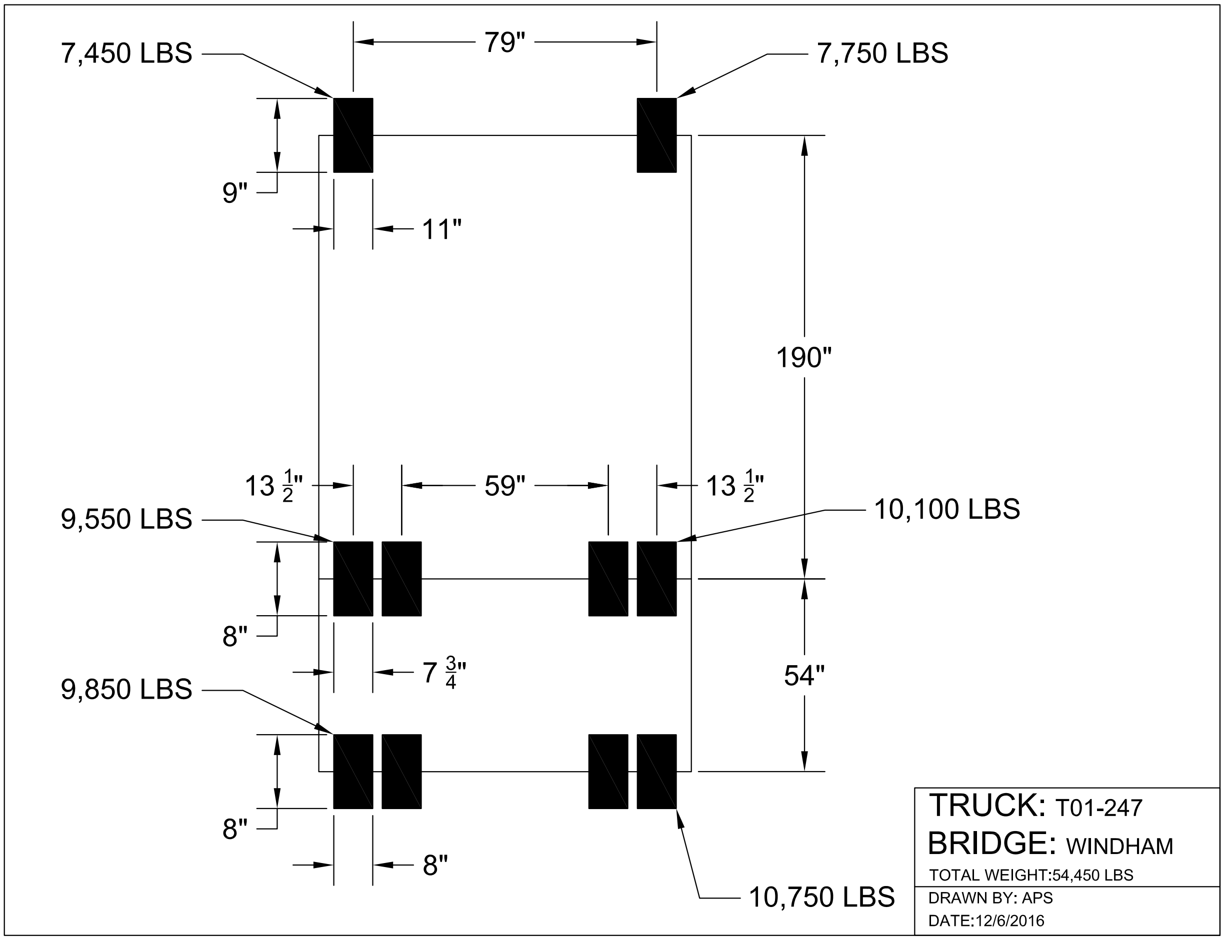


Figure 51: Windham No. 5298 Truck T01-247 loading

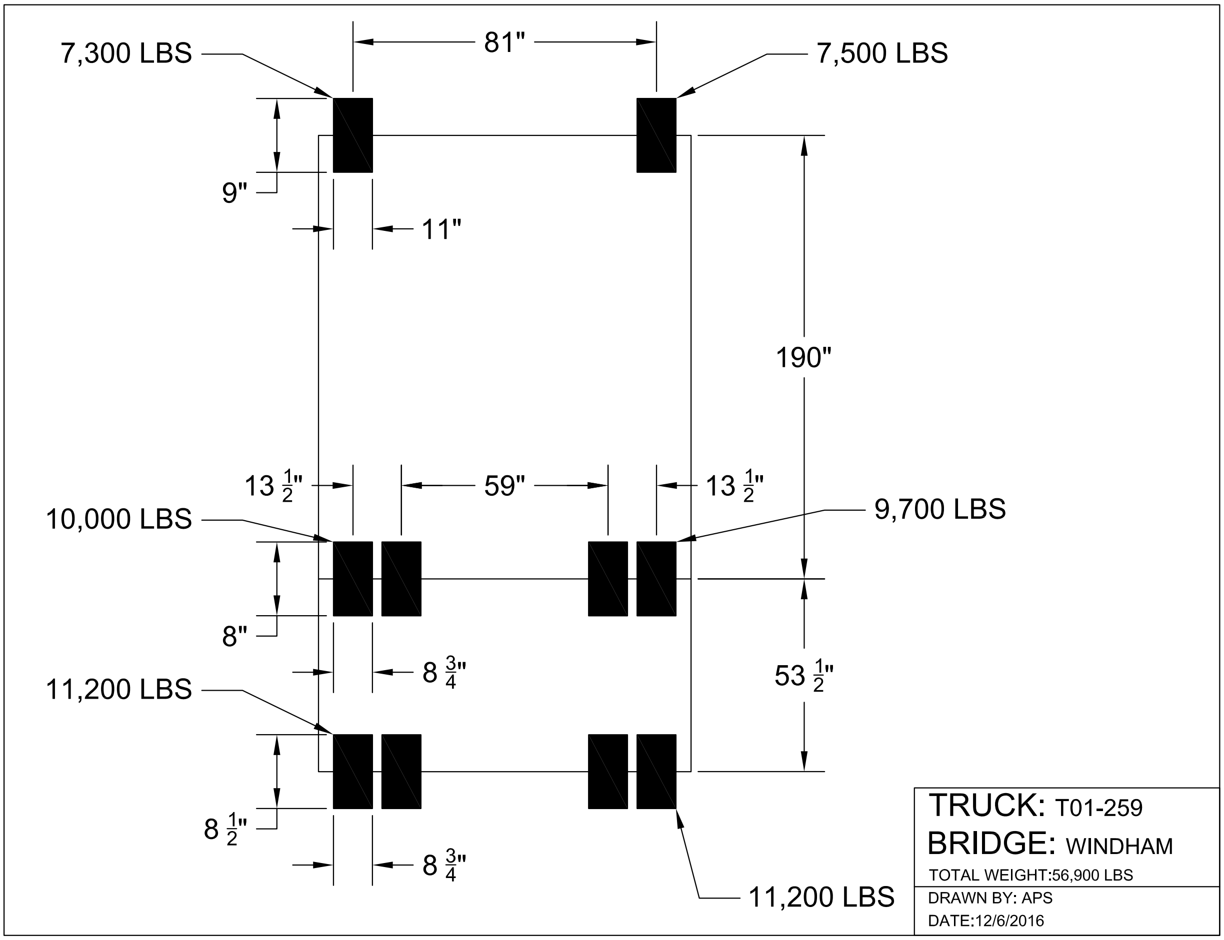


Figure 52: Windham No. 5298 Truck T01-259 loading

A.5.4 Representative Data Plots

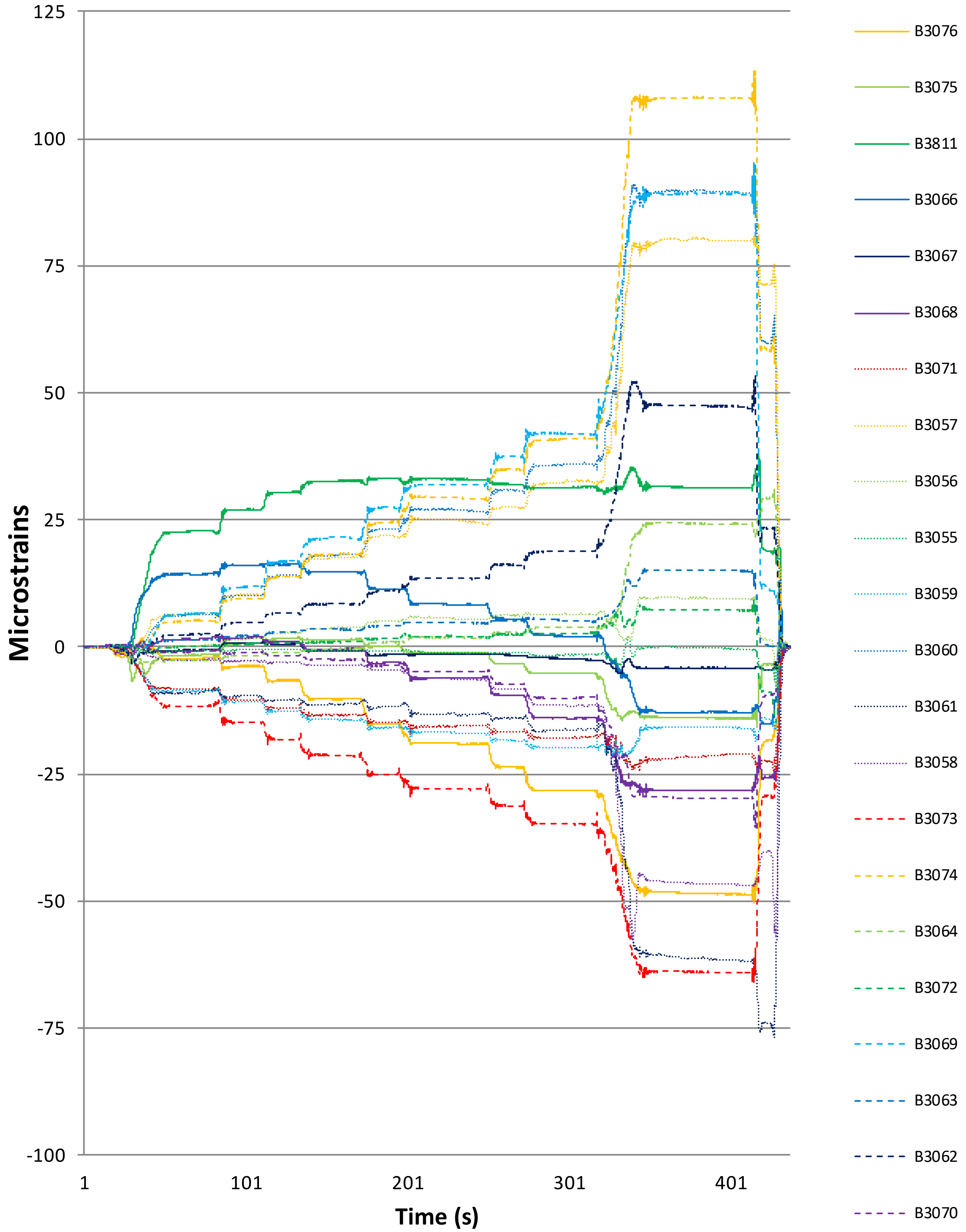


Figure 53: Windham No. 5298 - 2 trucks 2 lanes test 1 strains

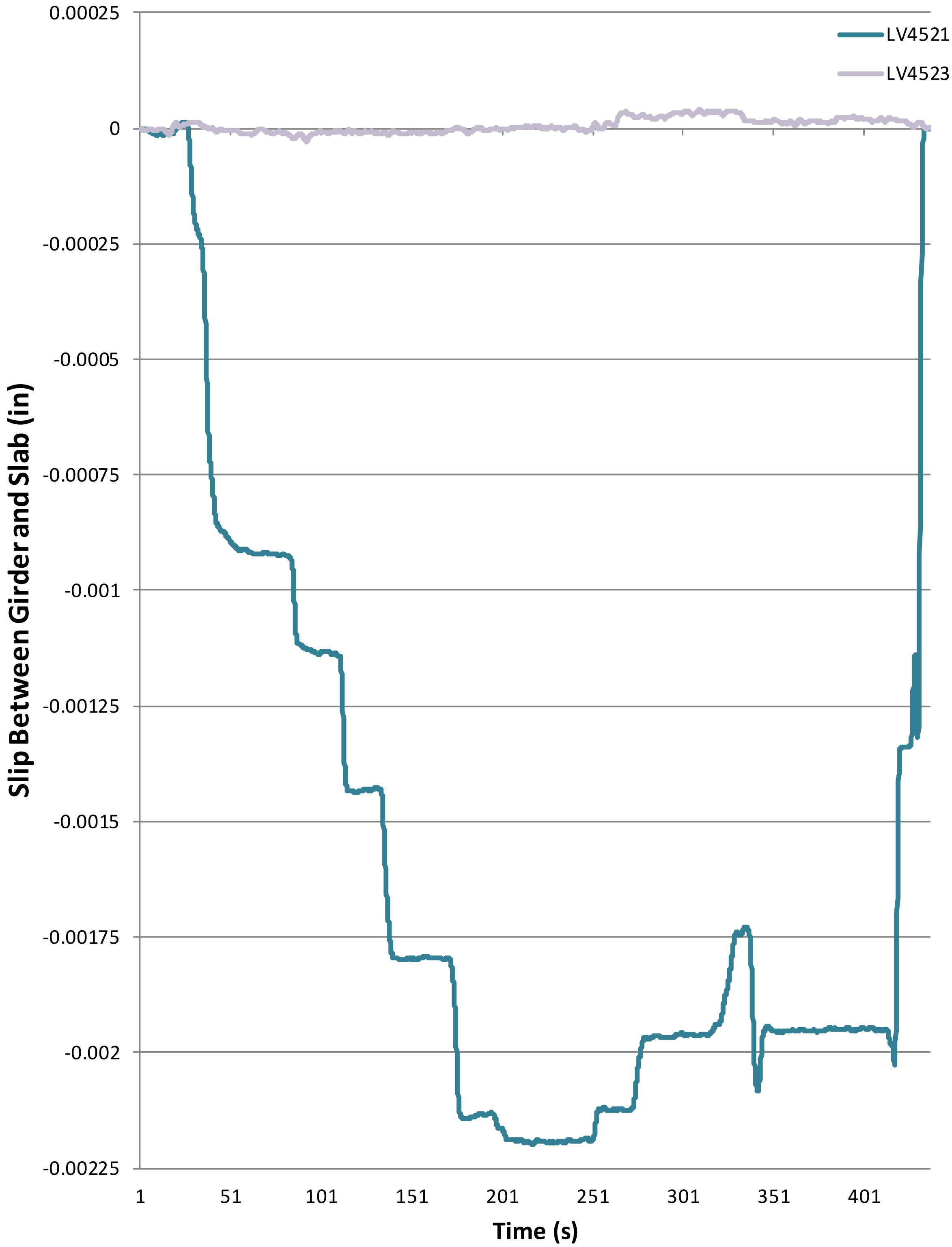


Figure 54: Windham No. 5298 - 2 trucks 2 lanes test 1 shear slip

