APPENDIX F

P-20-032 AAR STANDARD S-2043 SINGLE-CAR CERTIFICATION TESTS OF U.S. DEPARTMENT OF ENERGY BUFFER RAILCAR

AAR STANDARD S-2043 SINGLE-CAR CERTIFICATION TESTS OF U.S. DEPARTMENT OF ENERGY ATLAS RAILCAR DESIGN PROJECT BUFFER RAILCAR

Certification Report P-20-032

Prepared for U.S. Department of Energy
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TTCI is a wholly owned subsidiary of the Association of American Railroads.

ERRATA STATEMENT

Report: P-20-032

Errata refer to the correction of errors introduced to the article by the publisher. The following errors have been found and corrected since this report was originally submitted.

In MxV Rail report, P-20-032, “AAR Standard S-2043 Single-Car Certification Tests of U.S. Department of Energy Atlas Railcar Design Project Buffer Railcar,” one inadvertent typographical error was present. The corrected text is as follows.

- Section 5.1.4 - The coefficient of friction in the centerplate was estimated using the following equation:

$$\mathrm{\mu} = \frac{3\,(Torque - 2SBld \times SBdst \times \mu_{sb})(\mathrm{CPrad}^2 - \mathrm{Hrad}^2)}{2\,(\mathrm{Tld} - 2 \times \mathrm{SBld})(\mathrm{Cprad}^3 - \mathrm{Hrad}^3)}$$

For questions or comments on this document, contact **Russell_Walker@aar.com.**

EXECUTIVE SUMMARY

Transportation Technology Center, Inc., a subsidiary of the Association of American Railroads (AAR) performed certification testing on the United States Department of Energy's (DOE) buffer railcar. The buffer railcar has been developed as part of DOE's Atlas Railcar Design Project, which is intended to meet the need for future large-scale transport of spent nuclear fuel and high-level radioactive waste. Tests were performed according to AAR *Manual of Standards and Recommended Practices*, Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material," revised 2017.[1] The table below shows the tests performed and the results of the tests. Vehicle characterization tests are not listed because there are no criteria.

S-2043 Section	Critical Data (Criteria) for Conditions Not Met	Met/Not Met
5.2 Nonstructural Static Tests		
5.2.1 Truck Twist Equalization	Not Applicable	Met
5.2.2 Carbody Twist Equalization	Not Applicable	Met
5.2.3 Static Curve Stability	Not Applicable	Met
5.2.4 Horizontal Curve Negotiation	Not Applicable	Met
5.4 Structural Tests		
5.4.2 Squeeze (Compressive End) Load	Not Applicable	Met
5.4.3 Coupler Vertical Loads	Not Applicable	Met
5.4.4 Jacking	Not Applicable	Met
5.4.5 Twist	Not Applicable	Met
5.4.6 Impact	Not Applicable	Met
5.5 Dynamic Tests		
5.5.7 Hunting	Not Applicable	Met
5.5.8 Twist and Roll	Not Applicable	Met
5.5.9 Yaw and Sway	Not Applicable	Met
5.5.10 Dynamic Curving	Not Applicable	Met
5.5.11 Pitch and Bounce (Chapter 11)	Not Applicable	Met
5.5.12 Pitch and Bounce (Special)	Not Applicable	Met
5.5.13 Single Bump Test	Not Applicable	Met
5.5.14 Curve Entry/Exit	Not Applicable	Met
5.5.15 Curving with Single Rail Perturbation	Not Applicable	Met
5.5.16 Standard Chapter 11 Constant Curving	Not Applicable	Met
5.5.17 Special Trackwork	Not Applicable	Met

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1.0 INTRODUCTION

The United States Department of Energy (DOE) contracted with Transportation Technology Center, Inc. (TTCI) to perform certification testing on its buffer railcar developed as part of DOE's Atlas Railcar Design Project. The DOE project is intended to meet the needs for future large-scale transport of high-level radioactive material (HLRM) as defined in AAR Standard S-2043, which includes spent nuclear fuel and high-level waste.

All tests were performed according to Association of American Railroads' (AAR) *Manual of Standards and Recommended Practices* (MSRP), Standard S-2043, "Performance Specification for Trains used to carry High-level Radioactive Material," Section 5.0 – Single Car Tests.[2] Single car testing of the buffer railcar was conducted primarily at the U.S. Department of Transportation's Transportation Technology Center (TTC) near Pueblo, Colorado between April 2019 and February 2020. Static brake testing was conducted at the manufacturer's facility prior to delivery. The curving with single rail perturbation test was repeated on September 11, 2020 (see Paragraph 5.5.10).

2.0 BUFFER RAILCAR DESCRIPTION

The buffer railcar is a four-axle flatcar with a permanently attached ballast load (Figure 1). Kasgro Rail Corporation (Kasgro) manufactured two prototype buffer railcars in 2018. Figure 2 shows the general arrangement drawing of the buffer railcar. Table 1 shows the buffer railcar dimensions. The two prototype buffer railcars delivered to TTC were: IDOX 020001 and IDOX 020002. The tests described in this report were conducted on IDOX 020001.

Figure 1. Buffer Railcar during Static Testing

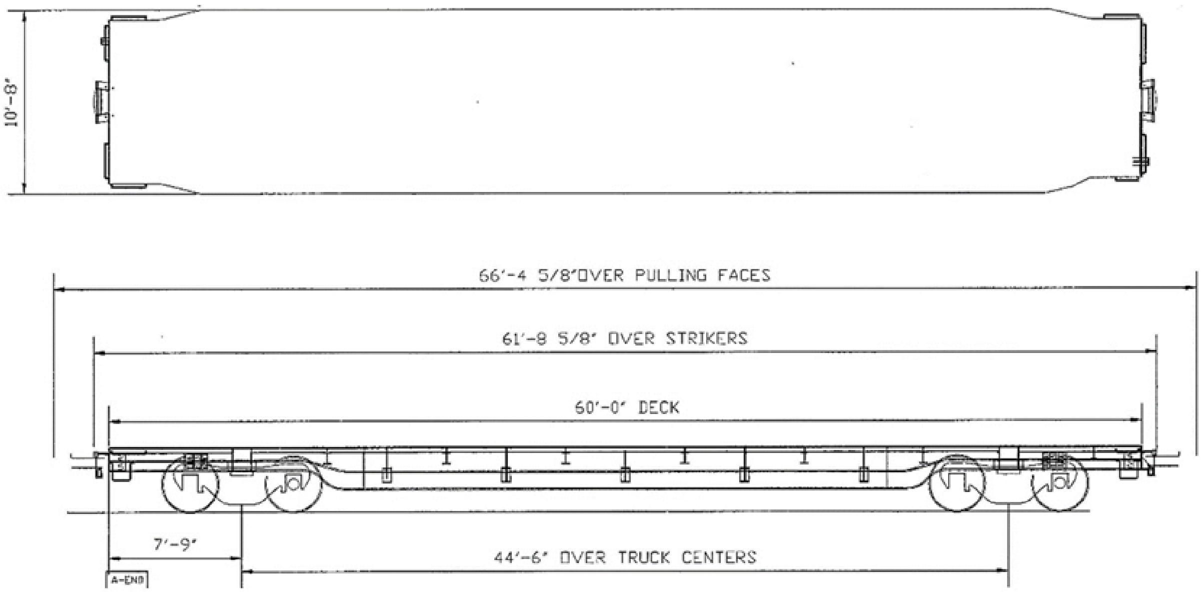

Figure 2. Buffer Railcar Arrangement Drawing

Table 1. Buffer Railcar Dimensions

Dimension	Value
Length over pulling faces	66 feet 4 5/8 inches
Length over strikers	61 feet 8 5/8 inches
Truck center spacing	44 feet 6 inches
Axle spacing on trucks	72 inches

Computer simulations required for AAR Standard S-2043 showed that an empty buffer railcar would not meet S-2043 requirements in the buff and draft curving regime (AAR Standard S-2043 Paragraph 4.3.13). To alleviate this, a ballast weight of 196,000 pounds was added in the model. The added weight was included in the model as permanently installed steel plates. Results of the revised model met buff and draft curving requirements at the resulting gross rail load of 263,000 pounds.[3]

The steel plates were permanently attached to the buffer railcar by welding during the manufacturing process, resulting in a railcar with a permanent gross rail load of 263,000 pounds. Because the railcar is not rated to carry any additional load, this is the only load condition that was tested.

The railcar uses two Swing Motion® trucks. Each truck uses two wheelsets having AAR Class K axles and AAR-1B narrow flange wheels. Narrow flange wheels are specified for this railcar, because the increased gauge clearance allows more lateral movement for better performance. The trucks are specially designed to use a polymer element between the bearing adapter and sideframe. This gives the truck a passive steering capability. Figure 3 shows a bearing adapter pad. Table 2 shows the truck configuration used for testing.

Figure 3. Bearing Adapter Pad

Table 2. Buffer Railcar Truck Configuration

Part	Description	
Secondary suspension (each nest, two per truck)	Five D7 outer coils, five D6 inner coils, five D6A inner inner coils, two 49427-1, two 49427-2 per nest	
Primary suspension (four per truck)	Adapter Plus pads, ASF-Keystone part number 10522A	
Side bearings (two per truck)	Miner TCC-III 60LT	
Friction wedge, composition-faced (four per truck)	ASF-Keystone part number 1-9249	
Bearings and adapters (four per truck)	AAR Class K 6 1/2 x 9 bearings with 6 1/2 x 9 special adapter ASF-Keystone Part number 10523A	
Center bowl plate (one per truck)	Metal horizontal and vertical liners	
Vertical hydraulic dampers (two per truck)	Koni damper 04A 2032	
Side frames (two per truck)	F9N-10FH-UB	
Bolsters (one per truck)	B9N-714N-FS	
	A-end Truck Average	**B-end Truck Average**
Spring nest height	7.75 inches	7.78 inches
Scale weight	131,200 pounds	131,975 pounds

3.0 TEST OVERVIEW

AAR Standard S-2043 requires testing to be conducted in two phases. Each railcar type that will eventually be included in an AAR Standard S-2043 compliant train must first undergo a series of single car tests as described in AAR Standard S-2043 paragraph 5.0. These tests are broken down into several groups: Vehicle Characterization, Nonstructural Static Tests, Static Brake Tests, Structural Tests, and Dynamic Tests. The Static Brake Tests were conducted by Kasgro before the railcars left its facility.

The single car tests are followed by a series of multiple car tests as described in AAR Standard S-2043 Paragraph 6.0. Multiple-car tests are designed to verify that the individual railcars do not adversely affect the performance of adjacent railcars. The multiple-car test train consist must match the anticipated HLRM train as closely as possible, with a minimum of one of each type of railcar to be used.

This report only provides single car test results for the buffer railcar. Single car test results for the other railcar types will be reported separately.

4.0 OBJECTIVE

The objective of the testing reported here was to determine if the DOE's buffer railcar meets the single car test requirements of AAR Standard S-2043, in preparation for inclusion in an AAR Standard S-2043 compliant train. If the AAR Equipment Engineering Committee (EEC) provides conditional approval based on this report (and test reports for additional railcars being prepared in parallel), DOE plans to move forward with multiple car tests. The train consist for multiple car testing is expected to include an Atlas cask car, buffer railcars, and a rail escort vehicle.

5.0 RESULTS

This section provides descriptions and results of each of the tests conducted at TTC under AAR Standard S-2043 as well as the static brake tests conducted at the Kasgro facility. Any variances from the specification will be noted. Each section contains a brief description of the test conducted. The test plan, presented in Appendix A, contains additional details describing the tests.

5.1 Vehicle Characterization

Characterization tests were conducted to verify that the buffer railcar and its components were constructed as designed. The vehicle characterization tests include the following:

- Component characterization
- Vertical suspension stiffness and damping
- Lateral suspension stiffness and damping
- Truck rotation stiffness and breakaway moment
- Interaxle longitudinal stiffness
- Modal characterization

AAR Standard S-2043 requires that measured suspension values be compared to the values used in the original model required by S-4043, Paragraph 4.3, and that the model be adjusted if values are measurably different than those used in the original model. Detailed comparisons of characterization results to model inputs will be provided in the "Post-Test Analysis Report" described in AAR Standard S-2043, Paragraph 8.5. Where possible, preliminary comparisons are provided in the test descriptions below.

Characterization test results are provided in Sections 5.1.1 to 5.1.6.

5.1.1 Component Characterization Tests

TTCI tested the secondary springs, constant contact side bearings (CCSB), and hydraulic vertical dampers to comply with component characterization requirements. Component characterization tests were carried out on a 50,000-pound MTS load frame. TTCI performed component characterization tests in April and May 2019 before any track testing began. Adam Klopp, TTCI

Principal Investigator I, witnessed the component characterization tests as the AAR Observer per S-2043 requirements.

Primary pads were not tested as a separate component because it was determined that a component test could not adequately capture the performance. Instead, the properties of the primary pads were measured during system characterization tests. As described in Sections 5.1.2, 5.1.3, and 5.1.5, the motions between the left and right side frame and the Axle 2 bearing adapters were measured using six Linear Variable Differential Transformers (LVDTs) on each side. The LVDTs were positioned to allow calculation of the relative motion between the side frame and bearing adapter in the longitudinal, lateral, vertical, roll, pitch, and yaw directions. For longitudinal and vertical directions, the individual force on the pad can be determined using the actuator forces and load bar forces, respectively. For the lateral direction the two pads on the same axle act in parallel so the combined or average stiffness may be calculated.

Figure 4 shows the spring configuration for the buffer railcar. Two samples of each spring type were selected from the railcar and characterized in the load frame. The following measurements were recorded:

- Free height
- Stiffness
- Solid height
- Wire diameter

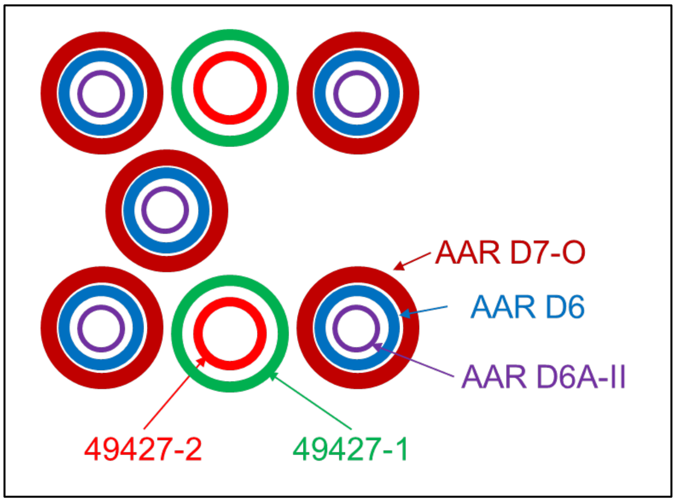

Figure 4. Buffer Railcar Spring Group

Table 3 shows the spring characteristics from either manufacturer or AAR specifications. Table 4 shows the test results of each spring type, and Table 5 shows a comparison of the manufacturer or AAR spring characteristics with the measured characteristics. The springs were within 7 percent or less of the AAR or manufacturer rated stiffness.

Table 3. Spring Characteristics from the Manufacturer

Type	Description	Quantity per Truck	Bar Diameter (in.)	Free HT (in.)	Solid HT (in.)	Spring Rate (lb./in.)
49427-1*	Control coil outer	2	13/16	11 5/16	6 9/16	1,359
49427-2*	Control coil inner	2	9/16	10 13/16	6 9/16	805
D7-O**	Main coil outer	5	15/16	10 13/16	6 9/16	2,033
D6***	Main coil inner	5	21/32	9 15/16	6 9/16	1,395
D6A-II****	Main coil inner inner	5	3/8	9	5 11/16	464

* Manufacturer provided

** Association of American Railroads. Last Revised: 1977. *Manual of Standards and Recommended Practices*. Section D, Trucks and Truck Details. Standard S-338 “Spring-D7, 4 ¼-IN TRAVEL” Washington, DC.

*** Association of American Railroads. Last Revised: 1976. *Manual of Standards and Recommended Practices*. Section D, Trucks and Truck Details. Standard S-336 “Spring-D6, 3 3/8-IN TRAVEL” Washington, DC.

**** Association of American Railroads. Last Revised: 2010. *Manual of Standards and Recommended Practices*. Section D, Trucks and Truck Details. Standard S-337 “Spring-D6A, 3 5/16-IN TRAVEL” Washington, DC.

Table 4. Spring Characteristics from Testing*

Spring Type	Description	Bar Diameter (in.)	Free HT (in.)	Solid HT (in.)	Spring Rate (lb./in.)
49427-1	Control coil outer (R3)	0.813	11.63	6.93	1,367
49427-1	Control coil outer (L4)	0.809	11.25	6.62	1,395
49427-2	Control coil inner (R3)	0.566	10.69	6.32	750
49427-2	Control coil inner (L4)	0.561	10.63	6.26	754
D6	Main coil inner (R3)	0.650	10.19	6.42	1,325
D6	Main coil inner (L4)	0.647	10.19	6.54	1,346
D7-O	Main coil outer (R3)	0.938	11.06	6.79	2,068
D7-O	Main coil outer (L4)	0.937	11.06	6.62	2,078
D6A-II	Main coil inner inner (R3)	0.377	9.13	5.77	449
D6A-II	Main coil inner inner (L4)	0.375	9.13	5.66	449
* Data includes two springs of each type, 10 of the 76 springs in the railcar.					

Table 5. Comparison of the Spring Characteristics from Testing to the Manufacturer’s Specification

		Percent Differences (%)			
Spring Type	Description	Bar Diameter (in.)	Free HT (in.)	Solid HT (in.)	Spring Rate (lb./in.)
49427-1	Control coil outer (R3)	0.1%	2.8%	5.6%	0.6%
49427-1	Control coil outer (L4)	-0.4%	-0.6%	0.8%	2.6%
49427-2	Control coil inner (R3)	0.6%	-1.2%	-3.6%	-6.8%
49427-2	Control coil inner (L4)	-0.3%	-1.7%	-4.6%	-6.3%
D6	Main coil inner (R3)	-1.0%	2.5%	-2.2%	-5.0%
D6	Main coil inner (L4)	-1.4%	2.5%	-0.4%	-3.5%
D7-O	Main coil outer (R3)	0.1%	2.3%	3.5%	1.7%
D7-O	Main coil outer (L4)	-0.1%	2.3%	0.9%	2.2%
D6A-II	Main coil inner inner (R3)	0.5%	1.4%	1.5%	-3.2%
D6A-II	Main coil inner inner (L4)	0.0%	1.4%	-0.4%	-3.2%

Although the test plan for this work showed the side bearings would be Miner TCC-III 80LT CCSB, the buffer railcar arrived with Miner TCC-III 60LT CCSB. Figure 5 shows the side bearings. The setup height of each CCSB is 5 1/16 inches. Two samples were installed in the load frame to measure the force and displacement characteristics. The side bearings were tested as complete components including the steel cages. The loads were applied using constant velocity inputs at a rate of about 0.37 inches per second. Figure 6 shows the test result from the A-truck left side bearing, and Figure 7 shows the test result from the A-truck right side bearing. The manufacturer's data for this model side bearing shows the force at setup height on the loading side of the curve is 5.8 kips. The measured forces at the corresponding point agree closely at 5.7 kips.

Figure 5. Miner TCC-III 60LT CCSB

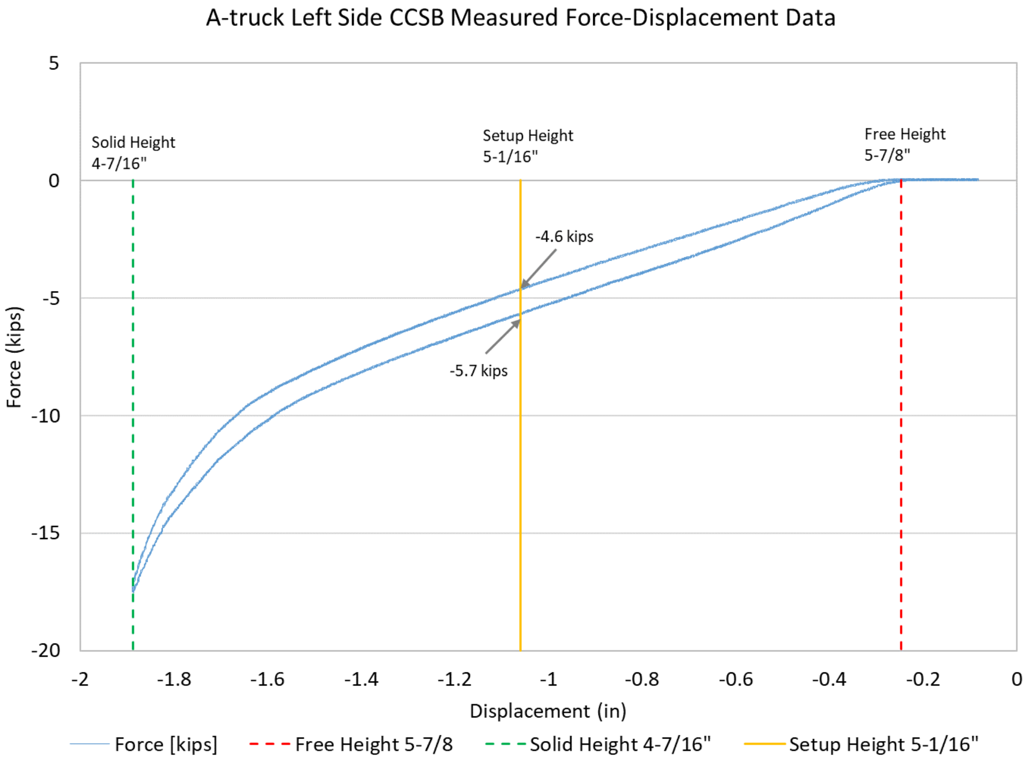

Figure 6. A-truck Left Side CCSB Measured Force-Displacement Data

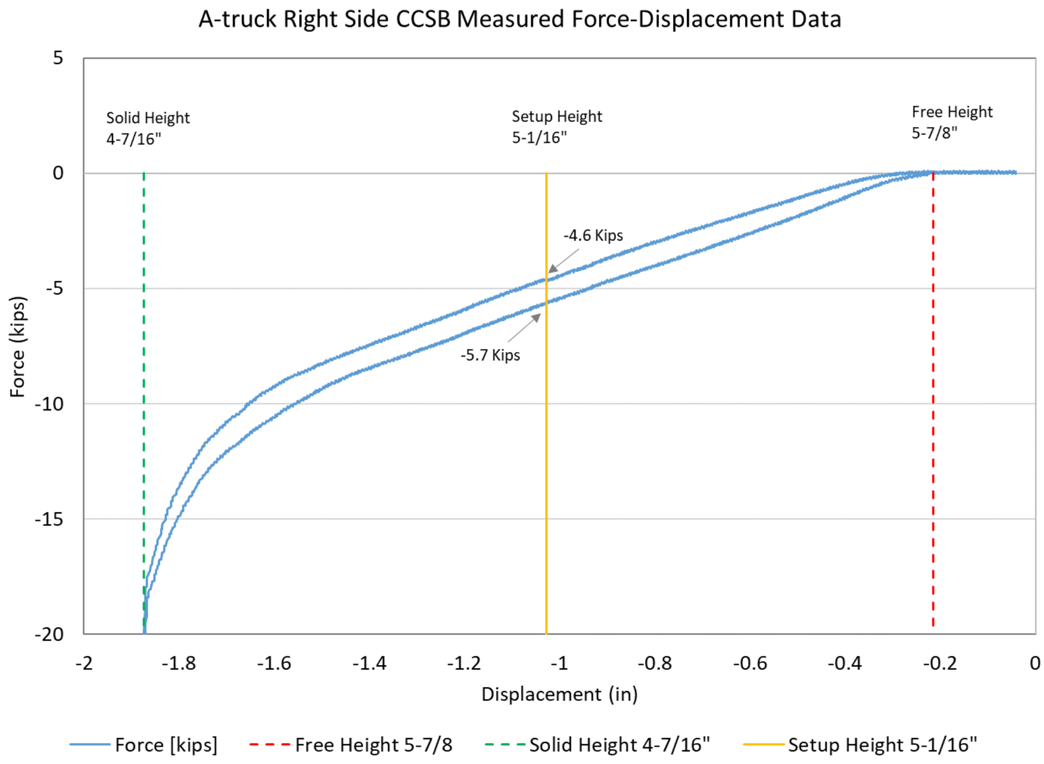

Figure 7. A-truck Right Side CCSB Measured Force-Displacement Data

The buffer railcar is equipped with four Koni 04A 2032 dampers (Figure 8). Technicians removed the dampers in the A-end left hand and A-end right hand positions for characterization. The dampers were tested on the load frame using triangle wave displacements to provide constant velocity inputs. Stroke velocities of 2-, 4-, 8-, 12-, and 14-inch/second were used for input. Koni drawing 0100 27 76 75 shows a 15 percent tolerance on the nominal forces. Figure 9 shows the characterization data for the two dampers together with the minimum and maximum forces from the Koni drawing, demonstrating that the dampers were operating within specification.

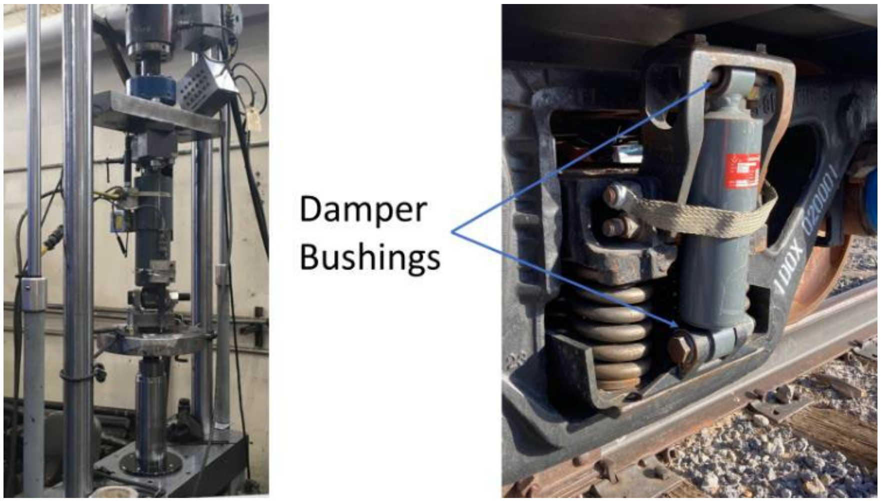

Figure 8. Koni Vertical Damper Mounted in MTS Load Frame (left) and on Buffer Railcar Truck (right)

TTCI also measured bushing displacements during the damper test to determine the stiffness of the damper bushings. Figure 10 shows the force-displacement data for each individual bushing together with the best fit lines and slopes for each. The two bushings of a damper operate in series. The series stiffness of the bushings of the AL and AR dampers is approximately 86,000 and 117,000 pounds per inch, respectively. These values are slightly higher than the 71,377 pounds per inch used in the NUCARS®* model used for pretest predictions.

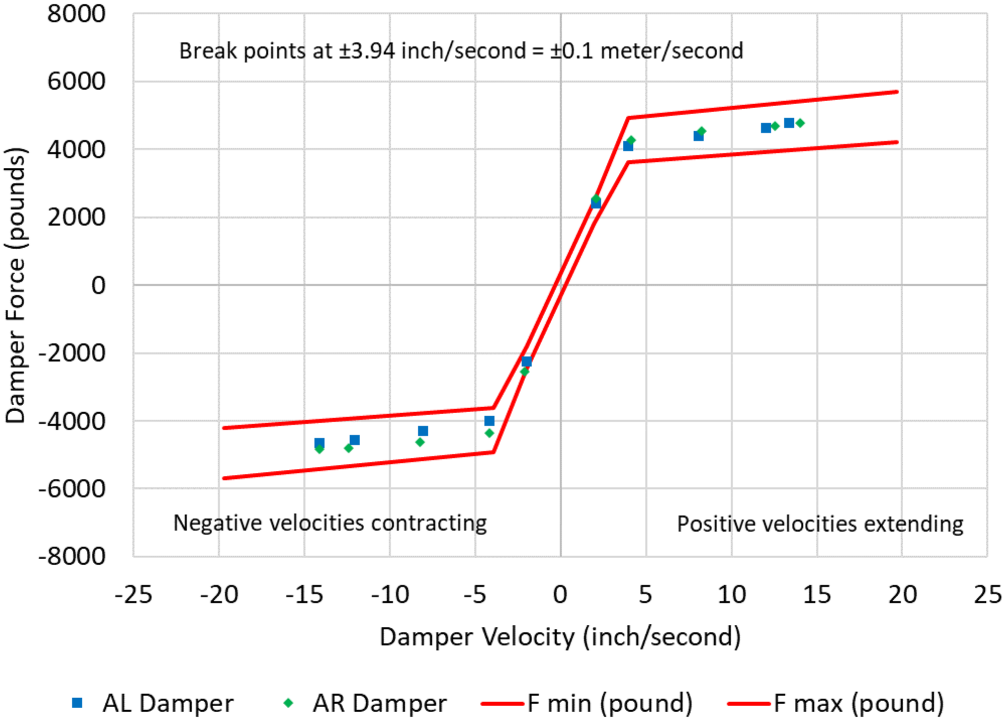

Figure 9. Damper Characterization Data

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* NUCARS® is a registered trademark of Transportation Technology Center, Inc., Pueblo, CO.

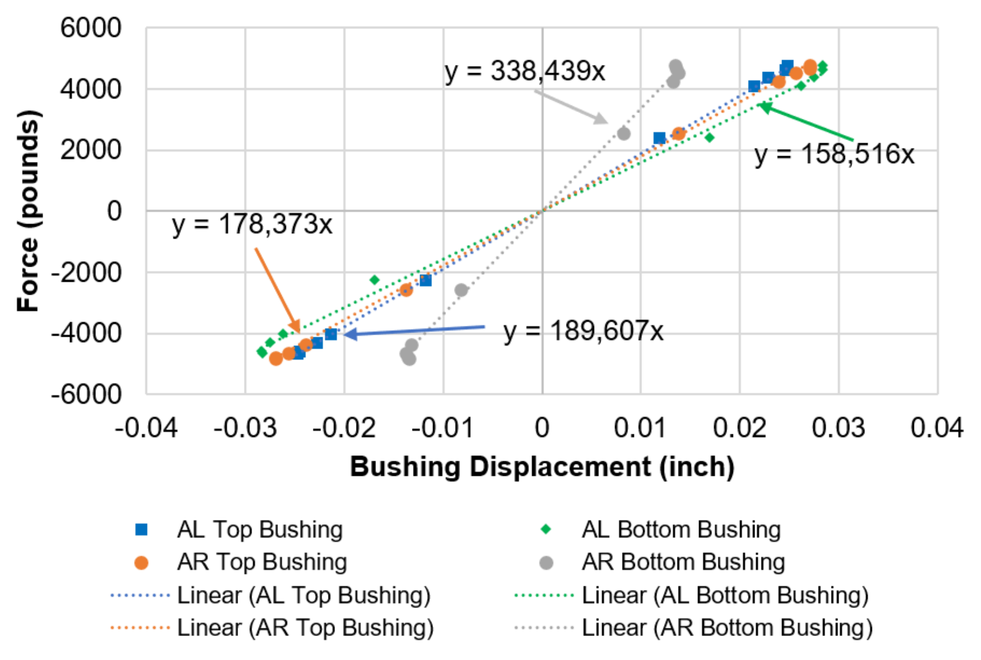


Figure 10. Damper Bushing Characterization Data

5.1.2 Vertical Suspension Stiffness and Damping

The vertical suspension stiffness of the assembled truck was measured on the Mini-Shaker Unit (MSU) in TTC's Rail Dynamics Laboratory. The B-end truck was tested. TTCI fabricated brackets that were welded on the B-end of the buffer railcar to provide connection points for the vertical and lateral actuators (Figure 11). Vertical suspension stiffness and damping tests were performed in October 2019 after most on-track dynamic tests were finished. Although the trucks were broken in, there was no noticeable wear. Abe Meddah, TTCI Principal Investigator II, witnessed the vertical suspension stiffness and damping tests as the AAR Observer per S-2043 requirements.

Figure 11. Brackets for Vertical and Lateral Actuators

The vertical tests were run on the following three configurations:

- Wedges and dampers installed
- Dampers removed
- Wedges and dampers removed

Each configuration was run at 0.1 Hz, 0.5 Hz, and 2 Hz, with the exception of the vertical test with both wedges and dampers removed, which was run at 0.1 Hz only to prevent exciting undamped rigid body modes. Input forces and displacements were adjusted for each run to achieve the desired input range within the capability of the MSU. At low frequencies (0.1 Hz) the suspension was pushed to the stops where possible, but lower amplitude inputs were used at higher frequencies.

The force supplied by the hydraulic actuators was measured by load cells installed between the actuators and the custom brackets where the vertical forces were applied. Forces were also measured on each wheel of the truck using load bars. Displacements across the secondary suspension were recorded using string potentiometers. Figure 12 shows the car installed in the MSU with the actuators configured to apply vertical loads. Examples of the instrumentation are shown in Figure 13 and Figure 14.

The motion between the left and right side frame and the Axle 2 bearing adapters was measured using six LVDTs on each side. The LVDTs were positioned to allow calculation of the relative motion between the side frame and bearing adapter in the longitudinal, lateral, vertical, roll, pitch, and yaw directions (Figure 15).

Data analysis consisted of preparing force versus displacement plots from the measured wheel/rail forces and displacements across the suspension components. These cross-plots were used to obtain suspension stiffness and damping values.

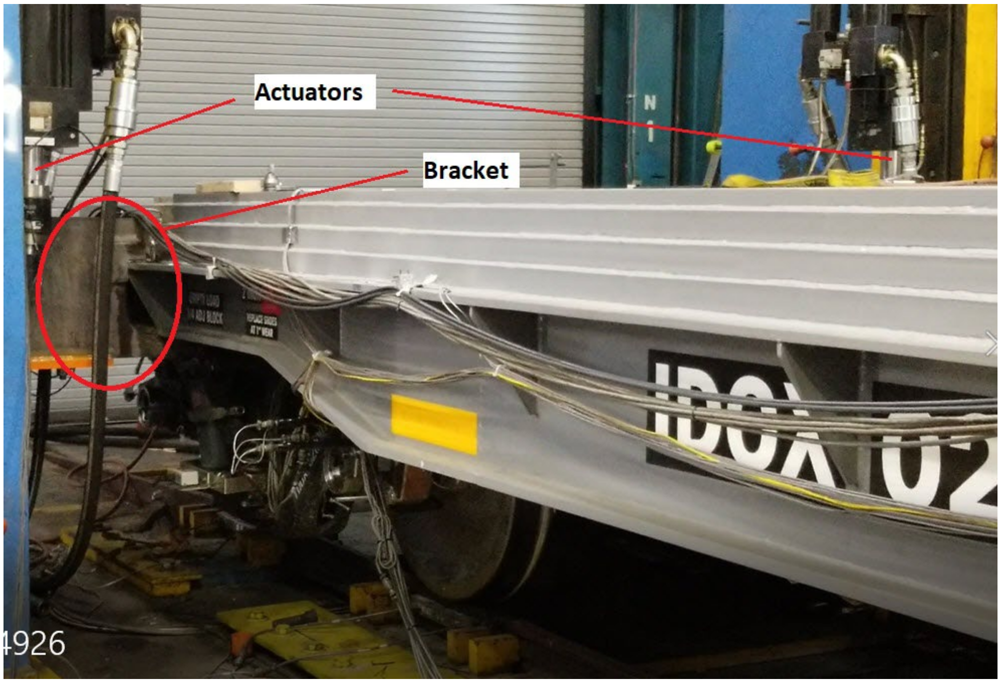


Figure 12. The Buffer Car Installed in the MSU while Configured for Vertical Suspension Testing

Figure 13. String Potentiometer for Measuring Spring Vertical Displacement (Damper Installed)

Figure 14. String Potentiometer with Damper Removed

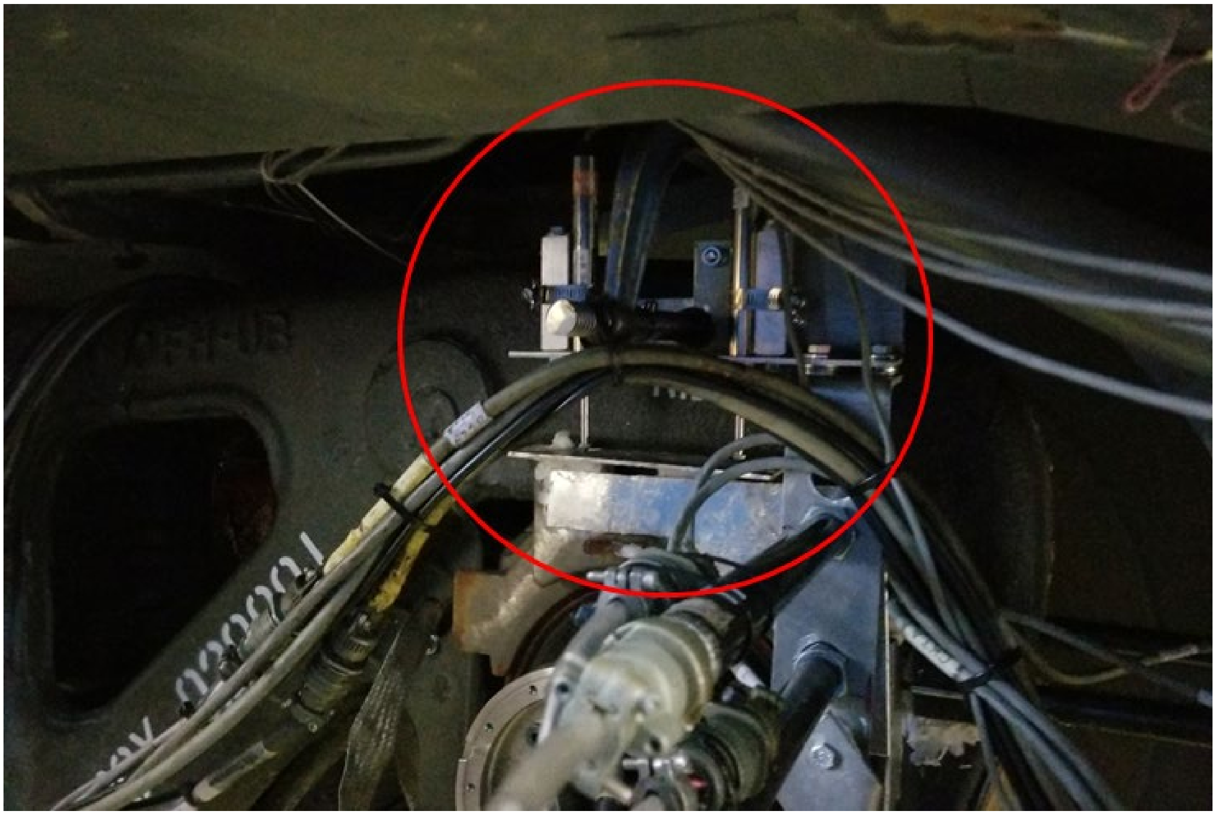


Figure 15. LVDTs for Measuring Pad Vertical Displacements

Tables 6 through 8 show the results for the three conditions tested at the different frequencies. Listed results are the average values per truck set, rather than individual values per spring nest or pad. Figure 16 and Figure 17 show examples of the data for both the springs and the pads. Negative displacements indicate compression, positive displacements indicate extension.

Figure 18 shows a plot of the total truck wheel load versus the average suspension displacement being cycled to the stop at 0.1 Hz. The plot shows that the springs begin to go solid at about -0.9 inch displacement from the static height.