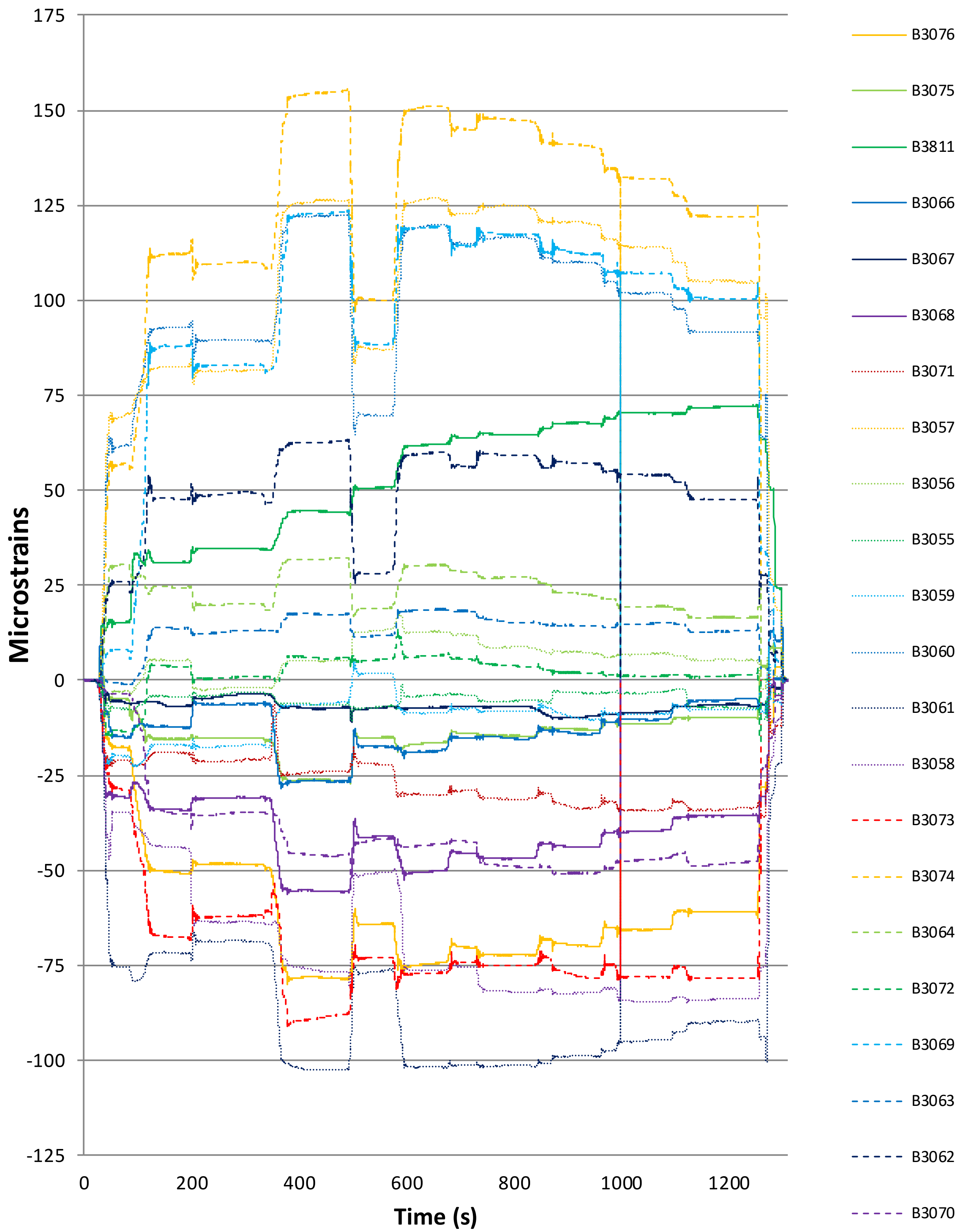


Figure 55: Windham No. 5298 - 4 trucks 2 lanes test 2 strains

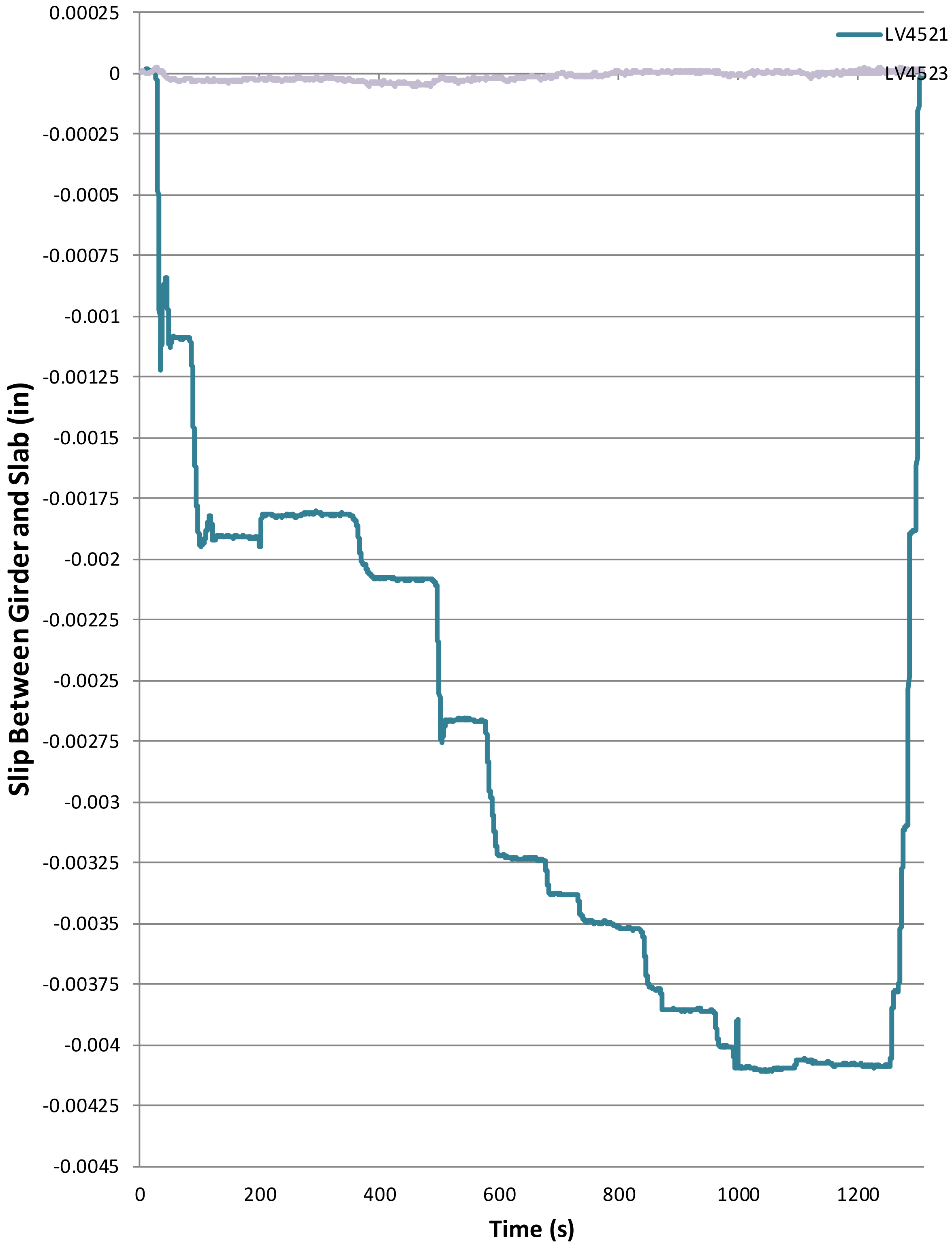


Figure 56: Windham No. 5298 - 4 trucks 2 lanes test 2 shear slip

A.5.5 Rating Factor Calculations

Figure 57: Windham No. 5298 Calculations

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 201611-03

Year Built: 1950

Table 6A.5.2.1-1—Minimum Compressive Strength of Concrete by Year of Construction

Year of Construction	Compressive Strength, f'_c, ksi
Prior to 1959	2.5
1959 and Later	3.0

$f'_c := 2.5\ ksi$

Table 6A.6.2.1-1—Minimum Mechanical Properties of Structural Steel by Year of Construction

Year of Construction	Minimum Yield Point or Minimum Yield Strength, F_y, ksi	Minimum Tensile Strength, F_u, ksi
Prior to 1905	26	52
1905 to 1936	30	60
1936 to 1963	33	66
After 1963	36	66

$fy := 33\ ksi$

$\gamma c := 150\ pcf$

$\gamma s := 490\ pcf$

$\gamma_{c\_mod} := 145\ pcf$

$Es := 29000\ ksi$

LRFD Design
Eq. 5.4.2.4-1

$$Ec := 33000 \cdot \gamma_{c\_mod}^{1.5} \cdot \sqrt[2]{f'_c}$$

$Ec := 2875.9\ ksi$

Bridge Length $L := 46\ ft$

Spacing between Girders $S := 5.33\ ft$

Deck thickness $ts := 6.0\ in$

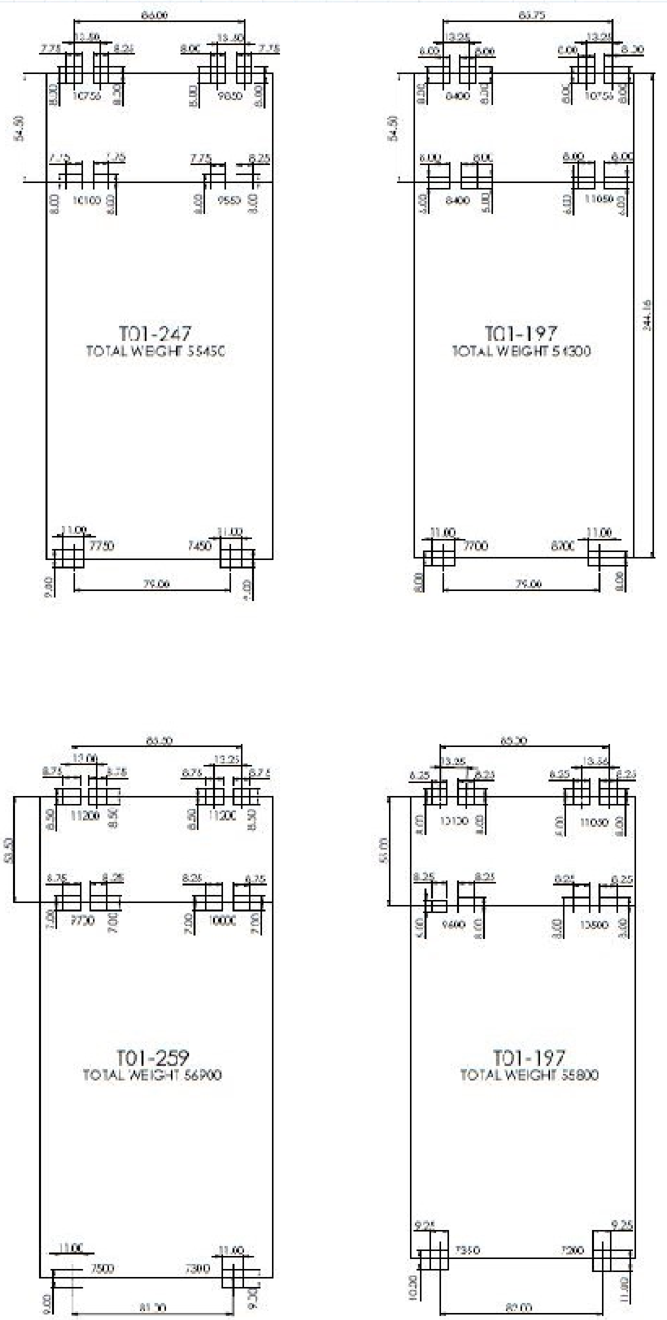
Wearing surface thickness $t_{w.s.} := 9.0\ in$ $\gamma_{w.s.} := 143\ pcf$

Page 1 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-03

Trucks Weight & Dimensions



Page 2 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 201611-03

Loads on the Interior Girder

DeadLoad:

$M_{DC} := 190\ ft \cdot kip$ VHB report

$M_{DW} := 155\ ft \cdot kip$ VHB report

$d := 29.83\ in$ $b_f := 10.48\ in$

Live Load :

We use the average truck weight and dimensions in this calculations

				Trucks Weight
	T01-197	T01-247	T01-164	T01-259
Front wheel	15700	15200	14550	14800
front rear wheel	19450	19650	20100	19700
Last Wheel	19150	20600	21150	22400

Page 3 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-03

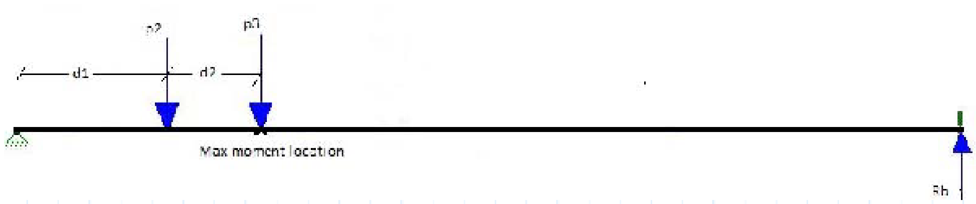
Live Load Analysis

Two trucks in two lanes

$p3 := 21.8\ kip$ $p2 := 19.9\ kip$ $p1 := 14.7\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 15\ ft$

Trucks at shear locations:



$$R_b(d1) := \frac{p2 \cdot d1 + p3 \cdot (d1 + d2)}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d2))$$

At o.5 d from support

$d1 := 0.5 \cdot d$

$M(d1) = 139.003\ ft \cdot kip$

$M_{0.5dtwotrucks} := 139\ ft \cdot kip$

$V_{shear2t} := p2 + p3 - R_b(d1) = ?\ kip$

At 1.0 dfrom support

$d1 := 1.0 \cdot d$

$M(d1) = 178.052\ ft \cdot kip$

$M_{1.0dtwotrucks} := 178 \cdot ft \cdot kip$

At 1.5 dfrom support

$d1 := 1.5 \cdot d$

$M(d1) = 214.301\ ft \cdot kip$

$M_{1.5dtwotrucks} := 214.3 \cdot ft \cdot kip$

At 2.0 dfrom support

$d1 := 2.0 \cdot d$

$M(d1) = 247.748\ ft \cdot kip$

$M_{2.0dtwotrucks} := 247.7 \cdot ft \cdot kip$

Page 4 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Albraheemi
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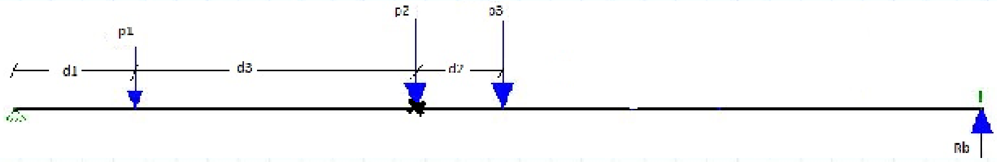
Date : 2016-11-03

Trucks at Maximum Moment location:

d1 distance between front wheel and the support



$$R_b(d1) := \frac{(p1 \cdot d1) + (p2 \cdot (d1 + d3)) + (p3 \cdot (d1 + d2 + d3))}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d3)) - p3 \cdot (d2)$$

$$R_b(96\ in) = 25.776\ kip$$

$$M(96\ in) = 483.85\ ft \cdot kip$$

$$M_{maxmomenttwotrucks} := 483.85\ (ft \cdot kip)$$

Page 5 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

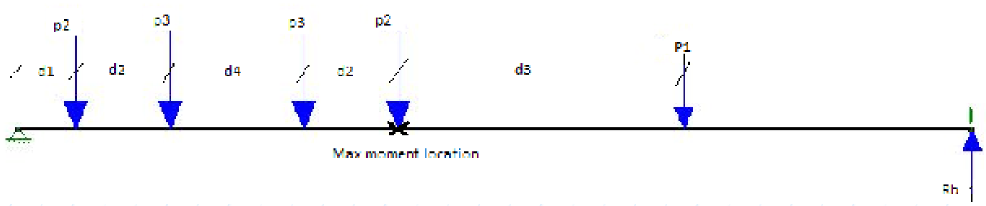
Four trucks in two lanes

$p1 := 15.1\ kip$ $p2 := 19.7\ kip$ $p3 := 20.8\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 15\ ft$

Trucks at shear locations:

d1 distance between front rear wheel and the support ; d4 distance between trucks



$$R_b(d1, d4) := \frac{p2 \cdot d1 + p3 \cdot (d1 + d2) + p3 \cdot (d1 + d2 + d4) + p2 \cdot (d1 + 2 \cdot d2 + d4) + p1 \cdot (d1 + 2 \cdot d2 + d4 + d3)}{L}$$

$$M(d1, d4) := (R_b(d1, d4) \cdot (L - (d1 + d2 + d4))) - (p2 \cdot (d2)) - (p1 \cdot (d3 + d2))$$