Table 6. Vertical Suspension Test (Wedges and Dampers Installed)

Frequency (Hz)	Secondary Spring Stiffness (kips/inch)	Primary Pad Stiffness (kips/inch)	Secondary Spring Hysterisis Band Width (kips)	Primary Pad Hysterisis Band Width (kips)
0.1	53	3,425	16	16
0.5	55	4,161	28	2
2	75	3,543	47	2

Table 7. Vertical Suspension Test (Wedges Installed, Dampers Removed)

Frequency (Hz)	Secondary Spring Stiffness (kips/inch)	Primary Pad Stiffness (kips/inch)	Secondary Spring Hysterisis Band Width (kips)	Primary Pad Hysterisis Band Width(kips)
0.1	52	3,051	10	19
0.5	53	4,509	17	7
2	53	4,924	24	5

Table 8. Vertical Suspension Test (Wedges and Dampers Removed)

Frequency (Hz)	Secondary Spring Stiffness (kips/inch)	Primary Pad Stiffness (kips/inch)	Secondary Spring Hysterisis Band Width (kips)	Primary Pad Hysterisis Band Width (kips)
0.1	42	3,693	3	12

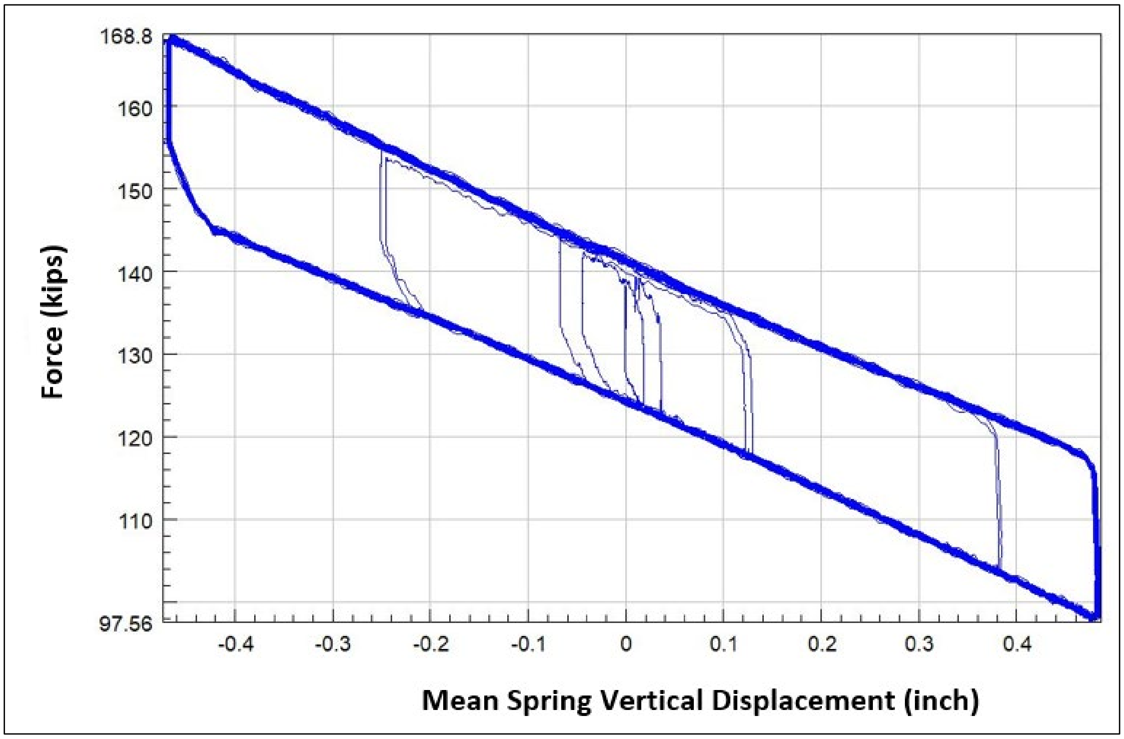


Figure 16. Truck Vertical Wheel Load Plotted against Average Secondary Suspension Displacement, Dampers Removed, 0.5hz

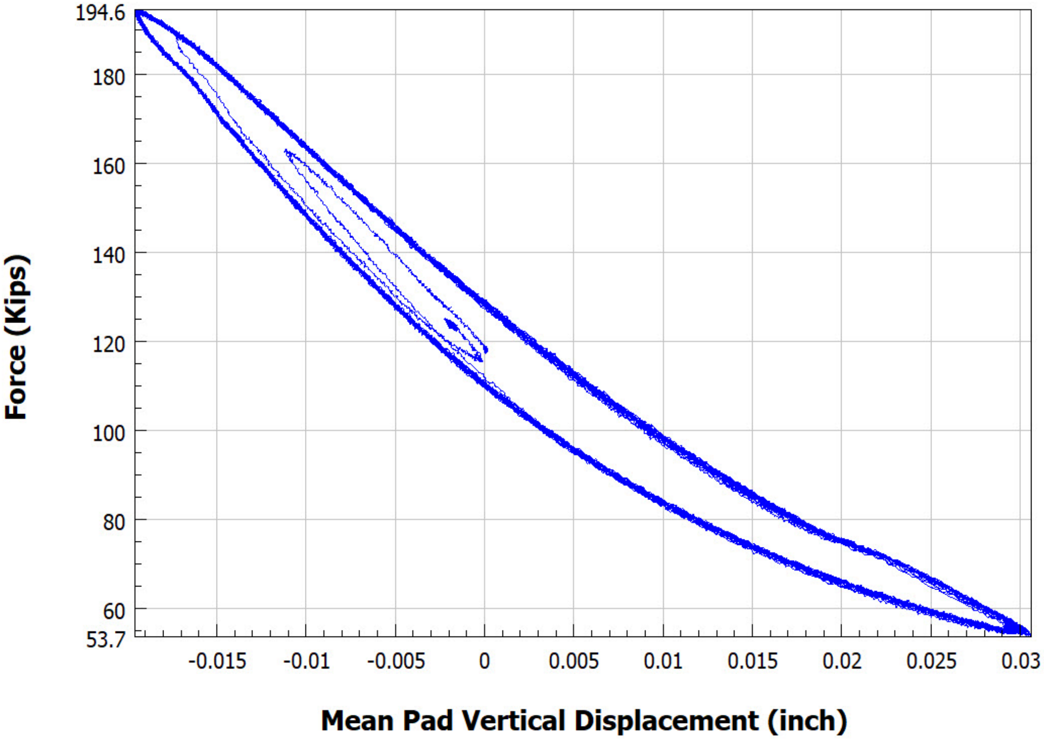


Figure 17. Truck Vertical Wheel Load Plotted against Average Primary Suspension Displacement, Dampers Removed, 0.1hz

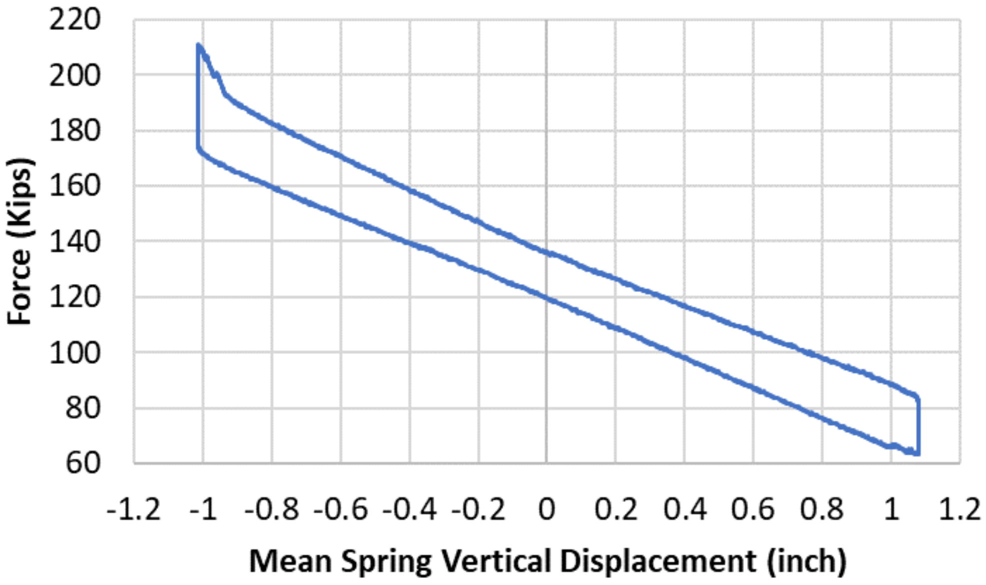


Figure 18. Truck Vertical Wheel Load versus Average Suspension Displacement at 0.1 Hz Input with Wedges and Dampers Installed

5.1.3 Lateral Suspension Stiffness and Damping

Lateral characterization tests were performed by connecting one actuator between the south MSU reaction mass and the carbody. The B-end truck was tested. Loads were applied at several frequencies: 0.1 Hz, 0.5 Hz, and 2.0 Hz, but the most consistent results were found at the lowest frequencies. Input forces and displacements were adjusted for each run to achieve the desired input range within the capability of the MSU. At low frequencies (0.1 Hz) the suspension was pushed to the stops where possible, but lower amplitude inputs were used at higher frequencies. Figure 19 shows a photograph of the MSU configured for lateral characterization testing. TTCI performed lateral suspension stiffness and damping tests in November 2019 after most on-track dynamic tests were finished. Although the trucks were broken in, there was no noticeable wear. Xinggao Shu, TTCI Principal Investigator II, and Adam Klopp, TTCI Principal Investigator I, witnessed the lateral suspension stiffness and damping tests as the AAR Observer per S-2043 requirements.

Figure 19. Buffer Railcar Ready for Lateral Force Test

The Swing Motion® truck design allows the side frames to roll slightly relative to the bolster, transom, and axles. This creates a gravitational stiffness in series with the lateral shear of the spring nest, a complicating factor for lateral characterization tests. The displacement between the bolster and transom was measured to determine the shear stiffness of the spring nests. Additional tests were run while restraining the transom displacement.

The lateral tests were run on the following four configurations at 0.1 Hz, 0.5 Hz, and 2 Hz:

- Wedges and dampers installed
- Dampers removed
- Wedges removed
- Wedges and dampers removed

The runs with the restrained transom were conducted at 0.1 Hz.

The force supplied by the hydraulic actuator was measured by a load cell installed between the actuator and the specially welded bracket where the lateral force was applied. The lateral displacements were measured with laser transducers and a series of LVDTs. Setup and examples of instrumentation are shown in Figure 20.

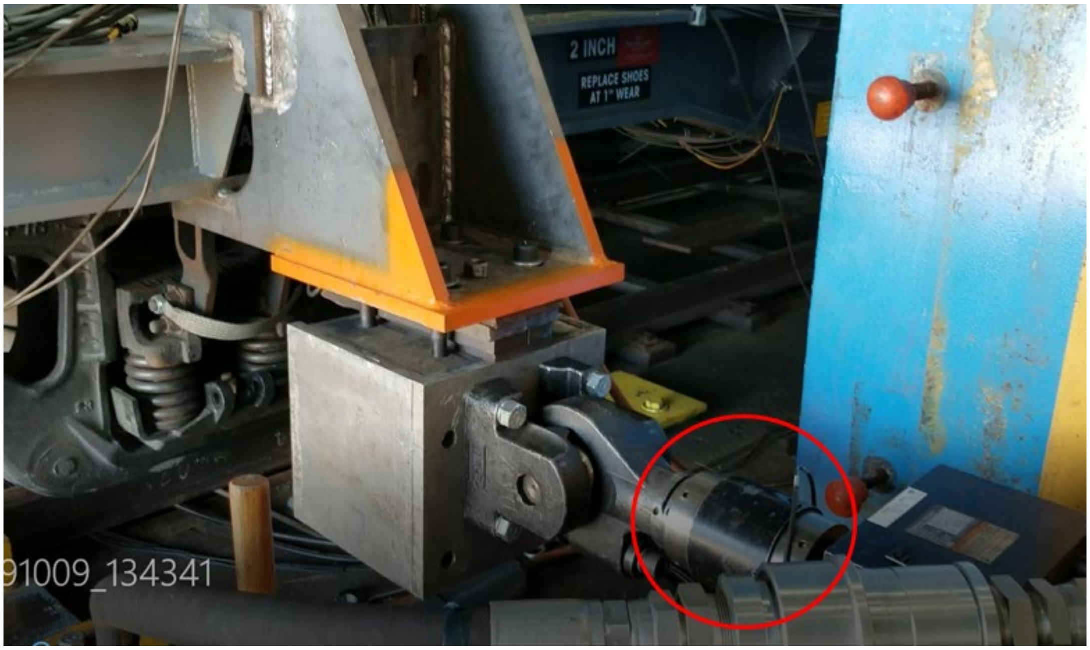


Figure 20. Load Cell for Lateral Force Measurements

The motion between the left and right side frame and the Axle 2 bearing adapters was measured using six LVDTs on each side. The LVDTs were positioned to allow calculation of the relative motion between the side frame and bearing adapter in the longitudinal, lateral, vertical, roll, pitch, and yaw directions (Figure 20). Because the two primary suspension pads work in parallel in the lateral direction, only the combined or average stiffness and damping can be measured. The Swing Motion truck is designed to allow the side frames to roll with relative to the axles, transom, and truck bolster. This action works in series with the secondary suspension lateral spring stiffness to provide a soft lateral suspension compared to other truck designs. For some runs, TTCI isolated the side frame roll motion from the secondary suspension spring shear by connecting the transom to the MSU reaction mass with a stiff bar to prevent it moving laterally due to side frame roll. TTCI then measured the secondary spring lateral displacement without side frame roll motions affecting the measurement. The primary pad stiffness and damping are not reported for transom restrained runs because some of the lateral load is carried by the restraint and is not carried through the pads.

As noted in Section 2.0, these trucks have a primary pad, which allows some lateral movement between the side frames and the axles that works in series with the effect of side frame roll. Lateral displacement was measured in two locations at each pad on one of the axles. The measurements were offset vertically so the roll and lateral shift between the side frame and axle could be determined. The lateral stiffness reported is relative to the lateral movement between the side frame and axle at a vertical position equal to the top of the bearing adapter. Figure 21 shows the instrumentation used to record the lateral movements of the pads.

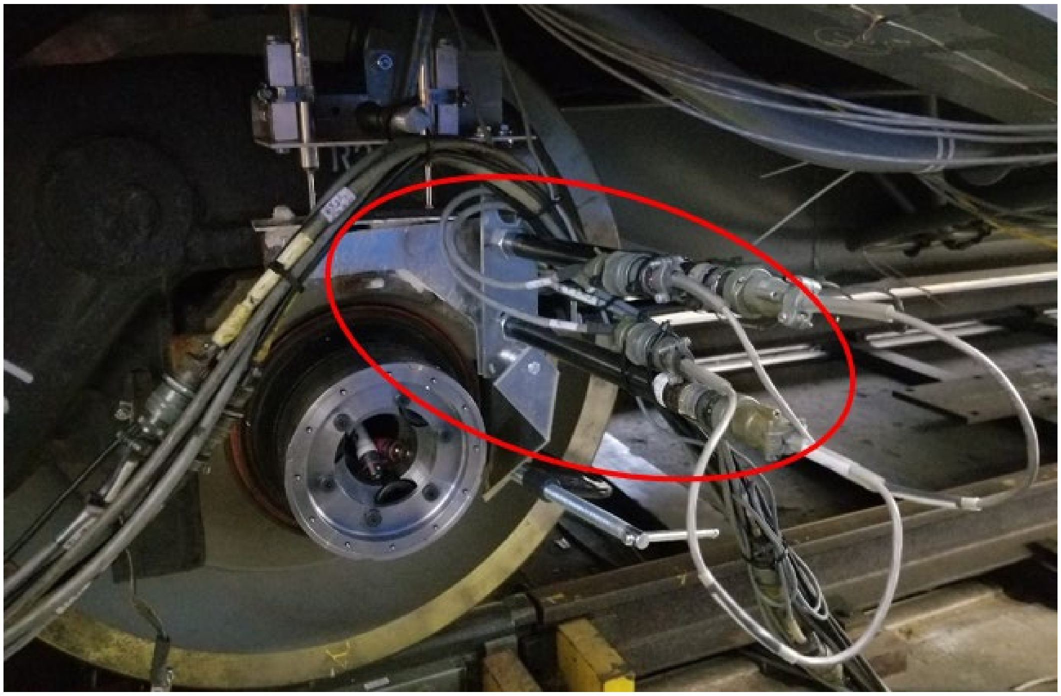


Figure 21. LVDTs used to Record Pad Lateral Movements

Tables 9 through 12 show the results for the lateral suspension and damping tests.

Table 9. Lateral Suspension Test (Wedges and Dampers Installed)

Frequency (Hz)	Spring Stiffness (kips/inch)	Pad Stiffness (kips/inch)	Spring Hysterisis Band Width (kips)	Pad Hysterisis Band Width (kips)
0.1	11	149	12	10
0.5	45	718	6	10
2.0	40	411	20	5
0.1 Transom Restrained	15	NA	13	NA

Table 10. Lateral Suspension Test (Wedges Installed, Dampers Removed)

Frequency (Hz)	Spring Stiffness (kips/inch)	Pad Stiffness (kips/inch)	Spring Hysterisis Band Width (kips)	Pad Hysterisis Band Width (kips)
0.1	12	146	12	9
0.5	13	159	15	14
2.0	37	376	28	12
0.1 Transom Restrained	17	NA	11	NA

Table 11. Lateral Suspension Test (Wedges Removed)

Frequency (Hz)	Spring Stiffness (kips/inch)	Pad Stiffness (kips/inch)	Spring Hysterisis Band Width (kips)	Pad Hysterisis Band Width (kips)
0.1	10	127	2	2
0.1 Transom Restrained	14	NA	3	NA

Table 12. Lateral Suspension Test (Dampers and Wedges Removed)

Frequency (Hz)	Spring Stiffness (kips/inch)	Pad Stiffness (kips/inch)	Spring Hysterisis Band Width (kips)	Pad Hysterisis Band Width (kips)
0.1	10	121	2	2
0.1 Transom Restrained	14	NA	4	NA

Figure 22 and Figure 23 show examples of the Lateral Suspension Stiffness and Damping Test results. Force to the north is positive, and displacement to the south is positive.

Figure 24 shows the lateral suspension with dampers and wedges removed, and the transom restrained, pushed to the left and right lateral stops. The total lateral clearance between the bolster and the transom is about 1.8 inches.

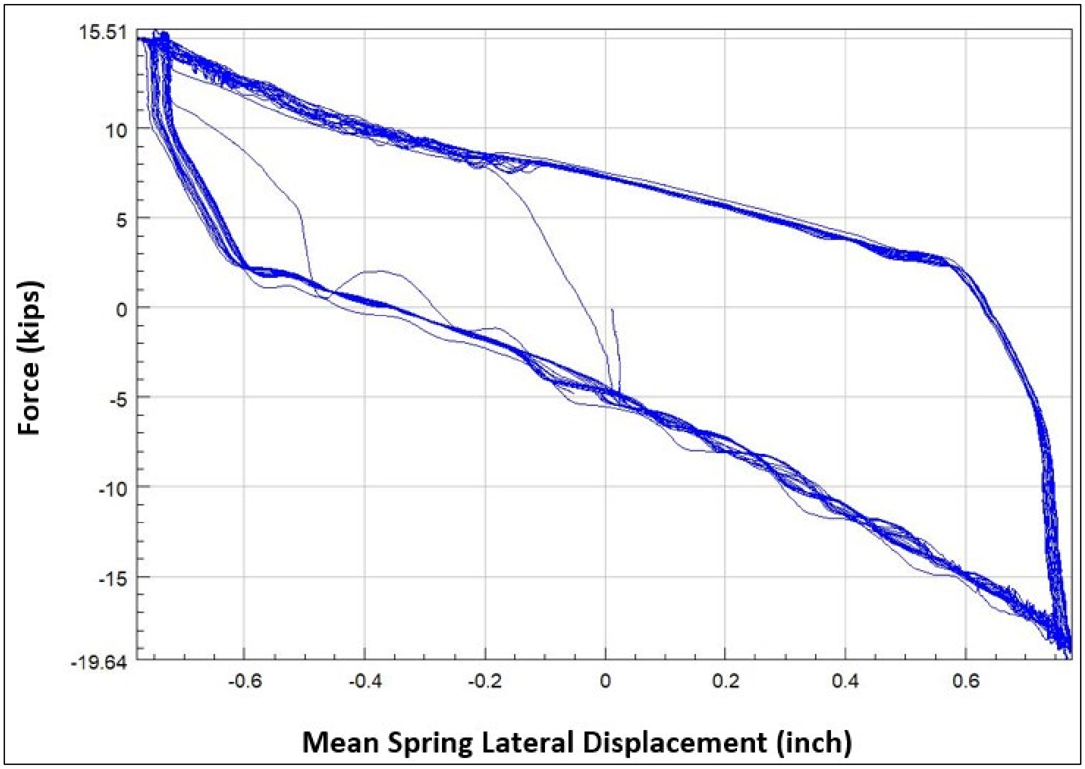


Figure 22. Truck Lateral Load Plotted against Lateral Secondary Suspension Displacement, Dampers Removed, 0.1 Hz

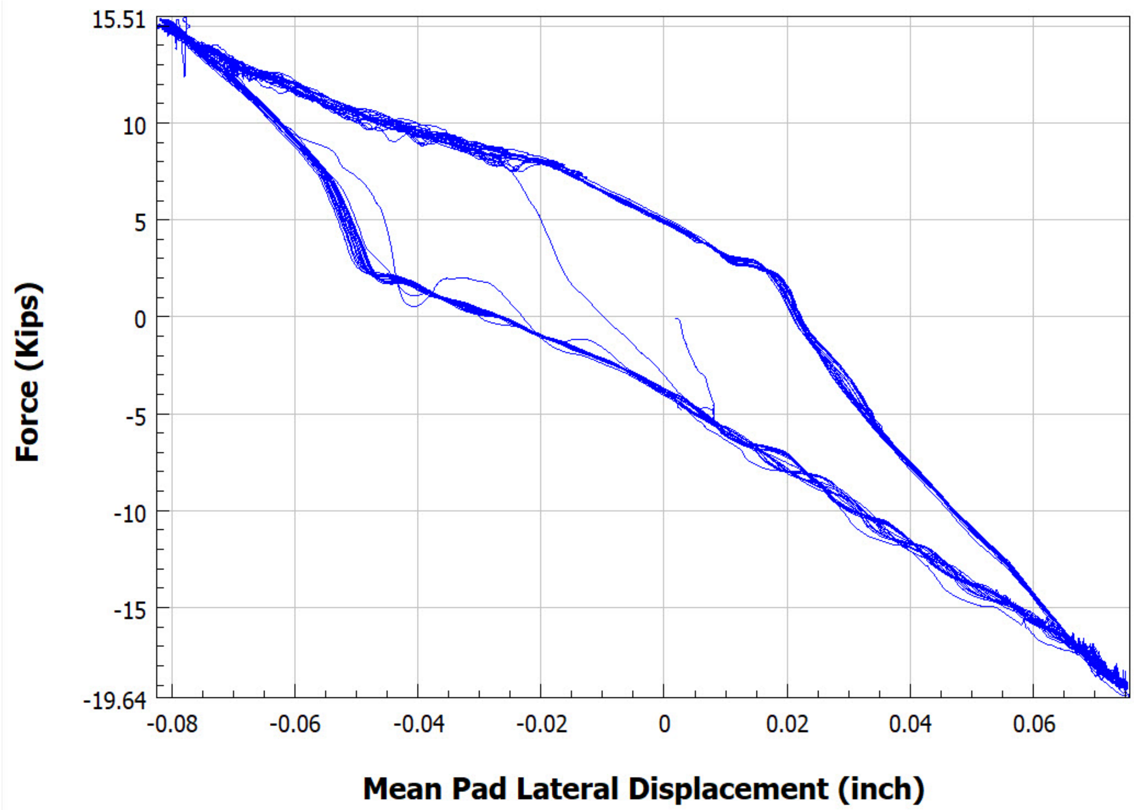


Figure 23. Truck Lateral Load Plotted against Lateral Primary Suspension Displacement, Dampers Removed, 0.1 Hz.

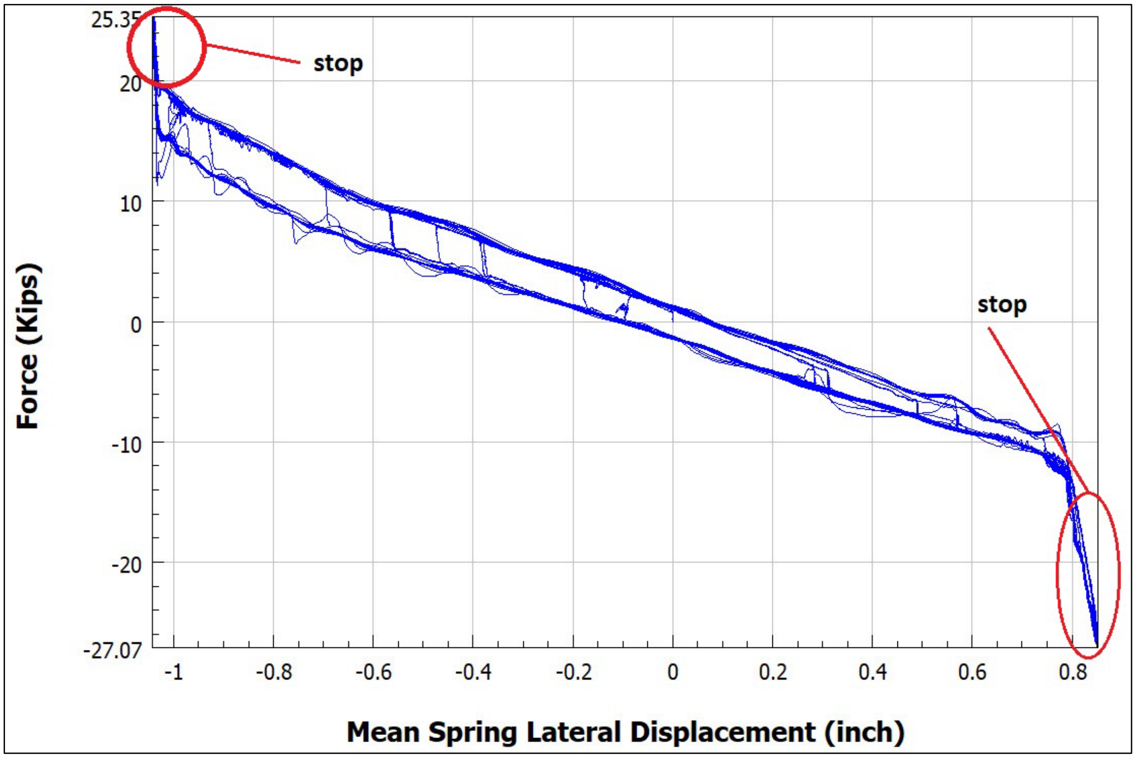


Figure 24. Secondary Suspension with Wedges and Dampers Removed and with the Transom Restrained Showing Displacement to the Lateral Stops

5.1.4 Truck Rotation Stiffness and Breakaway Moment

Truck rotation stiffness and breakaway moment were measured by supporting one end of the buffer railcar on an air bearing table and measuring the force required to rotate the truck relative to the carbody. These tests were performed on the A-end truck. Figure 25 shows the A-end truck of the buffer railcar positioned on the air bearing table. The actuator and load cell are circled in blue, and one of the truck rotation measurements is circled in red. TTCI performed truck rotation tests in May 2019 before any track testing began. The centerplates were lubricated with a lubrication disk. The constant-contact side bearings were installed during the test. Adam Klopp, TTCI Principal Investigator I, witnessed the truck rotation stiffness and breakaway test as the AAR Observer per S-2043 requirements.

Figure 25. Buffer Railcar Positioned on Air Bearing Table

Figure 26 shows the moment versus truck rotation for the buffer railcar. The breakaway moment is the moment just as the truck begins to move from its centered position at zero degree. The plot shows data from several test runs, and all runs were consistent with each other.

The plot appears to have a wider hysteresis for positive rotations (CCW when looking down on the truck). The actuators were installed near the corners of the air bearing table, perpendicular to the table rather than perpendicular to a line that passes through the center of rotation. As a result, the lever arm the actuators act on gets longer for CW rotations and shorter for CCW rotations. The moments and friction values shown are taken as the truck is moving through the zero-rotation position when the length of the lever is as measured.

Table 13 shows the measured friction moment. The typical value is shown. The coefficient of friction in the centerplate was estimated using the following equation:

$$\mu = \frac{3\,(Torque - 2SBld \times SBdst \times \mu_{sb})(\mathrm{CPrad}^2 - \mathrm{Hrad}^2)}{2\,(\mathrm{Tld} - 2 \times \mathrm{SBld})(\mathrm{Cprad}^3 - \mathrm{Hrad}^3)}$$

Where:

- Torque is the average turning torque measured in the test = 232 kip-inch
- SBld is the CCSB preload measured during side bearing component characterization = 5.16 kips
- μ_{sb} is the assumed coefficient of friction between the CCSB and the body = 0.4
- CPrad is the centerplate radius, 8 inches
- Hrad is the centerplate hole radius, 1 inch
- Tld is the A-end truck load, which is the A-end scale weight[†]: 131 kips – 11 kips truck weight = 120 kips on the side bearings and center plate

Side bearing preload is estimated from the hysteresis loop shown in Figure 6.

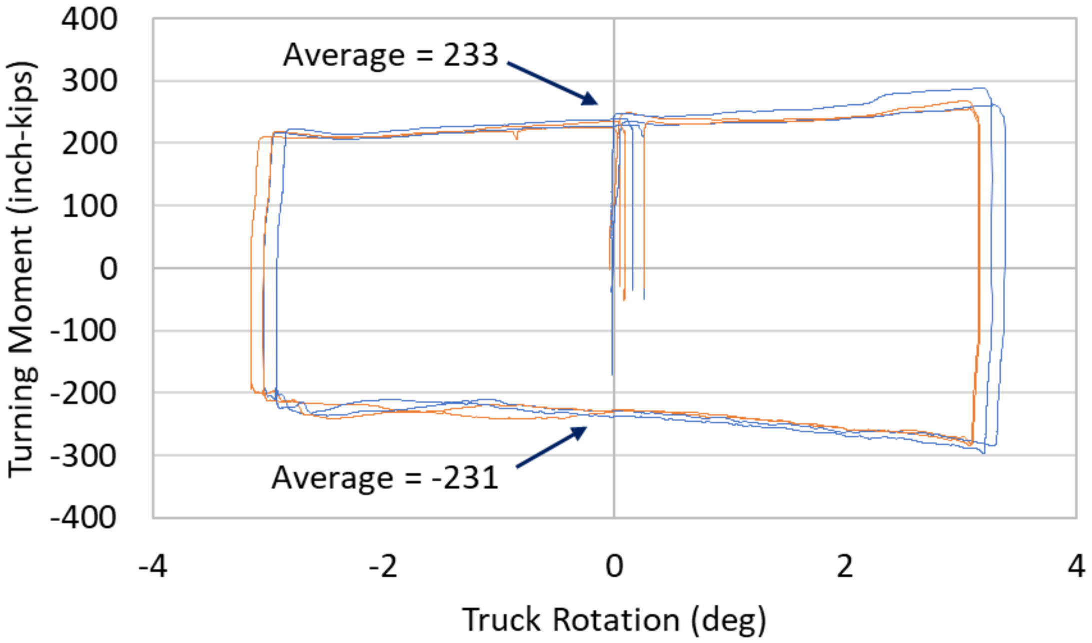


Figure 26. Truck Rotation Data for Buffer Railcar A-truck

Table 13. Truck Rotation Moment and Estimate of the Associated Friction Coefficient

A-Truck	Mean Torque 1,000 inch-pound	Center Plate Friction Coefficient (μ)
	232	0.22

[†] TTCI measured the A-end weight with a calibrated track scale on May 22, 2019.

5.1.5 Interaxle Longitudinal Stiffness

The longitudinal stiffness of the axle to side frame connection is critical to vehicle performance in curving and high-speed stability regimes. The interaxle longitudinal stiffness is measured by installing independently rotating wheels in the truck with spindles at the bearing endcaps and then forcing the axles apart and pulling them together while measuring the force and displacement (Figure 27). Runs were performed while pushing and pulling in phase on each side of the truck and separately while pushing on one side of the truck and pulling on the other side. TTCI performed the interaxle longitudinal stiffness test in November 2019 after most of the on-track dynamic testing was complete. Adam Klopp, TTCI Principal Investigator I, witnessed the interaxle longitudinal stiffness tests as the AAR Observer per S-2043 requirements.

Figure 27. Buffer Railcar Interaxle Test Actuator and Load Cell

The motion between the left and right side frame and the Axle 2 bearing adapters was measured using six LVDTs on each side. The LVDTs were positioned to allow calculation of the relative motion between the side frame and bearing adapter in the longitudinal, lateral, vertical, roll, pitch, and yaw directions.

The applied force was offset vertically from the level of the axle to side frame connection. This caused the bearing adapters to pitch and shear laterally. The shear stiffness data in Table 14 are based on longitudinal displacements at the level of the top of the bearing adapter. Pitch stiffness data are based on a rotation of the bearing adapter around the bearing. Axle centerline stiffness data are based on the longitudinal motion of the axle at its axis of rotation. Figure 28 shows example data for longitudinal axle stiffness tests.

Axle yaw stiffness data were determined during push-pull runs. Axle yaw stiffness can be expressed as two longitudinal stiffnesses separated by the bearing centerline distance. The effective longitudinal stiffness was calculated from the axle yaw stiffness by this method for comparison to the direct measurements of primary longitudinal stiffness. Given the large variation in the direct measurement of axle centerline longitudinal stiffness, the values derived from axle yaw stiffness reasonably agree with the average values from the direct measurements. These values were weighted and averaged to establish an effective longitudinal value of 13,000 pounds per inch per pad, which is the key result that will be used in the post-test analysis.

Table 14. Side frame to Axle Properties Stiffness Data per Pad

Shear stiffness (1,000 pounds/inch)	Average	43
	Minimum	26
	Maximum	57
	Standard deviation	13
Pitch stiffness (1,000 inch-pounds/rad)	Average	596
	Minimum	345
	Maximum	750
	Standard deviation	192
Axle centerline stiffness from direct measurement (1,000 pounds/inch)	Average	12
	Minimum	7
	Maximum	15
	Standard deviation	4
Axle yaw stiffness (1,000 inch-pounds/rad)	Average	46,664
	Minimum	41,545
	Maximum	51,782
	Standard deviation	7,239
Axle centerline stiffness derived from axle yaw (1,000 pounds/inch)	Average	14.9

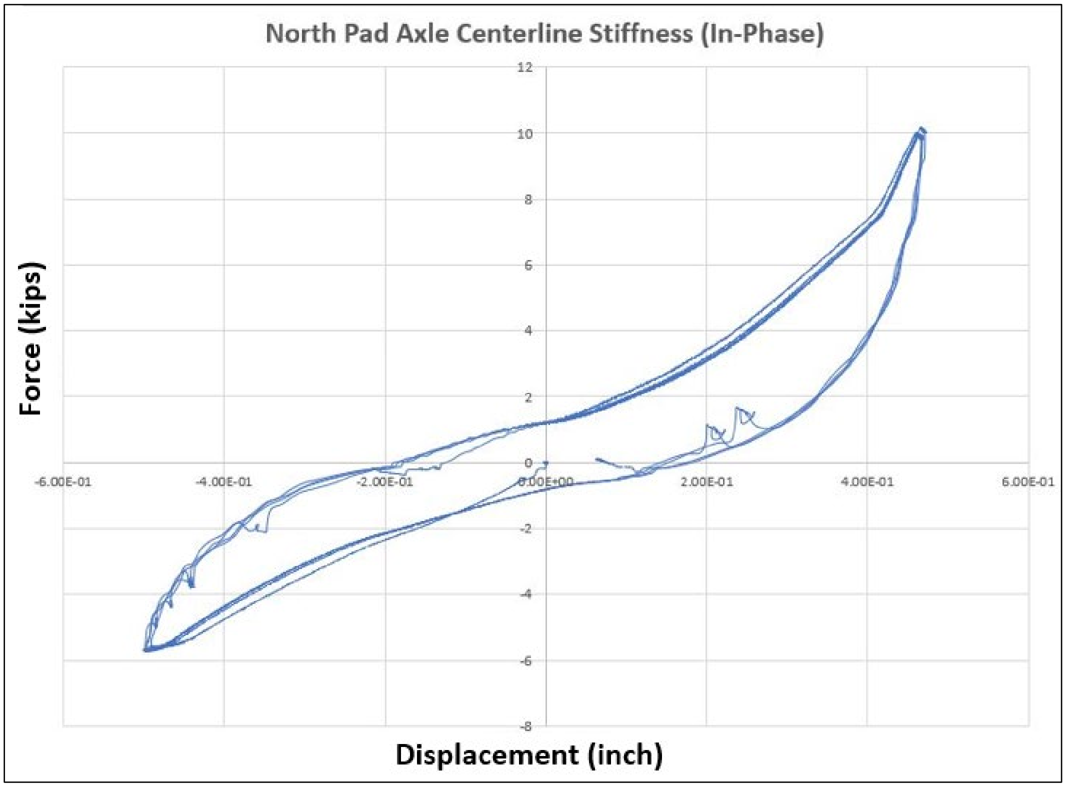


Figure 28. Example Data for Longitudinal Axle Stiffness Tests

5.1.6 Modal Characterization

Modal characterization is performed to identify the rigid and flexible body modes of vibration for the vehicle.

The buffer railcar was excited through actuators attached to the special brackets described in Section 5.1.2. Figure 29 shows the railcar setup for vertical inputs. Dampers and wedges, including the control coils, were removed for all tests because initial testing showed it was not possible to excite the modes with dampers and wedges in place.

Actuators were operated in force control at lower frequencies (0.2 to 10 Hz) and in displacement control input at higher frequencies (3 to 30 Hz). In practice, the displacement control inputs were intended to be constant displacement but were limited by the actuator response and displacement amplitude reduced as frequency increased. Frequency was increased linearly with time for the frequency sweeps, and then the frequency of peak amplitudes were confirmed with dwell runs at discrete frequencies. Inputs included:

- Lateral excitation with one actuator.
- Vertical excitation with two actuators operating in phase.
- Vertical excitation with two actuators operating 180 degrees out of phase.

The buffer railcar deck was instrumented with five vertical accelerometers on the right edge, five vertical accelerometers along the left edge, and five lateral accelerometers along the right edge. The input forces and displacements were also recorded. Figure 30 shows the distribution of the accelerometers used during the modal test. Adam Klopp, TTCI Principal Investigator I, and Abe Meddah, TTCI Principal Investigator I, witnessed the modal characterization tests as the AAR Observer per S-2043 requirements.