At 2.0 d from support

$d1 := 2.0 \cdot d$ $d4 := 89\ in$

$M(d1, d4) = 639.872\ ft \cdot kip$

$M_{2.0dfourtrucks} := 639.872\ (ft \cdot kip)$

$Ra := 2 \cdot p2 + 2 \cdot p3 + p1 - R_b(d1, d4) = 59.738\ kip$

$V_{shear} := Ra = 59.738\ kip$

At 3.0 d from support

$d1 := 3 \cdot d$ $d4 := 91\ in$

$M(d1, d4) = 683.464\ ft \cdot kip$

$M_{3.0dfourtrucks} := 683.464\ (ft \cdot kip)$

At 4.0 d from support

$d1 := 4 \cdot d$ $d4 := 91\ in$

$M(d1, d4) = 701.567\ ft \cdot kip$

$M_{4.0dfourtrucks} := 701.567\ (ft \cdot kip)$

Page 6 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Albraheemi
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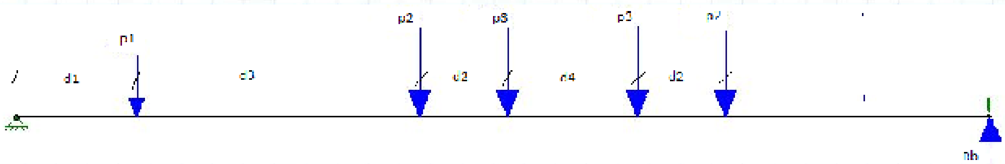
Date : 201611-03

Trucks at Maximum Moment location:

d1 distance between front wheel and the support ; d4 distance between trucks



At Maximum Moment:

$$R_b(d1,d4) := \frac{p1 \cdot d1 + p2 \cdot (d1+d3) + p3 \cdot (d1+d3+d2) + p3 \cdot (d1+d3+d2+d4) + p2 \cdot (d1+d3+2 \cdot d2+d4)}{L}$$

$$M(d1,d4) := (R_b(d1,d4) \cdot (L-(d1+d3+d2))) - (p2 \cdot (d2+d4)) - (p3 \cdot d4)$$

$$R_b(42\ in, 92\ in) = 49.279\ kip$$

$$M(42\ in, 92\ in) = 699.79\ ft \cdot kip$$

$M_{maxmomentfourtrucks} := 700\ (ft \cdot kip)$ $\quad$ $V_{moment} := R_b(42\ in, 92\ in) = ?\ kip$

Page 7 of14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Abraheemi
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Date : 2016-11-03

Section Properties and Distribution Factors

Girder Section Properties					
component	width	thickness	modular ratio	transf. area	y
Slab	69	9	10.00	62.1	34.8

Moment Distribution factors (Interior Girders)

VHB report

$DF_{onelane} := 0.444$

$DF_{twolanes} := 0.574$

Calculated Distribution factors based on actual measurements

$DF_{onelane} = 0.404$

$DF_{twolanes} := 0.523$

$DF_{shear} := 0.652$

Section Properties: Fully composite

$y' := 28.1\ in$ $I := 13116 \cdot in^4$ $S_{bot} := 466.1 \cdot in^3$ $Q_{slab} := 416.5 \cdot in^3$

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-03

Maximum Live Load Moment calculation in each load case for the interior girder

Two trucks in two lanes

$Mt_{0.5dtwotrucks} := DF_{twolanes} \cdot M_{0.5dtwotrucks} = 73\ ft \cdot kip$

$Mt_{1.0dtwotrucks} := DF_{twolanes} \cdot M_{1.0dtwotrucks} = 93\ ft \cdot kip$

$Mt_{1.5dtwotrucks} := DF_{twolanes} \cdot M_{1.5dtwotrucks} = 112\ ft \cdot kip$

$Mt_{2.0dtwotrucks} := DF_{twolanes} \cdot M_{2.0dtwotrucks} = 130\ ft \cdot kip$

$Mt_{maxmomenttwotrucks} := DF_{twolanes} \cdot M_{maxmomenttwotrucks} = 253\ ft \cdot kip$

Four trucks in two lanes

$Mt_{2.0dfourtrucks} := DF_{twolanes} \cdot M_{2.0dfourtrucks}$

$Mt_{3.0dfourtrucks} := DF_{twolanes} \cdot M_{3.0dfourtrucks}$

$Mt_{maxmomentfourtrucks} := DF_{twolanes} \cdot M_{maxmomentfourtrucks} = 366\ ft \cdot kip$

Actual section Response

Four Trucks					
Position	LV4521	B3076	B3075	B3811	LV4523
Max Mom	-0.00208445	-78.423732	-26.3542	44.29619	-4E-05
4.0d	-0.00323712	-74.50521	-16.4794	62.01858	-1E-05
3.0d	-0.003866164	-69.951864	-12.9873	67.6924	5.82E-06
2.0d	-0.004086198	-60.897547	-9.78585	72.16478	1.94E-05

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-03

Four Trucks

$y'_{2.0d} := 29.4\ in$ $S_{2.0d} := 466.1\ in^3$ Fully composite

$y'_{3.0d} := 29.4\ in$ $S_{3.0d} := 466.1\ in^3$ Fully composite

$y'_{maxmoment} := 30.2\ in$ $S_{maxmoment} := 466.1\ in^3$ Fully composite

$$M_{fourtrucks} := \begin{bmatrix} Mt_{2.0dfourtrucks} \\ Mt_{3.0dfourtrucks} \\ Mt_{maxmomentfourtrucks} \end{bmatrix} ; \quad y_{fourtrucks} := \begin{bmatrix} y'_{2.0d} \\ y'_{3.0d} \\ y'_{maxmoment} \end{bmatrix} ; \quad S_{fourtrucks} := \begin{bmatrix} S_{2.0d} \\ S_{3.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \dfrac{Mt_{2.0dfourtrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{3.0dfourtrucks}}{S_{3.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 297.097 \\ 317.338 \\ 325.015 \end{bmatrix}$$

$$\frac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \cdot 10^6 = 325.015$$

$Kb := 0.5$

$$Ka := \frac{325.01}{154.9} - 1 = 1.098$$

$K := 1 + Kb \cdot Ka = 1.55$

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Alabraheemi
Checked By: SMT
Date : 2016-11-03

Two Trucks

$y'_{0.5d} := 30.2\ in$ $\quad S_{0.5d} := 466.1\ in^3$

$y'_{1.0d} := 30.2\ in$ $\quad S_{1.0d} := 466.1\ in^3$

$y'_{2.0d} := 30.7\ in$ $\quad S_{2.0d} := 466.1\ in^3$

$y'_{3.0d} := 30.2\ in$ $\quad S_{3.0d} := 466.1\ in^3$

$y'_{maxmoment} := 31.1\ in$ $\quad S_{maxmoment} := 466.1\ in^3$

$$M_{twotrucks} := \begin{bmatrix} Mt_{0.5dtwotrucks} \\ Mt_{1.0dtwotrucks} \\ Mt_{2.0dtwotrucks} \\ Mt_{maxmomenttwotrucks} \end{bmatrix} \quad y_{twotrucks} := \begin{bmatrix} y'_{0.5d} \\ y'_{1.0d} \\ y'_{2.0d} \\ y'_{maxmoment} \end{bmatrix} \quad S_{twotrucks1} := \begin{bmatrix} S_{0.5d} \\ S_{1.0d} \\ S_{2.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \dfrac{Mt_{0.5dtwotrucks}}{S_{0.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.0dtwotrucks}}{S_{1.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{2.0dtwotrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{maxmomenttwotrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 64.539 \\ 82.647 \\ 115.009 \\ 224.655 \end{bmatrix}$$

$$\frac{Mt_{maxmomenttwotrucks}}{S_{maxmoment} \cdot 29000\ ksi} \cdot 10^6 = 224.655$$

$Kb := 0.5$

$$Ka := \frac{224.65}{108.15} - 1 = 1.077$$

$K := 1 + Kb \cdot Ka = 1.54$

Page 11 of 14

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 201611-03

Shear Flow Calculation

Four Trucks maximum moment

maximum shearforce $V_{moment} = 49.279\ kip$

$$\tau := \frac{V_{moment} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 97.4\ psi$$

Fully composite

Four Trucks maximum shear

maximum shearforce $V_{shear} = 59.738\ kip$

$$\tau := \frac{V_{shear} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 118\ psi$$

Fully composite

Two Trucks maximum shear

maximum shearforce $V_{shear2t} = 38.204\ kip$

$$\tau := \frac{V_{shear2t} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f} = 75.475\ psi$$

Fully composite

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 201611-03

Calculation of Actual Distribution Factors

Moment of Inertia =		23760.663	in^4		
S_bottom =		706.8	in^3		
Mmidspan	210.2980214				
Mt	210.2980214				

Four Trucks maxmoment DF analysis

$Total\_moment := 727\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.518	0.431
"girder2"	0.285	0.523
"girder3"	0.480	0.523
"girder4"	0.136	0.523
"girder5"	0.579	0.431

Two Trucks max moment DF analysis

$Total\_moment := 519\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.479	0.431
"girder2"	0.309	0.523
"girder3"	0.470	0.523
"girder4"	0.155	0.523
"girder5"	0.588	0.431

Bridge #5298 Windham ME
Route Windham Center Road
Crossing Pleasant River

Prepared By: Mahmood J. Albraheemi
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Date : 2016-11-03

$DF_{external} := 0.431$

Four trucks maximum moment

$M_{maxmomentfourtrucks} = 700\ ft \cdot kip$

$S_{4trucksexternal} := 617.6\ in^3$

$measured\_strain\_4 := 125.97$

$$\varepsilon_{4external} := \frac{M_{maxmomentfourtrucks} \cdot DF_{external}}{S_{4trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 202.14$$

$K_b := 0.5$

$$K_{a4} := \frac{\varepsilon_{4external}}{measured\_strain\_4} - 1$$

$K_4 := 1 + K_b \cdot K_{a4} = 1.302$

Two trucks maximum moment

$M_{maxmomenttwotrucks} = 483.85\ ft \cdot kip$

$S_{2trucksexternal} := 640.8\ in^3$

$measured\_strain\_2 := 80.13$

$$\varepsilon_{2external} := \frac{M_{maxmomenttwotrucks} \cdot DF_{external}}{S_{2trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 134.663$$

$$K_{a2} := \frac{\varepsilon_{2external}}{measured\_strain\_2} - 1 = 0.681$$

$K_2 := 1 + K_b \cdot K_{a2} = 1.34$

Page 14 of 14

A.6 Buckfield No. 5452

A.6.1 Input Data, Experimental Configuration, and Experimental Data Collected

Table 15:Buckfield No. 5452 Bridge Input Data, Experimental Configuration, and Experimental Data Collected

File Contents	*File Name*	*File Type*
Bridge Geometry and Materials	Br5452 _Geom.csv	CSV Format
Exterior Section Data	Br5452 _Ext.csv	CSV Format
Interior Section Data	Br5452 _Int.csv	CSV Format
Sensors	Br5452 _Sensors.csv	CSV Format
Sensor Layout	Br5452_SensorLayout.csv	CSV Format
Truck Weight and Dimensions	Br5452_SensorLayout.mat	MATLAB Data File
Truck Starting Position	TestStart.m > Br5452 _TestStart	MATLAB Data File
Truck Position Measurements	Br5452 _Tk_Positions.mat	MATLAB Data File
Sensor Data	Br5452 _1Tks_1Lns_1.xlsx	Microsoft Excel
	Br5452 _2Tks_1Lns_1.xlsx	Microsoft Excel
	Br5452 _2Tks_2Lns_1.xlsx	Microsoft Excel
	Br5452 _4Tks_2Lns_1.xlsx	Microsoft Excel
Data Time Indices	Br5452_1Tks_1Lns_1_Time.csv	CSV Format
	Br5452_2Tks_1Lns_1_Time.csv	CSV Format
	Br5452_2Tks_1Lns_1_Time.csv	CSV Format
	Br5452_4Tks_2Lns_1_Time.csv	CSV Format

A.6.2 Instrumentation

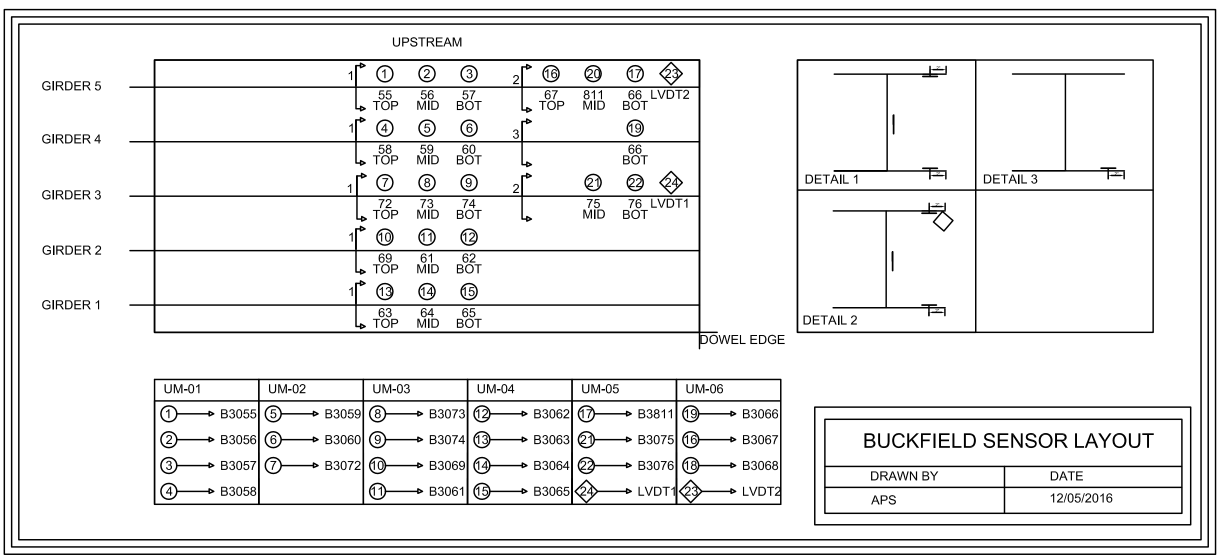

Figure 58: Buckfield No. 5452 sensor layout

A.6.3 Loading

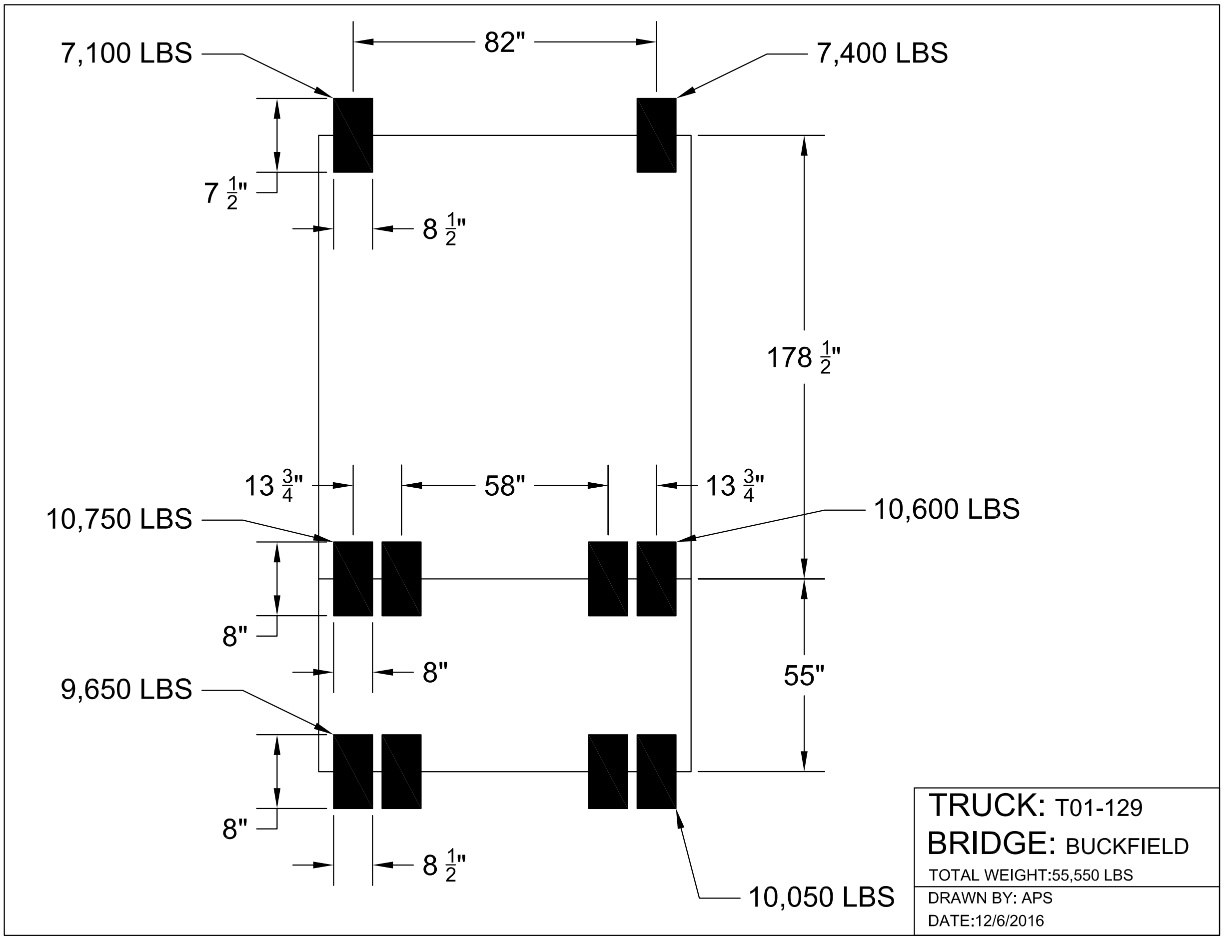

Figure 59: Buckfield No. 5452 Truck T01-129 loading

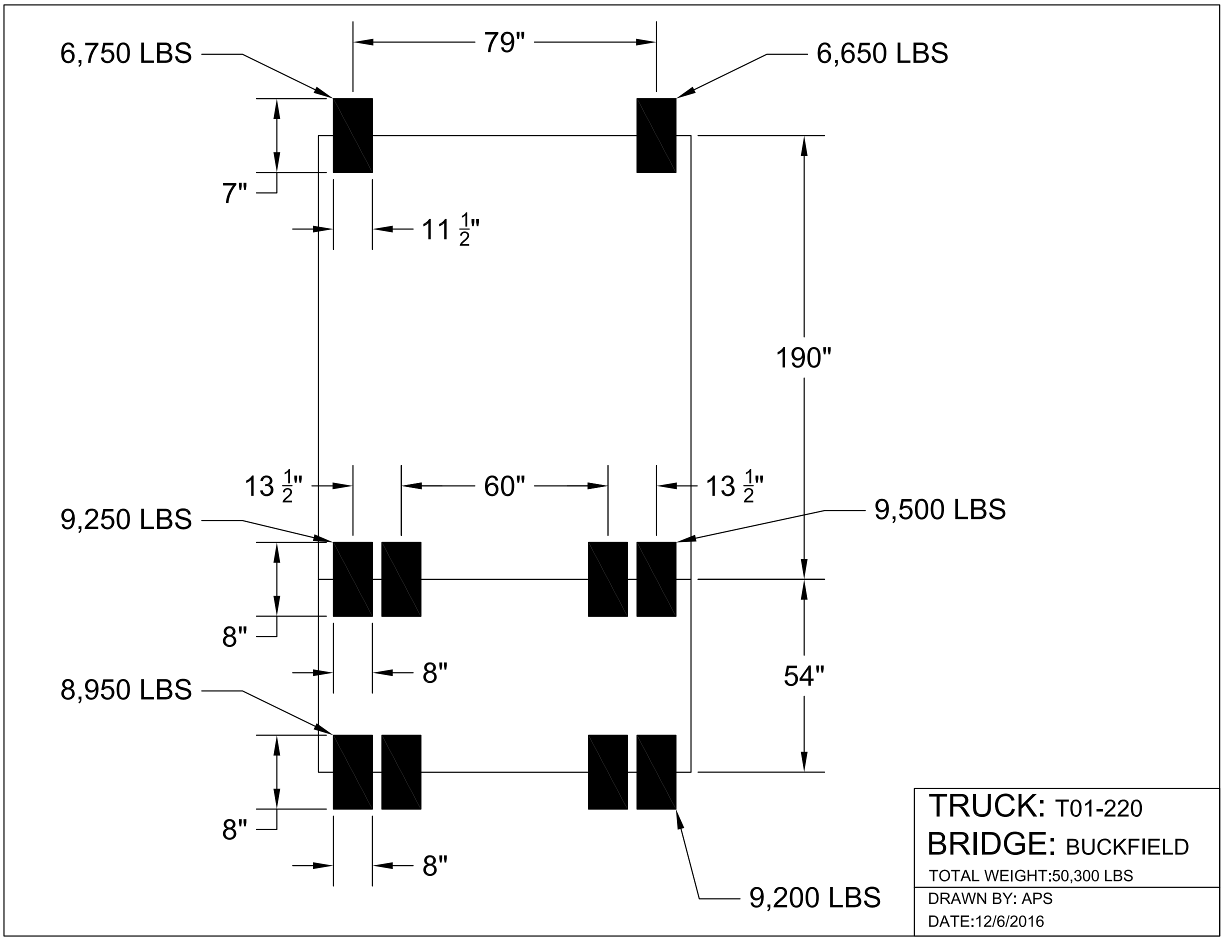

Figure 60: Buckfield No. 5452 Truck T01-220 loading

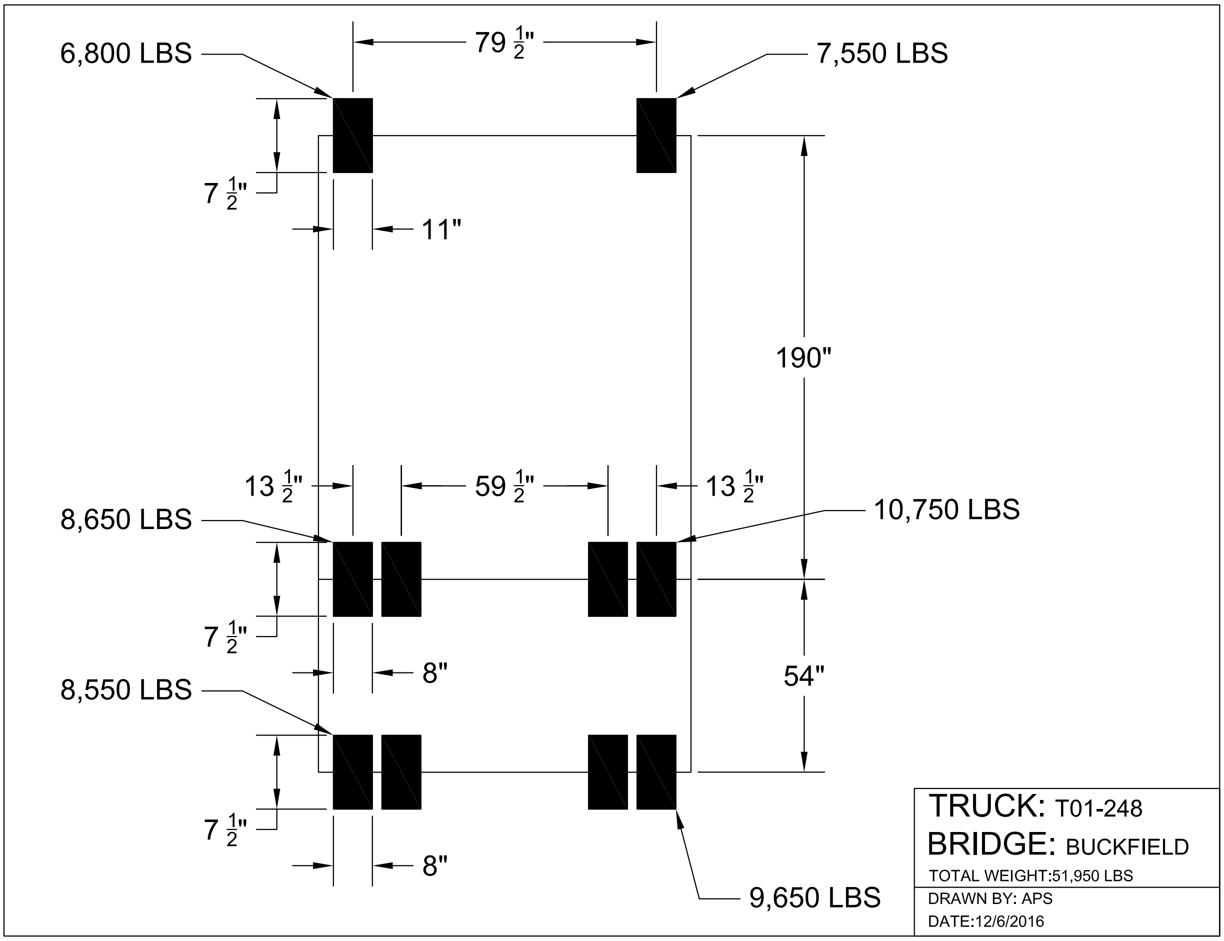

Figure 61: Buckfield No. 5452 Truck T01-246 loading

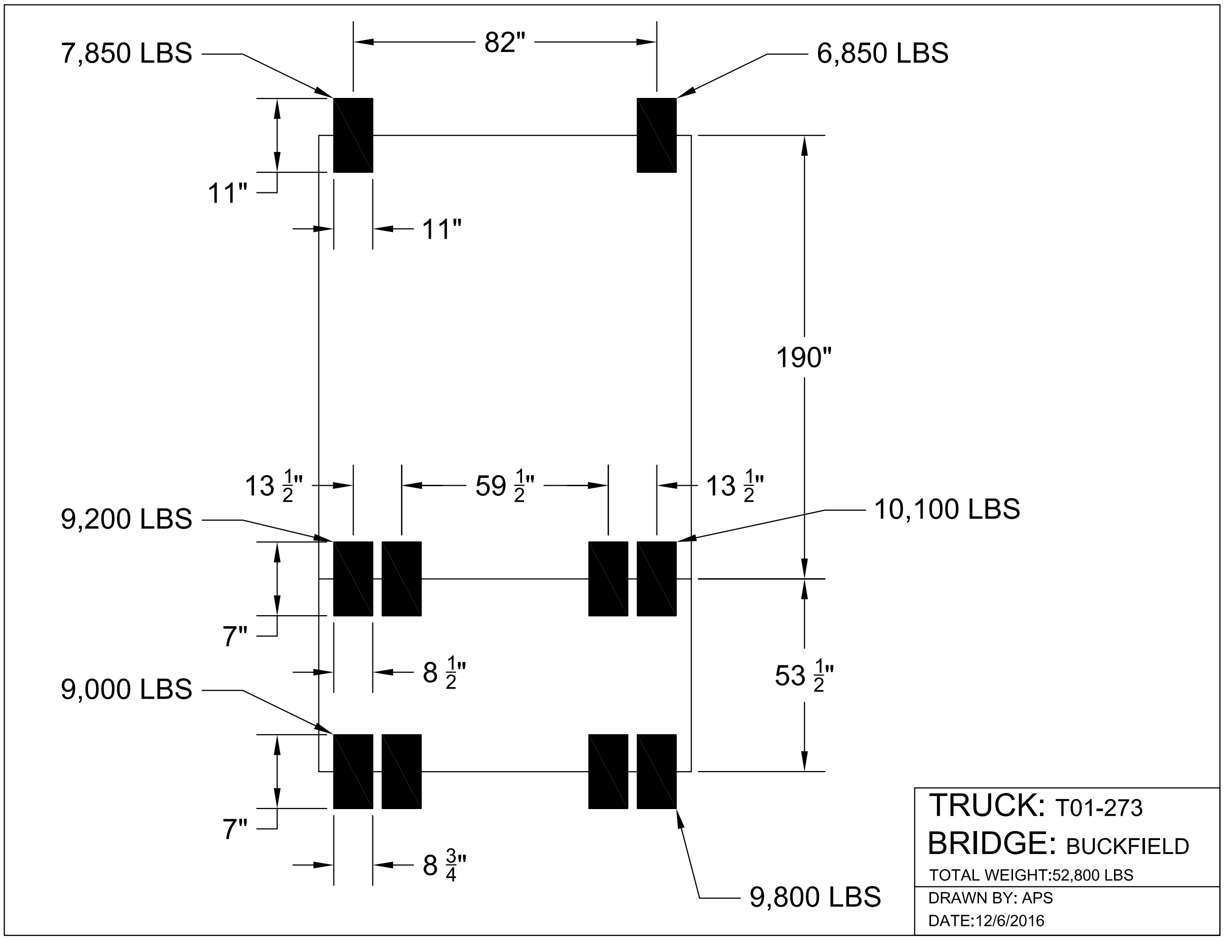

Figure 62: Buckfield No. 5452 Truck T01-273 loading

A.6.4 Representative Data Plots

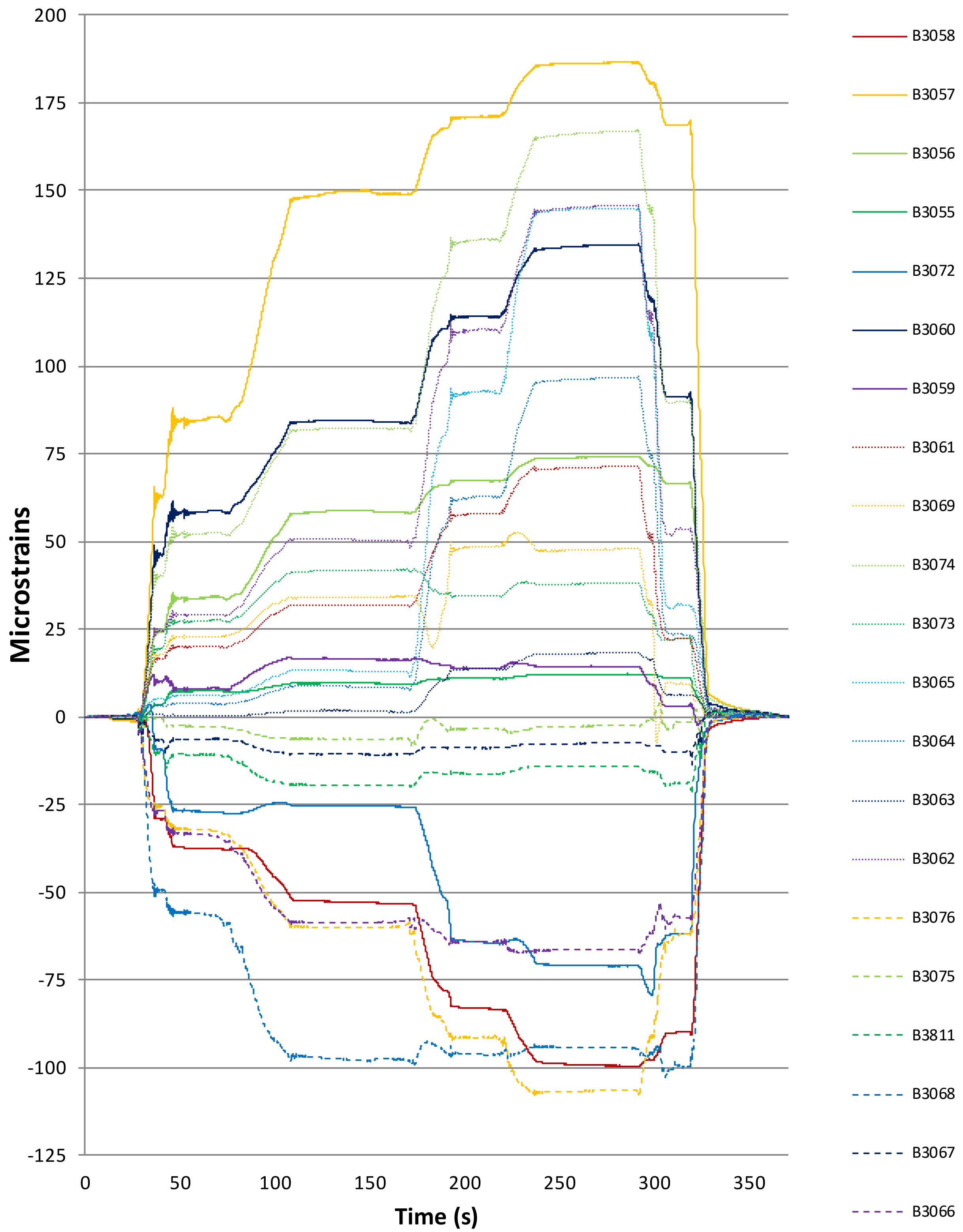

Figure 63: Buckfield No. 5425 - 4 trucks 2 lanes test 1 strains

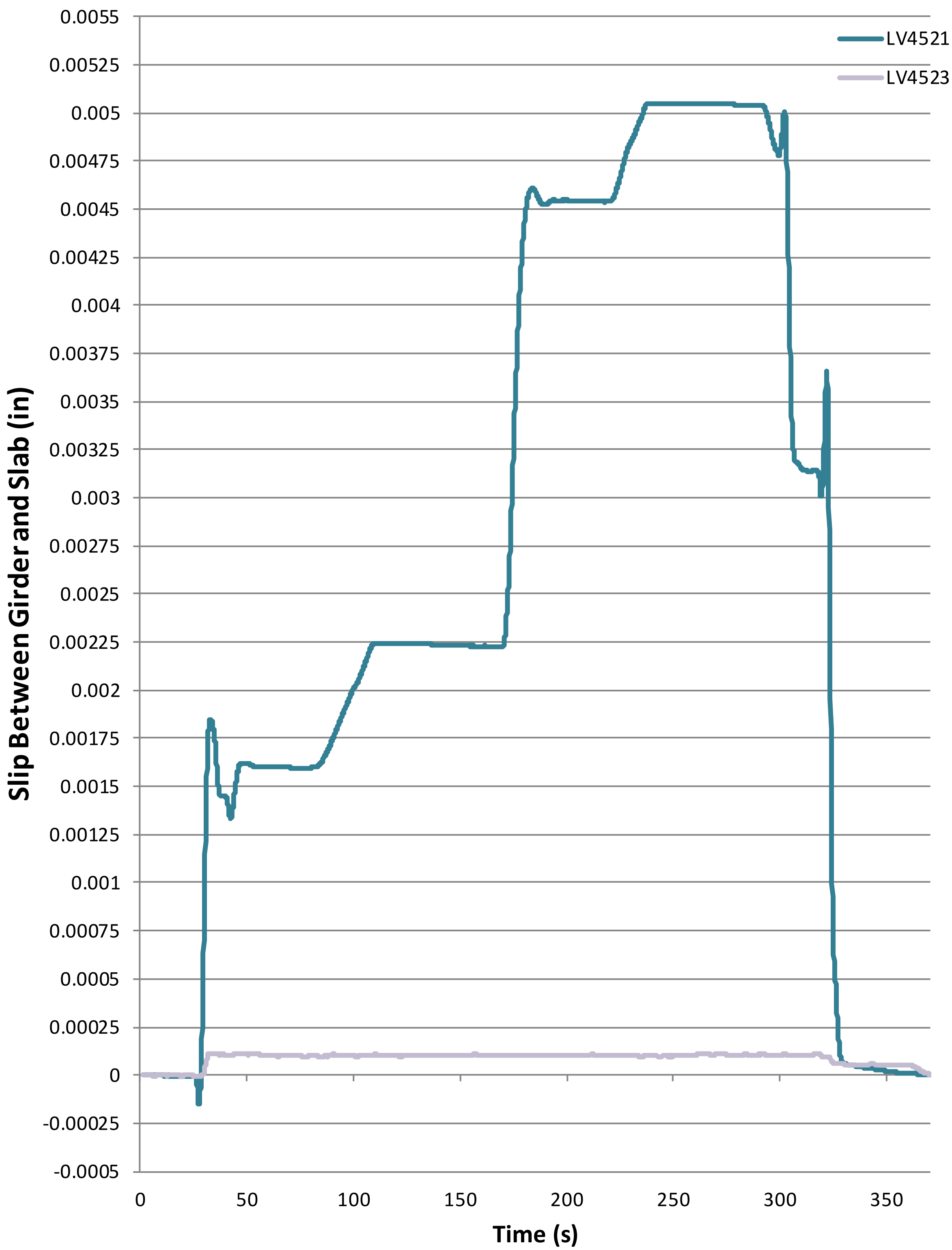

Figure 64: Buckfield No. 5425 - 4 trucks 2 lanes test 1 shear slip

A.6.5 Rating Factor Calculations

Figure 65: Buckfield No. 5452 Calculations

Bridge#5452Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 201611-14

YearBuilt: 1951

Table 6A.5.2.1-1—Minimum Compressive Strength of Concrete by Year of Construction

Year of Construction	Compressive Strength, f'_c, ksi
Prior to 1959	2.5
1959 and Later	3.0

$f'_c := 2.5\ ksi$

Table 6A.6.2.1-1—Minimum Mechanical Properties of Structural Steel by Year of Construction