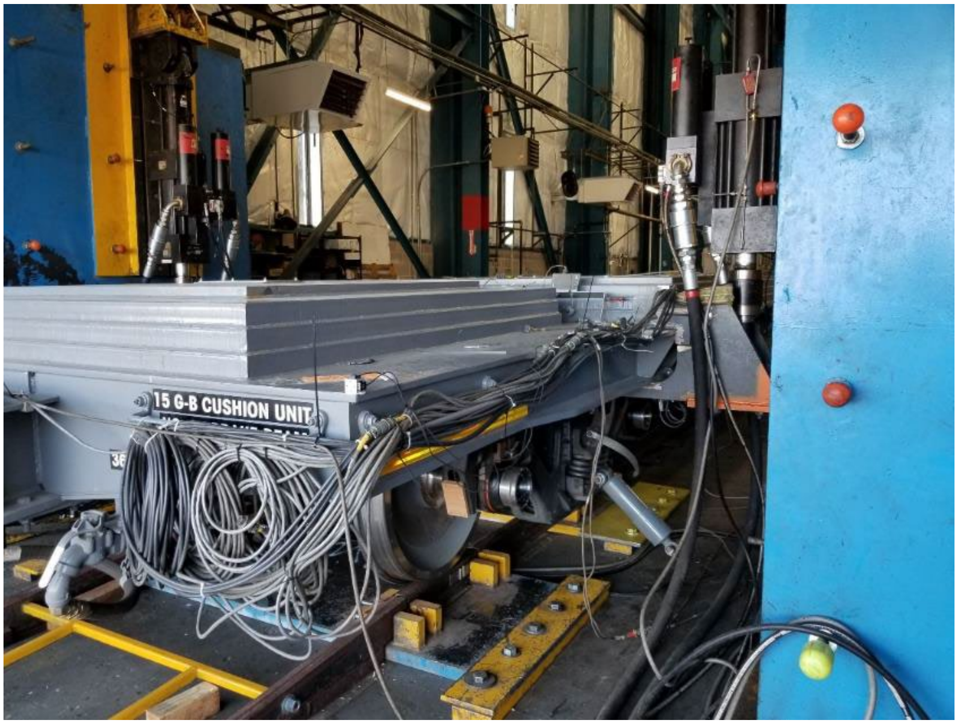


Figure 29. Actuators Attached to Buffer Railcar during Modal Testing with Vertical Input

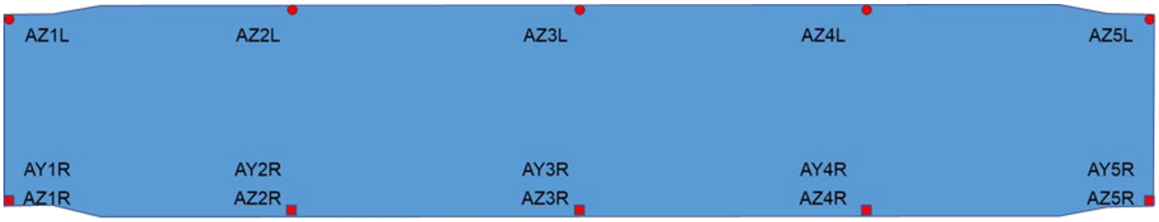


Figure 30. Distribution of Accelerometers during the Buffer Railcar Modal Test

The test was performed according to the following sequence:

1. Vertical rigid body test runs (force control).
2. Roll rigid body test runs (force control).
3. Vertical flexible body test runs (displacement control).
4. Twist flexible body test runs (displacement control).
5. Lateral rigid body test runs (force control).
6. Lateral flexible body test runs (displacement control).

Transfer functions were calculated for each accelerometer with respect to the appropriate input. The transfer functions were examined to identify resonant frequencies. Amplitude and phasing for each accelerometer location were examined at that frequency to identify the mode shape. Table 15 shows results from the modal characterization tests. The rigid body yaw mode could not be excited during these tests because there was a large amount of damping in the system. The flexible body lateral bending mode also could not be excited during these tests. TTCI believes this is because the steel ballast weights welded to the buffer railcar deck increased the stiffness of the railcar, and consequently the lateral flexible body bending frequency was higher than the MSU is able to excite. This frequency is likely higher than would affect vehicle dynamic performance. This case is marked as “Not observed.”

Table 15. Modal Characterization Results

Mode Type	Mode	Frequency (Hz)
Rigid Body	Bounce	1.71
	Pitch	2.44
	Upper center roll	2.19
	Lower center roll	0.98
	Yaw	Not observed
Flexible Body	Twist	16.36
	Lateral bending	Not observed
	Vertical bending	9.00

Figure 31 and Figure 32 show the time history for the identification of the Bounce Mode and its corresponding frequency analysis. The maximum amplitude of the signal is found at 1.71 Hz.

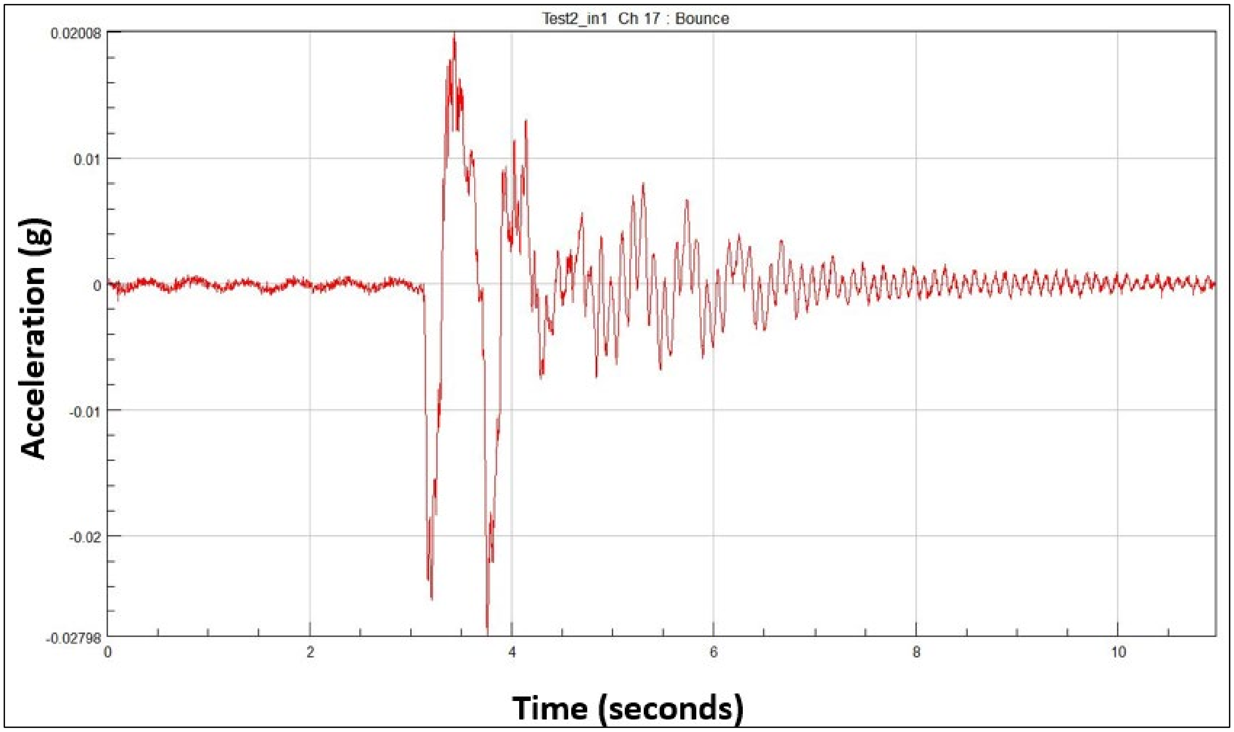


Figure 31. Time History Plot for Bounce Mode

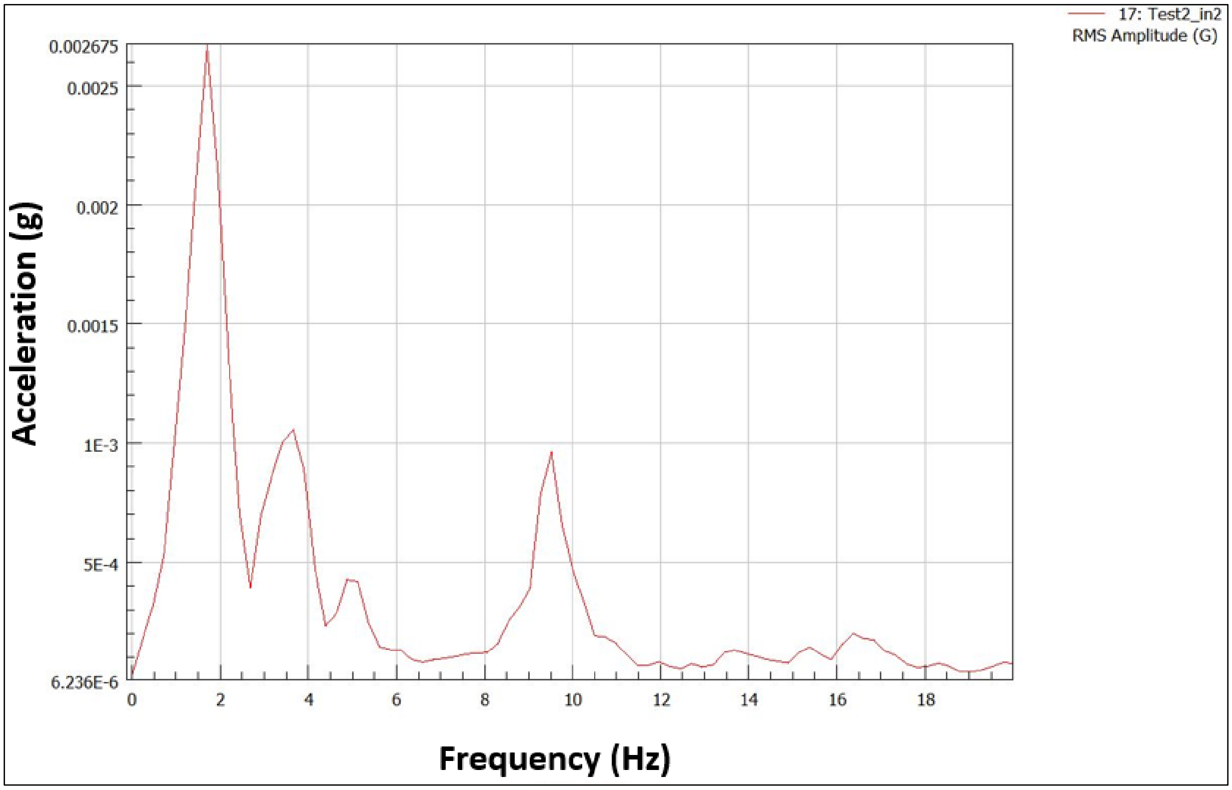


Figure 32. Frequency Analysis for the Bounce Mode

5.2 Nonstructural Static Tests

Nonstructural static tests are performed to verify the vehicle equalizes load properly under common conditions. Test results are provided in Sections 5.2.1 to 5.2.4. The Nonstructural static tests included:

- Truck twist equalization
- Carbody twist equalization
- Static curve stability
- Horizontal curve negotiation

5.2.1 Truck Twist Equalization

The truck twist equalization requirement is to ensure adequate truck load equalization. With the buffer railcar on level track, vertical wheel loads were measured while raising and lowering one wheel from 0.0 inch to 3.0 inches in increments of 0.5 inch. At 2.0 inches of deflection, vertical load at any wheel may not fall below 60 percent of the nominal static load. At 3.0 inches of deflection, vertical load at any wheel may not fall below 40 percent of the nominal static load. Two different wheels were used to monitor truck twist (Left 1 and Right 3).

The truck twist equalization tests were completed on July 26, 2019. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the truck twist equalization tests as the AAR Observer per S-2043 requirements. The buffer railcar met the AAR Standard S-2043 requirements. Table 16 shows the worst-case truck twist equalization results. Figure 33 displays the wheel load result for all wheels during the lifting and lowering of the L1 wheel.

Table 16. Truck Twist Equalization Results

Condition	L1 Wheel Location	
	Percent Load	Wheel
2-inch lowering	82	Axle 1 Left
3-inch lowering	77	Axle 1 Left
Condition	**R3 Wheel Location**	
	Percent Load	**Wheel**
2-inch lowering	81	Axle 3 Right
3-inch lowering	77	Axle 3 Right

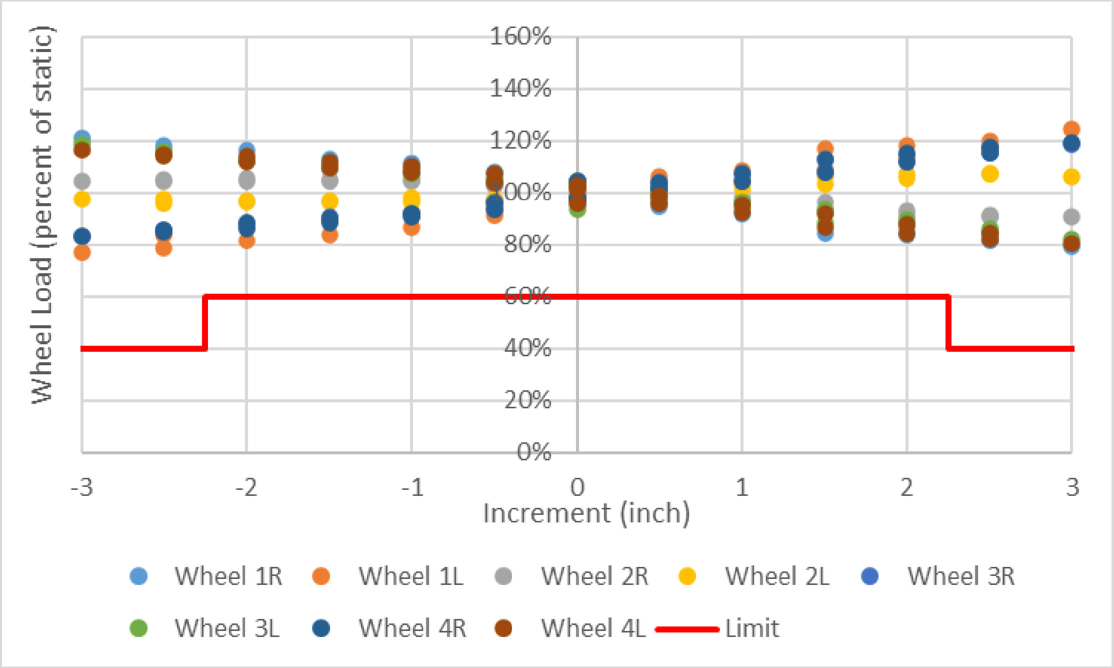


Figure 33. L1 Truck Twist Result for All Increments

5.2.2 Carbody Twist Equalization

The carbody twist equalization requirement is to document wheel unloading under carbody twist, such as during a spiral negotiation.

With the buffer railcar on level track, vertical wheel loads were measured while raising both wheels on one side of a truck. Tests were performed on all four corners of the railcar.

At 2.0 inches of deflection, vertical load at any wheel may not fall below 60 percent of the nominal static load. At 3.0 inches of deflection, no permanent damage should be produced and vertical load at any wheel may not fall below 40 percent of the nominal static load.

Carbody twist tests were completed July 26, 2019. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the carbody twist equalization tests as the AAR Observer per S-2043 requirements. The buffer railcar met criteria for carbody twist equalization. No permanent deformation occurred at 3 inches of carbody twist.

Table 17 shows the worst-case test results. Figure 34 displays the percent load for all wheels during the test where L3 and L4 wheels were lifted.

Table 17. Carbody Twist Equalization Results

Condition	**B-End Right Truck Side Location**	
	Percent Load	**Wheel**
2-inch raise	88	Axle 4 Right
3-inch raise	81	Axle 3 Right and Axle 4 Right
Condition	**B-End Left Truck Side Location**	
	Percent Load	**Wheel**
2-inch raise	77	Axle 3 Left
3-inch raise	74	Axle 3 Left and Axle 4 Left
Condition	**A-End Right Truck Side Location**	
	Percent Load	**Wheel**
2-inch raise	79	Axle 2 Right
3-inch raise	74	Axle 1 Right and Axle 2 Right
Condition	**A-End Left Truck Side Location**	
	Percent Load	**Wheel**
2-inch raise	75	Axle 2 Left
3-inch raise	74	Axle 1 Left and Axle 2 Left

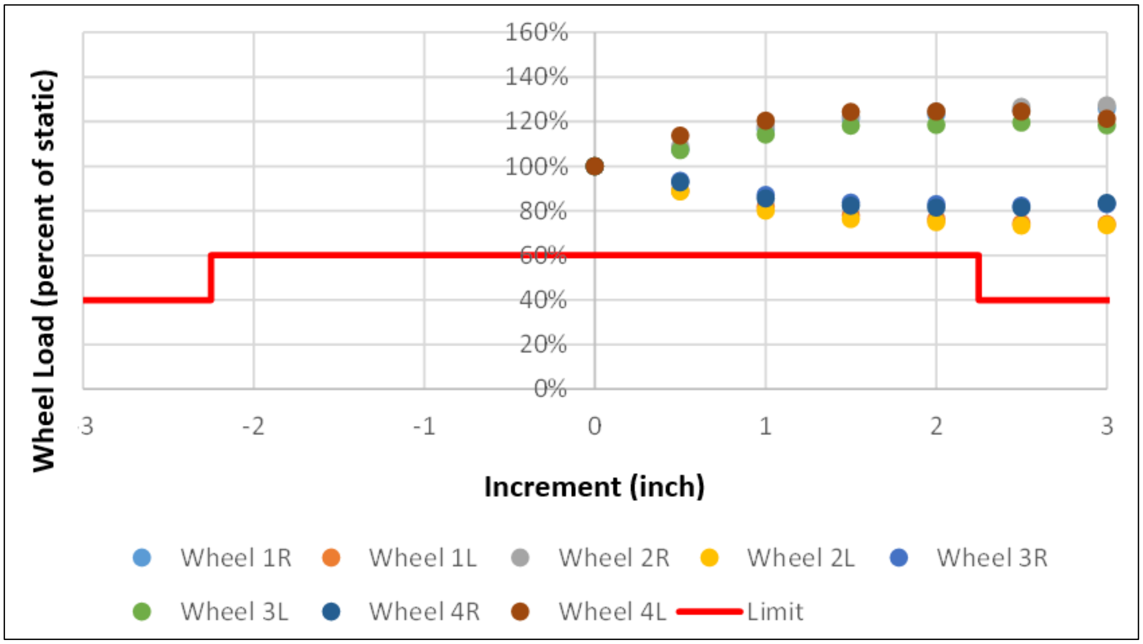


Figure 34. Carbody Twist for L3 and L4 Results for All Wheels

5.2.3 Static Curve Stability

The static curve stability test was performed July 29, 2019. Abe Meddah, TTCI Principal Investigator II, and Adam Klopp, TTCI principal Investigator I, witnessed the static curve stability test as the AAR Observer per S-2043 requirements. The buffer railcar was coupled to a short base car on one end and a long car having 90-foot over strikers, 66-foot truck centers, 60-inch couplers, and conventional draft gear on the other end. The 200,000-pound load was applied and held for more than 20 seconds. The train was chocked in a 10-degree flat curve at the Urban Rail Building at TTC.

The railcar must not experience wheel lift or suspension separation during this test. Wheel lift is defined as 1/8-inch lift when measured 2 5/8 inches from the rim face with a feeler gauge. Figure 35 shows the buffer railcar during the static curve stability test. Figure 36 shows the clearance being checked with a feeler gauge. The buffer railcar met the criteria for the static curve stability test.

Figure 35. Buffer Railcar during the Static Curve Stability Test

Figure 36. Checking Clearance during the Static Curve Stability Test

5.2.4 Horizontal Curve Negotiation

The horizontal curve negotiation test is performed to identify areas of interference between components of buffer railcar suspension, structure, and brake system. The test was performed in a 150-foot radius curve on July 30, 2019. Adam Klopp, TTCI Principal Investigator I, witnessed the horizonal curve negotiation test as the AAR Observer per S-2043 requirements. No interference was noted; therefore, the buffer railcar met the criteria for this test. Figure 37 displays an area where clearance was closest. Note: an inspector noted that the rubber brake cylinder gasket contacted the center sill; however, it was determined that it was not significant.

Figure 37. Clearance between Brake Cylinder and Center Sill with Buffer Railcar in 150-foot Radius Curve

5.3 Static Brake Tests

AAR Standard S-2043 requires that static brake force measurements be made per AAR MSRP Section E, Standard S-401 and that a single-car air brake test must be performed per the AAR MSRP Section E, Standard S-486. These tests were conducted by Kasgro prior to delivery of the buffer railcar to TTC.

The static brake force measurements were conducted on IDOX 20001 and 20002, at the Kasgro facility in New Castle, Pennsylvania on December 4 and 5, 2019. The single car air brake tests were conducted on IDOX 20001 and 20002, also at the Kasgro facility, Pennsylvania on February 11, 2019.

AAR Standard S-401 testing is documented in a letter from Matt DeGeorge to Jon Hannafious (TTCI) dated August 20, 2020. AAR Standard S-486 testing is documented in a letter from Mike Yon to David Cackovic (TTCI) dated March 12, 2019. Both letters are included in Appendix B.

5.4 Structural Tests

Structural tests were conducted to demonstrate the railcar's ability to withstand the rigorous railroad load environment and to verify the accuracy of the structural analysis. AAR Standard S-2043 refers to AAR MSRP Section C Part II, Specification M-1001, paragraph 11.3 (Reference 1) for structural testing details and criteria.

The AAR Standard S-2043 requirement calls for dimensional measurements at the start and conclusion of the structural tests and strain measurements during testing. In addition, visual inspections for damage are required before and after the individual tests. A key criterion from Reference 1 is that no permanent deformation shall be produced by the testing. This is interpreted as no strain exceeding material yield.

The buffer railcar was instrumented with 51 strain gauges. Gauges were located on the top and bottom of the railcar in key locations specified by Kasgro, the railcar designer. These measurements were used to monitor strain during each of the structural tests and to verify finite element analysis. Figure 35 shows the location of strain measurements. A description of each location is included in Appendix A, and further detail on the locations, placement, and orientation of the gages is found in Appendix C. The gauges were zeroed before each test. Results have been converted from microstrain (με) to stress (σ, ksi) with a positive value indicating tension and a negative value indicating compression using the following formula:

$$\sigma = E\mu\varepsilon/1{,}000{,}000$$

Where:
σ = stress (ksi)
E = Young's modulus (29,000 ksi)
$\mu\varepsilon$ = microstrain (inch/inch)

The MSRP section C-II, Paragraph 4.2.2.4, states "…the allowable design stress shall be the yield or 80% of ultimate, whichever is lower, or the critical buckling stress." Kasgro's critical buckling analysis (Appendix D) shows that buckling is not limiting for the buffer car. The allowable compressive or tensile stress is yield strength of the material the strain gages were applied to, 50,000 psi for all the buffer car body components, per Kasgro.

The structural tests include the following:

- Preliminary and post-test inspection
- Squeeze (compressive end) load
- Coupler vertical loads
- Jacking
- Twist
- Impact

Structural test results are provided in Sections 5.4.1 to 5.4.6.

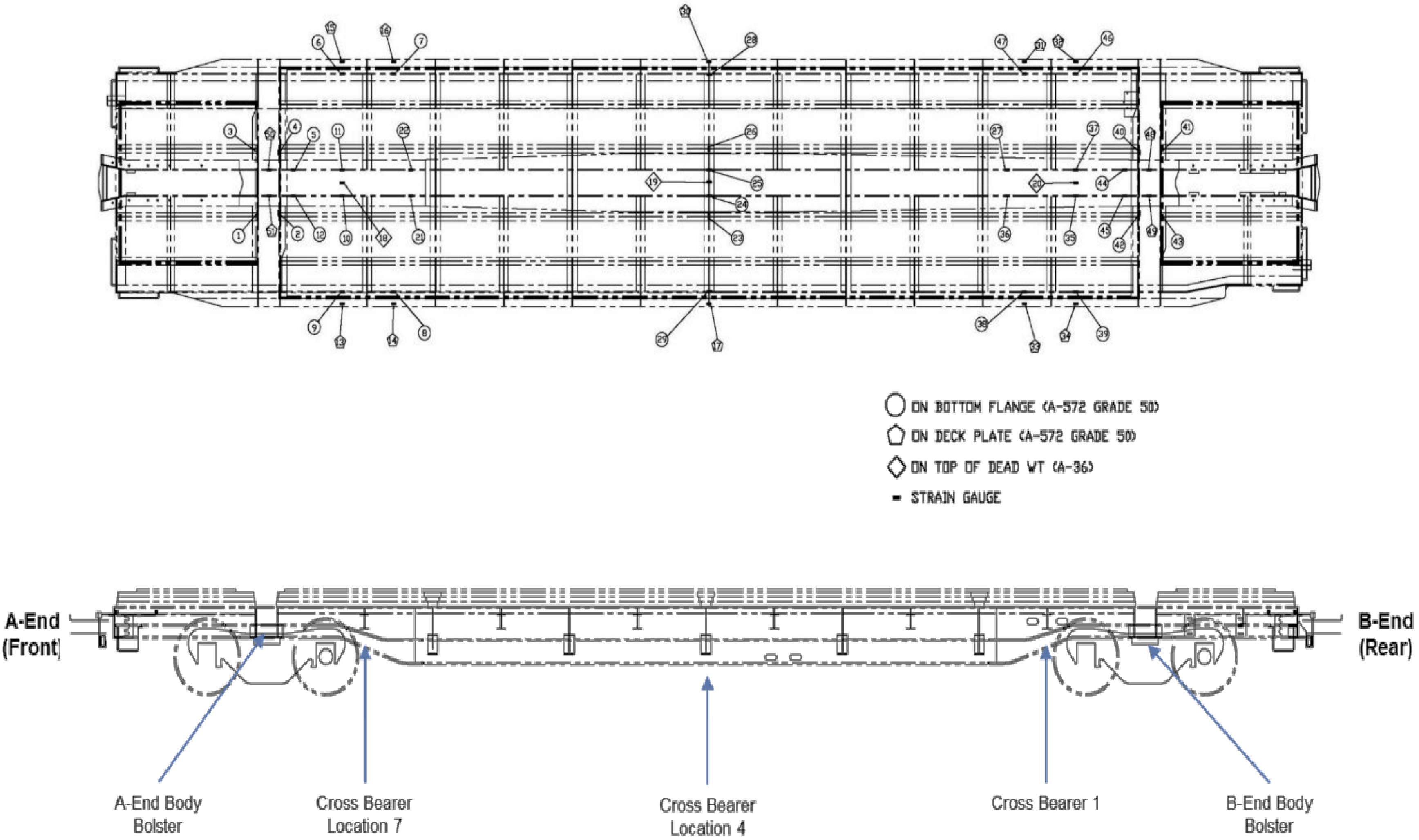


Figure 38. Location of Strain Measurements Monitored during Structural Testing

5.4.1 Preliminary and Post Test Inspection

The buffer railcar length was measured from striker to striker, as well as over the pulling faces. Table 18 shows the results of these measurements before and after tests were performed. The maximum variation in the measurements 9/16 inch, which is considered negligible considering the various clearances in the railcar and the measurement accuracy.

A survey total station was used to measure the shape of the railcar deck before and after testing. The final structural test performed was the 1 million-pound squeeze test. It was considered prudent to document the shape of the deck both before and after this test was conducted so that if any deformation did occur the source of the failure could be more easily identified. Figure 39 shows the results of the level measurements at several points during testing. No change in shape of the deck was noted.

Table 18. Survey Measurements

Condition	Striker to Striker	Length over Pulling Faces
Initial Measurement	61 feet 8 1/16 inches	66 feet 6 5/16 inches
Post Squeeze	61 feet 8 1/2 inches	66 feet 6 1/2 inches

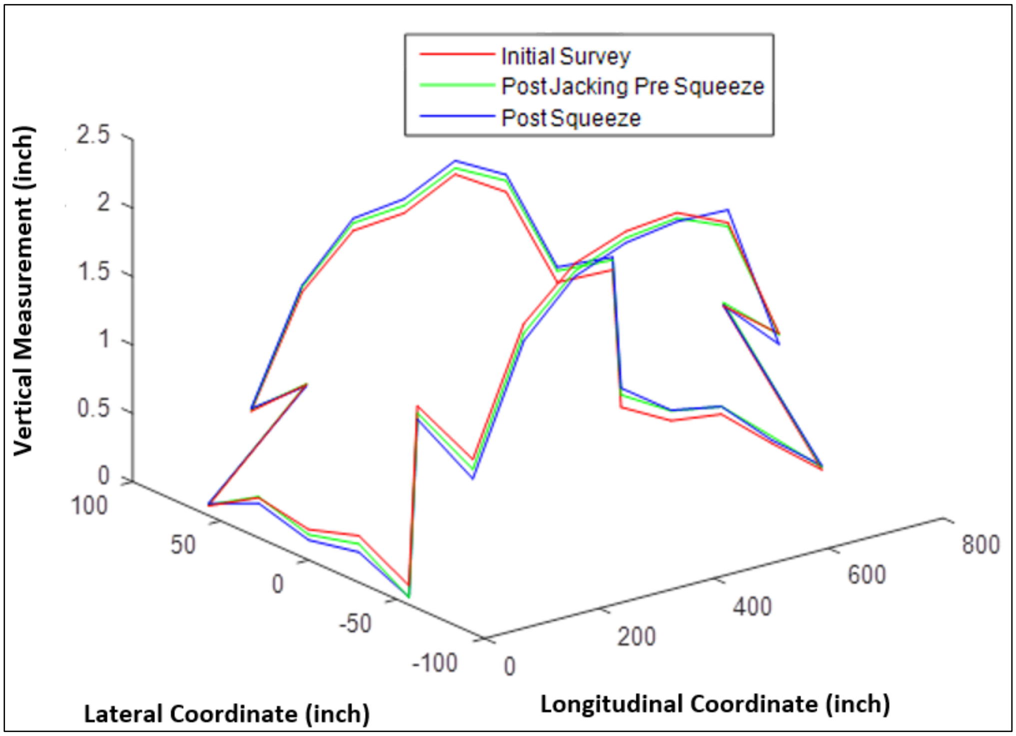


Figure 39. Results of Level Loop around the Buffer Railcar Deck, Zero Inches Longitudinal at A-End of Car

5.4.2 Squeeze (Compressive End) Load

The squeeze (compressive end) load test was performed on November 20, 2019, to verify that the buffer railcar can withstand compressive longitudinal loads. Adam Klopp, TTCI Principal Investigator I, witnessed the squeeze (compressive end) test as the AAR Observer per S-2043 requirements. A horizontal compressive static load was applied at the centerline of the draft system of car interface areas using TTCI's squeeze fixture. The load was cycled up to 750,000 pounds three times, and then on the fourth cycle the load was increased to 1,000,000 pounds. The applied load was monitored with a load cell. The railcar met criteria for the compressive end load test. No permanent deformation or suspension separation was noted. The maximum measured stress was 60 percent of material yield.

Table 19 shows the summary results from the compressive end load test for the locations with highest measured stress at 1,000,000 pounds of applied load. No evidence of gradual zero-shift (plastic deformation) was noted. A complete set of stress results at maximum compressive load are shown in Appendix E, including a time history plot of the highest stressed areas showing no residual strain.

Table 19. Highest Stress Locations from Compressive End Load Test

Channel Name	Approximate Location	Measured Stress (ksi)	Yield Stress (ksi)	Measured Stress as Percent of Yield
SGBF11	RH edge of bottom flange of center sill, forward of cross bearer 7	-30	50	60%
SGBF10	LH edge of bottom flange of center sill, forward of cross bearer 7	-28	50	56%
SGBF37	RH edge of bottom flange of center sill, aft of cross bearer 1	-26	50	52%
SGDP35	LH edge of bottom flange of center sill, aft of cross bearer 1	-24	50	48%

5.4.3 Coupler Vertical Loads

A 50,000-pound vertical load was applied to the coupler in the upward and downward directions. The test was performed on August 1, 2019, and August 6, 2019. Abe Meddah, TTCI Principal Investigator II, witnessed the test on August 1, 2019, and Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the coupler vertical loads tests on August 6, 2019, as the AAR Observer per S-2043 requirements. The buffer railcar met criteria for the 50,000-pound coupler vertical load test. No permanent deformation was noted. The maximum measured stress was 26 percent of material yield.

The railcar was inspected before and after the tests with no damage noted. Figure 40 shows no damage to the coupler carrier plate after the coupler vertical load test.

Table 20 shows summary results from the coupler vertical load test for the locations with the highest measured stress. No evidence of gradual zero-shift (plastic deformation) was noted. A complete summary of stress results at the 50,000-pound load is shown in Appendix F.

Figure 40. Coupler Carrier Plate after the Coupler Vertical Load Test

Table 20. Buffer Railcar Vertical Coupler Force Test Results Summary

Channel Name	Approximate Location	Measured Stress (ksi)	Yield Stress (ksi)	Measured Stress as Percent of Yield
Load applied upward				
SGDP35	LH edge of bottom flange of center sill, aft of cross bearer 1	12	50	24%
SGBF37	RH edge of bottom flange of center sill, aft of cross bearer 1	13	50	26%
Load applied downward				
SGDP35	LH edge of bottom flange of center sill, aft of cross bearer 1	-12	50	24%
SGBF37	RH edge of bottom flange of center sill, aft of cross bearer 1	-13	50	26%

5.4.4 Jacking

The jacking test was performed to verify a fully loaded railcar can be lifted free of the trucks when supported at the jacking pads. The test was conducted on July 31, 2019. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the jacking test as the AAR Observer per S-2043 requirements. The buffer railcar met criteria for the jacking test. No permanent deformation was noted. The maximum measured stress was 12 percent of material yield.

The test was conducted on the B-end of the buffer railcar. The maximum stress during the test occurred on gauge SGBF40 and gauge SGBF42. Figure 41 shows the location of these gauges. Table 21 presents the summary results. No evidence of gradual zero-shift (plastic deformation) was noted. Plots are provided in Appendix G for all gauges.

Table 21. Buffer Railcar Jacking Test Results Summary

Channel Name	Approximate Location	Measured Stress (ksi)	Yield Stress (ksi)	Measured Stress as Percent of Yield
SGBF42	Front of bottom flange of B-end body bolster near center sill – LH side	6.2	50	12%
SGBF40	Front of bottom flange of B-end body bolster near center sill – RH side	6.1	50	12%

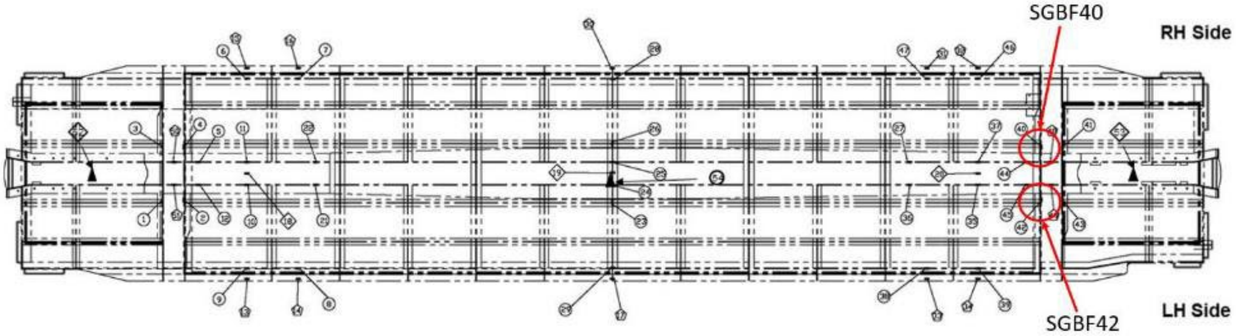


Figure 41. Maximum Stressed Locations SGBF40 and SGBF42

As Figure 42 in the section below shows, the jacking test was conducted while the MSU actuator brackets were installed for other testing. Because of this, the jacks on the B-end could not be placed directly at the jacking pad location and were instead placed approximately 10 inches further away from the railcar centerline. Kasgro simulated the jacking test using FEA assuming the jacks were placed at the jacking pad locations and separately with the jacks placed at the MSU brackets and found that the predicted stress at these gage locations changed from 5.3 ksi when loaded at the jacking pads to 4.4 ksi when loaded at the MSU brackets. The measured and predicted stresses are low with respect to the yield stress for either the jacking pad or MSU bracket loading positions.

5.4.5 Twist

The twist test consists of two parts. The buffer railcar met criteria for both parts of the twist test. No permanent deformation was noted. The maximum measured stress was 18 percent of material yield.

The first part was performed at the same time as the carbody twist equalization test described in Section 5.2.2. As with the carbody twist equalization, vertical wheel loads were measured while raising both wheels on one side of a truck. Tests were performed on all four corners of the buffer railcar. The only additional requirement for the structural test is that strain data be measured. This portion (Part 1) of the twist test was completed on July 26, 2019. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the twist (Part 1) test as the AAR Observer per S-2043 requirements.

The largest strain measured during the test corresponds to 1.2 ksi, recorded on strain gauge SGDP48, when the wheels on the A-end, LH side were raised 3 inches. Table 22 presents the results summary for the buffer railcar twist test Part 1.

Table 22. Summary of Buffer Railcar Twist Test Part 1 Results

Channel Name	Corner Raised	Approximate Location	Measured Stress (ksi)	Yield Stress (ksi)	Measured Stress as Percent of Yield
SGDP48	A-LH	Top of deck plate, longitudinally centered over B-end body bolster, above RH edge of center sill	1.2	50	2%
SGDP49	A-RH	Top of deck plate, longitudinally centered over B-end body bolster, above LH edge of center sill	0.82	50	2%
SGDP49	B-LH	Top of deck plate, longitudinally centered over B-end body bolster, above LH edge of center sill	0.84	50	2%
SGDP48	B-RH	Top of deck plate, longitudinally centered over B-end body bolster, above RH edge of center sill	1.1	50	2%

The second portion (Part 2) of the carbody twist test requires that the loaded carbody be supported on the four jacking locations. One corner is then lowered 3 inches. This test was conducted on July 31, 2019. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the second portion of the carbody twist test as the AAR Observer per S-2043 requirements. Figure 42 shows the end of the carbody supported on jacks during this test. Table 24 presents the results summary for the buffer railcar twist test Part 2. No evidence of gradual zero-shift (plastic deformation) was noted. Additional plots for all gauges are shown in Appendix H.

Figure 42. The End of the Railcar Supported by Four Pneumatic Jacks during the Twist Test

Table 23 shows the measurements at the four corners during the test, with the planned drop being about 3 inches. However, as the B-end, left hand jack was lowered to 3 inches, the carbody only dropped 2 11/16 inches. No obstructions/supports allowed weight to be carried in another path (CCSBs, etc.); the carbody torsional stiffness limited this deflection. Table 24 shows the maximum measured stress. The carbody strain gauges SGBF40 and SGBF11 showed the maximum (tension) and minimum (compression) stress during the test. Gauge SGBF40 showed a maximum peak value of -3.3 ksi, and gauge SGBF11 showed a minimum peak value of 7.6 ksi. These locations (shown on Figure 43) were inspected after the test and no indication of yielding was found.

Table 23. Height of the Four Corners of the Loaded Carbody

Location	Height Before Test	Height During Test
AL	37 inches	36 7/8 inches
AR	37 1/8 inches	37 1/8 inches
BL	37 1/8 inches	34 7/16 inches
BR	37 inches	37 inches

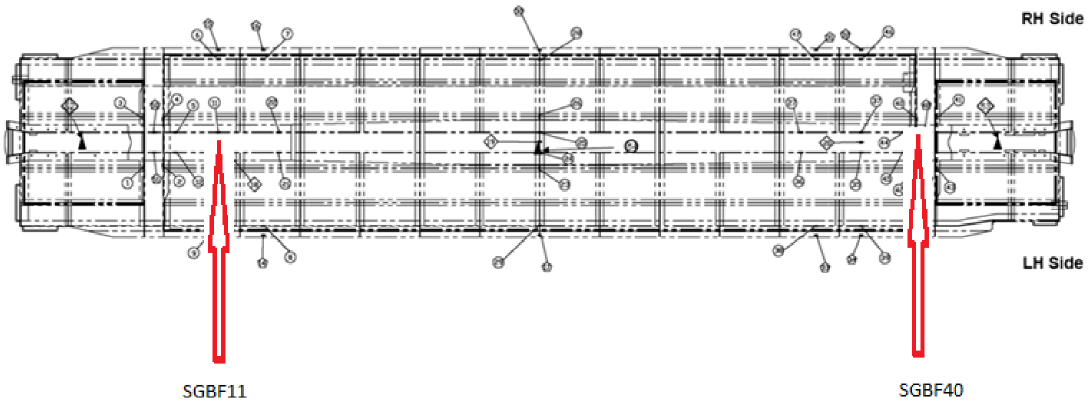


Figure 43. SGBF11 and SGBF40 Locations

Table 24. Summary of Buffer Railcar Twist Part 2 Test Results

Channel Name	Approximate Location	Measured Stress (ksi)	Yield Stress (ksi)	Measured Stress as Percent of Yield
SGBF11	RH edge of bottom flange of center sill, forward of cross bearer 7	-3.3	50	7%
SGBF40	Front of bottom flange of B-end body bolster near center sill – RH side	7.6	50	15%

As Figure 42 shows, the twist test was conducted while the MSU actuator brackets were installed for other testing. Because of this, the jacks on the B-end could not be placed directly at the jacking pad location and were instead placed approximately 10 inches further away from the railcar centerline. Kasgro simulated the twist test with FEA assuming the jacks were placed at the jacking pad locations and separately with the jacks placed at the MSU brackets and found that the predicted stress at SGBF11 changed from -5 ksi when loaded at the jacking pads to -1.9 ksi when loaded at the MSU brackets. The predicted stress at SGBF40 changed from 7.4 ksi when loaded at the jacking pads to 6.7 ksi when loaded at the MSU brackets. The measured and predicted stresses are low with respect to the yield stress for either the jacking pad or MSU bracket loading positions.

5.4.6 Impact

Impact tests were conducted August 1, 2019. Abe Meddah, TTCI Principal Investigator II, witnessed the impact test as the AAR Observer per S-2043 requirements. The buffer railcar met criteria for the impact tests. The railcar was inspected after the test, and no damage was found. There was no permanent deformation of the railcar. The maximum measured strain was 21 percent of material yield.

The test was conducted by pulling the railcar a specified distance up a constant grade and allowing it to roll into a standing string of three loaded hopper cars equipped with M-901E draft gears. No brakes were applied on the anvil string except for the handbrake on the last railcar. There was no free slack between anvil cars, but the draft gears were not compressed.

The lead hopper car had an instrumented coupler installed to measure the force during coupling. The speed was measured with a speed tach mounted on the railcar. Data was recorded at 1,250 samples per second. Test runs were stopped at 9.6 mph, because at that speed the coupler force was greater than the 600,000-pound design load specified in Section 4.1.10 for a railcar equipped with a 15-inch cushion unit.

The peak magnitude stress was found for each run. In cases where the peak magnitude stress is compressive, it is shown as a negative value. In contrast to most of the other structural tests, the stress value given is dynamic, or relative to the stress just before the test. Table 25 shows the maximum stress for each test run. In each case, the maximum stress is at location SGBF37. No evidence of gradual zero-shift (plastic deformation) was noted. Appendix I provides additional plots of all gauges during the tests.

AAR Standard S-2043 refers to MSRP Section C Part II, Specification M-1001, paragraph 11.3.4.1 (Reference 1) for impact testing details. Successive tests are required at 2-mph increments starting at 6 mph or less. As Table 25 shows, the increment between the first two test runs slightly exceeded the specified 2-mph. This was considered acceptable due to the inherent variation in speed for this type of testing and because the coupler forces remained low.

Table 25. Maximum Stresses Measured during Impact Tests

Speed	Coupler Load (pounds)	Gauge Location	Measured Stress (ksi)	Yield Stress (ksi)	Measured Stress as percent of Yield
4.7	196,081	SGBF37*	-3.6	50	7%
7.2	406,914	SGBF37	-11	50	22%
8.4	492,319	SGBF37	-12	50	24%
9.6	611,648	SGBF37	-16	50	32%
*SGBF 37 is at the right edge of the bottom flange of the center sill, aft of cross bearer 1.					

5.4.7 Securement System

AAR Standard S-2043, Paragraph 5.4.7, requires verification of securement system strength. This paragraph refers to the system of attachment for the HLRM cask to the railcar. It does not apply to the buffer railcar because it is not equipped to carry HLRM. Kasgro analyzed the securement of the ballast weight against the open top loading rules (Appendix J).

5.5 Dynamic Tests

Dynamic tests required by AAR Standard S-2043 include:

- Hunting
- Twist and roll
- Yaw and sway
- Dynamic curving
- Pitch and bounce (Chapter 11)
- Special pitch and bounce
- Single bump test
- Limiting spiral negotiation
- Normal spiral negotiation
- Curving with single rail perturbation
- Standard Chapter 11 constant curving
- Special trackwork

The dynamic tests are conducted to measure compliance with criteria listed in Table 5.1 of AAR Standard S-2043. That table is reproduced here as Table 26. Test results are provided in this report Sections 5.5.1 to 5.5.12.

AAR Standard S-2043 specifies that non-curving tests be performed up to 75 mph where deemed safe by the test engineer. However, the AAR Standard S-2043 limiting criteria do not apply to tests at speeds over 70 mph. These tests are performed only to further quantify performance and establish trends. Test results from tests at speeds over 70 may be included in worst-case performance statistics depending on the following results:

- If the results of tests at speeds over 70 mph meet the test criteria, the results are considered when compiling performance statistics.
- When tests over 70 mph do not meet the criteria, the runs are excluded from consideration for performance statistics, and suitable comments are made in the body of that section.

The buffer railcar was pulled from the B-end during most dynamic tests. Instrumented wheelsets (IWS) for measuring wheel/rail forces were placed in Axles 1 through 4, as Figure 44 shows. Also, AAR Standard S-2043 requires that curving tests and special trackwork tests be performed in the trailing position; therefore, these tests were repeated with the A-end leading as seen at the bottom of Figure 44.

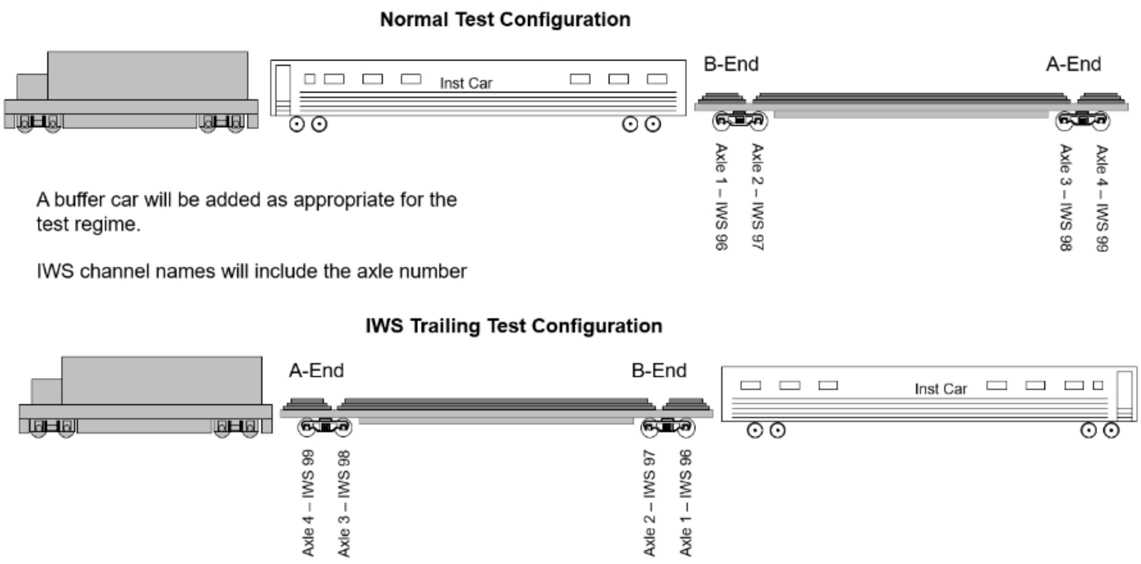
Standard S-2043 and, by reference, MSRP Section C Part II, Specification M-1001 (Reference 1) require a minimum rail coefficient of friction of 0.4 for hunting, twist and roll, dynamic curve, limiting spiral negotiation, and constant curve tests. Rail friction levels were measured for each of the dynamic tests and are reported in the appropriate sections.

Table 26. AAR Standard S-2043 Dynamic Testing Performance Criteria

Criterion	Limiting Value	Notes
Maximum car body roll angle (degree)	4	Peak-to-peak.
Maximum wheel L/V	0.8	Not to exceed indicated value for a period greater than 50 msec. and for a distance greater than 3 feet per instance*.
95th percentile single wheel L/V (constant curving tests only)	0.6	Not to exceed indicated value. Applies only for constant curving tests.
Maximum truck side L/V	0.5	Not to exceed indicated value for a duration equivalent to 6 feet of track per instance.
Minimum vertical wheel load (%)	25	Not to fall below indicated value for a period greater than 50 msec. and for a distance greater than 3 feet per instance*.
Peak-to-peak car body lateral acceleration (G)	1.3 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum car body lateral acceleration (G)	0.75 0.35	For non-passenger-carrying railcars For passenger-carrying railcars
Car body lateral acceleration standard deviation (G)	0.13	Calculated over a 2,000-foot sliding window every 10 feet over a tangent track section that is a minimum of 4,000 feet long.
Maximum car body vertical acceleration (G)	0.90 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum vertical suspension deflection (%)	95	Suspension bottoming not allowed. Maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height.
Maximum vertical dynamic augment acceleration (g)	0.9	Suspension bottoming not allowed. Vertical dynamic augment accelerations of a loaded car shall not exceed 0.9 G.

AAR Standard S-2043 states that these criteria must be met for all tests performed according to Sections 5.5.7 to 5.5.16. Some exceptions are:

- The notes for carbody lateral acceleration standard deviation require it be computed over a 2,000-foot sliding window in a 4,000-foot tangent track section so that value will only be reported for high-speed stability tests.
- L/V and vertical wheel load data is not available for high-speed stability tests with KR wheels.


Normal Test Configuration

A buffer car will be added as appropriate for the test regime.

IWS channel names will include the axle number

IWS Trailing Test Configuration

Figure 44. Location of IWS during Dynamic Tests

5.5.1 Hunting

Hunting tests were performed twice, first with wheelsets having KR profiles, and second with IWS having AAR-1B narrow flange profiles. Table 27 shows the date each test was conducted and the measured rail friction. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the hunting test with KR profiles on May 22, 2019, and Adam Klopp, TTCI Principal Investigator I, witness the hunting test with IWS on August 15, 2019, as the AAR Observer per S-2043 requirements. The buffer railcar met the criteria for hunting in both conditions.

Table 27. Buffer Railcar Hunting Test Dates and Rail Friction Data

Test Condition	Date	Coefficient of Friction	
		Inside Rail	Outside Rail
Buffer Car with KR profiles	May 22, 2019	0.50	0.50
Buffer Car with IWS AAR-1B narrow flange profiles	August 15, 2019	0.49	0.49

Accelerations above the maximum criteria were observed in the curves adjacent to the test zone with KR profiles. TTCI notified EEC of higher accelerations during their June 2019 monthly meeting. The EEC determined that the criteria do not apply in the curve, and that because the buffer railcar was stable in the tangent test zone, criteria were met. Criteria were met in both tangent and the adjacent curves with AAR-1B narrow flange profiles.

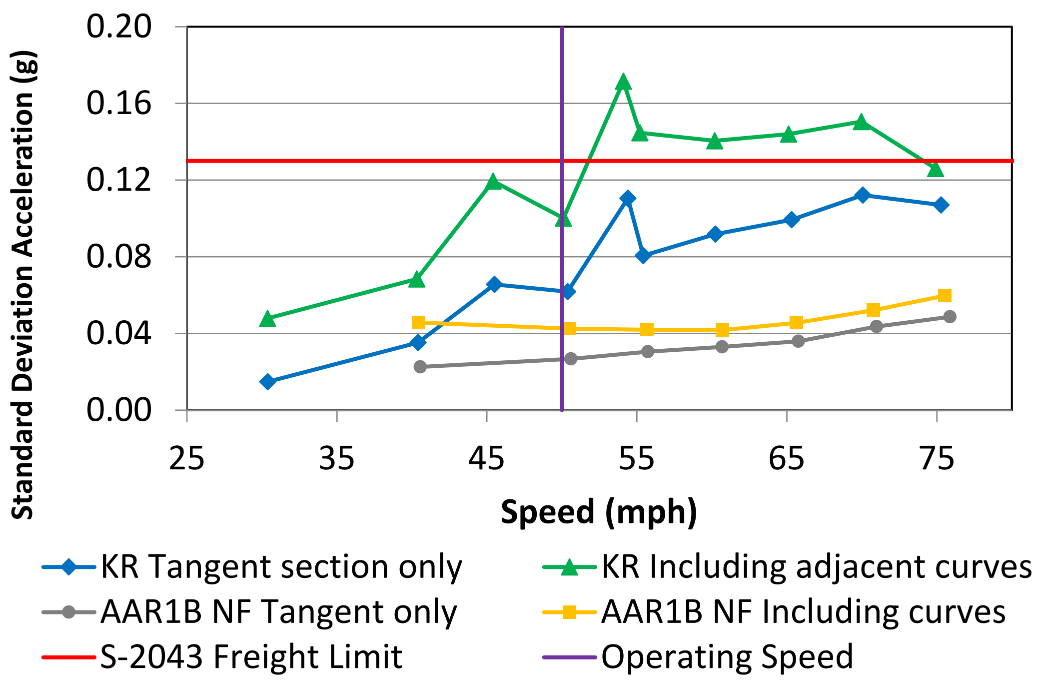
Hunting tests are performed on a tangent section of the Railroad Test Track (RTT) between markers R39 and R33.45. Data is also recorded in the curves adjacent to the test zone to monitor performance. In Table 28, data labeled “including adjacent curves” refers to data collected between R43 and R26, which includes portions of the adjacent curves and spirals. Data labeled “tangent section only” refers to data collected in the tangent section between R39 and R33.45. As noted, the EEC determined that only tangent zone data should be compared to criteria, but the data is included here for reference. Table 28 shows a summary of buffer railcar hunting test results, and Figure 45 shows a plot of 2,000-foot standard deviation of lateral acceleration versus speed for the tangent zone and the zone including adjacent curves. Figure 45 shows a line labeled Operating Speed at 50 mph on the graph. This reflects the recommendation in AAR Circular OT-55-O "Recommended Railroad Operating Practices for Transportation of Hazardous Materials" that trains carrying spent nuclear fuel or HLRM be restricted to a maximum speed of 50 mph.

Table 28. Buffer Railcar Hunting Test Results

Criterion	Limiting Value	KR Wheel Profile	IWS with AAR 1B Narrow Flange Wheel Profile
		Including Adjacent curves/ Tangent Section only	
Maximum carbody roll angle (degree)	4	0.8 / 0.7	0.5 / 0.4
Maximum Wheel L/V Ratio	0.80	Not Measured*	0.26 / 0.12
Maximum Truck Side L/V Ratio	0.50	Not Measured*	0.17 / 0.11
Minimum Vertical Wheel Load (%)	25%	Not Measured*	64% / 77%
Peak-to-peak carbody lateral acceleration (g)	1.3	0.67 / 0.37	0.32 / 0.25
Maximum carbody lateral acceleration (g)	0.75	0.48 / 0.20	0.19 / 0.18
Lateral carbody acceleration standard deviation (g)	0.13	0.17** / 0.11	0.06 / 0.05
Maximum carbody vertical acceleration (g)	0.9	0.29 / 0.28	0.29 / 0.27
Maximum vertical suspension deflection (%)	95	41% / 31%	53% / 53%
Critical Speed	70 mph	50mph** / >75 mph	>75 mph

* L/V and vertical wheel load data is not available for high-speed stability tests with KR wheels (IWS required).

** During their June 2019 monthly meeting the EEC confirmed testing in the curve was not required. They also noted that the curve does not represent revenue service track. Results are presented for completeness.



** During their June 2019 monthly meeting the EEC confirmed testing in the curve was not required. They also noted that the curve does not represent revenue service track. Results are presented for completeness.

Figure 45. 2,000-foot Standard Deviation of Lateral Acceleration versus Speed

5.5.2 Twist and Roll

The twist and roll test was performed on August 20, 2019, and the coefficient of friction was greater than 0.50 on the east rail and greater than 0.50 on the west rail. Adam Klopp, TTCI Principal Investigator I, witnessed the twist and roll test as the AAR Observer per S-2043 requirements. The buffer railcar met the criteria for twist and roll. Table 29 contains a summary of the data from twist and roll tests, and Figure 46 shows a plot of peak-to-peak carbody roll versus speed.

Table 29. Buffer Railcar Twist and Roll Test Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4.0	1.7
Maximum wheel L/V	0.8	0.2
Maximum truck side L/V	0.5	0.16
Minimum vertical wheel load (%)	25%	66%
Lateral peak-to-peak acceleration (g)	1.3	0.55
Maximum lateral acceleration (g)	0.75	0.31
Maximum vertical acceleration (g)	0.90	0.26
Maximum vertical suspension deflection (%)	95%	48%

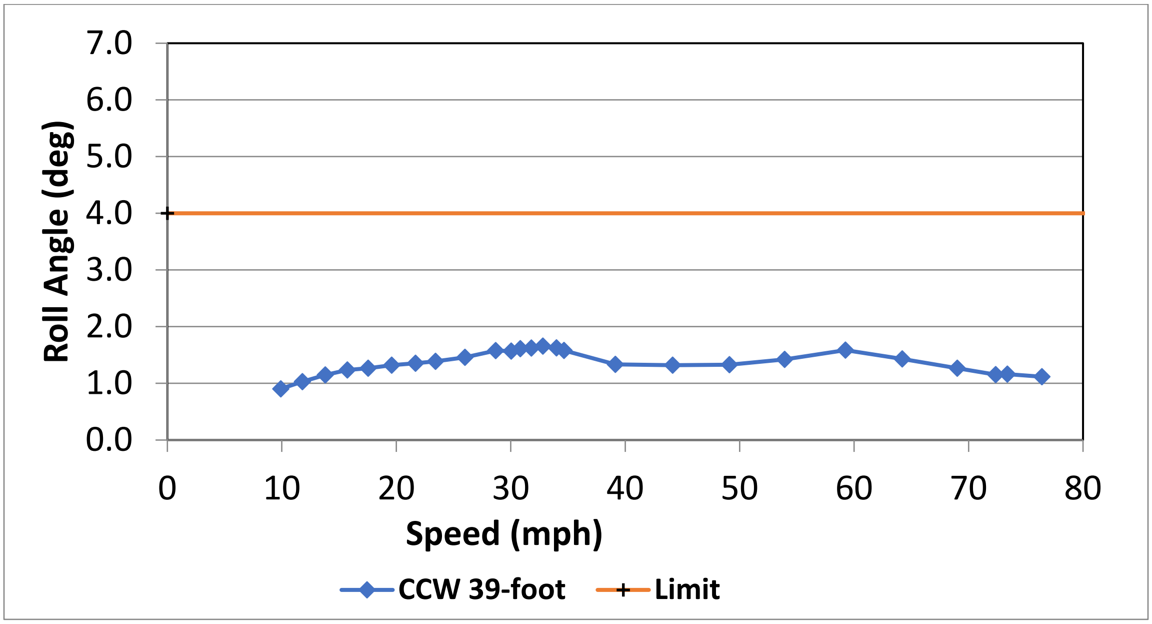


Figure 46. Buffer Railcar Twist and Roll Test, Maximum Carbody Roll versus Speed

5.5.3 Yaw and Sway

Yaw and Sway tests were conducted on August 21, 2019, and the coefficient of friction was 0.49 on the east rail and 0.50 on the west rail. Adam Klopp, TTCI Principal Investigator I, witnessed the yaw and sway test as the AAR Observer per S-2043 requirements. The buffer railcar met the criteria for yaw and sway. Table 30 shows the results of the tests up to 75 mph. Figure 47 shows a plot of the peak-to-peak lateral acceleration versus speed.

Table 30. Yaw and Sway Test Results to 75 mph

Criterion	Limiting Value	Test Result
Roll angle (degree)	4.0	2.0
Maximum wheel L/V	0.8	0.6
Maximum truck side L/V	0.5	0.3
Minimum vertical wheel load (%)	25%	50%
Lateral peak-to-peak acceleration (g)	1.3	0.9
Maximum lateral acceleration (g)	0.75	0.5
Maximum vertical acceleration (g)	0.9	0.3
Maximum vertical suspension deflection (%)	95%	67%

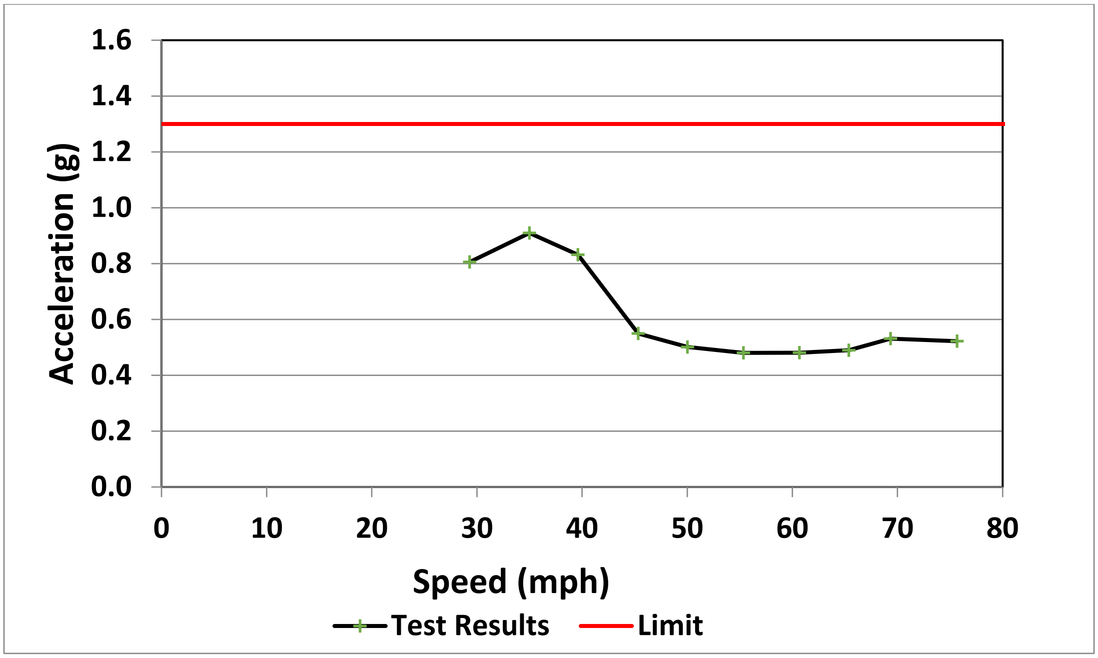


Figure 47. Buffer Railcar Yaw and Sway Test, Maximum Peak-to-peak Lateral Acceleration versus Speed

5.5.4 Dynamic Curving

Dynamic curve testing was conducted in the CW and CCW direction, with A-end leading and with B-end leading. Table 31 lists the test dates and the rail friction data. Adam Klopp, TTCI Principal Investigator I, witnessed the dynamic curving test as the AAR Observer per S-2043 requirements. The buffer railcar met criteria for dynamic curving. Table 32 contains a summary of the buffer railcar dynamic curving test results. Figure 48 shows a plot of maximum wheel L/V versus speed.

Table 31. Buffer Railcar Dynamic Curving Test Dates and Rail Friction Data

Test Condition	Date	Coefficient of Friction	
		Inside Rail	Outside Rail
Buffer car, A-end leading, CW	8-18-2019	0.48	0.46
Buffer car, A-end leading, CCW	8-19-2019	0.47	0.48
Buffer car, B-end leading, CW	8-16-2019	0.42	0.42
Buffer car, B-end leading, CCW	8-18-2019	0.42	0.45

Table 32. Buffer Railcar Dynamic Curving Test Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	1.4
Maximum wheel L/V	0.8	0.66
Maximum truck side L/V	0.5	0.45
Minimum vertical wheel load (%)	25%	34%
Lateral peak-to-peak acceleration (g)	1.3	0.96
Maximum lateral acceleration (g)	0.75	0.69
Maximum vertical acceleration (g)	0.90	0.16
Maximum vertical suspension deflection (%)	95%	42%

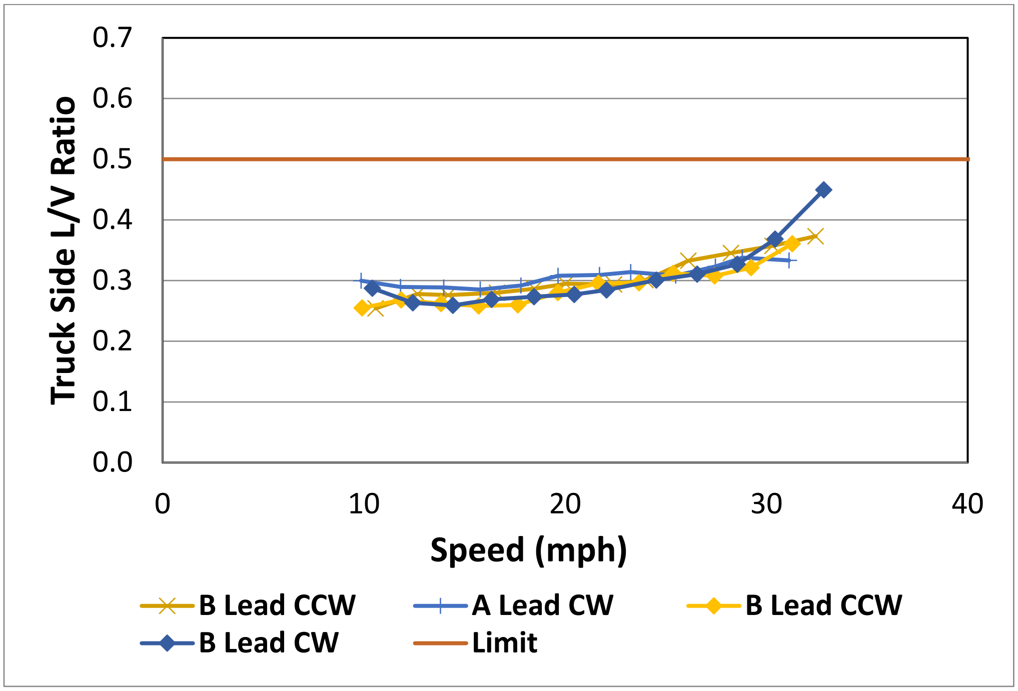


Figure 48. Buffer Railcar Dynamic Curve Wheel L/V Results versus Speed

5.5.5 Pitch and Bounce (Chapter 11)

The pitch and bounce (Chapter 11) test was performed on August 20, 2019. Adam Klopp, TTCI Principal Investigator I, witnessed the pitch and bounce (Chapter 11) test as the AAR Observer per S-2043 requirements. The coefficient of friction was greater than 0.50 on the east rail and greater than 0.50 on the west rail. The buffer railcar met the criteria for pitch and bounce. Note that the results are at the limit for maximum vertical suspension deflection.

Table 33 shows a summary of pitch and bounce test results, and Figure 46 shows a plot of maximum vertical acceleration versus speed.

Table 33. Summary of Pitch and Bounce Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	0.4
Maximum wheel L/V	0.8	0.19
Maximum truck side L/V	0.5	0.13
Minimum vertical wheel load (%)	25%	50%
Lateral peak-to-peak acceleration (g)	1.3	0.31
Maximum lateral acceleration (g)	0.75	0.25
Maximum vertical acceleration (g)	0.90	0.80
Maximum vertical suspension deflection (%)	95%	86%

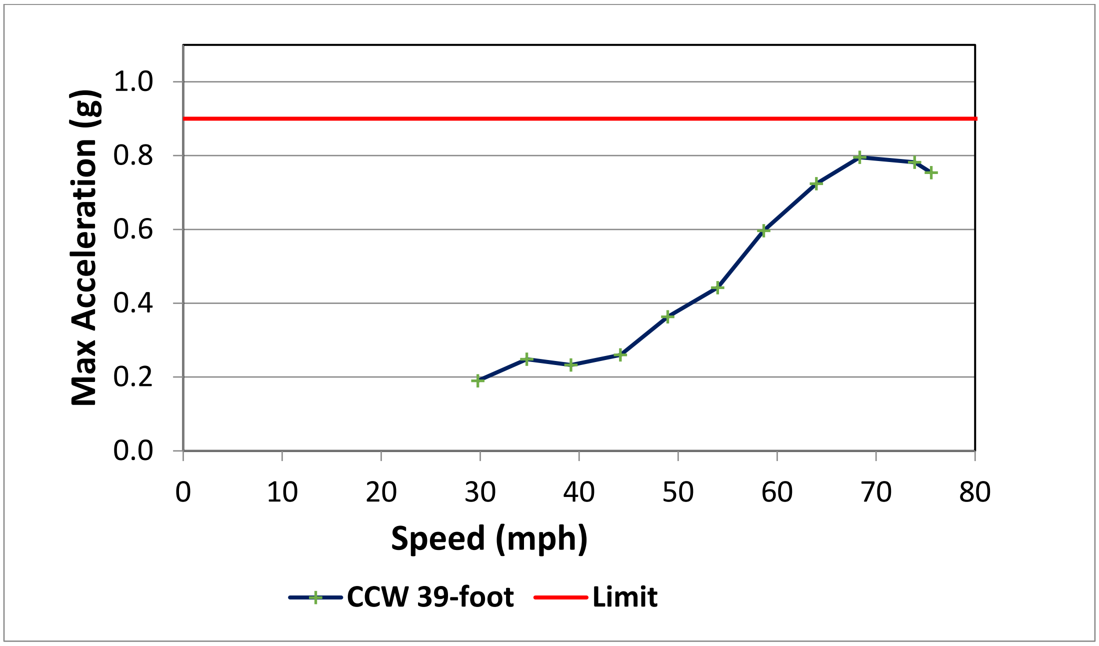


Figure 49. Maximum Vertical Acceleration versus Speed for Pitch and Bounce

5.5.6 Special Pitch and Bounce

AAR Standard S-2043 requires that a special section of track with 3/4-inch bumps at a wavelength equal to the truck center spacing (44.5 foot) be built for the test. TTCI installed ten parallel perturbations of 44.5-foot wavelength and 3/4-inch vertical amplitude on the Transit Test Track (TTT) between TTT-13 and TTT-14.

A special pitch and bounce test was performed on September 5, 2019. Steve Belport, TTCI Principal Investigator II, witnessed the special pitch and bounce test as the AAR Observer per S-2043 requirements. The coefficient of friction was greater than 0.50 on the east rail and greater than 0.50 on the west rail. The buffer railcar met the criteria for the special pitch and bounce test.

Table 34 shows a summary of the special pitch and bounce test results, and Figure 50 shows a plot of maximum vertical acceleration versus speed.

Table 34. Summary of Special Pitch and Bounce Test Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	0.4
Maximum wheel L/V	0.8	0.13
Maximum truck side L/V	0.5	0.09
Minimum vertical wheel load (%)	25%	57%
Lateral peak-to-peak acceleration (g)	1.3	0.22
Maximum lateral acceleration (g)	0.75	0.18
Maximum vertical acceleration (g)	0.90	0.5
Maximum vertical suspension deflection (%)	95%	71%

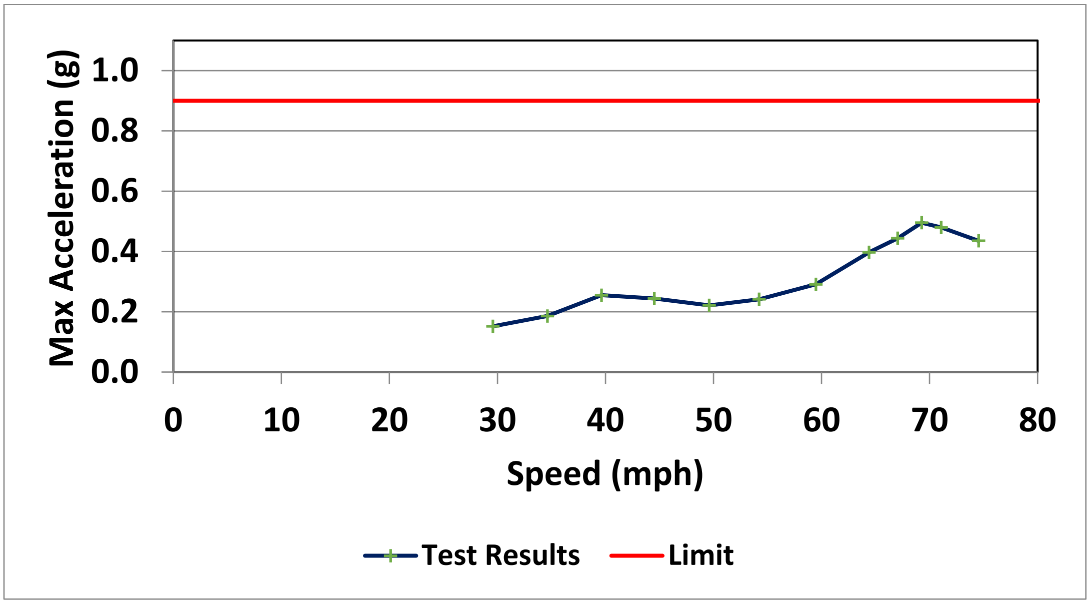


Figure 50. Maximum Vertical Acceleration versus Speed for Special Pitch and Bounce

5.5.7 Single Bump Test

The buffer railcar single bump test was performed on September 5, 2019. Steve Belport, TTCI Principal Investigator II, witnessed the twist and roll test as the AAR Observer per S-2043 requirements. This test is intended to represent a grade crossing and was installed at T15 on the TTT at the TTC. The single bump was a flat-topped ramp with the initial elevation change over 7 feet, a steady elevation over 20 feet, ramping back down over 7 feet. The coefficient of friction on the southeast rail was 0.55 and the coefficient of friction on the northwest rail was 0.55. The buffer railcar met the criteria for the single bump test. Table 35 shows a summary of the test results. Figure 51 shows a plot of maximum vertical acceleration versus speed for the single bump test.

Table 35. Summary of Test Results for the Buffer Railcar Single Bump Test

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	0.5
Maximum wheel L/V	0.8	0.19
Maximum truck side L/V	0.5	0.10
Minimum vertical wheel load (%)	25%	58%
Lateral peak-to-peak acceleration (g)	1.3	0.28
Maximum lateral acceleration (g)	0.75	0.19
Maximum vertical acceleration (g)	0.90	0.56
Maximum vertical suspension deflection (%)	95%	73%

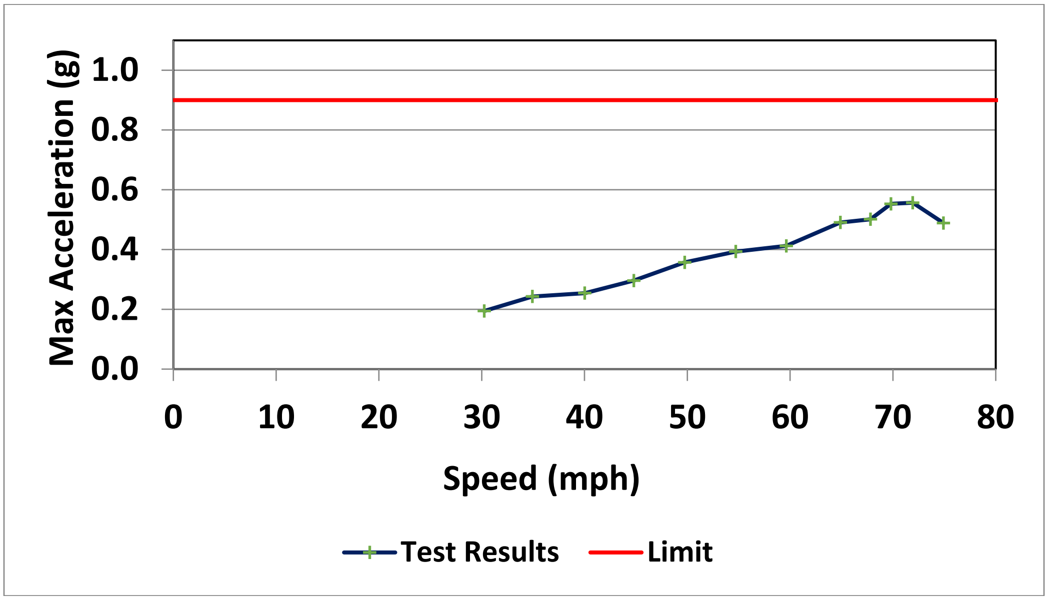


Figure 51. Maximum Vertical Acceleration versus Speed for Buffer Railcar Single Bump Test

5.5.8 Limiting Spiral Negotiation

Limiting spiral testing was conducted in the clockwise (CW) and counterclockwise (CCW) directions and with A-end leading and B-end leading at the same time as dynamic curving tests (see Section 4.5.8). CW tests correspond to spiral entry and CCW tests correspond to spiral exit. Table 36 lists the test dates and the rail friction data. Adam Klopp, TTCI Principal Investigator I, witnessed the limited spiral negotiation test as the AAR Observer per S-2043 requirements. The buffer railcar met the criteria for limiting spiral tests.

Table 36. Buffer Railcar Dynamic Curving Test Dates and Rail Friction Data

Test Condition	Date	Coefficient of Friction	
		Inside Rail	Outside Rail
Buffer car, A-end Leading, CW	8-18-2019	0.48	0.46
Buffer car, A-end Leading, CCW	8-19-2019	0.48	0.48
Buffer car, B-end Leading, CW	8-16-2019	0.5	0.5
Buffer car, B-end Leading, CCW	8-18-2019	0.42	0.45

Table 37 shows a summary of the test results. Figure 52 shows the wheel L/V results versus speed for the limiting spiral test.

Table 37. Buffer Railcar Limiting Spiral Summary of Test Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	0.7
Maximum wheel L/V	0.8	0.39
Maximum truck side L/V	0.5	0.28
Minimum vertical wheel load (%)	25%	59%
Lateral peak-to-peak acceleration (g)	1.3	0.17
Maximum lateral acceleration (g)	0.75	0.15
Maximum vertical acceleration (g)	0.90	0.12
Maximum vertical suspension deflection (%)	95%	56%

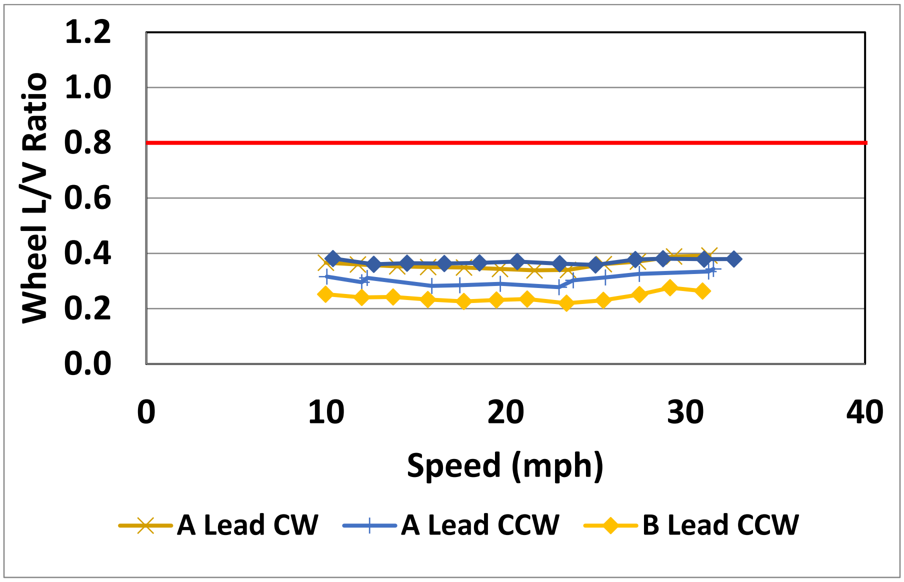


Figure 52. Buffer Railcar Limiting Spiral Wheel L/V Results versus Speed

5.5.9 Normal Spiral Negotiation

Normal spiral negotiation tests were conducted during the constant curving tests. Testing was conducted in the CW and CCW direction and with A-end leading and B-end leading. Test speeds corresponded to -3, 0, and 3 inches of unbalance. Two test runs were recorded at each speed.