Year of Construction	Minimum Yield Point or Minimum Yield Strength, F_y, ksi	Minimum Tensile Strength, F_u, ksi
Prior to 1905	26	52
1905 to 1936	30	60
1936 to 1963	33	66
After 1963	36	66

$fy := 33\ ksi$

$\gamma c := 150\ pcf$

$\gamma s := 490\ pcf$

$\gamma_{c\_mod} := 145\ pcf$

$Es := 29000\ ksi$

LRFD Design
Eq. 5.4.2.4-1

$$Ec := 33000 \cdot \gamma_{c\_mod}^{1.5} \cdot \sqrt[2]{f'_c}$$

$Ec := 2875.9\ ksi$

Bridge Length $L := 42.5\ ft$

Spacing between Girders $S := 5.75\ ft$

Deck thickness $ts := 6\ in$

Wearing surface thickness $t_{w.s.} := 6\ in$ $\gamma_{w.s.} := 152\ pcf$ VHB Report

Page 1 of 13

Bridge#5452Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Albraheemi
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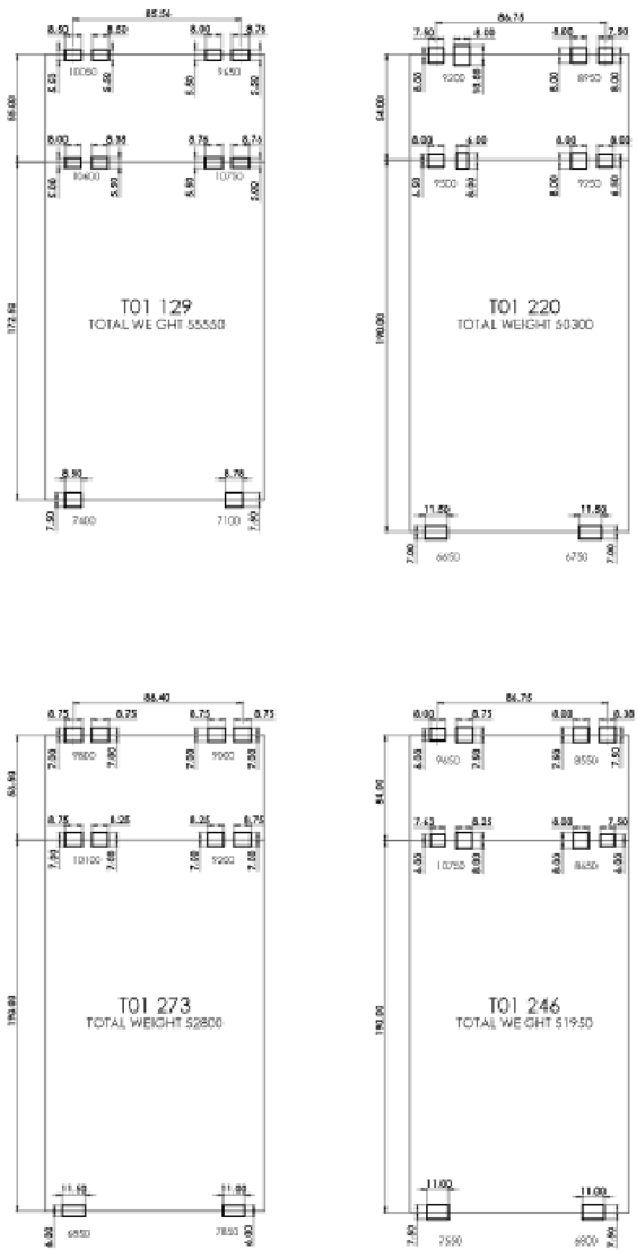
Date : 201611-14

Trucks Weight & Dimensions



Page 2 of13

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Abraheemi
Checked By: SMT
Date : 2016-11-14

Loads on the Interior Girder

DeadLoad:

$M_{DC} := 156.47\ ft \cdot kip$ VHB report

$M_{DW} := 75.5\ ft \cdot kip$ VHB report

$d := 27.09\ in$ $b_f := 10.015\ in$

Live Load :

We use the average truck weight and dimensions in this calculations

				Trucks Weight
	T01-220	T01-129	T01-248	T01-273