Data are summarized from the spirals at each end of each test curve except the 12-degree north spiral. The 12-degree north spiral is not a normal spiral, because although the curvature changes steadily over 200 feet, the superelevation change takes place in the middle 100 feet.

Table 38 shows the test dates and the rail friction data for the different test configurations. When two or more test configurations were done on the same day, rail friction was only measured once. Adam Klopp, TTCI Principal Investigator I, witnessed the twist and roll test as the AAR Observer per S-2043 requirements.

Table 38. Buffer Railcar Constant Curving/Normal Spiral Negotiation Test Dates and Rail Friction Data

Test Condition	Date	Coefficient of Friction					
		7.5-degree		10-degree		12-degree	
		Inside	Outside	Inside	Outside	Inside	Outside
A-end Leading, CW	8-16-2019	0.45	0.44	0.50	0.46	0.50	0.50
A-end Leading, CCW	8-16-2019	0.40	0.44	0.46	0.47	0.50	0.50
B-end Leading, CW	8-16-2019	0.40	0.44	0.46	0.47	0.50	0.50
B-end Leading, CCW	8-18-2019	0.50	0.50	0.44	0.45	0.50	0.49

The buffer railcar met criteria for the normal spiral tests. Table 39 shows a summary of the test results. Figure 53 shows maximum 50-millisecond wheel L/V ratio versus speed for the 12-degree south spiral where the highest values were measured in this regime.

Table 39. Buffer Railcar Normal Spiral Summary of Test Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	0.4
Maximum wheel L/V	0.8	0.38
Maximum truck side L/V	0.5	0.23
Minimum vertical wheel load (%)	25%	60%
Lateral peak-to-peak acceleration (g)	1.3	0.29
Maximum lateral acceleration (g)	0.75	0.15
Maximum vertical acceleration (g)	0.90	0.15
Maximum vertical suspension deflection (%)	95%	39%

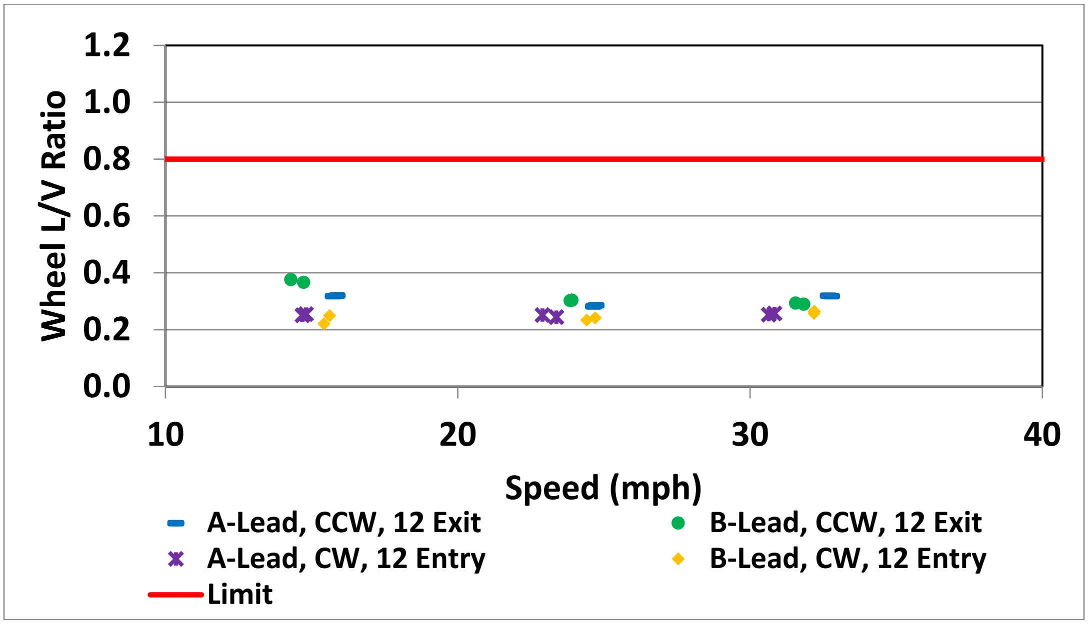


Figure 53. Buffer Railcar Normal Spiral Wheel L/V Results versus Speed for the South Spiral of the 12-Degree Curve

5.5.10 Curving with Single Rail Perturbation

The curving with single rail perturbation tests (bump and dip) were initially conducted on January 30 and February 05, 2020. At that time, the buffer railcar did not meet the single rail L/V criterion for the curving with single rail perturbation tests. However, as part of the subsequent test of the DOE Atlas railcar, it was determined that variations in curvature and alignment existed in the test zone that likely influenced the test results. These variations were corrected as described below. The buffer railcar was retested on September 11, 2020, and the curving with single rail perturbation criteria were met. Adam Klopp, TTCI Principal Investigator I, witnessed both sets of curving with single rail perturbation tests as the AAR Observer per S-2043 requirements.

The curve with single rail perturbation test is intended to represent a low or high joint in a yard or a poorly maintained lead track. Two test scenarios were run, one with a 2-inch outside rail dip and the other with a 2-inch inside rail bump. Both tests were conducted in a 12-degree curve with less than 1/2-inch nominal superelevation (the URB north Y track at TTC). The inside rail bump was a flat-topped ramp with an elevation change over 6 feet, a steady elevation over 12 feet, ramping back down over 6 feet. The outside rail dip was the reverse. The dip and the bump were approximately 300 feet apart on the curve so that performance over one perturbation would not influence performance over the other.

In July 2020, it was found that there were alignment and curvature variations in the curve with the single bump test zone that could potentially influence test results. While AAR Standard S-2043 included detailed specifications for rail surface and cross level in the perturbations, it did not include any specific tolerances for track curvature or alignment.

Because the curvature and alignment variations introduced factors to the test zones that were likely not the intent of AAR Standard S-2043, and that could introduce inconsistency between tests of various vehicles over time, TTCI proposed revisions to AAR Standard S-2043 to include specific tolerances for track curvature and alignment. The proposed revision would leave the existing requirements for the vertical perturbation in place, but limit curvature variation to ±0.5-degree and alignment variations to FRA Class 4 for the length of the railcar being tested before and after the perturbations. EEC approved the proposed revision during its August 20, 2020, webcast meeting.

Testing with the buffer railcar was repeated on the curving with single rail perturbation after the track was adjusted to meet the revised specification. Table 40 shows the coefficient of friction measured in each zone on each day.

Table 40. Friction Coefficient measured during Curving with Single Rail Perturbation Tests

Test Zone	Date	Inside Rail Friction	Outside Rail Friction
Bump	January 30, 2020	0.52	0.54
Bump	February 5, 2020	0.46	0.46
Dip	January 30, 2020	0.54	0.55
Dip	February 5, 2020	0.49	0.49
Bump	September 11, 2020	0.48	0.51
Dip	September 11, 2020	0.42	0.48

Table 41 shows test results from both series of tests. The buffer railcar met the criteria for the curving with single rail perturbation tests with the adjusted track geometry. The initial test exceptions for single wheel L/V ratio criterion for curving occurred in the dip perturbation during two runs of testing in the CCW direction with the A-end leading. The right wheel of axle 2 had the high L/V ratios. The highest value occurred at 6 mph.

Table 41. Summary of Curving with Single Rail Perturbation Test Results

Criterion	Limiting Value	Jan./Feb. 2020 Not Applicable due to S-2043 Qualification		Sept. 2020	
		Test Result Bump	Test Result Dip	Test Result Bump	Test Result Dip
Roll angle (degree)	4	1.7	1.5	1.5	1.4
Maximum wheel L/V	0.8	0.57	0.81	0.57	0.70
Maximum truck side L/V	0.5	0.32	0.44	0.37	0.36
Minimum vertical wheel load (%)	25%	57%	59%	58%	60%
Lateral peak-to-peak acceleration (g)	1.3	0.17	0.19	0.15	0.17
Maximum lateral acceleration (g)	0.75	0.18	0.21	0.12	0.13
Maximum vertical acceleration (g)	0.90	0.17	0.17	0.14	0.18
Maximum vertical suspension deflection (%)	95%	77%	80%	63%	68%

Figure 54 and Figure 52 shows results from the September 2020 tests. Figure 51 shows a plot of maximum wheel L/V versus speed for the bump section and Figure 55 shows a plot of maximum wheel L/V versus speed for the dip section. Figure 56 shows a plot of maximum wheel L/V versus speed for the dip section during the initial tests, showing the L/V exceeding the 0.81 limit at 6 mph.

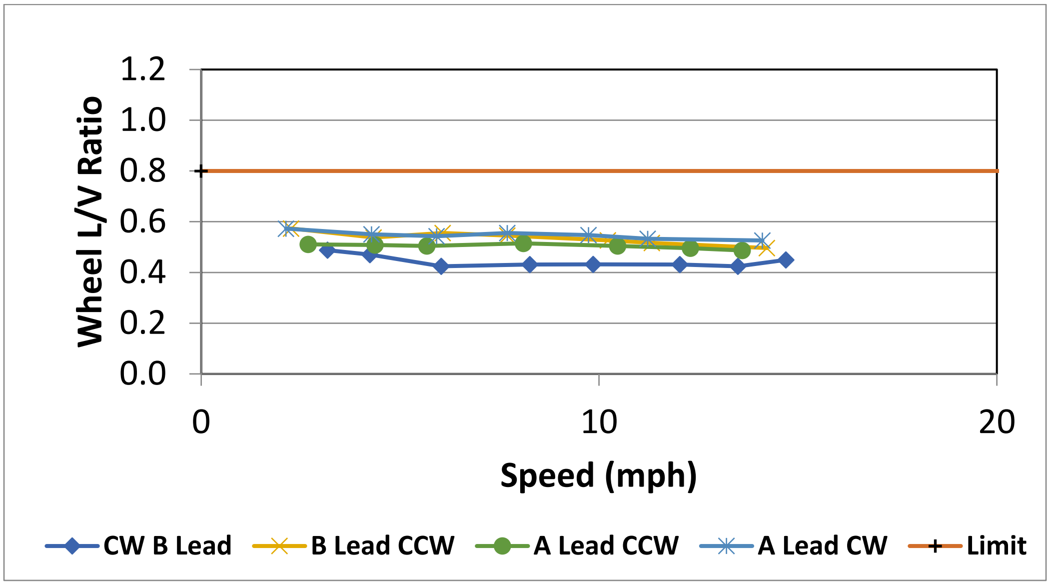


Figure 54. Curving with Single Rail Bump Perturbation Single Wheel L/V Ratio versus Speed (September 2020)

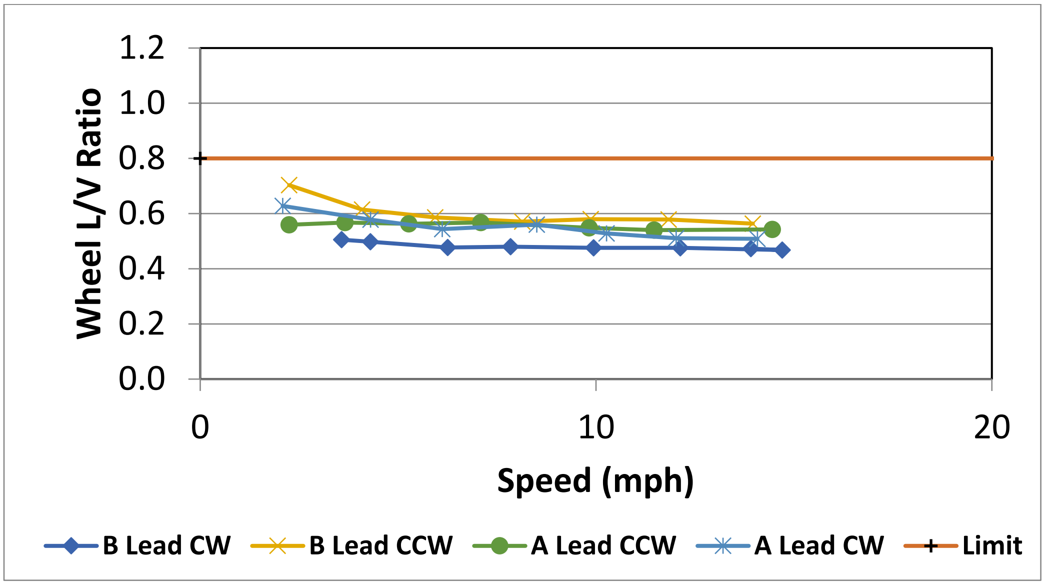


Figure 55. Curving with Single Rail Dip Perturbation Single Wheel L/V Ratio versus Speed (September 2020)

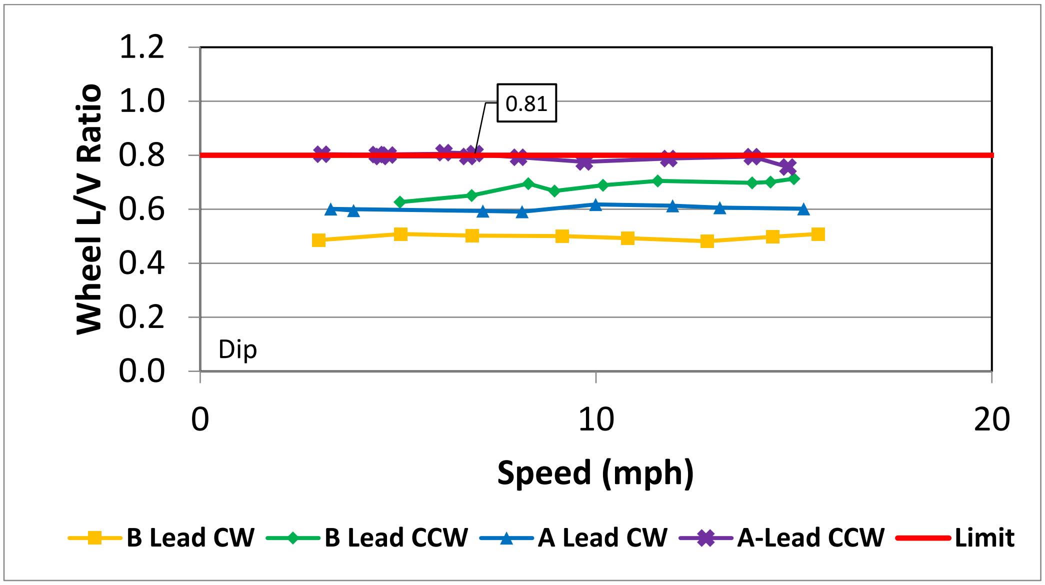


Figure 56. Distance Plot of the Highest Measured Single Wheel L/V ratio during the Curving with Single Dip Perturbation Test (Jan/Feb 2020). Not Applicable to S-2043 qualification.

5.5.11 Standard Chapter 11 Constant Curving

Constant curving tests were conducted with normal spiral negotiation tests (Section 5.5.9). Friction measurements are listed in Section 5.5.9. Constant curve testing was conducted in the CW and CCW directions and with A-end leading and B-end leading. Data are summarized from the 7.5-, 12-, and 10-degree curves on the Wheel Rail Mechanism (WRM) loop for speeds corresponding to 3-inches under balance, balance, and 3-inches over balance speed.

The buffer railcar met the criteria for the constant curving tests. Table 42 shows a summary of the test results. Figure 57 shows the 95th percentile single wheel L/V ratio versus speed in the 12-degree curve.

Table 42. Summary of Buffer Railcar Constant Curving Test Results

Criterion	Limiting Value	Test Result
Roll angle (degree)	4	0.4
Maximum wheel L/V	0.8	0.48
95% Wheel L/V	0.6	0.35
Maximum truck side L/V	0.5	0.28
Minimum vertical wheel load (%)	25%	63%
Lateral peak-to-peak acceleration (g)	1.3	0.21
Maximum lateral acceleration (g)	0.75	0.18
Maximum vertical acceleration (g)	0.90	0.14
Maximum vertical suspension deflection (%)	95%	34%

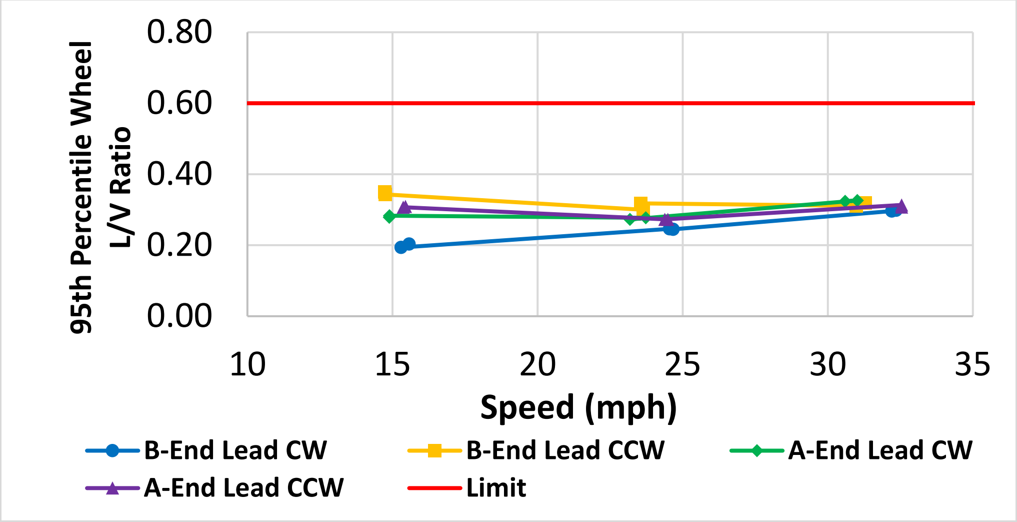


Figure 57. Buffer Railcar Constant Curving 95th Percentile Wheel L/V Ratio versus Speed in 12-degree Curve

5.5.12 Special Trackwork

The buffer railcar turnout tests were conducted on January 30 and February 5, 2020. Adam Klopp, TTCI Principal Investigator I, witnessed the turnout tests as the AAR Observer per S-2043 requirements. Dr. Xinggao Shu, TTCI Principal Investigator II, witnessed the crossover tests as the AAR Observer per S-2043 requirements. The tests were performed with A-end leading and B-end leading. Table 43 shows the top of rail friction measurements for special trackwork tests.

Table 43. Top of Rail Friction Measurements for Special Trackwork Tests

Test	Location	Inside Rail Friction	Inside Rail Friction	Date
Crossover Test	SW 212 A	0.54	0.55	2020-01-29
	Crossover	0.50	0.51	2020-01-29
	SW 212 B	0.55	0.55	2020-01-29
Turnout Test	SW 704	0.50	0.51	2020-01-30
	SW 704	0.47	0.48	2020-02-05

The buffer railcar met AAR Standard S-2043 criteria for the special trackwork tests.

The turnout test was performed at TTC on the 704 switch between the TTT and the north Urban Rail Building (URB) wye. The train was operated through the turnout at walking speed to check clearances, and then speeds were increased to 15 mph in 2 mph increments. Table 44 shows a summary of the turnout test results, and Figure 58 shows a plot of wheel L/V ratio versus speed for the turnout test.

Table 44. Summary of Turnout Test Results

Criterion	Limiting Value	B-End Lead Facing Point	B-End Lead Trailing Point	A-End Lead Facing Point	A-End Lead Trailing Point
Roll angle (degree)	4	0.2	0.2	0.3	0.2
Maximum wheel L/V	0.8	0.54	0.50	0.57	0.54
Maximum truck side L/V	0.5	0.30	0.30	0.29	0.32
Minimum vertical wheel load (%)	25%	79%	81%	79%	78%
Lateral peak-to-peak acceleration (g)	1.3	0.21	0.17	0.19	0.19
Maximum lateral acceleration (g)	0.75	0.18	0.11	0.14	0.16
Maximum vertical acceleration (g)	0.90	0.14	0.13	0.14	0.13
Maximum vertical suspension deflection (%)	95%	46%	43%	24%	29%

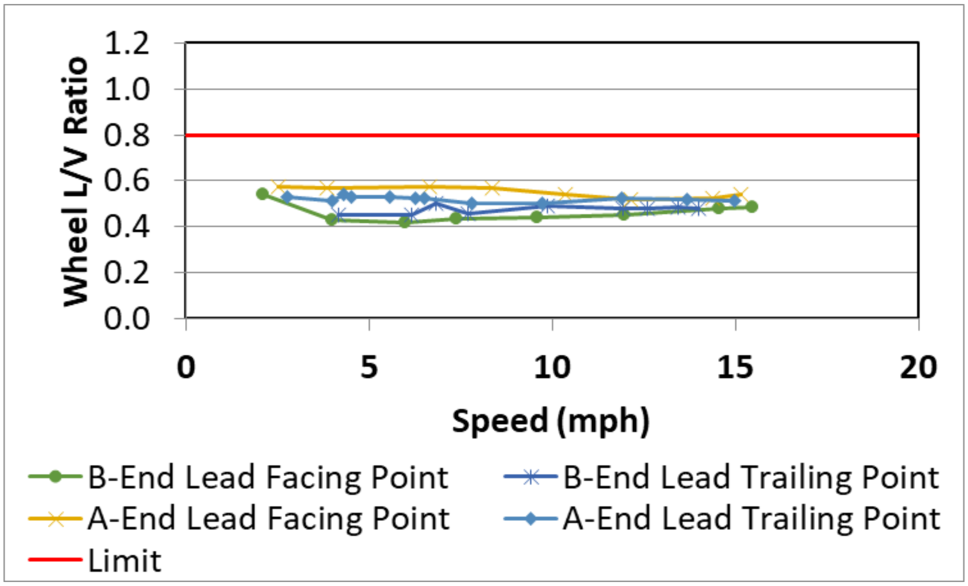


Figure 58. Maximum 50-millisecond Wheel L/V Ratio versus Speed for the Turnout Test

The crossover test was performed on the 212 crossover between the Facility for Accelerated Service Testing (FAST) wye and Impact track. The train was operated through the crossover at walking speed to check clearances, and then speeds were increased to 20 mph in 5 mph increments. Table 45 shows a summary of the crossover test results, and Figure 59 shows a plot of wheel L/V ratio versus speed for the crossover test.

Table 45. Summary of Crossover Test Results

Criterion	Limiting Value	B-End Lead West	B-End Lead East	A-End Lead West	A-End Lead East
Roll angle (degree)	4	0.3	0.2	0.3	0.3
Maximum wheel L/V	0.8	0.54	0.54	0.56	0.58
Maximum truck side L/V	0.5	0.28	0.27	0.30	0.29
Minimum vertical wheel load (%)	25%	75%	77%	65%	72%
Lateral peak-to-peak acceleration (g)	1.3	0.21	0.19	0.30	0.26
Maximum lateral acceleration (g)	0.75	0.14	0.12	0.22	0.19
Maximum vertical acceleration (g)	0.90	0.15	0.15	0.12	0.13
Maximum vertical suspension deflection (%)	95%	38%	31%	31%	35%

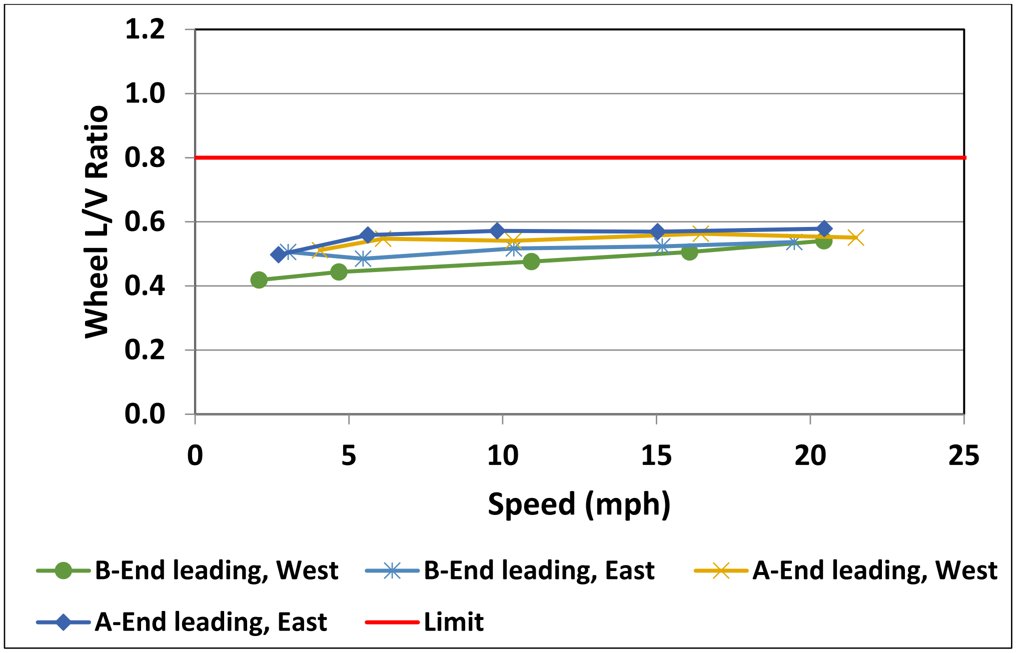


Figure 59. Maximum 50-millisecond Wheel L/V ratio versus Speed for the Crossover Test

AAR Standard S-2043 includes specific requirements for track geometry for the special trackwork tests. However, because of the inherent difficulty in defining turnout alignment specifications, it is acceptable to measure the turnout alignment prior to the commencement of the tests as a baseline and assure that for subsequent tests on that site alignment is maintained within 1/4 inch of the baseline alignment measurement. EEC determined that this was not meant to maintain the same geometry in the long run (the last set of tests at TTC was approximately 10 years prior).

AAR Standard S-2043 also requires that the alignment measurement be included with the test results. Figure 60 and Figure 61 show the X and Y measurements of the track centerline for the turnout and crossover test zones taken prior to the buffer railcar tests. These measurements will be used as a baseline for the 1/4-inch alignment tolerance for subsequent tests through these test zones.

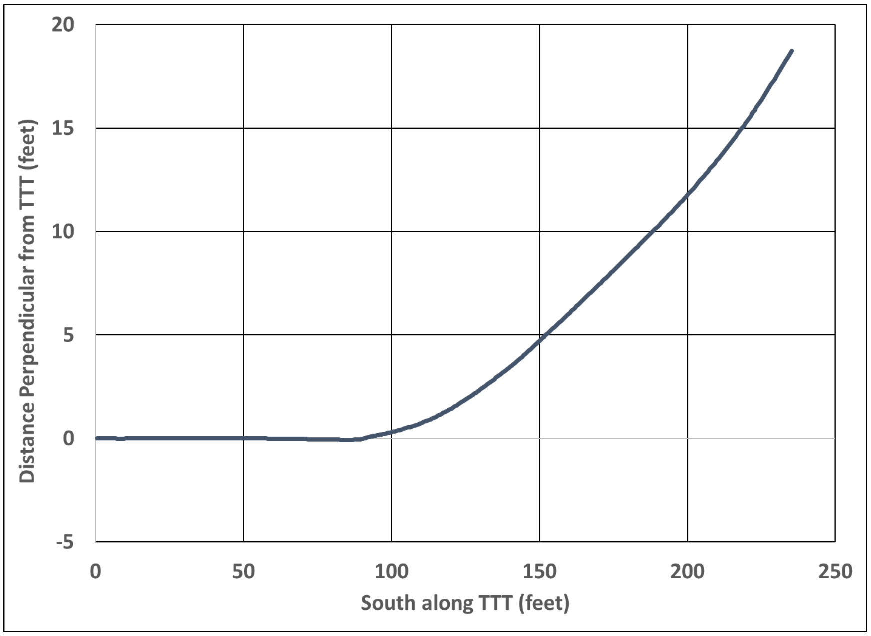


Figure 60. Pre-test Survey Alignment Measurements for Turnout Test Zone

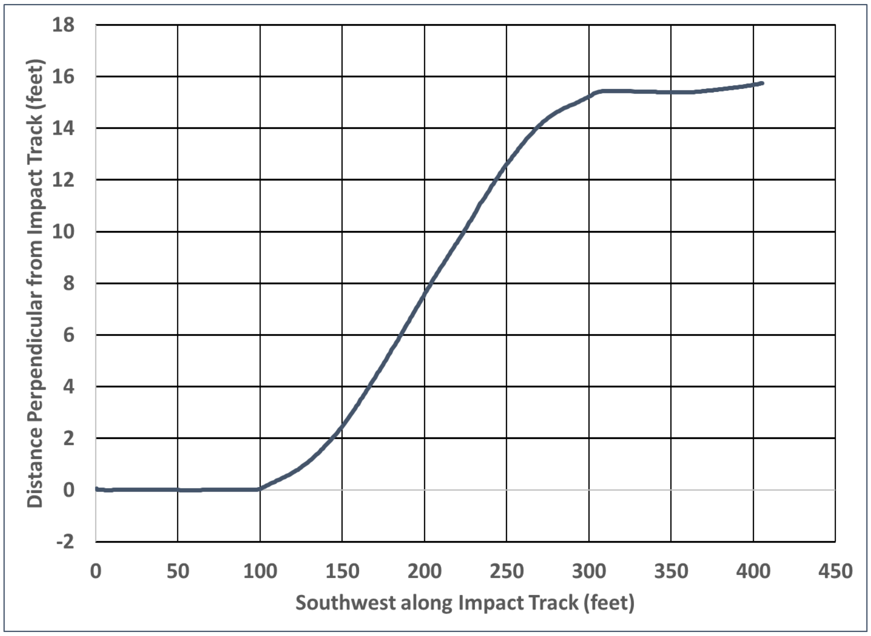


Figure 61. Pre-test Survey Alignment Measurements for Crossover Test Zone

Table 46 shows the description of the track work components contained in the special track work test zones to further document the test conditions.

Table 46. Special Track Work Components

Location	Switch Point		Stock Rail		Frog
	Left	Right	Left	Right	
SW 704	119 pound, 16-foot 6-inch length, standard straight	119 pound, 16-foot 6-inch length, standard straight	119 pound, 39-foot length standard straight	119 pound, 39-foot length standard bent	#8 Rail Bound Manganese
SW 212 A (Impact)	136 pound, 16-foot 6-inch length, samson straight	136 pound, 16-foot 6-inch length, samson straight	136 pound, 39-foot length, samson curved	136 pound, 39-foot length, samson straight	#10 Rail Bound Manganese
SW 212 B (Fast Wye)	136 pound, 16-foot 6-inch length, standard straight	136 pound, 16-foot 6-inch length, standard straight	136 pound, 39-foot length, standard straight	136 pound, 39-foot length, standard bent	#10 Rail Bound Manganese

5.6 Ride Quality

Ride quality testing is not applicable for the buffer railcar because AAR Standard S-2043 requires ride quality testing only for passenger-carrying railcars.

6.0 ADDITIONAL TESTS

Paragraph 5.6 of AAR Standard S-2043 includes a provision for the EEC to require additional testing under special conditions. The EEC has specified no additional for the buffer railcar.

7.0 CONCLUSIONS

Criteria for all AAR Standard S-2034 test regimes were met. Table 46 contains a summary of the test results.

Table 47. Summary of Test Results

S-2043 Section	Critical Data (Criteria) for Conditions Not Met	Met/Not Met
5.2 Nonstructural Static Tests		
5.2.1 Truck Twist Equalization	Not Applicable	Met
5.2.2 Carbody Twist Equalization	Not Applicable	Met
5.2.3 Static Curve Stability	Not Applicable	Met
5.2.4 Horizontal Curve Negotiation	Not Applicable	Met
5.4 Structural Tests		
5.4.2 Squeeze (Compressive End) Load	Not Applicable	Met
5.4.3 Coupler Vertical Loads	Not Applicable	Met
5.4.4 Jacking	Not Applicable	Met
5.4.5 Twist	Not Applicable	Met
5.4.6 Impact	Not Applicable	Met
5.5 Dynamic Tests		
5.5.7 Hunting	Not Applicable	Met
5.5.8 Twist and Roll	Not Applicable	Met
5.5.9 Yaw and Sway	Not Applicable	Met
5.5.10 Dynamic Curving	Not Applicable	Met
5.5.11 Pitch and Bounce (Chapter 11)	Not Applicable	Met
5.5.12 Pitch and Bounce (Special)	Not Applicable	Met
5.5.13 Single Bump Test	Not Applicable	Met
5.5.14 Curve Entry/Exit	Not Applicable	Met
5.5.15 Curving with Single Rail Perturbation	Not Applicable	Met
5.5.16 Standard Chapter 11 Constant Curving	Not Applicable	Met
5.5.17 Special Trackwork	Not Applicable	Met

REFERENCES

1. Association of American Railroads. 2008. *Manual of Standards and Recommended Practices*, Section C, Car Construction, Fundamentals and Details, Washington, D.C.
2. AAR *Manual of Standards and Recommended Practices*, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2017, Association of American Railroads, Washington, D.C.
3. Walker, Russell and Shawn Trevithick, Rev. November 20, 2017, "S-2043 Certification: Preliminary Simulations of Kasgro Buffer Railcar," P-17-023, TTCI. Pueblo, CO.

APPENDIX A: TEST PLAN

TEST IMPLEMENTATION PLAN:

SINGLE CAR TEST OF THE BUFFER RAILCAR IN ACCORDANCE WITH ASSOCIATION OF AMERICAN RAILROADS STANDARD S-2043

For the U.S. Department of Energy (DOE)

Prepared by
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA

January 7, 2019

EXECUTIVE SUMMARY

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete single car testing of the U.S. Department of Energy (DOE) Buffer Railcar as required by the Association of American Railroads (AAR) S-2043 standard titled “Performance Specification for Trains used to Carry High-level Radioactive Material,” Section 5.0 – Single Car Tests. This test plan addresses all of the requirements of S-2043 Paragraph 5. A separate test plan will be provided for the Atlas cask cars.

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1.0 INTRODUCTION

1.1 Purpose

The intent of this Test Implementation Plan (TIP) is to detail the test procedures that will be used to complete single car testing of the U.S. Department of Energy (DOE) Buffer Railcar as required by the Association of American Railroads (AAR) S-2043 standard titled "Performance Specification for Trains used to Carry High-level Radioactive Material," Section 5.0 – Single Car Tests[1]. S-2043 refers to MSRP Section C-Part II, M-1001, Chapters 2 and 11 for descriptions of several of the tests[2, 3]. A separate test plan will be provided for the Atlas cask cars.

1.2 Car Description

The car to be tested is a 4-axle flat car with a permanently attached ballast load. Some basic car dimensions, used in preparing the test plan are shown in Table 1. The design uses Swing Motion® trucks. AMSTED Rail designed the trucks to use primary pads to improve steering performance and vertical KONI dampers to control carbody motion. Figure 62 shows the buffer car arrangement drawing.

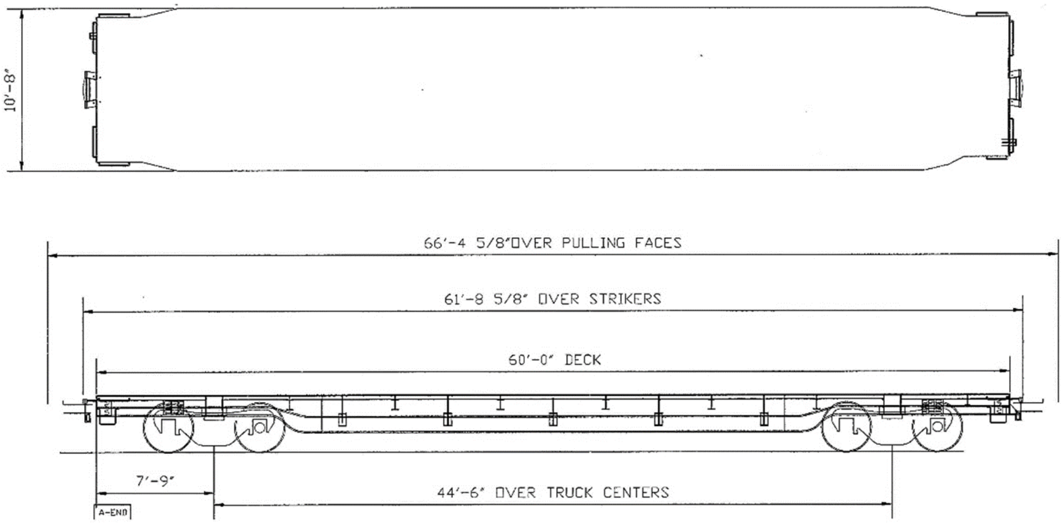


Figure 62. Buffer Railcar Arrangement Drawing

Table 1. Car Dimensions

Dimension	Value
Length over pulling faces	66' 4-5/8"
Length over strikers	61' 8-5/8"
Truck Center Spacing	44' 6"
Axle Spacing on trucks	72"

The requirements for single car tests are described in Section 5.0 of the AAR S-2043 specification. The AAR specification requires that all single car tests and subsequent data analysis be witnessed by a qualified AAR observer. Transportation Technology Center, Inc. (TTCI) will provide the qualified AAR observer to meet this requirement of the specification.

1.3 Test Tracks

Testing is planned on various test tracks at the Transportation Technology Center including the Railroad Test Track (RTT), the Wheel Rail Mechanisms (WRM) Loop, the Precision Test Track (PTT), the URB Wye, the Tight Turn Loop (TTL or Screech Loop), and a crossover between the Impact Track and FAST Wye. These tracks are described in Attachment A.

2.0 SAFETY

Work is to be conducted in accordance with the most current versions of TTCI's Safety Rulebook[4] and Operating Rulebook[5], which are maintained on TTCI's intranet site.

S-2043 requires that maximum test speeds for all non-curving tests be increased to 75 mph from the standard Chapter 11 maximum of 70 mph where deemed safe by the TTCI test team (see Paragraph 8.0 of this document). The applicable test procedures' maximum test speed is listed as 75 mph; however, it is the responsibility of the TTCI test team to determine the maximum safe test speed.

3.0 TEST LOAD

Based on dynamic modeling predictions, the buffer car must be ballasted to a gross rail load of 263,000 pounds to meet the S-2043 Buff-Draft Curving requirements. Because of this, the car was designed with a permanently attached steel ballast weight and only this one load condition will be tested as the car is not rated to carry any additional load.

4.0 VEHICLE CHARACTERIZATION

Vehicle characterization will be performed to verify that the components and vehicle as a whole were built as designed. Tests will be performed to characterize the properties of the carbody and its suspension in the Rail Dynamics Laboratory (RDL) at the Transportation Technology Center (TTC). Results of these tests will be used to verify the component and vehicle characteristics used to perform the multi-body dynamic analysis of the vehicle as described in Section 4.3 of the AAR S-2043 specification.

The Mini-Shaker Unit (MSU), a specialized test facility housed in the Rail Dynamics Laboratory (RDL), will be used extensively to measure vehicle truck suspension system characteristics (see Figure 63). The MSU is comprised of reaction masses and computer controlled hydraulic actuators capable of applying vertical, lateral, or roll input dynamic forces to the vehicle undergoing tests. This unit is especially useful in modal characterization of railcar components and partial rail car systems. The MSU can be configured to perform the rigid and flexible body modal studies of strategic components of the vehicle structure.