Front wheel	13400	14500	14350	14700
front rear wheel	18750	21350	19400	19300
Last Wheel	18150	19700	18200	18800

Page 3 of 13

Bridge#5452Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 201611-14

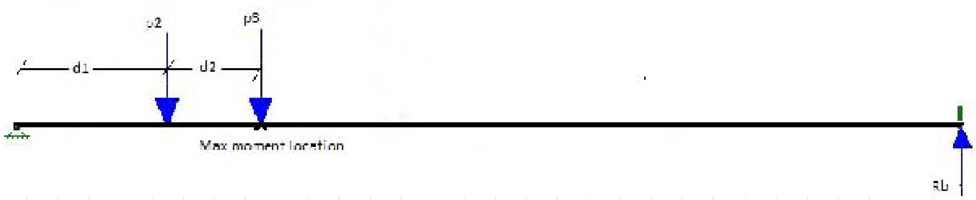
Live Load Analysis

Two trucks in two lanes

$p3 := 18.5\ kip$ $p2 := 19.4\ kip$ $p1 := 14.5\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 16\ ft$

Trucks at shear locations:



$$R_b(d1) := \frac{p2 \cdot d1 + p3 \cdot (d1 + d2)}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d2))$$

At 0.5 d from support
$d1 := 0.5 \cdot d$
$M(d1) = 115.772\ ft \cdot kip$
$M_{0.5dtwotrucks} := M(d1) = 115.772\ kip \cdot ft$

At 1.0 dfrom support
$d1 := 1.0 \cdot d$
$M(d1) = 147.653\ ft \cdot kip$
$M_{1.0dtwotrucks} := M(d1) = 147.653\ kip \cdot ft$

At 1.5 dfrom support
$d1 := 1.5 \cdot d$
$M(d1) = 177.262\ ft \cdot kip$
$M_{1.5dtwotrucks} := M(d1) = 177.262\ kip \cdot ft$

At 2.0 dfrom support
$d1 := 2.0 \cdot d$
$M(d1) = 204.599\ ft \cdot kip$
$M_{2.0dtwotrucks} := M(d1) = 204.599\ kip \cdot ft$

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

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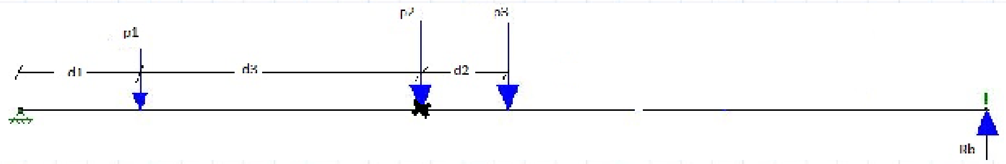
Date : 2016-11-14