The MSU is also used for quantifying the suspension characteristics of assembled suspensions for use in multi-body dynamic models. Measured suspension deflections, reaction forces and wheel/rail forces will be used to determine engineering values for the suspension characteristics.

The MSU is equipped with special instrumented rail sections to measure wheel/rail forces. The use of air bearing tables under the wheels of a vehicle or independently rotating wheels allows for inter-axle shear and yaw stiffness measurements.

Several tests will require trucks to be individually tested in the MSU underneath TTCI's standard truck characterization test flatcar (DOTX 304).

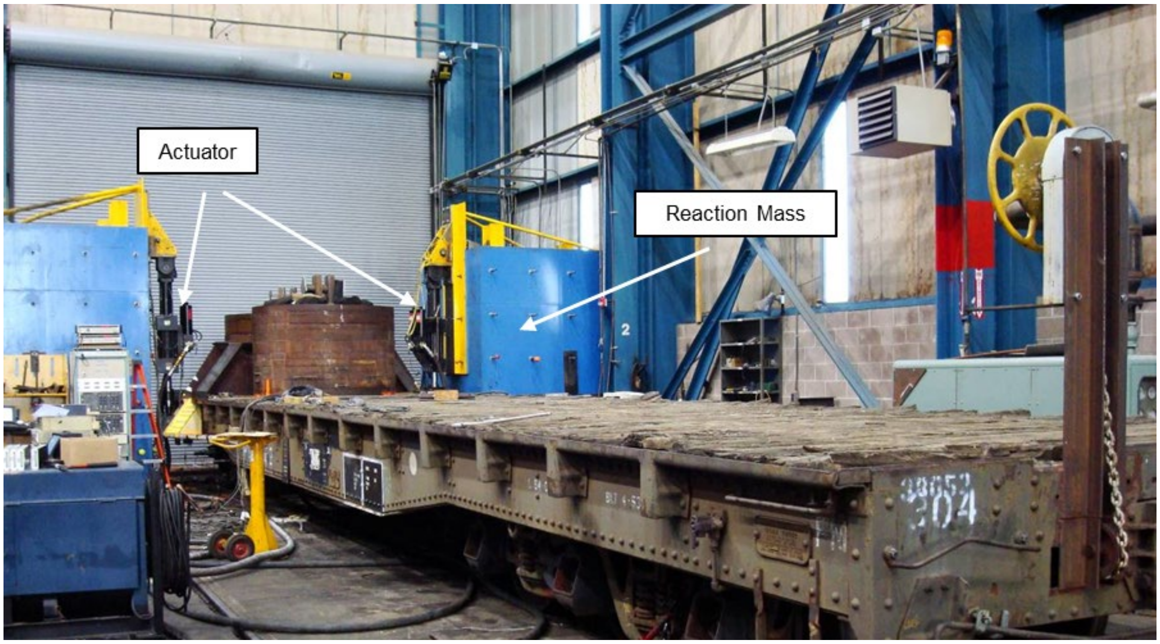


Figure 63. Truck Characterization Test Set-Up in MSU, Showing TTCI Standard Test Car and Vertical Actuators attached to Reaction Masses

Characterization tests are summarized in Table 2. A description of each test is provided in the following subsections. The design of each of these tests is based on the vehicle and suspension arrangement described in the comprehensive report on the multi-body dynamic analyses which TTCI compiled for Kasgro.[6]

Table 2. Vehicle Characterization

Test Name	Comments
5.1.3 Component Characterization	Two samples of each type of spring used will be tested. 2 constant contact side bearings will be tested. 2 hydraulic dampers will be tested.
5.1.4.3 Vertical Suspension Stiffness and Damping	Tests will be performed under DOTX 304. One truck will be tested
5.1.4.4 Lateral Suspension Stiffness and Damping	Tests will be performed under DOTX 304. One truck will be tested
5.1.4.5 Truck Rotation Stiffness and Break Away Moment	Test trucks under each end of the car
5.1.4.6 Inter-Axle Longitudinal Stiffness	Tests will be performed under DOTX 304. One truck will be tested
5.1.4.7 Modal Characterization	Actuators will be attached to the Buffer Carbody. Actuators will be operated in force control at lower frequencies (0.2-10 Hz) and in displacement control for constant acceleration input at higher frequencies (3-30 Hz).

4.1 Component Characterization (S-2043 Paragraph 5.1.3)

Tests will be performed to measure the stiffness and damping characteristics of the following individual suspension components, to meet the requirements of S-2043 section 5.1.3:

- Secondary suspension coil springs
- Constant contact side bearings
- Hydraulic Dampers

4.1.1 Secondary Suspension Coil Springs

The Buffer Railcar uses the spring group arrangement shown in Figure 64. Table 3 shows description for all springs

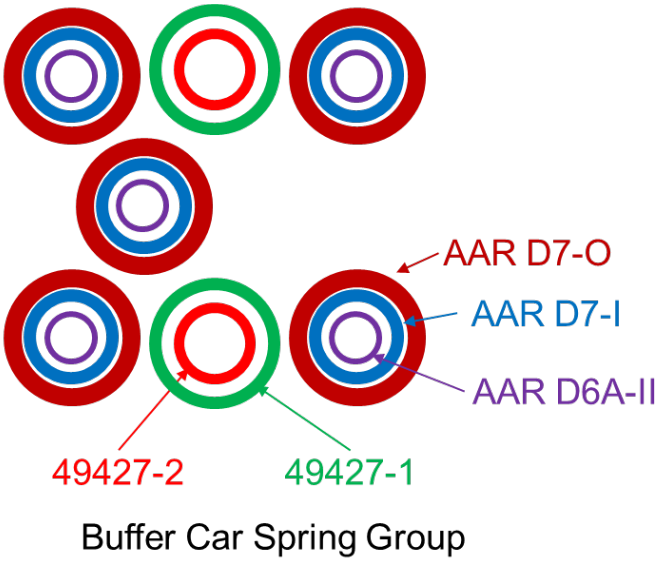


Figure 64. Spring Group Arrangement

Table 3. Secondary Suspension Spring Types

Type	Description	Quantity per Truck	Bar Diameter	Free HT	Solid HT	Spring Rate
			(inch)	(inch)	(inch)	(pound/inch)
49427-1	Control Coil Outer	2	13/16	11 5/16	6 9/16	1359
49427-2	Control Coil Inner	2	9/16	10 13/16	6 9/16	805
D7-O	Main Coil Outer	5	15/16	10 13/16	6 9/16	2033
D7-I	Main Coil Inner	5	5/8	10 3/4	6 9/16	981
D6A-II	Main Coil Inner Inner	5	3/8	9	5 11/16	464

Two of each spring type will be selected from the car and tested in a load frame to characterize the stiffness of the springs. The force-displacement characteristics will be measured. The following measurements will also be recorded:

- Unloaded free height
- Solid height
- Wire diameter

4.1.2 Constant Contact Side Bearings

The car is equipped with Miner TCC-III 80LT constant contact side bearings (CCSB). The set-up height of each CCSB will be measured and recorded. Two sample CCSB will be installed in a load frame to measure the force–displacement characteristics.

Output results will include a graph of the force - displacement characteristic, including: Unloaded Free Height, Stiffness, and Fully Compressed Height.

4.1.3 Hydraulic Dampers

The car is equipped with four Koni 04A 2032 vertical dampers using the damping rate shown in Figure 65. Two sample dampers will be installed in a load frame to measure the force velocity characteristics of the damper and the force displacement characteristics of the damper's bushings for comparison to the values input to the model.

The length of the dampers as installed on the car and the secondary spring height will be measured and recorded. The average damper length will be used as the zero point for characterization tests. Simulations predict that the highest damper displacements are about ±1 inch. The amplitude (up to ±1 inch) and frequency (up to 3.5 Hz) of the inputs will be adjusted to match the velocities specified in the run list Table 4.

Table 5 shows the measurement list for the damper characterization tests.

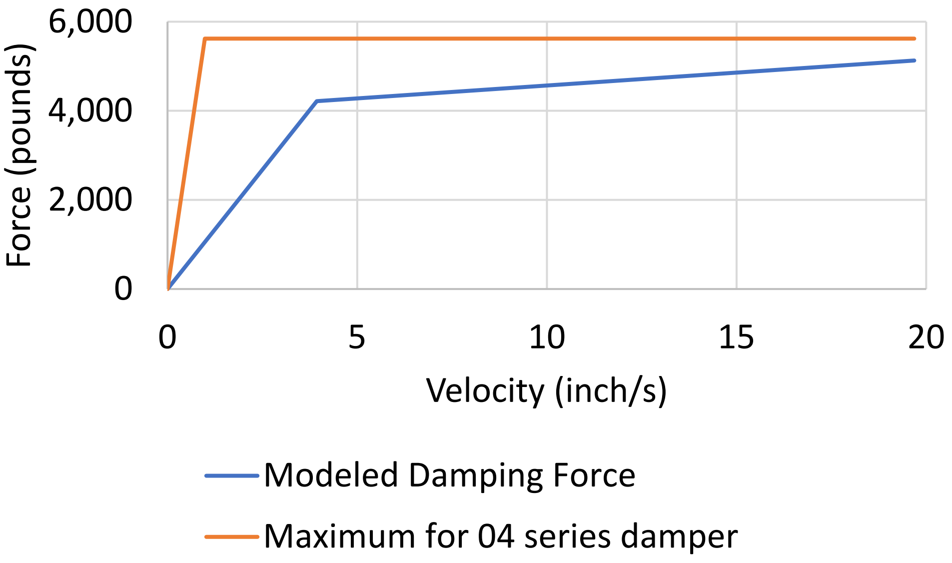


Figure 65. Damping Rate Modeled for the Buffer Car

Table 4. Damper Characterization Run List

Test Run	Stroke Velocity (inch/second)	Comments
1	1	Triangle wave
2	2	Triangle wave
3	4	Triangle wave
4	6	Triangle wave
5	10	Triangle wave
6	15	Triangle wave. Velocity limited by maximum capacity of test machine
7	15	Sine wave. Velocity limited by maximum capacity of test machine

Table 5. Measurements for Damper Characterization Tests

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy	Comments
1	ZFF	Load Frame Force	±6000 pounds	≥15Hz	≥150Hz	better than 1%	From test machine
2	ZDF	Load Frame Displacement	±4 inches	≥15Hz	≥150Hz	better than 1%	From test machine
3	ZDD	Damper Body Displacement	±4 inches	≥15Hz	≥150Hz	better than 1%	
4	ZDB1	Top Damper Bushing Displacement	±0.1 inch	≥15Hz	≥150Hz	better than 1%	
5	ZDB2	Bottom Damper Bushing Displacement	±0.1 inch	≥15Hz	≥150Hz	better than 1%	

4.2 Vertical Suspension Stiffness and Damping (S-2043 Paragraph 5.1.4.3)

Twist and roll and pitch and bounce performance of a railcar are primarily determined by the characteristics of the vertical suspension. The vertical stiffness and damping characteristics will be measured for the secondary coil spring suspension using the MSU.

For this test, equal measured vertical loads will be applied across the spring groups ranging from zero to 1.5 times the static weight, if possible, but at least to the static weight of the buffer car. These tests will be conducted on one truck. The truck will be tested in the MSU underneath the DOTX 304 flatcar. The flatcar will be ballasted to a load equivalent to the weight of the buffer railcar. Vertical hydraulic actuators will be attached to each side of the carbody and the MSU reaction masses, as shown Figure 63. Vertical deflections across the primary and secondary suspensions of each truck will be measured using displacement transducers and force versus displacement plots will be generated based upon the measured data.

Tests of both trucks will be conducted with the friction wedge control coils installed, and then repeated with the friction wedges and wedge control coils removed. Tests will be conducted for input frequencies of 0.1 Hz, 0.5 Hz and 2.0 Hz. The 0.1 Hz tests will be conducted to move the suspension through its full vertical stroke. The 0.5 and 2.0 Hz tests will be limited in travel due to the limitation of the hydraulic flow rate of the actuators, and to avoid damaging the wear surfaces of the friction wedges.

Tests will be performed with and without dampers installed.

The data channels to be recorded are listed in Table 6. The test runs required are summarized in Table 7.

Table 6. Measurements for Vertical and Lateral Suspension Characterization

Channel Name	Description	Units	Expected Range
VinpActN	Input signal North actuator	V	±10
VinpActS	Input signal South actuator	V	±10
FZActN	North actuator force	1000-lb	-50 to 77
FZActS	South actuator force	1000-lb	-50 to 77
DZActN	North actuator displacement	In	±10
DZActS	South actuator displacement	In	±10
FZRailNE	North East rail vertical force	1000-lb	0 to 100
FZRailNW	North West rail vertical force	1000-lb	0 to 100
FZRailSE	South East rail vertical force	1000-lb	0 to 100
FZRailSW	South West rail vertical force	1000-lb	0 to 100
FYRailNE	North East rail lateral Force	1000-lb	-20 to 50
FYRailNW	North West rail lateral force	1000-lb	-20 to 50
FYRailSE	South East rail lateral force	1000-lb	-20 to 50
FYRailSW	South West rail lateral force	1000-lb	-20 to 50
DZSprN	North Vertical bolster to sideframe disp.	In	10
DZSprS	South Vertical bolster to sideframe disp.	In	10
DYSprST	Lateral bolster to sideframe disp. – top South	In	10
DYSprSB	Lateral bolster to sideframe disp. – bot. South	In	10
DYSprST	Lateral bolster to sideframe disp. – top North	In	10
DYSprSB	Lateral bolster to sideframe disp. – bot. North	In	10
DXPadNE1	Longitudinal displacement, NE pad, outside	In	2
DXPadNE2	Longitudinal displacement, NE pad, inside	In	2
DYPadNE1	Lateral displacement, NE pad, outside	In	2
DYPadNE2	Lateral displacement, NE pad, inside	In	2
DZPadNE1	Vertical displacement, NE pad, outside	In	2
DZPadNE2	Vertical displacement, NE pad, inside	In	2
DXPadSE1	Longitudinal displacement, SE pad, outside	In	2
DXPadSE2	Longitudinal displacement, SE pad, inside	In	2
DYPadSE1	Lateral displacement, SE pad, outside	In	2
DYPadSE2	Lateral displacement, SE pad, inside	In	2
DZPadSE1	Vertical displacement, SE pad, outside	In	2
DZPadSE2	Vertical displacement, SE pad, inside	In	2

Table 7. Run Matrix for Vertical Characterization.

Run	Description
1	Vertical 0.1 Hz (full stroke)
2	Vertical 0.5 Hz (partial stroke)
3	Vertical 2.0 Hz (partial stroke)
4	Vertical 0.1 Hz (full stroke) no dampers
5	Vertical 0.5 Hz (partial stroke) no dampers
6	Vertical 2.0 Hz (partial stroke) no dampers
7	Vertical 0.1 Hz (full stroke) no dampers, no wedges

4.3 Lateral Suspension Stiffness and Damping (S-2043 Paragraph 5.1.4.4)

Twist and roll, yaw and sway, and hunting performance of a railcar are affected by the stiffness and damping characteristics of the lateral suspension. The lateral suspension test will be performed for static vertical loads representing the buffer car weight. The testing method will ensure that static friction does not limit lateral motion during this test.

These tests will be conducted on one truck. The truck will be tested in the MSU underneath the DOTX 304 flatcar. The flatcar will be ballasted to a load equivalent to the load on the truck when installed in the buffer car. Tests will be conducted with the friction wedge control coils installed, and then repeated with the friction wedges and wedge control coils removed.

Vertical deflections across the primary and secondary suspensions of each truck will be measured using displacement transducers and force versus displacement plots will be generated based upon the measured data. A lateral hydraulic actuator will be mounted between the carbody and the MSU reaction mass. Tests will be conducted for lateral input frequencies of 0.1 Hz, 0.5 Hz and 2.0 Hz. The 0.1 Hz tests will be conducted to move the suspension through its full lateral stroke, as determined by the lateral stops between the transoms and the bolsters. The 0.5 and 2.0 Hz tests will probably be limited in travel due to the limitation of the hydraulic flow rate of the actuators, and to avoid damaging the wear surfaces of the friction wedges.

The force will be input at a level above the truck suspension. To minimize carbody roll it may be necessary to use a solid connection (oak blocking or steel shims) between the truck bolster and carbody at the side bearing location.

Lateral deflections across the primary and secondary suspensions of each truck will be measured using displacement transducers. Sufficient displacement transducers will be applied to measure both the lateral and rocking motions of the sideframe and the primary and secondary suspensions.

The channels to be measured are the same as those to be measured during the vertical suspension characterizations as listed in Table 6. The test runs required are summarized in Table 8. Force versus displacement plots will be generated based upon the measured data.

Table 8. Run Matrix Lateral Characterization.

Test Run	Description
1	Lateral 0.1Hz (full Stroke)
2	Lateral 0.5Hz (partial stroke)
3	Lateral 2.0Hz (partial stroke)
4	Lateral 0.1Hz (full Stroke) no wedges
5	Lateral 0.1Hz (full Stroke) no damper
6	Lateral 0.5Hz (partial stroke) no damper
7	Lateral 2.0Hz (partial stroke) no damper
8	Lateral 0.1Hz (full Stroke) no damper, no wedges

4.4 Truck Rotation Stiffness and Break Away Moment (S-2043 Paragraph 5.1.4.5)

Truck rotation stiffnesses and/or break-away moment will also be measured.

For these tests air bearing tables will be used to float the truck at one end of the car to ensure the wheels are unrestrained during the test (Figure 66). The opposite end of the car will be raised up to ensure that the car is level when the air tables are inflated. Hydraulic actuators will be used to rotate the table. To ensure that equal loads are applied on each side of the truck, and to minimize lateral motion and skewing of the air tables the actuators will face in opposite directions during these tests. The air table pit in the Storage Maintenance Building at TTC may be used for these tests.

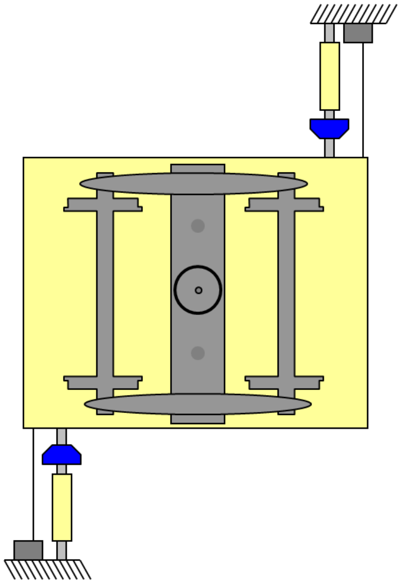


Figure 66. Air Bearing Table Configuration for Truck Rotation Tests

Actuator force and truck bolster rotation relative to the carbody will be measured. This test will be performed at a very low rotational frequency and is considered a static test. Table 9 shows the measurements to be made during truck rotation characterization.

Table 9. Measurements for Truck Rotation Characterization

Channel Name	Description	Units	Expected Range
FYActN	North actuator force	1,000-lb.	±10
FYActS	South actuator force	1,000-lb.	±10
DXTBR	Longitudinal displacement carbody to truck bolster right	In	±5
DXTBL	Longitudinal displacement carbody to truck bolster left	In	±5
DYTBI	Lateral displacement carbody to truck bolster inside	In	±5
DYTBO	Lateral displacement carbody to truck bolster outside	In	±5

Figure 67 shows a sketch of how the string pots might be placed to measure truck rotation. The selection and placement of the string pots must be established so that they are relatively sensitive to translation as well as rotation. The translations of the center plate in the center bowl help the analyst determine if edge contact is occurring, thereby enabling better interpretation of the data. The position of the string pots and load cells relative to the center of rotation must be recorded.

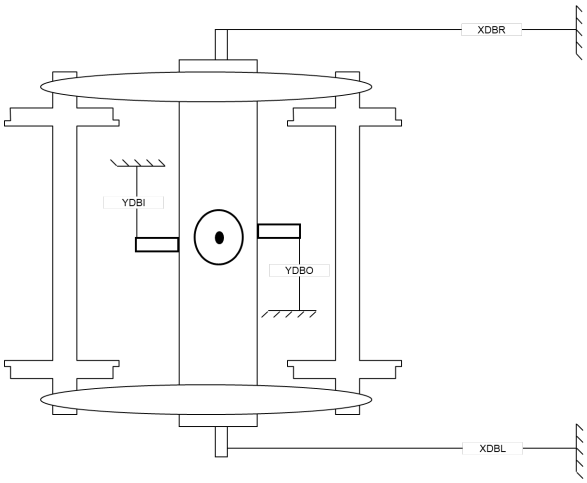


Figure 67. Possible Layout of String Pots for Truck Rotation Tests

4.5 Inter-Axle Longitudinal and Yaw Stiffness (S-2043 Paragraph 5.1.4.6)

The longitudinal stiffness of the primary suspension system will be determined through two tests. These tests will be conducted in the MSU at the same time as the vertical and lateral truck characterization tests (Sections 4.2 and 4.3) with wheelsets with independently rotating wheels (IRWs) installed to eliminate any effects of wheel rolling resistance and slip resistance. Tests will be conducted for the car ballasted to a load equivalent to the buffer car.

The test method uses longitudinal actuators attached between two axles within a truck, at each roller bearing end cap, as shown in Figure 68. The actuators will first be operated in phase in both directions. Longitudinal stiffness will be determined by plotting force versus displacement. The actuators will then be operated out of phase to determine axle yaw stiffness. These tests will be performed at a very low frequency and are considered static tests.

During these tests, sufficient displacement transducers will be applied to measure both the longitudinal motions of the axles (bearing adaptors) relative to the sideframe, and the pitching motion of the bearing adaptors relative to the sideframes, as shown in Figure 69. The measurements to be recorded are listed in Table 10.

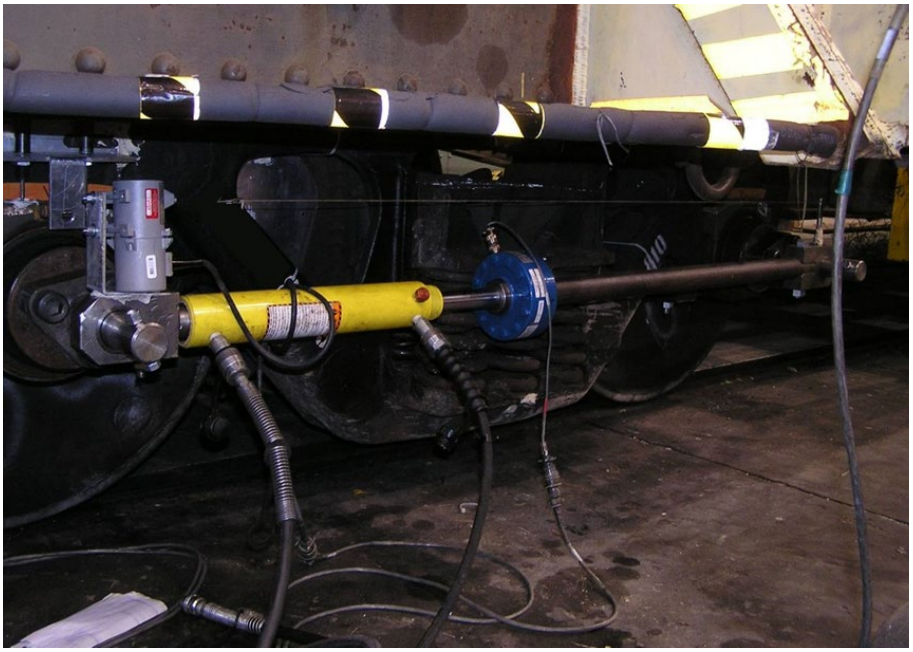


Figure 68. Longitudinal Actuator Installation for Performing Inter-Axle Stiffness Tests

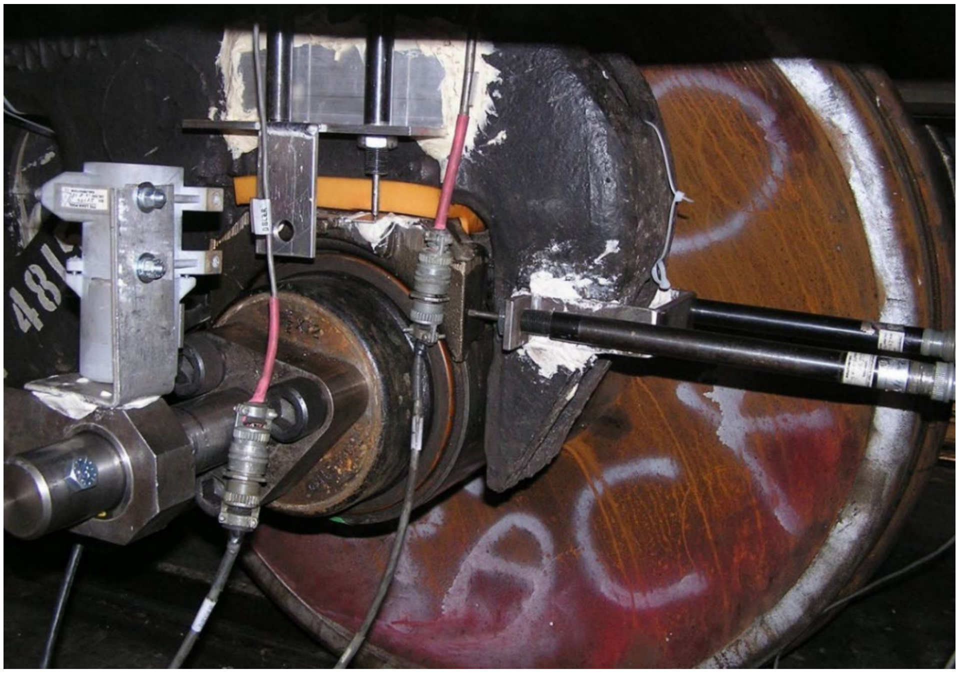


Figure 69. Inter–Axle Stiffness Test Setup Showing LVDTs for Measuring Pitching and Yawing of Bearing Adaptor

Table 10. Measurements for Interaxle Yaw Stiffness Measurements

Channel Name	Description	Units	Expected Range
FXActN	North hydraulic cylinder force	1000-lb	-10 to 20
FXActS	South hydraulic cylinder force	1000-lb	-10 to 20
DXActN	North hydraulic cylinder displacement	In	±10
DXActS	South hydraulic cylinder displacement	In	±10
DXPadNE1	Longitudinal displacement, NE pad, inside	In	2
DXPadNE2	Longitudinal displacement, NE pad, outside	In	2
DYPadNE1	Lateral displacement, NE pad, bottom	In	2
DYPadNE2	Lateral displacement, NE pad, top	In	2
DZPadNE1	Vertical displacement, NE pad, outside	In	2
DZPadNE2	Vertical displacement, NE pad, inside	In	2
DXPadSE1	Longitudinal displacement, SE pad, inside	In	2
DXPadSE2	Longitudinal displacement, SE pad, outside	In	2
DYPadSE1	Lateral displacement, SE pad, bottom	In	2
DYPadSE2	Lateral displacement, SE pad, top	In	2
DZPadSE1	Vertical displacement, SE pad, outside	In	2
DZPadSE2	Vertical displacement, SE pad, inside	In	2

4.6 Modal Characterization (S-2043 Paragraph 5.1.4.7)

The entire railcar will be characterized to identify critical rigid and flexible body modes. The objective of the test is to identify frequencies for the following modes:

Rigid Body
- Bounce
- Pitch
- Yaw
- Lower Center Roll
- Upper Center Roll

Flexible Body
- First mode vertical bending
- First mode twist (torsion)
- First mode lateral bending

The modal tests will be performed on the Buffer railcar in the MSU. Brackets will be welded to the carbody at the carbody bolster on the B-end of the car so the actuators can be attached to the car (Figure 70). TTCI will work with Kasgro to develop a bracket arrangement that does not interfere with the trucks, and to identify allowable areas for welding the brackets to the carbody structure. TTCI will remove the bracket at the conclusion of modal characterization testing.

Figure 70. Example of Actuator Attachment Bracket to be Welded to Car

The carbody will be fitted with enough accelerometers to identify bounce, pitch, roll, yaw, sway, vertical bending, lateral bending, and torsion modes of vibration. The railcar will be excited vertically to induce bounce, pitch, and bending modes. Similarly, the railcar will be excited laterally to identify sway, yaw, and bending, and torsionally to identify lower center roll, upper center roll, and torsion modes. In addition to identifying mode shapes with accelerometers, input force and displacement will be measured to help determine damping rates. The data channels to be recorded during modal tests are listed in Table 11. The approximate measurement locations are shown in Figure 71.

Table 11. Measurements for Modal Characterization

Channel Name	Description	Units	Expected Range
VinpActN	Input signal North actuator	V	±10
VinpActS	Input signal South actuator	V	±10
FZActN	North actuator force	1,000-lb.	-50 to 77
FZActS	South actuator force	1,000-lb.	-50 to 77
DZActN	North actuator displacement	In	±10
DZActS	South actuator displacement	In	±10
AZ1R	Vertical accelerometer, B-end, right side	g	±2
AY1R	Lateral accelerometer, B-end, right side	g	±2
AZ1L	Vertical accelerometer, B-end, left side	g	±2
AZ2R	Vertical accel, ¼ from B-End, right side	g	±2
AY2R	Lateral accel, ¼ from B-End, right side	g	±2
AZ2L	Vertical accel, ¼ from B-End, left side	g	±2
AZ3R	Vertical accelerometer, center, right side	g	±2
AY3R	Lateral accelerometer, center, right side	g	±2
AZ3L	Vertical accelerometer, center, left side	g	±2
AZ4R	Vertical accel, ¼ from A-End, right side	g	±2
AY4R	Lateral accel, ¼ from A-End, right side	g	±2
AZ4L	Vertical accel, ¼ from A-End, left side	g	±2
AZ5R	Vertical accelerometer, A-end, right side	g	±2
AY5R	Lateral accelerometer, A-end, right side	g	±2
AZ5L	Vertical accelerometer, A-end, left side	g	±2

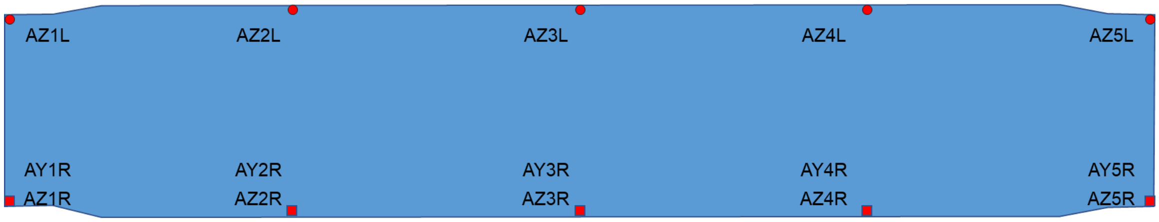


Figure 71. Locations of Modal Accelerometers

Table 12 shows a list of the runs to be performed during modal testing. Rigid body runs will be done using the actuators in force control. Flexible body runs will be done with the actuators in displacement control for constant g runs. The frequency and amplitude values given for each run were based on previous tests[7]. Some changes may be made to frequency and amplitudes used for these runs based on test results.

Table 12. Run List for Modal Testing

Run	Description	Actuator Configuration	Control	Frequency (Hz)	Amplitude
Lateral Rigid Body					
1	Lateral Rigid Body	Lateral	Force	0.2 to 10	5 kips
2	Lateral Rigid Body	Lateral	Force	0.2 to 10	10 kips
3	Lateral Rigid Body	Lateral	Force	0.2 to 10	15 kips
Lateral Flexible Body					
4	Lateral Flexible Body	Lateral	Disp.	3 to 30	0.1 g
5	Optional Lateral Flex Body	Lateral	Disp.	3 to 30	0.2 g
6	Optional Lateral Flex Body	Lateral	Disp.	3 to 30	0.3 g
Vertical Rigid Body					
7	Vertical Rigid Body	Vertical (in phase)	Force	0.2 to 10	5 kips
8	Vertical Rigid Body	Vertical (in phase)	Force	0.2 to 10	10 kips
9	Vertical Rigid Body	Vertical (in phase)	Force	0.2 to 10	15 kips
Vertical Flexible Body					
10	Vertical Flexible Body	Vertical (in phase)	Disp.	3 to 30	0.1 g
11	Optional Vertical Flex Body	Vertical (in phase)	Disp.	3 to 30	0.2 g
12	Optional Vertical Flex Body	Vertical (in phase)	Disp.	3 to 30	0.3 g
Roll Rigid Body					
13	Roll Rigid Body	Vertical (out of phase)	Force	0.2 to 10	5 kips
14	Roll Rigid Body	Vertical (out of phase)	Force	0.2 to 10	10 kips
15	Roll Rigid Body	Vertical (out of phase)	Force	0.2 to 10	15 kips
Twist Flexible Body					
16	Twist Flexible Body	Vertical (out of phase)	Disp.	3 to 30	0.1 g
17	Optional Twist Flex Body	Vertical (out of phase)	Disp.	3 to 30	0.2 g
18	Optional Twist Flex Body	Vertical (out of phase)	Disp.	3 to 30	0.3 g

4.6.1 Rigid Body Vertical Procedure

The actuators will be cycled in phase. Input frequencies will be increased from 0.2 Hz to 10 Hz. The actuators will be operated in force control with 5, 10, and 15 kip sinusoidal inputs. Pitch and Bounce modes will be determined by the phase relationship between the A and B end accelerometers.

4.6.2 Rigid Body Roll Procedure

The actuators will be cycled 180 degrees out of phase. Input frequencies will be increased from 0.2 Hz to 10 Hz. The actuators will be operated in force control with 5, 10, and 15 kip sinusoidal inputs. Roll modes will be determined by the phase relationship between the accelerometers mounted at different positions on the car.

4.6.3 Flexible Body Vertical Procedure

The actuators will be cycled in phase. Input frequencies will be increased from 3 Hz to 30 Hz. The actuators will be operated in displacement control and operated to achieve a constant g input.

4.6.4 Flexible Body Twist Procedure

The actuators will be cycled out of phase. Input frequencies will be increased from 3 Hz to 30 Hz. The actuators will be operated in displacement control and operated to achieve a constant g input.

4.6.5 Rigid Body Lateral Procedure

The actuators will be reconfigured so that one actuator is mounted to excite the car laterally. Input frequencies will be increased from 0.2 Hz to 10 Hz. The actuators will be operated in force control with 5, 10, and 15 kip sinusoidal inputs. The Yaw mode will be determined by the phase relationship between the A and B end accelerometers.

4.6.6 Flexible Body Lateral Procedure

This test will be performed while the actuators are in the lateral configuration. Input frequencies will be increased from 3Hz to 30Hz. The actuators will be operated in displacement control and operated to achieve a constant g input.

5.0 NON-STRUCTURAL STATIC TESTING

Several static tests will be performed to demonstrate the ability of the railcar to maintain adequate vertical wheel loads in extreme load conditions and poor track geometry environments. A summary of the non-structural static tests is presented in Table 13. The data channels to be recorded are presented in Table 14.

Table 13. Summary of Non-Structural Static Tests

Test Name	Instrumentation	Comments
5.2.1 Truck Twist Equalization	This test will be done using 8 load measuring rails. (load bars)	
5.2.2 Carbody Twist Equalization	This test will be done using 8 load measuring rails (load bars)	
5.2.4 Static Curve Stability	Feeler gages	Currently planning to use the AAR short car/long car
5.2.5 Horizontal Curve Negotiation	Visual inspection	Screech loop

5.1 Instrumentation

Figure 72 shows load bar installation locations and Table 14 provides additional details of measurements for the Non-Structural Static Tests.

Figure 72. Load Bar Installation Locations

Table 14. Measurements for Non-Structural Static Tests

Channel Name	Description	Units	Expected Range
1[t	Load bar, axle 1, right wheel	kips	0-60
LB1L	Load bar, axle 1, left wheel	kips	0-60
LB2R	Load bar, axle 2, right wheel	kips	0-60
LB2L	Load bar, axle 2, left wheel	kips	0-60
LB3R	Load bar, axle 3, right wheel	kips	0-60
LB3L	Load bar, axle 3, left wheel	kips	0-60
LB4R	Load bar, axle 4, right wheel	kips	0-60
LB4L	Load bar, axle 4, left wheel	kips	0-60
IC	Instrumented Coupler	kips	±200

5.2 Truck Twist Equalization (S-2043, Paragraph 5.2.1)

This requirement is to ensure adequate truck load equalization. Load bars will be used to measure wheel loads as shown in Figure 72.

- With the car on level track shim each wheel three inches in height. This is the zero condition.
- For one wheel in each truck, measure vertical wheel loads while raising one wheel from 0.0 inch to 3.0 inches, then lowering to -3 inches, then raising back to 0 inches in increments of 0.5 in.
- At 2.0 inches of deflection, vertical load at any wheel may not fall below 60% of the nominal static load.
- At 3.0 inches of deflection, vertical load at any wheel may not fall below 40% of the nominal static load.

Figures 11 and 12 of the dynamic analysis report[6] show that the trucks used in this vehicle are symmetrical front to back and left to right so this test will be performed by raising and lowering just one wheel in every truck.

5.3 Carbody Twist Equalization (S-2043, Paragraph 5.2.2)

This test will be performed in conjunction with the truck twist test. This requirement is to document wheel unloading under carbody twist, such as during a spiral negotiation. Load bars will be used to measure wheel loads as shown in Figure 72. The railcar shall be jacked by 3.0 in. in 0.5-in. increments from underneath the wheels on one side of all trucks at one end of the car. At 2.0 in. of lift, vertical load at any wheel may not fall below 60% of the nominal static load. At 3.0 in., no permanent damage shall be produced and no static wheel load may fall below 40% of the nominal static wheel load.

This test must be performed by raising and lowering each of the four corners of the railcar individually.

5.4 Static Curve Stability (S-2043, Paragraph 5.2.3)

The curve stability test shall follow the requirements of M-1001 paragraph 11.3.3.3. The test consist will undergo a squeeze and draft load of 200,000 pounds without carbody suspension separation or wheel lift. Load application shall simulate a static load condition and shall be of minimum 20 seconds sustained duration.

For the purpose of this test, wheel lift is defined as a separation of wheel and rail exceeding 1/8-in. when measured 2 5/8-in. from the rim face with a feeler gauge.

The car will be subjected to squeeze and draft load on a 10-degree curve located at the Urban Rail Building at TTC. The test car will be coupled to a base car as defined in paragraph 2.1.4.2.3 of the AAR M-1001 specification, and a long car having 90-ft over strikers, 66-ft truck centers, 60-in. couplers, and conventional draft gear.

Coupler forces will be measured during the test.

5.5 Horizontal Curve Negotiation (S-2043, Paragraph 5.2.4)

A horizontal curve negotiation test must be performed per M-1001, paragraph 2.1.4. The specification requires that this car be able to negotiate a curve of 150-foot radius uncoupled. The test will be performed on the screech loop at TTC which has a radius of 150 feet. The test car will be coupled to three short hopper cars so that the test car can be pushed into the curve without the locomotive entering the curve. The car will be pushed into the curve in stages. At each stage personnel will inspect the car paying special attention to:

- Clearance between wheels and carbody
- Clearance between wheels and brake rigging (including brake cylinder)
- Clearance between truck bolster and brake rigging

6.0 STATIC BRAKE TESTS

Static brake shoe force tests are to be conducted by Kasgro at their facility. Kasgro has arranged for the assistance of New York Air Brake and an AAR observer. A TTCI engineer will also be present for testing. The TTCI engineer will confirm that the tests are conducted as described below.

6.1 Static Brake Force Measurements

Static brake force measurements will be conducted per MSRP Section E, Standard S-401 to demonstrate compliance with S-2043 paragraph 4.4. Braking ratios for freight operation must be verified. Brake shoe force variations must also be within the limits provided in Standard S-401.

6.2 Single-Car Air Brake Test

In addition, a single-car air brake test must be performed per the AAR Manual of Standards and Recommended Practices, Section E, Standard S-486, or other applicable standard.

7.0 STRUCTURAL TESTS

Structural tests will be conducted to demonstrate the railcar's ability to withstand the rigorous railroad load environment and to verify the accuracy of the structural analysis. The Chapter 11 requirement of “no permanent deformation” is interpreted as no stress exceeding material yield for the tests described in the following sections. The structural tests are summarized in Table 15.

Table 15. Structural Tests

Test Name	Lead End	Instrumentation	Comments
5.4.2 Squeeze (Compressive End) Load		50-Strain gages, million pound load cell.	
5.4.3 Coupler vertical loads		50-Strain gages, 50K load cell.	Apply 50K pounds up and down at pulling face of coupler.
5.4.4 Jacking		50-Strain gages	
5.4.5 Twist		50-Strain gages, 8 load bars	5.4.5.1 performed in conjunction with 5.2.2. 5.4.5.2 performed separately.
5.4.6 Impact	B	50-Strain gages, Instrumented coupler	

7.1 Special Measurements (S-2043, Paragraph 5.4.1)

A survey of the car will be performed before and after all the structural tests have been conducted. The purpose of this survey is to verify the shape and integrity of the car. In addition, a visual inspection of the car will be made after each structural test. The survey will include:

- Measure the length over strikers
- Measure the length over pulling faces
- Using a theodolite, measure a level loop around the car deck to check for a change in camber or twisting of the carbody

7.2 Instrumentation

Strain measurements are to be taken from gauges installed on the railcar under frame and deck surface for each of the tests described in sections 7.3 - 7.7. Strains will be used for post-test comparison to finite-element analysis (FEA) predictions. The car designer has determined the location for the gauges as required by S-2043 paragraph 5.4.1.2, based on design FEA results. In addition, thermocouples will be installed in 3 locations for temperature compensation of strain measurements.

Table 16 list the measurements for the structural tests. Strain gauge and thermocouple locations, descriptions, material properties at measurement locations, channel names, measurement units, and expected range are included in Attachment B.

Table 16. Measurements for Structural Tests*

Channel Name	Description	Units	Expected Range
LC1	Load cell for compressive end load	kips	0-1,000
LC2	Load cell for coupler test	kips	0-50
IC	Instrumented Coupler for impact test	kips	0-1250
SPD	Speed Tachometer for impact test	mph	0-15

*See Attachment B for details of strain gauge and thermocouple locations on carbody

Most structural tests are static or quasi-static so filter and sample rates are not critical. Data should be filtered at ≥10-Hz and sampled at a minimum of twice the chosen filter frequency. The exception is the impact test regime, where data will be filtered at a rate ≥100-Hz and < (sample rate/2). The minimum sample rate for impact tests is 1000-Hz. Impact test data will be digitally filtered at 100-Hz during data analysis.

7.3 Squeeze Load (Compressive End Load) (S-2043, Paragraph 5.4.2)

The squeeze test shall follow the requirements of M-1001 paragraph 11.3.3.1. A horizontal compressive static load of 1,000,000 pounds will be applied at the centerline of draft to the draft system of car interface areas using TTCI's squeeze fixture (Figure 73) and sustained for a minimum of 60 seconds. The car tested will simulate an axially loaded beam having rotation-free translation-fixed end restraints. No other restraints, except those provided by the suspension system in its normal running condition, will be permissible.

Prior to testing the squeeze load should be cycled to 750,000 pounds three times to stress relieve the railcar, providing a better correlation between FEA predictions and measured stresses.

Figure 73. 2 1/2 Million-Pound Squeeze Test Fixture with Passenger Car Taken to Structural Failure

7.4 Coupler Vertical Loads (S-2043, Paragraph 5.4.3)

The coupler vertical load test shall follow the requirements of M-1001 paragraph 11.3.3.2. A load of 50,000 pounds shall be applied in both directions to the coupler head as near to the pulling face as practicable and held for 60 seconds. This test will utilize a hydraulic cylinder positioned on cribbing to apply the upward force. An A-frame fixture that attaches to the rail and a hydraulic cylinder will be used to apply the downward force (Figure 74).

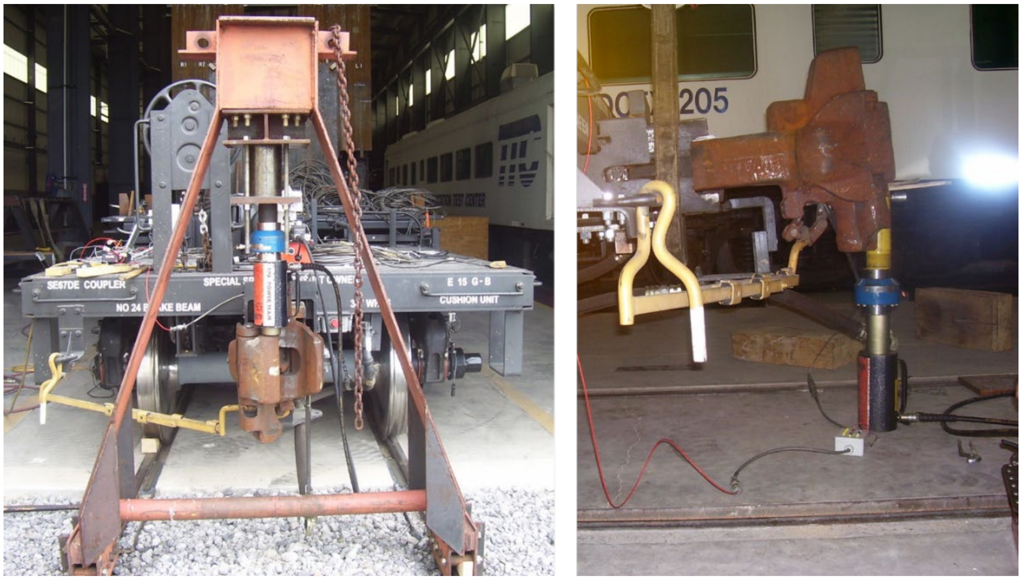


Figure 74. Applying Coupler Vertical Loads

7.5 Jacking (S-2043, Paragraph 5.4.4)

The jacking test shall follow the requirements of M-1001 paragraph 11.3.3.4. Vertical load capable of lifting a fully loaded car will be applied at designated jacking locations sufficient to lift the unit and permit removal of the truck or suspension arrangement nearest to the load application points. M-1001, Chapter 11 requires that the car withstand the test without permanent deformation of car structure. Strain data will be recorded while the carbody is jacked high enough to permit removal of the truck.

7.6 Twist (S-2043, Paragraph 5.4.5)

The twist test shall follow the requirements of M-1001 paragraph 11.3.3.5. The loaded car will be jacked 3 inches from underneath the wheels on one side of one truck at one end of the car. M-1001, Chapter 11 requires that the car withstand the test without permanent deformation of the car structure. This test will be performed in conjunction with the test described in Section 0.

In addition, the carbody will be supported at all four jacking pads and one corner will be allowed to drop 3 in.

Strain data will be recorded during these tests.

7.7 Impact (S-2043, Paragraph 5.4.6)

The impact test shall follow the requirements of M-1001 paragraph 11.3.4.1. The loaded candidate car is to be impacted into a string of three standing, fully loaded cars of at least 70-ton capacity. The impact string will be equipped with M-901E draft gear on the struck end and the hand brake will be fully set on the last car (opposite end).

Free slack between cars will be removed; however, draft gears will not be compressed. No restraint other than the hand brake on the last car will be used.

A series of impacts will be made on tangent track section of the Precision Test Track (PTT) at TTC. Successive impacts will be made in increments of 2 mph or less starting at 4 mph or less until the design coupler force of the car (600,000 pounds) as specified in paragraph 4.1.10 or a speed of 14 mph has been reached, whichever occurs first. The coupler force shall not exceed 1,250,000 pounds during any impact with a speed of 6 mph or less.

Strain data, coupler load, and speed will be measured during these tests.

7.8 Securement System (S-2043, Paragraph 5.4.7)

The buffer car does not include a securement system.

8.0 DYNAMIC TESTS

Dynamic tests include testing as described MSRP Section C Part II, Specification M-1001, Chapter 11, as well as additional requirements. Where Chapter 11 and HLRM criteria differ, the car shall meet both requirements. Table 17 summarizes the required dynamic tests.

M-1001, Chapter 11 specifies a maximum test speed of 70 mph for all non-curving tests. S-2043 requires the maximum speed be increased to 75 mph where deemed safe by the TTCI test team. Tests at speeds over 70 mph shall be used to quantify performance, and limiting criteria will not apply.

Table 18 summarizes S-2043 dynamic limiting criteria. Figure 75 illustrates the application of 50 millisecond and 3 ft. distance limits for L/V ratio and minimum vertical wheel load.

For buffer car tests IWS will be placed in both axles of the B-end truck. The truck with instrumented wheel sets can be placed in either leading or trailing position as required by the particular test.

Table 17. Dynamic Tests

Test Name	Lead End	IWS Position	Comments
5.5.7 Hunting	B	Axles 1-2	Separately with KR wheels
5.5.8 Twist and Roll	B	Axles 1-2	
5.5.9 Yaw and Sway	B	Axles 1-2	
5.5.10 Dynamic Curving	B A	Axles 1-2*	
5.5.11 Pitch and Bounce (Chapter XI)	B	Axles 1-2	
5.5.12 Pitch and Bounce Special	B	Axles 1-2	Create zone with 44-foot 6-inch wavelength
5.5.13 Single bump test	B	Axles 1-2	
5.5.14 Curve Entry/Exit	B A	Axles 1-2*	5.5.13.1 Limiting Spiral tests will be done during Dynamic Curving tests. 5.5.13.2 Spiral Negotiation tests will be done during Constant Curving tests.
5.5.15 Curving with Single Rail Perturbation	B A	Axles 1-2*	Perturbation will be installed on URB north Y. (Two tests, inside bump and outside bump.)
5.5.16 Standard M-1001 Chapter 11 Constant Curving	B A	Axles 1-2*	These tests will be performed on the WRM track in the 7.5-, 10-, and 12-degree curves. Testing will be done clockwise and counterclockwise
5.5.17 Special Track Work	B A	Axles 1-2*	Turnout tests will be carried out on the URB north Y track, possibly in conjunction with 5.5.15 tests. The crossover tests will be conducted on the Impact track to Fast Y crossover.

*This means IWS do not move; for B-end leading tests they are in the leading end, for A-end leading tests they are in the trailing end.

Table 18. Dynamic Limiting Criteria

Criterion	Limiting Value	Notes
Maximum carbody roll angle (degree)	4	Peak-to-peak.
Maximum wheel L/V	0.8	Not to exceed indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
95th percentile single wheel L/V (constant curving tests only)	0.6	Not to exceed indicated value. Applies only for constant curving tests.
Maximum truck side L/V	0.5	Not to exceed indicated value for a duration equivalent to 6 ft. of track per instance.
Minimum vertical wheel load (%)	25	Not to fall below indicated value for a period greater than 50 msec. and for a distance greater than 3 ft. per instance*.
Peak-to-peak carbody lateral acceleration (G)	1.3 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum carbody lateral acceleration (G)	0.75 0.35	For non-passenger-carrying railcars For passenger-carrying railcars
Carbody lateral acceleration standard deviation (G)	0.13	Calculated over a 2000-ft sliding window every 10 ft. over a tangent track section that is a minimum of 4000 ft. long.
Maximum carbody vertical acceleration (G)	0.90 0.60	For non-passenger-carrying railcars For passenger-carrying railcars
Maximum vertical suspension deflection (%)	95	Suspension bottoming not allowed. Maximum compressive spring travel shall not exceed 95% of the spring travel from the empty car height of the outer load coils to solid spring height.
Maximum vertical dynamic augment acceleration (g)	0.9	Suspension bottoming not allowed. Vertical dynamic augment accelerations of a loaded car shall not exceed 0.9 G.
*Figure 75 illustrates the application of 50 millisecond and 3 ft. distance limits for L/V ratio and minimum vertical wheel load.		

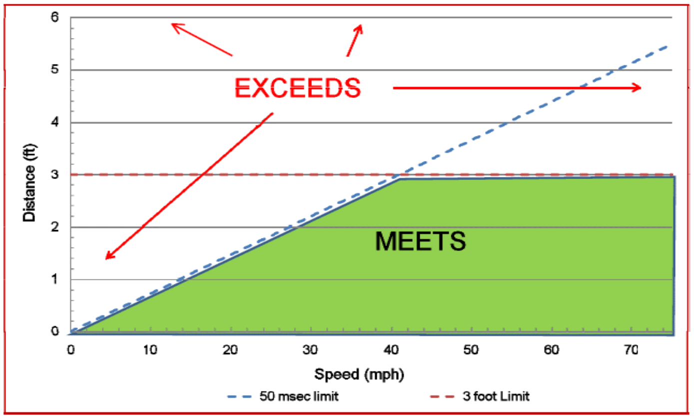


Figure 75. Time and Distance to Climb Limits

8.1 Track geometry (S-2043, Paragraph 5.5.6)

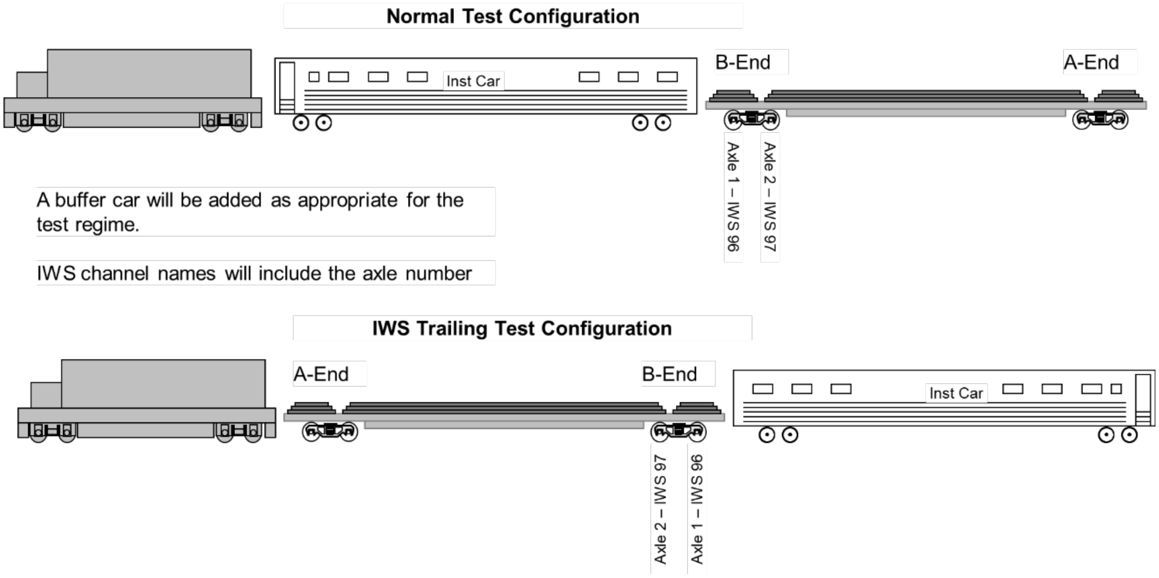
Unless otherwise specified, the track geometry in each test regime must conform to the requirements of MSRP Section C Part II, Specification M-1001, paragraph 11.7.2.5, Table 11.2.

8.2 Instrumentation

The instrumentation / data collection package for these tests will be provided by TTCI and will include all of the necessary transducers for comparison with S-2043 performance measures. Measurements for dynamic tests are listed in Table 19.

To provide precise measurements of wheel/rail forces, two instrumented wheel sets[‡] will be installed in both axles of the B-truck, which can be placed in either the leading or trailing position as required by the particular test (see Figure 76).

Carbody lateral acceleration, carbody roll angle measurements, and spring group vertical displacement will be taken on each end of the vehicle.



Normal Test Configuration

A buffer car will be added as appropriate for the test regime.

IWS channel names will include the axle number

IWS Trailing Test Configuration

Figure 76. IWS Configuration

Data channels will include:

- Two each – Roll gyroscopes
- Two each – Vertical accelerometers
- Two each – Lateral accelerometers
- Four each – 10-in. string potentiometers
- Two each – Instrumented wheelsets
- One each – Speed tachometer
- One each – Automatic location device

[‡] Instrumented wheelsets must meet requirements of M-1001, Appendix C

Table 19. Measurement List for Instrumented Wheel Set Testing

NO.	Channel Name	Measurement Description	Expected Range	Measurement Frequency Response	Digital Sample Rate	Estimated Accuracy
1	Speed	Speed	0-80mph	0-1Hz	≥300Hz	better than 1%
2	ALD	Automatic Location Device	0-5V	≥15Hz	≥300Hz	better than 2%
3	VLX VRX LVLX LVRX TSLVL1 TSLVR1 X=Axle Num.	IWS in Axle 1		≥15Hz	≥300Hz	better than 5%
4		IWS in Axle 2		≥15Hz	≥300Hz	better than 5%
5	ZACBB	Lead carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
6	ZACBA	Trail carbody vertical acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
7	YACBB	Lead carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
8	YACBA	Trail carbody lateral acceleration*	between ±2g and ±10g	≥15Hz	≥300Hz	better than 1%
9	ZDSNBL	Vertical Displacement B truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
10	ZDSNBR	Vertical Displacement B truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
11	ZDSNAL	Vertical Displacement A truck Left Side	>5 inch	≥15Hz	≥300Hz	better than 1%
12	ZDSNAR	Vertical Displacement A truck Right Side	>5 inch	≥15Hz	≥300Hz	better than 1%
13	RDCBB	Carbody roll rotation, B-end	±4deg	≥15Hz	≥300Hz	better than 1%
14	RDCBA	Carbody roll rotation, A-end	±4deg	≥15Hz	≥300Hz	better than 1%
15	GPS	GPS	n/a	≥1Hz	≥1Hz	better than 1%

*Accelerometers to be placed as close as possible to truck centers

8.2.1 Data Acquisition

Data will be filtered at a rate ≥15 Hz and ≤ (sample rate/2). The minimum sample rate is 300 Hz. Data will be post filtered as required (15 Hz) and analyzed in near-real time using the performance criteria for dynamic testing provided in Table 18.

8.2.2 Functional Checks

Functional checks of the instrumentation should be made to verify that all the measurements are working correctly. These functional checks are not a calibration function, but are done to verify the setup.

Common setup errors are faulty transducers, cabling errors, improper gain settings, etc. Perform functional checks to verify that the cables go where they are supposed to and measure about the right value. If a functional check of a transducer shows more than 10% error, look closely at the setup to make sure there are no mistakes.

- Record the functional checks in a data file so you can refer to them later if necessary.
- Perform the functional checks in a specific order and verify that the order matches what you observe in the data file.
- Pay attention to the sign of the output.

The following are typical functional checks for some transducers.

- Roll the accelerometers 90 degrees for a 1g input.
- Pull string pots and verify that extension is positive and that they read 1-inch when pulled one inch.
- Use a block of known size to check LVDTs and bending beams.
- Check speed measurements against GPS speed
- Verify load cells with an R-cal resistor and a breakout box.
- If possible, apply a known force to a load cell. For example, use the car weight and the track grade from your Operating Rule Book to estimate the average expected force on the appropriate channel for a particular piece of track during resistance testing.

Instrumented wheel sets are a special case. The following are suggested for functional tests of IWS. As IWS technology changes the steps might change.

- Verify the cable is connected where you think it is by disconnecting the cable at the wheelset and verifying that the “Disconnected” light comes on at the decoder box where you expect it to.
- Push the R-cal button on the Decoder box and verify that you see the step change in the correct IWS channels.
- Record data on a portion of tangent track.
  - Vertical loads should match the scale weight to within 5%
  - Lateral loads should be small, resulting in L/V ratios of about 0.05. This may vary depending on truck design and condition.
  - Contact position output should be around zero. This may vary depending on truck design and condition.
  - If the wheelset is equipped with a torque bridge its average should be around zero. This may vary depending on truck design and condition.

- If a truck is fully instrumented with IWS, you can compare the net lateral load to a calculated value for a curve.

8.3 Hunting (S-2043, Paragraph 5.5.7)

The high-speed stability (hunting) tests must conform to the requirements of M-1001 paragraph 11.7.2, with the exception of limiting criteria. High-speed stability testing is conducted to confirm that hunting (lateral oscillating instability in the trucks) does not occur within normal operating speeds of the train. Hunting is inherent in typical railroad freight truck designs when components are allowed to wear beyond normal limits.

The car will be equipped with wheel sets having KR wheel profiles (100,000-mile average worn profile), and will be operated at speeds up to 75 mph on tangent track.

8.3.1 Hunting Test Procedure and Test Conditions

The high-speed stability tests shall be conducted under the following conditions:

- The car will be placed at the end of a consist following a stable buffer car (can be the instrumentation car)
- Maximum speed of 70 mph, 75 mph if deemed safe by the TTCI test team
- Track with FRA class 6 or better designation
- Rail profile is AREA 136 lb. or equivalent
- 56 5/16 in. < Track Gauge < 57 in.
- Wheels shall all have KR profile (100,000-mile average worn profile)
- Minimum coefficient of wheel/rail friction of 0.4

Data will be recorded in a short (about 1000-foot) section of the entry and exit spiral at each end of the tangent hunting zone to confirm performance in shallow curves.

8.3.2 Hunting Test Instrumentation and Test Conduct

Because instrumented wheel sets are not available with the KR wheel profile, the hunting tests must be conducted in two configurations:

- Using IWS with the AAR-1B narrow flange profile[7] that is required for all other dynamic tests. During these tests, the wheel sets in positions that are not instrumented must also have the AAR-1B narrow flange wheel profile.
- Using wheel sets (not instrumented) having the KR wheel profile in all positions.

The test car will be instrumented as described in Table 19 with or without instrumented wheel sets as appropriate. Sustained truck hunting shall be determined by measuring the lateral acceleration of the carbody in 2,000-ft windows sliding every 10-ft over a tangent track section that is a minimum of 4,000-ft long. Time histories of the worst-case results that exceed criteria shall be submitted with the report.

Hunting tests will be performed on the RTT track between R39 and R33.5. At a minimum, data will be recorded from R40 to R33 to observe performance in the entry and exit spiral and curve. If hunting is observed during the test it must be reported, even if it occurs in the non-tangent test section. Table 20 shows the run list. Additional speeds may be added by the TTCI test team depending on car performance.

Table 20. Hunting Run List

Filename	Speed (mph)	Comments
	30	Track Conditioning Run
	40	
	50	
	55	
	60	
	65	
	70	
	75	If deemed safe by the TTCI test team

8.4 Twist and Roll (S-2043, Paragraph 5.5.8)

The twist and roll tests must conform to the requirements of M-1001 paragraph 11.8.2, with the exception of limiting criteria. The twist and roll test is conducted to determine the car's ability to negotiate oscillatory cross level perturbations. These perturbations are designed to excite the natural twist and roll motions of the car. The twist and roll test will be conducted on the Precision Test Track (PTT), station 1644+10 to 1651+70. Figure 77 provides a description of the Twist and Roll test zone.

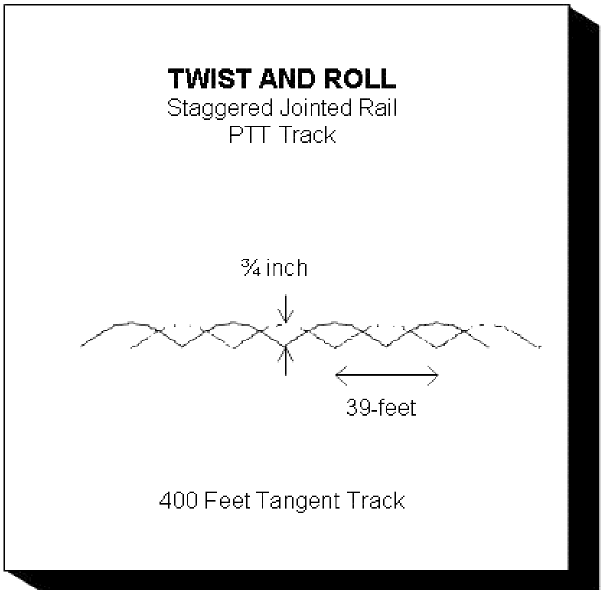


Figure 77. Twist and Roll Test Zone

8.4.1 Twist and Roll Test Procedure and Test Conditions

Twist and roll tests shall be conducted given the following conditions:

- Test car has a stable buffer car at each end (one can be the instrumentation car)
- AAR-1B wheel profiles
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.

- Starting test speed is well below predicted resonance and increases in 2 mph increments (or less) until resonance is passed. It is acceptable to approach a resonant condition from a higher speed.
- Minimum coefficient of friction is 0.4
- Tangent track
- Ten staggered perturbations of 39-ft wavelength and 0.75-in. cross-level (see Figure 77)
- Otherwise class 5 or better track

8.4.2 Twist and Roll Instrumentation and Test Conduct

Axles 1 and 2 will be equipped with IWSs as shown in Figure 76. The test shall be conducted with the B end leading (IWS-equipped truck leading). The test car will be instrumented as described in Table 19.

The individual wheel forces and the roll angles at each end if the carbody shall be measured continuously through the test zone. Time histories of the worst-case results that exceed criteria, and the number of exceedances over the various run speeds (as applicable) shall be submitted with the report.

Table 21 shows suggested runs for the twist and roll tests. Runs are performed starting at 10 mph and increasing in 2-mph increments until the lower center roll resonance is passed. Once lower center roll resonance is passed speeds are increased in 5-mph increments until 70 mph is reached. If performance is close to the limits smaller speed increments should be used to assure safety and closely identify the critical speed. If deemed safe by the TTCI test team, a 75-mph run will be performed.

Table 21. Twist and Roll Test Runs.

Filename	Speed	Comments
	10	
	12	
	14	
	16	
	18	
	20	
	22	
	24	
	26	Transition from 2-mph increments to 5-mph increments at the discretion of TTCI test team
	30	
	35	
	40	
	45	
	50	
	55	

	60	
	65	
	70	
	75	If deemed safe by the TTCI test team

8.5 Yaw and Sway (S-2043, Paragraph 5.5.9)

The yaw and sway tests must conform to the requirements of M-1001 paragraph 11.8.4, with the exception of limiting criteria. The yaw and sway test is conducted to determine the ability of the car to negotiate laterally misaligned track, which will excite the car in a yaw and sway motion. The speeds at which the resonant dynamic reactions occur will be found if they occur before 75 mph is reached. Station 1921 to 1927 of the PTT is the test site for the Yaw and Sway Test. Figure 78 provides a description of the Yaw and Sway test zone.

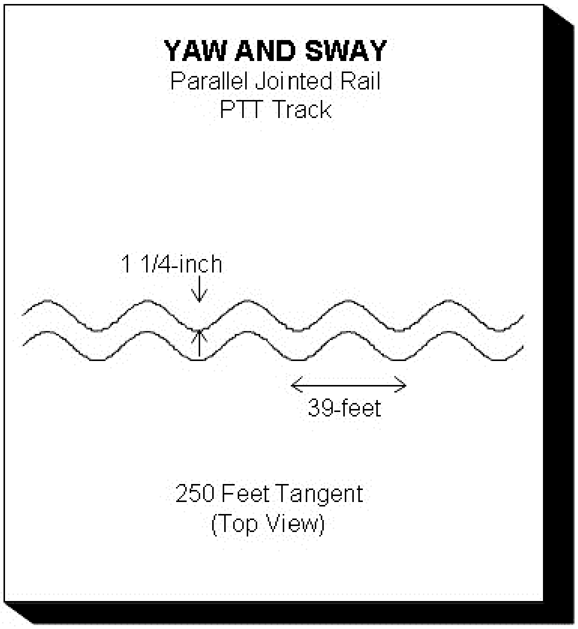


Figure 78. Yaw and Sway Test Zone

8.5.1 Yaw and Sway Test Procedure and Test Conditions

Yaw and sway tests shall be conducted given the following conditions:

- As built (with permanent ballast)
- Test car has a leading stable buffer with a minimum truck center of 45 ft. (can be the instrumentation car)
- No Trailing buffer car
- Minimum coefficient of friction is 0.4
- AAR-1B wheel profiles
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Starting test speed is well below predicted resonance and increases in 5 mph increments (or less) until resonance, an unsafe condition, or 75 mph is reached.

- Tangent track
- Constant wide gauge of 57.5 inch
- Five parallel perturbations of 39-ft wavelength and maximum 1.25-in. lateral amplitude (see Figure 78).
- Track is otherwise class 5 or better

8.5.2 Yaw and Sway Instrumentation and Test Conduct

Axles 1-2 will be equipped with IWSs as shown in Figure 76. Dynamic modeling predictions show that the last truck in the car has truck side L/V ratios that are slightly higher than other locations. Because of this the test shall be conducted with the A end leading (IWS-equipped truck trailing). The wheel forces shall be measured continuously through the test zone. Time histories of the worst-case results that exceed criteria shall be submitted with the report.

Table 22 shows suggested runs for the yaw and sway test. Runs are performed starting at 30 mph and increasing in 5 mph increments until 70 mph is reached. If performance is close to the limits smaller speed increments may be used to assure safety and closely identify the critical speed. If deemed safe by the TTCI test team, a 75 mph run will be performed.

Table 22. Loaded Yaw and Sway Test Runs

Filename	Speed	Comments
	30	
	35	
	40	
	45	
	50	
	55	
	60	
	65	
	70	
	75	If deemed safe by the TTCI test team

8.6 Dynamic Curving (S-2043, Paragraph 5.5.10)

The dynamic curving tests must follow the requirements of M-1001 paragraph 11.8.5, with the exception of limiting criteria. The dynamic curving test is designed to determine the ability of the car to negotiate curved track with simultaneous cross level and gage (vertical and lateral) misalignments. The dynamic curving test is conducted on the 10-degree bypass curve of the WRM track. Figure 79 provides a description of the Dynamic Curve Test location.

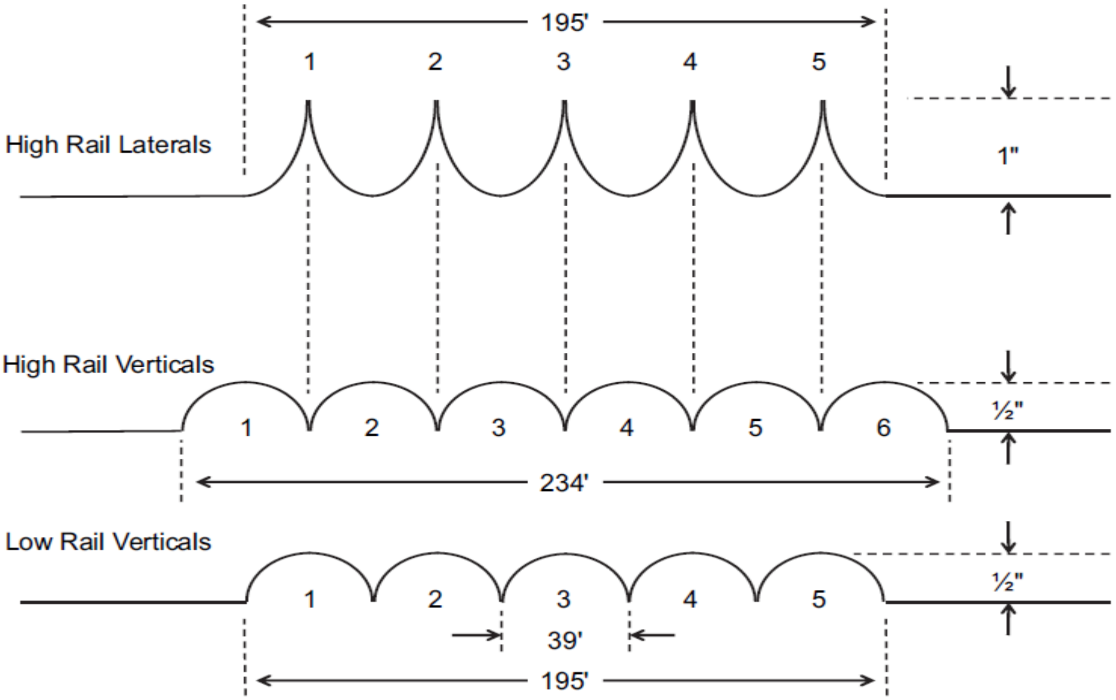


Figure 79. Dynamic Curving Test Zone

8.6.1 Dynamic Curving Test Procedure and Test Conditions

Dynamic curve tests shall be conducted given the following conditions:

- Test car between two stable buffers (one can be the instrumentation car)
- Minimum coefficient of friction is 0.4
- AAR-1B wheel profiles
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Curvature is between 10° and 15° with a balance speed between 15 and 25.
- Starting test speed is –3 in. under-balance with (but not limited to) 2 mph increments and a maximum of +3 in. over-balance. The resonance point may be approached from a higher speed.
- Five staggered perturbations of 39-ft wavelength and 0.5-in. cross-level (see Figure 79)
- Five alignment cusps having the maximum gauge of 57.5 in. coincident with low points of the outside rail and the 56.5 in. gauge points associated with the inner rail low points (see Figure 79). There are no alignment variations on the low rail.
- It is recommended that a guard rail be used to prevent unpredicted derailment; however, it must not be in contact with the wheel during normal test running.

8.6.2 Dynamic Curving Instrumentation and Test Conduct

Axles 1 and 2 will be equipped with instrumented wheel sets as shown in Figure 76. IWS Configuration. Testing is required with both B and A ends leading (IWS-equipped truck leading and trailing). The carbody roll angle shall also be measured at one end. The lateral and vertical wheel forces and the roll angle shall be measured continuously through the test zone. Time histories of the worst-case results that exceed criteria, along with a count of the number of occurrences (as applicable) shall be submitted with the report.

Table 23 shows required runs for the dynamic curving test for each leading end condition. Tests are done CW and CCW.

Table 23. Dynamic Curving Test Runs

Filename	Speed	Direction	Comments
	10	CW	
	12	CW	
	14	CW	
	16	CW	
	18	CW	
	20	CW	
	22	CW	
	24	CW	
	26	CW	
	28	CW	
	30	CW	
	32	CW	
	10	CCW	
	12	CCW	
	14	CCW	
	16	CCW	
	18	CCW	
	20	CCW	
	22	CCW	
	24	CCW	
	26	CCW	
	28	CCW	
	30	CCW	
	32	CCW	

8.7 Pitch and Bounce (S-2043, Paragraph 5.5.11)

The pitch and bounce tests must follow the requirements of M-1001 paragraph 11.8.3, with the exception of limiting criteria. The pitch and bounce test is designed to determine the dynamic pitch and bounce response of the car as it is excited by inputs from the track. The pitch and bounce test is conducted on the PTT track, stations 1710 and 1715. Figure 80 provides a description of the Pitch and Bounce test zone.

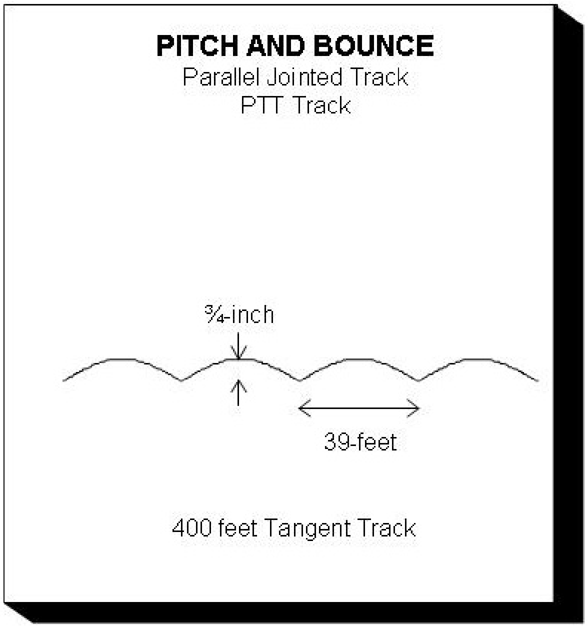


Figure 80. Pitch and Bounce Test Zone

8.7.1 Pitch and Bounce Test Procedure and Test Conditions

Pitch and bounce tests shall be conducted given the following conditions:

- Test car has a stable buffer car at each end with a minimum 45-ft truck center (one can be the instrumentation car)
- AAR-1B wheel profiles
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Starting test speed is well below predicted resonance and increases in 5 mph increments (or less) until resonance, an unsafe condition, or 75 mph is reached. It is acceptable to approach a resonant condition from a higher speed.
- Tangent track
- Ten parallel perturbations of 39-ft wavelength and maximum 0.75-in. vertical amplitude (see Figure 80)
- Otherwise class 5 or better track

8.7.2 Pitch and Bounce Instrumentation and Test Conduct

Axles 1 and 2 will be equipped with IWSs as shown in Figure 76. The test shall be conducted with the B end leading (IWS-equipped truck leading). The vertical wheel forces shall be measured continuously through the test zone. Time histories of the worst-case results that exceed criteria, along with a count of the number of occurrences (as applicable) shall be submitted with the report.

Table 24 shows suggested runs for the pitch and bounce test. Runs are performed starting at 30 mph and increasing in 5 mph increments until 70 mph is reached. A 75-mph run will be performed if deemed safe by the TTCI test team. If performance is close to the limits smaller speed increments should be used to assure safety and closely identify the critical speed.

Table 24. Pitch and Bounce Test Runs

Filename	Speed	Comments
	30	
	35	
	40	
	45	
	50	
	55	
	60	
	65	
	70	
	75	If deemed safe by the TTCI test team

8.8 Pitch and Bounce Special (S-2043, Paragraph 5.5.12)

S-2043 requires that a special section of track with 3/4-inch bumps at a wavelength equal to the truck center spacing be built for the car being tested. This distance is 44 feet 6 inches for the buffer car.

TTCI will install 10 parallel perturbations of 44.5-ft wavelength and 0.75-in. vertical amplitude at a location to be determined.

Table 26 shows suggested runs for the special pitch and bounce test. Runs are performed starting at 40 mph and increasing in 5 mph increments until 70 mph is reached. A 75-mph run will be performed if deemed safe by the TTCI test team. If performance is close to the limits smaller speed increments should be used to assure safety and closely identify the critical speed.

Table 25. Special Pitch and Bounce Test

Filename	Speed	Comments
	30	TCR
	40	
	45	
	50	
	55	
	60	
	65	
	70	
	75	If deemed safe by the TTCI test team

8.9 Single Bump Test (S-2043, Paragraph 5.5.13)

This test is intended to represent a grade crossing. Tests will be performed over a 1.0-in. bump on tangent track. The single bump will be a flat-topped ramp with the initial elevation change over 7 ft., a steady elevation over 20 ft., ramping back down over 7 ft. Track geometry for the single bump test must be maintained to the following tolerances:

- ±1/8-inch amplitude for the bump
- ±1/8-inch cross level
- ±1/4-inch gage

The test zone will be installed on the transit test track at T-15 using rail bent specifically for this purpose.

Table 26 shows suggested runs for the single bump test. Runs are performed starting at 40 mph and increasing in 5 mph increments until 70 mph is reached. A 75-mph run will be performed if deemed safe by the TTCI test team. If performance is close to the limits smaller speed increments should be used to assure safety and closely identify the critical speed.