Trucks at Maximum Moment location:

d1 distance between front wheel and the support



$$R_b(d1) := \frac{(p1 \cdot d1) + (p2 \cdot (d1 + d3)) + (p3 \cdot (d1 + d2 + d3))}{L}$$

$$M(d1) := R_b(d1) \cdot (L - (d1 + d3)) - p3 \cdot (d2)$$

$$R_b(108\ in) = 27.541\ kip$$

$$M(108\ in) = 389.471\ ft \cdot kip$$

$$M_{maxmomenttwotrucks} := M(108\ in) = 389.471\ ft \cdot kip$$

Page 5 of 13

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

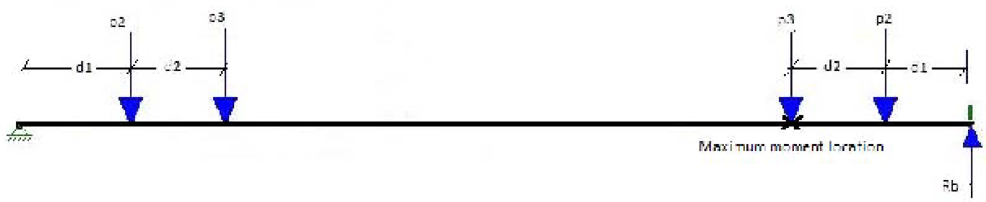
Prepared By: Mahmood J. Alraheemi
Checked By: SMT
Date : 2016-11-14

Four trucks in two lanes

$p1 := 14.2\ kip$ $p2 := 19.7\ kip$ $p3 := 18.7\ kip$ page #3 average axle weight

d2: distance between rear wheels $d2 := 4.5\ ft$
d3 distance between front wheel and front rear wheel $d3 := 16\ ft$

Trucks at Maximum shear locations



$R_b(d1) := p2 + p3$

$M(d1) := R_b(d1) \cdot (d1 + d2) - p2 \cdot d2$

At o.5 d from support
$d1 := 0.5 \cdot d$
$M_{0.5fourtrucks} := M(d1)$ $M_{0.5fourtrucks} = 127.494\ ft \cdot kip$

At 1.0 d from support
$d1 := 1.0 \cdot d$
$M_{1.0fourtrucks} := M(d1)$ $M_{1.0fourtrucks} = 170.838\ ft \cdot kip$

At 1.5 d from support
$d1 := 1.5 \cdot d$
$M_{1.5fourtrucks} := M(d1)$ $M_{1.5fourtrucks} = 214.182\ ft \cdot kip$

At 2.0 d from support
$d1 := 2.0 \cdot d$
$M_{2.0fourtrucks} := M(d1)$ $M_{2.0fourtrucks} = 257.526\ ft \cdot kip$

$V_{shear} := R_b(d1) = 38.4\ kip$

Page 6 of 13

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

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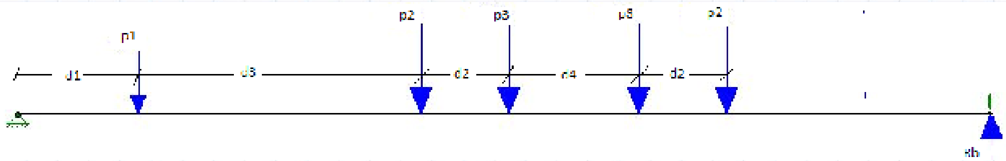
Checked By: SMT
Date : 2016-11-14

Trucks at Maximum Moment location:

d1 distance between front wheel and the support ; d4 distance between trucks



At Maximum Moment:

$$R_b(d1, d4) := \frac{p1 \cdot d1 + p2 \cdot (d1 + d3) + p3 \cdot (d1 + d3 + d2) + p3 \cdot (d1 + d3 + d2 + d4) + p2 \cdot (d1 + d3 + 2 \cdot d2 + d4)}{L}$$

$$M(d1, d4) := (R_b(d1, d4) \cdot (L - (d1 + d3 + d2))) - (p2 \cdot (d2 + d4)) - (p3 \cdot d4)$$

$$R_b(7\ in, 85\ in) = 44.694\ kip$$

$$M(7\ in, 85\ in) = 596.541\ ft \cdot kip$$

$$M_{maxmomentfourtrucks} := 596.541\ (ft \cdot kip)$$

$$V_{moment} := R_b(7\ in, 85\ in) = 44.694\ kip$$

Page 7 of 13

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Abraheemi
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Date : 2016-11-14

Section Properties and Distribution Factors

Interior Girder Section Properties					
component	width	thickness	modular ratio	transf. area	y
Slab	69	9	10.00	62.1	33.6

Moment Distribution factors (Interior Girders)

VHB report

$DF_{onelane} = 0.403$

$DF_{twolanes} = 0.518$

Calculated Distribution factors based on actual measurements

$DF_{onelane} := 0.413$

$DF_{twolanes} := 0.53$

$DF_{shear} := 0.652$

Section Properties: Fully composite

$y' := 27.2\ in$ $I := 12078 \cdot in^4$ $S_{bot} := 444.4 \cdot in^3$ $Q_{slab} := 405.2 \cdot in^3$

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

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Maximum Live Load Moment calculation in each loadcase for the interior girder

Four trucks in two lanes

$Mt_{0.5fourtrucks} := DF_{twolanes} \cdot M_{0.5fourtrucks} = 67.572\ ft \cdot kip$

$Mt_{1.0fourtrucks} := DF_{twolanes} \cdot M_{1.0fourtrucks} = 90.544\ ft \cdot kip$

$Mt_{1.5fourtrucks} := DF_{twolanes} \cdot M_{1.5fourtrucks} = 113.516\ ft \cdot kip$

$Mt_{2.0fourtrucks} := DF_{twolanes} \cdot M_{2.0fourtrucks} = 136.489\ ft \cdot kip$

$Mt_{maxmomentfourtrucks} := DF_{twolanes} \cdot M_{maxmomentfourtrucks} = 309\ ft \cdot kip$

Actual section Response

			y_bar =	17.8	in from bottom
		Moment of Inertia =		5726.910814	in^4
		S_bottom =		321.0	in^3
		Q_slab =		127.7	in^3
Max moment					

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Abraheemi
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Date : 201611-14

Four Trucks

Look at the critical girder the interior girder

$y'_{0.5d} := 21.2\ in$ $\quad S_{0.5d} := 374.7\ in^3$ Partial composite

$y'_{1.0d} := 17.3\ in$ $\quad S_{1.0d} := 310.6\ in^3$ Partial composite

$y'_{1.5d} := 20\ in$ $\quad S_{1.5d} := 357.7\ in^3$ Partial composite

$y'_{2.0d} := 17.8\ in$ $\quad S_{2.0d} := 321\ in^3$ Partial composite

$y'_{maxmoment} := 18.4\ in$ $\quad S_{maxmoment} := 331.5\ in^3$ Partial composite

$$M_{fourtrucks} := \begin{bmatrix} Mt_{0.5fourtrucks} \\ Mt_{1.0fourtrucks} \\ Mt_{1.5fourtrucks} \\ Mt_{2.0fourtrucks} \\ Mt_{maxmomentfourtrucks} \end{bmatrix};\quad y_{fourtrucks} := \begin{bmatrix} y'_{0.5d} \\ y'_{1.0d} \\ y'_{1.5d} \\ y'_{2.0d} \\ y'_{maxmoment} \end{bmatrix};\quad S_{fourtrucks} := \begin{bmatrix} S_{0.5d} \\ S_{1.0d} \\ S_{1.5d} \\ S_{2.0d} \\ S_{maxmoment} \end{bmatrix}$$

Strain based on actual response

$$\varepsilon_{computed} := \begin{bmatrix} \dfrac{Mt_{0.5fourtrucks}}{S_{0.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.0fourtrucks}}{S_{1.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{1.5fourtrucks}}{S_{1.5d} \cdot 29000\ ksi} \\ \dfrac{Mt_{2.0fourtrucks}}{S_{2.0d} \cdot 29000\ ksi} \\ \dfrac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \end{bmatrix} \cdot 10^6 = \begin{bmatrix} 74.622 \\ 120.626 \\ 131.318 \\ 175.944 \\ 394.653 \end{bmatrix}$$

$$\frac{Mt_{maxmomentfourtrucks}}{S_{maxmoment} \cdot 29000\ ksi} \cdot 10^6 = 394.653$$

$Kb := 0.5$

$$Ka := \frac{394.65}{166.85} - 1 = 1.365$$

$K := 1 + Kb \cdot Ka = 1.68$

$Kb := 1.0$

$$Ka := \frac{394.65}{301.33} - 1 = ?$$

$K := 1 + Kb \cdot Ka = ?$

Bridge #5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Albraheemi
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Date : 201611-14

Shear Flow Calculation

Four Trucks maximum shear

maximum shearforce $V_{shear}=38.4\ kip$ $Q_{shear}:=127.7 \cdot in^3$ $I_{shear}:=5727\ in^4$

$$\tau:=\frac{V_{shear} \cdot DF_{shear} \cdot Q_{shear}}{I_{shear} \cdot b_f}=55.743\ psi$$ Actual shear flow

$$\tau:=\frac{V_{shear} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f}=83.87\ psi$$ Shear flow if fully composite

Four Trucks maximum moment

maximum shear force $V_{moment}:=44.69\ kip$ $Q_{moment}:=144.9\ in^3$ $I_{moment}:=6107 \cdot in^4$

$$\tau:=\frac{V_{moment} \cdot DF_{shear} \cdot Q_{moment}}{I_{moment} \cdot b_f}=69.032\ psi$$ Actual shear flow

$$\tau:=\frac{V_{moment} \cdot DF_{shear} \cdot Q_{slab}}{I \cdot b_f}=97.607\ psi$$ Shear flow if fully composite

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

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Date : 2016-11-14

Calculation of Actual Distribution Factors

Total M	634.4908	
DF girde	0.18	0.366

Four Trucks maxmoment DF analysis

$Total\_moment := 634.5\ ft \cdot kip$

Girder	Actual_DF	AASHTO_DF
"girder1"	0.366	0.44
"girder2"	0.493	0.53
"girder3"	0.421	0.53
"girder4"	0.301	0.53
"girder5"	0.418	0.44

Bridge#5452 Buckfield ME
North Buckfield Road
Over NEZNSCOT River

Prepared By: Mahmood J. Albraheemi
Checked By: SMT
Date : 2016-11-14

$DF_{external} := 0.44$

Four trucks maximum moment

$M_{maxmomentfourtrucks} = 596.541\ ft \cdot kip$

$S_{4trucksexternal} := 294.2\ in^3$

$measured\_strain\_4 := 186.48$

$$\varepsilon_{4external} := \frac{M_{maxmomentfourtrucks} \cdot DF_{external}}{S_{4trucksexternal} \cdot 29000 \cdot ksi} \cdot 10^6 = 369.176$$

$K_b := 0.5$

$$K_{a4} := \frac{\varepsilon_{4external}}{measured\_strain\_4} - 1$$

$K_4 := 1 + K_b \cdot K_{a4} = 1.49$

Page 13 of 13