Table 26. Single Bump Test Runs

Filename	Speed	Comments
	40	
	45	
	50	
	55	
	60	
	65	
	70	
	75	If deemed safe by the TTCI test team

8.10 Curve Entry/Exit (S-2043, Paragraph 5.5.14)

8.10.1 Limiting Spiral Negotiation

The spiral negotiation tests must conform to the requirements of M-1001 paragraph 11.7.4, with the exception of limiting criteria. Spiral negotiation, or curve entry and curve exit, tests will be performed in conjunction with the dynamic curving tests. A spiral is the transition from a tangent track to a curve that includes constant rates of change in cross level and curvature with distance. The limiting spiral consists of a steady curvature change from 0 degree to 10 degrees and a steady super elevation change of 4 3/8 inches in 89 feet. The purpose of the exaggerated limiting spiral is to twist the trucks and the carbody.

The limiting spiral test zone is located at the beginning of the 10-degree bypass curve of the Wheel/Rail Mechanisms (WRM) track (see Figure 81) during clockwise operation. Tests are done at the same time as the dynamic curving test and in both the clockwise and counter-clockwise directions, with both B and A ends leading (IWS-equipped truck leading and trailing). Curve entry and exit performance will also be examined for the 7.5-, 12-, and 10-degree curves (see Figure 81).

8.10.2 Spiral Negotiation Test Procedure and Test Conditions

This test will be carried out concurrently with the curving tests conducted on the WRM track. Curving tests will be performed under the following conditions:

- Speed corresponding to 3 in. of cant (superelevation) deficiency, balance speed, and speed corresponding to 3 in. of cant (superelevation) excess (-3 in., 0 in., and +3 in.)
- Use of a leading and trailing buffer car (one of which can be the instrumentation car)
- Test in both directions (turning consist)
- Minimum coefficient of friction is 0.4
- AAR-1B wheel profiles
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Minimum curvature is 7° with a balance speed of 20 to 30 mph
- Class 5 track or better
- Spiral geometry shall have a super elevation change rate of 3 in. in 62 ft. and a minimum length of 89 ft.

8.10.3 Spiral Negotiation Instrumentation and Test Conduct

Axles 1-2 will be equipped with instrumented wheel sets as shown in Figure 76. Testing is required with both B and A ends leading (IWS-equipped truck leading and trailing). The lateral and vertical forces and their ratio, L/V, shall be measured continuously through qualified spirals in both directions, and their maxima and minima computed. Time histories of the worst-case results that exceed criteria, along with a count of the number of occurrences (as applicable) shall be submitted with the report.

Table 27 shows required runs for the limiting spiral test. Test speeds correspond to 3-inches under balance, balance, and 3-inches over balance. Tests are done CW and CCW directions. Two runs will be done at each speed.

Table 27. Limiting Spiral Test Runs.

Filename	Speed	Direction	Comments
	12	CW	
	12	CW	
	24	CW	
	24	CW	
	32	CW	
	32	CW	
	12	CCW	
	12	CCW	
	24	CCW	
	24	CCW	
	32	CCW	
	32	CCW	

8.11 Curving with Single Rail Perturbation (S-2043, Paragraph 5.5.15)

This test is intended to represent a low or high joint in a yard or a poorly maintained lead track. Two test scenarios will be run, one with a 2-inch outside rail dip and the other with a 2-inch inside rail bump. Both tests will be conducted on the URB north wye track, a 12-degree curve with less than 1/2-inch nominal superelevation. The inside rail bump shall be a flat-topped ramp with an elevation change over 6-ft, a steady elevation over 12 ft., ramping back down over 6 ft. The outside rail dip shall be the reverse. Two rails have been bent for these perturbations. The two perturbations will be installed in the URB north wye curve about 250 feet apart. Track geometry for the single bump test must be maintained to the following tolerances:

- ±1/8-inch amplitude for the bump
- ±1/8-inch cross level
- ±1/4-inch gage

Table 28 shows required runs for the curving with single rail perturbation test. Tests will be performed in 2-mph increments for 4 mph to 14 mph. Test runs will be performed traveling south on the Transit test track through the diverging route of the turnout onto the north wye track with B-end of the car leading.

Table 28. Curving with Single Rail Perturbation Test Runs

Filename	Speed	Comments
	4	
	6	
	8	
	10	
	12	
	14	

8.12 Standard Chapter 11 Constant Curving (S-2043, Paragraph 5.5.16)

The constant curving tests must follow the requirements of M-1001 paragraph 11.7.3, with the exception of limiting criteria. Constant curving tests were designed to determine the car's ability to negotiate well-maintained track curves. This test is intended to verify that a car will not experience wheel climb or impart large lateral forces to the rails during curving.

As presented in Table 18, maximum wheel L/V ratio shall not exceed 0.8 for more than 50 msec. and the 95th percentile wheel L/V shall not exceed 0.6.

The train will be operated on the 7.5-, 10-, and 12-degree curves of WRM track at speeds corresponding to three inches under balance, balance, and three inches over balance (12, 24, and 32 mph). Tests will be run in both clockwise and counterclockwise directions. Wheel L/V ratios will be monitored to ensure safe test operation. Figure 81 provides a description of the curving test zone.

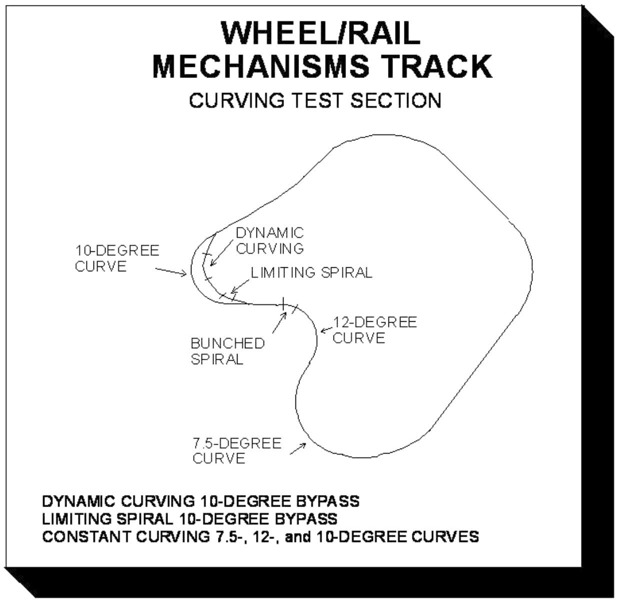


Figure 81. Curving Test Zone

8.12.1 Curving Test Procedure and Test Conditions

Curving tests will be performed under the following conditions:

- Speed corresponding to 3 in. of cant (superelevation) deficiency, balance speed, and speed corresponding to 3 in. of cant (superelevation) excess (-3 in., 0 in., and +3 in.)
- Use of a leading and trailing buffer car (one of which can be the instrumentation car)
- Test in both directions (turning consist)
- Minimum coefficient of friction is 0.4
- AAR-1B wheel profiles
- Rail must not have more than 0.25 in. of gauge wear nor have plastic flow on the gauge side greater than 0.25 in.
- Minimum curvature is 7° with a balance speed of 20 to 30 mph
- Class 5 track or better
- Curve length must be a minimum of 500 ft.

8.12.2 Curving Instrumentation and Test Conduct

Axles 1 and 2 will be equipped with instrumented wheel sets as shown in Figure 76. Testing is required with both B and A ends leading (IWS-equipped truck leading and trailing). The lateral and vertical forces and their ratio, L/V, shall be measured for the length of the body of the curve. A time history of the worst-case results that exceed criteria must be submitted in the report.

Table 29 shows required runs for the steady state curving test. Test speeds correspond to 3-inches under balance, balance, and 3-inches over balance. Tests are done CW and CCW. Repeat each run at least once.

Table 29. Standard Chapter 11 Constant Curving Test Runs

Filename	Speed (mph)	Direction	Comments
	12-15-12	CW	3 in. underbalance speeds for 7.5-, 12-, and 10-degree curves on WRM loop, respectively.
	12-15-12	CW	3 in. underbalance speeds for 7.5-, 12-, and 10-degree curves on WRM loop, respectively.
	24	CW	Approximate balance speed for all curves
	24	CW	Approximate balance speed for all curves
	32	CW	Approximate 3 in. overbalance speed for all curves
	32	CW	Approximate 3 in. overbalance speed for all curves
	12-15-12	CCW	3 in. underbalance speeds for 7.5-, 12-, and 10-degree curves on WRM loop, respectively.
	12-15-12	CCW	3 in. underbalance speeds for 7.5-, 12-, and 10-degree curves on WRM loop, respectively.
	24	CCW	Approximate balance speed for all curves
	24	CCW	Approximate balance speed for all curves
	32	CCW	Approximate 3 in. overbalance speed for all curves
	32	CCW	Approximate 3 in. overbalance speed for all curves

8.13 Special Track Work (S-2043, Paragraph 5.5.17)

The railcar will be run through various switches, turnouts, and crossovers while measuring wheel/rail forces. The railcar must be run through an AREMA straight point turnout with a number 8 or tighter frog angle. The test will be performed in both directions, at speeds from walking speed to the switch speed limit. Similar tests must be performed through a crossover with number 10 or tighter turnouts on 15-ft or narrower track centers.

Switch number 704 between the Transit Test Track and the North URB Wye will be used for the turnout tests. Crossover number 212 between the Impact Track and the FAST Wye will be used for crossover tests.

During the walking speed tests, the railcar will be monitored visually to note any binding or interference between the trucks and carbody.

Axles 1-2 will be equipped with instrumented wheel sets as shown in Figure 76. Testing is required with both B and A ends leading (IWS-equipped truck leading and trailing). The lateral and vertical forces and their ratio, L/V, shall be measured for the length of the body of the curve. A time history of the worst-case results that exceed criteria must be submitted in the report.

Table 30 shows required runs for the special track work turnout test. Test speeds are from walking speed to the turnout speed limit. Tests are done in both directions (switch point leading and trailing) along the diverging route and with B- and A-end leading.

Table 30. Special Track Work Turnout Test

Filename	Speed	Direction	Comments
	Walking	Facing Point	Check Clearances
	4	Facing Point	
	6	Facing Point	
	8	Facing Point	
	10	Facing Point	
	12	Facing Point	
	14	Facing Point	
	15	Facing Point	
	Walking	Trailing Point	Check Clearances
	4	Trailing Point	
	6	Trailing Point	
	8	Trailing Point	
	10	Trailing Point	
	12	Trailing Point	
	14	Trailing Point	
	15	Trailing Point	1

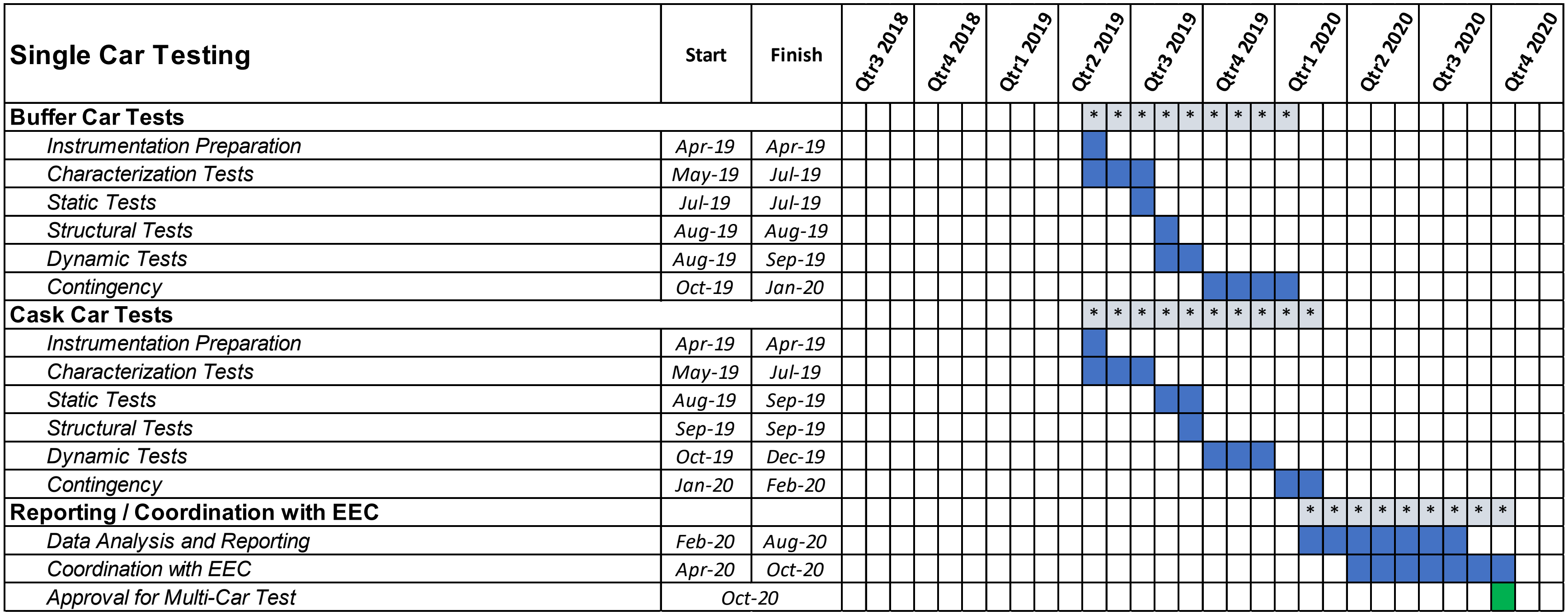
Table 31 shows required runs for the special track work crossover test. Test speeds are from walking speed to the crossover speed limit. Tests are done in both directions and with B- and A-end leading.

Table 31. Special Track Work Crossover Test

Filename	Speed	Direction	Comments
	Walking	Impact-Fast Wye	Check Clearances
	5	Impact-Fast Wye	
	10	Impact-Fast Wye	
	15	Impact-Fast Wye	
	20	Impact-Fast Wye	
	Walking	Fast Wye-Impact	Check Clearances
	5	Fast Wye-Impact	
	10	Fast Wye-Impact	
	15	Fast Wye-Impact	
	20	Fast Wye-Impact	

9.0 TEST SCHEDULE

Figure 82 provides a preliminary test schedule. Detailed scheduling will be based on resource and facility availability. TTCI is evaluating the potential for accelerating the schedule based on anticipated arrival of the railcar in February 2018.



Single Car Testing	Start	Finish	Qtr3 2018			Qtr4 2018			Qtr1 2019			Qtr2 2019			Qtr3 2019			Qtr4 2019			Qtr1 2020			Qtr2 2020			Qtr3 2020			Qtr4 2020		
Buffer Car Tests													*	*	*	*	*	*	*	*	*											
Instrumentation Preparation	*Apr-19*	*Apr-19*											🟦																			
Characterization Tests	*May-19*	*Jul-19*											🟦	🟦	🟦																	
Static Tests	*Jul-19*	*Jul-19*													🟦																	
Structural Tests	*Aug-19*	*Aug-19*														🟦																
Dynamic Tests	*Aug-19*	*Sep-19*														🟦	🟦															
Contingency	*Oct-19*	*Jan-20*																🟦	🟦	🟦	🟦											
Cask Car Tests													*	*	*	*	*	*	*	*	*	*										
Instrumentation Preparation	*Apr-19*	*Apr-19*											🟦																			
Characterization Tests	*May-19*	*Jul-19*											🟦	🟦	🟦																	
Static Tests	*Aug-19*	*Sep-19*														🟦	🟦															
Structural Tests	*Sep-19*	*Sep-19*															🟦															
Dynamic Tests	*Oct-19*	*Dec-19*																🟦	🟦	🟦												
Contingency	*Jan-20*	*Feb-20*																			🟦	🟦										
Reporting / Coordination with EEC																						*	*	*	*	*	*	*	*	*		
Data Analysis and Reporting	*Feb-20*	*Aug-20*																				🟦	🟦	🟦	🟦	🟦	🟦	🟦				
Coordination with EEC	*Apr-20*	*Oct-20*																						🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Approval for Multi-Car Test	*Oct-20*																														🟩		

Figure 82. Preliminary Test Schedule

References

1. AAR Manual of Standards and Recommended Practices, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2017, Association of American Railroads, Washington, DC

2. AAR Manual of Standards and Recommended Practices, Section C—Part II, Car Construction Fundamentals and Details, Design, Fabrication, and Construction of Freight Cars, Chapter 2, General Data, Implemented 11/2017, Association of American Railroads, Washington, DC

3. AAR Manual of Standards and Recommended Practices, Section C—Part II, Car Construction Fundamentals and Details, Design, Fabrication, and Construction of Freight Cars, Chapter 11, Service-Worthiness Tests and Analyses for New Freight Cars, Implemented 09/2017, Association of American Railroads, Washington, DC

4. Safety Rule Book, TTCI, January 2018 or Latest Revision

5. Operating Rule Book, TTCI, January 2018 or Latest Revision

6. Walker, Russell and Shawn Trevithick. "S-2043 Certification: Preliminary Simulations of Kasgro Buffer Railcar", Report P-17-023, TTCI, Pueblo, CO, November 2017

7. Walker, Russell and Satima Anankitpaiboon. "S-2043 Certification Tests of Kasgro M-290 12-Axle Flat Car". Report No. P-09-044, TTCI, Pueblo, CO, December 2009

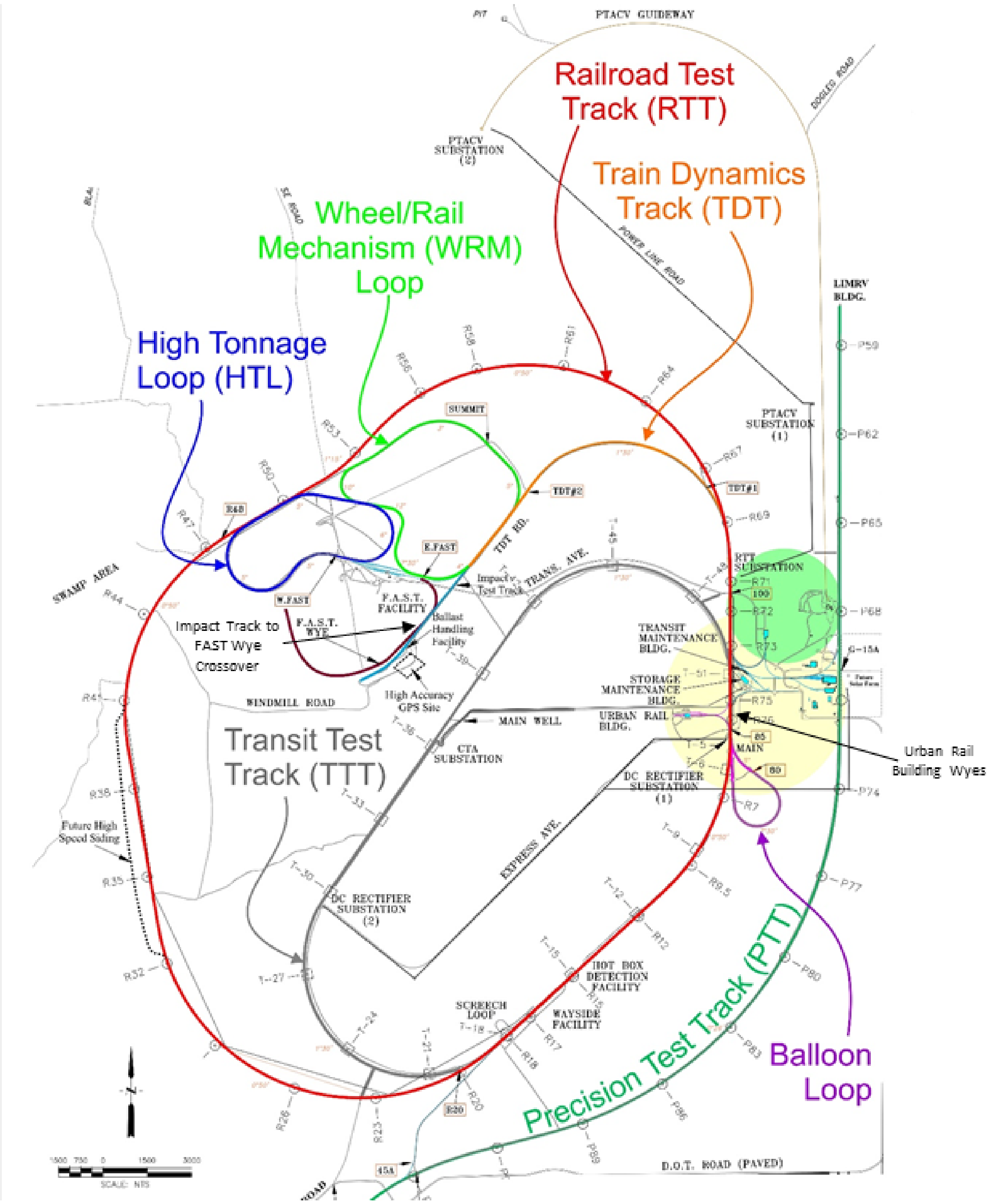
8. Manual of Standards and Recommended Practices Section G Safety and Operations -- Wheels and Axles, Figure B12, Effective September 2016, Association of American Railroads, Washington, DC

9. TTCI network: \DOE Controlled Document Folder\DW - Drawings and Specifications\DW-18-002 Kasgro SG Location Cask and Buffer Car .zip\1155-47 Kasgro SG Location Buffer Car.dwg

ATTACHMENT A – Test Track Details

INTRODUCTION

Testing is planned on various test tracks at the Transportation Technology Center including the Railroad Test Track (RTT), the Wheel Rail Mechanisms (WRM) Loop, the Precision Test Track (PTT), the URB Wye, the Tight Turn Loop (TTL or Screech Loop), and a crossover between the Impact Track and FAST Wye. Figure below shows locations of the various tracks. Sections 2.0 to 6.0 describe the tracks planned to be used for the Atlas and Buffer car testing.



Test Tracks at TTC

RAILROAD TEST TRACK (RTT)

The 13.5-mile Railroad Test Track (RTT) will be used for High Speed Stability (Hunting) testing of the Atlas and buffer cars. The RTT alignment is designed to test passenger vehicles with tilt technology at a maximum running speed of 165 mph. Maximum speed for non-tilting vehicles is typically 124 mph. Freight vehicle testing is limited to 80 mph operating speed, unless qualified for higher speeds.

WHEEL / RAIL MECHANISMS (WRM) LOOP

The Wheel / Rail Mechanisms (WRM) Loop incorporates curve variations constructed to meet the curved track test requirements of AAR Specification M-1001, Chapter 11. These variations are also applicable to S-2043 testing and will be used for several tests of the Atlas and buffer cars. The WRM is maintained as a non-lubricated track for test purposes. Strain gages have been installed in some of the curves for measuring Wheel/Rail interaction forces. The figure below shows details of track in a siding on the inside of the 10-degree curve that is the location of dynamic curve track perturbations.

Adjustable Tie Plates and Perturbations on the WRM

PRECISION TEST TRACK (PTT)

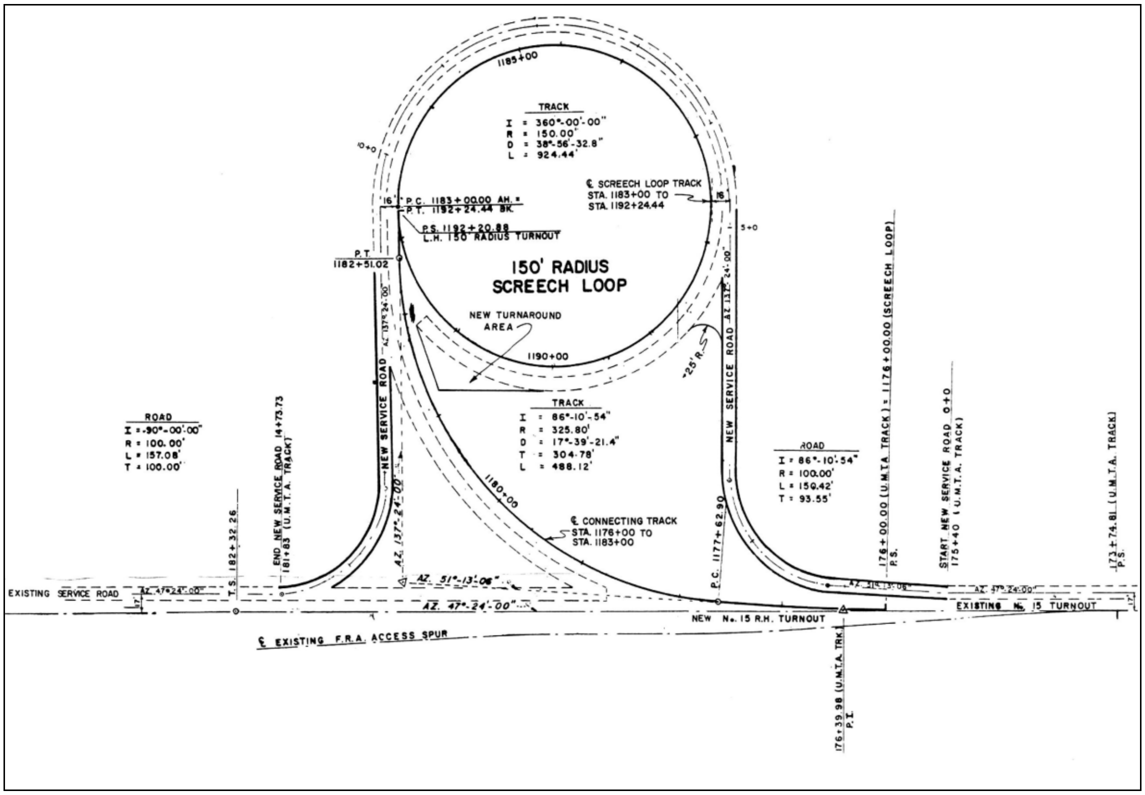
The Precision Test Track (PTT) is a 7.4-mile track section that is used to test for vehicle dynamic response under perturbed track conditions. Three perturbed track test sections have been installed:

- Twist and roll test section in the north tangent section (PTT Stations 1644+10 to 1651+70). Due to the location of these perturbations, and the limited acceleration capability of TTC locomotives, the maximum test speed through this test section is typically about 70 mph, although preparations are being made to achieve 75 mph for this test program.
- Pitch and bounce test section in the south end of the same tangent section (PTT Stations 1710 to 1715).
- Yaw and Sway test section on the south end of the PTT (PTT Approx. Stations 1921 to 1927)

The perturbation sections for twist and roll, and pitch and bounce have been re-built using new ties and adjustable alignment plates with elastic fasteners, screw spikes, and steel shim plates. The adjustable tie plate system is the same that is in place on the WRM Loop.

TIGHT TURN LOOP

The Tight Turn Loop (TTL), also called the screech loop, will be used for the Horizontal Curve Negotiation test. It is located at the lower end of the southeast tangent section of the Transit Test Track. The TTL layout is as shown in the figure below. It consists of a 150' radius loop (38.9-degree curve) constructed as a ballasted track with 119-pound continuous welded rail on wood ties. The loop is connected with a short spur track having a 17 2/3-degree curve. The main purpose of the TTL is to provide a facility for the detailed investigation of wheel noise, truck curving behavior, and rail vehicle stability under extreme curvature conditions.

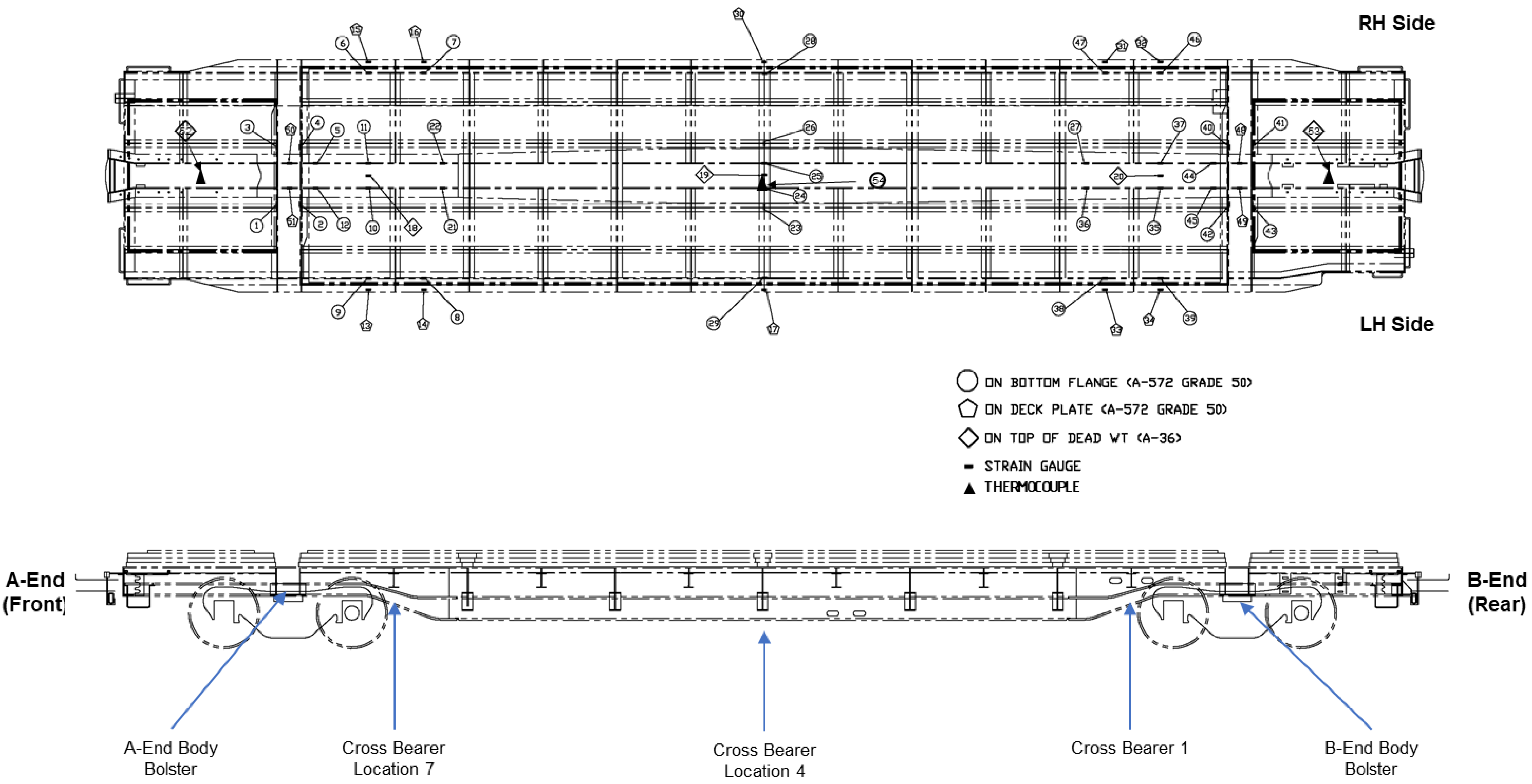


Tight Turn Loop Layout

OTHER LOCATIONS

Testing is also planned on the North URB Wye, which connects the Urban Rail Building access track to the TTT, and on the crossover between the Impact Track and the FAST Wye.

ATTACHMENT B – STRAIN GAUGE LOCATIONS FOR STRUCTURAL TESTS



Strain Gauge/Thermocouple Locations

Strain Gauge and Thermocouple Channel)

Figure B1 Ref	Channel Name	Approximate Locations (confirm based on latest version of Kasgro Drawing 1155-47)[9]	Yield Strain at gauge location (µstr)	Modulus of Elasticity at Gauge Location (10^6 ksi)	Units	Expected Range
1	SGBF1	Front of bottom flange of A-end body bolster near center sill -- LH side	1724	29	µstr	±2,000
2	SGBF2	Rear of bottom flange of A-end body bolster near center sill -- LH side	1724	29	µstr	±2,000
3	SGBF3	Front of bottom flange of A-end body bolster near center sill -- RH side	1724	29	µstr	±2,000
4	SGBF4	Rear of bottom flange of A-end body bolster near center sill -- RH side	1724	29	µstr	±2,000
5	SGBF5	RH edge of bottom flange of center sill, aft of A-end body bolster	1724	29	µstr	±2,000
6	SGBF6	Center of bottom flange of RH side sill, forward of cross bearer 7	1724	29	µstr	±2,000
7	SGBF7	Center of bottom flange of RH side sill, aft of cross bearer 7	1724	29	µstr	±2,000
8	SGBF8	Center of bottom flange of LH side sill, aft of cross bearer 7	1724	29	µstr	±2,000
9	SGBF9	Center of bottom flange of LH side sill, forward of Cross Bearer Location 7	1724	29	µstr	±2,000
10	SGBF10	LH edge of bottom flange of center sill, forward of cross bearer 7	1724	29	µstr	±2,000
11	SGBF11	RH edge of bottom flange of center sill, forward of cross bearer 7	1724	29	µstr	±2,000
12	SGBF12	LH edge of bottom flange of center sill, aft of A-end body bolster	1724	29	µstr	±2,000

Figure B1 Ref	Channel Name	Approximate Locations (confirm based on latest version of Kasgro Drawing 1155-47)[9]	Yield Strain at gauge location (µstr)	Modulus of Elasticity at Gauge Location (10^6 ksi)	Units	Expected Range
13	SGDP13	LH edge of deck plate, forward of cross bearer 7	1724	29	µstr	±2,000
14	SGDP14	LH edge of deck plate, aft of cross bearer 7	1724	29	µstr	±2,000
15	SGDP15	RH edge of deck plate, forward of cross bearer 7	1724	29	µstr	±2,000
16	SGDP16	RH edge of deck plate, aft of cross bearer 7	1724	29	µstr	±2,000
17	SGDP17	LH edge of deck plate, at longitudinal center of car	1724	29	µstr	±2,000
18	SGDW18	Top of dead weight at lateral center of car, forward of cross bearer 7	1241	29	µstr	±1,500
19	SGDW19	Top of dead weight, at lateral and longitudinal center of car	1241	29	µstr	±1,500
20	SGDW20	Top of dead weight at lateral center of car, aft of cross bearer 1	1241	29	µstr	±1,500
21	SGBF21	LH edge of bottom flange of center sill, forward of cross bearer 6	1724	29	µstr	±2,000
22	SGBF22	RH edge of bottom flange of center sill, forward of cross bearer 6	1724	29	µstr	±2,000
23	SGBF23	Bottom flange of cross bearer 4, LH side of center sill, at longitudinal center of car	1724	29	µstr	±2,000
24	SGBF24	LH edge of bottom flange of center sill, at longitudinal center of car	1724	29	µstr	±2,000
25	SGBF25	RH edge of bottom flange of center sill, at longitudinal center of car	1724	29	µstr	±2,000

Figure B1 Ref	**Channel Name**	**Approximate Locations (confirm based on latest version of Kasgro Drawing 1155-47)[9]**	**Yield Strain at gauge location** (µstr)	**Modulus of Elasticity at Gauge Location (10^6 ksi)**	**Units**	**Expected Range**
26	SGBF26	Bottom flange of cross bearer 2, RH side of center sill, at longitudinal center of car	1724	29	µstr	±2,000
27	SGBF27	RH edge of bottom flange of center sill, aft of cross bearer 2	1724	29	µstr	±2,000
28	SGBF28	Center of bottom flange of RH side sill, at longitudinal center of car	1724	29	µstr	±2,000
29	SGBF29	Center of bottom flange of LH side sill, at longitudinal center of car	1724	29	µstr	±2,000
30	SGDP30	RH edge of deck plate, at longitudinal center of car	1724	29	µstr	±2,000
31	SGDP31	RH edge of deck plate, forward of cross bearer 2	1724	29	µstr	±2,000
32	SGDP32	RH edge of deck plate, aft of cross bearer 2	1724	29	µstr	±2,000
33	SGDP33	LH edge of deck plate, forward of cross bearer 2	1724	29	µstr	±2,000
34	SGDP34	LH edge of deck plate, aft of cross bearer 2	1724	29	µstr	±2,000
35	SGBF35	LH edge of bottom flange of center sill, aft of cross bearer 1	1724	29	µstr	±2,000
36	SGBF36	LH edge of bottom flange of center sill, aft of cross bearer 2	1724	29	µstr	±2,000
37	SGBF37	RH edge of bottom flange of center sill, aft of cross bearer 1	1724	29	µstr	±2,000
38	SGBF38	Center of bottom flange of LH side sill, forward of cross bearer 1	1724	29	µstr	±2,000
39	SGBF39	Center of bottom flange of LH side sill, aft of cross bearer 1	1724	29	µstr	±2,000

Figure B1 Ref	**Channel Name**	**Approximate Locations (confirm based on latest version of Kasgro Drawing 1155-47)[9]**	**Yield Strain at gauge location** (µstr)	**Modulus of Elasticity at Gauge Location (10^6 ksi)**	**Units**	**Expected Range**
40	SGBF40	Front of bottom flange of B-end body bolster near center sill – RH side	1724	29	µstr	±2,000
41	SGBF41	Rear of bottom flange of B-end body bolster near center sill -- RH side	1724	29	µstr	±2,000
42	SGBF42	Front of bottom flange of B-end body bolster near center sill – LH side	1724	29	µstr	±2,000
43	SGBF43	Rear of bottom flange of B-end body bolster near center sill -- LH side	1724	29	µstr	±2,000
44	SGBF44	RH edge of bottom flange of center sill, forward of B-end body bolster	1724	29	µstr	±2,000
45	SGBF45	LH edge of bottom flange of center sill, forward of B-end body bolster	1724	29	µstr	±2,000
46	SGBF46	Center of bottom flange of RH side sill, aft of cross bearer 1	1724	29	µstr	±2,000
47	SGBF47	Center of bottom flange of RH side sill, forward of cross bearer 1	1724	29	µstr	±2,000
48	SGDP48	Top of deck plate, longitudinally centered over B-End body bolster, above RH edge of center sill	1,724	29,000	µstr	±2,000
49	SGDP49	Top of deck plate, longitudinally centered over B-End body bolster, above LH edge of center sill	1,724	29,000	µstr	±2,000
50	SGDP50	Top of deck plate, longitudinally centered over A-End body bolster, above RH edge of center sill	1,724	29,000	µstr	±2,000

Figure B1 Ref	**Channel Name**	**Approximate Locations (confirm based on latest version of Kasgro Drawing 1155-47)[9]**	**Yield Strain at gauge location** (μstr)	**Modulus of Elasticity at Gauge Location (10^6 ksi)**	**Units**	**Expected Range**
51	SGDP52	Top of deck plate, longitudinally centered over A-End body bolster, above LH edge of center sill	1,724	29,000	μstr	±2,000
52	TC52	Laterally and longitudinally centered on top of deck plate forward of A-end body bolster	n/a	n/a	°F	-40 to 150
53	TC53	Laterally and longitudinally centered on top of deck plate forward of A-end body bolster	n/a	n/a	°F	-40 to 150
54	TC54	Bottom flange of cross bearer 4 at lateral and longitudinal center of car	n/a	n/a	°F	-40 to 150

APPENDIX B: STATIC BRAKE FORCE TEST DOCUMENTATION

TRANSPORTATION
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Email: matt_degeorge@aar.com

August 20, 2020

Subject: Static Brake Force Test Observations Specification Testing of IDOX 020001, 020002, and IDOX 010001 A-End and B-End

Mr. Jon Hannafious
Senior Manager - Equipment Engineering
Transportation Technology Center, Inc.
Pueblo, CO 81001
Email: Jon_Hannafious@aar.com

Dear Mr. Hannafious,

The static brake force specification testing of the buffer cars (IDOX 020001 and 020002) and the Atlas car (IDOX 010001 A-End and B-End) has been completed. Testing was performed at the Kasgro Rail Corporation facility in New Castle, Pennsylvania on December 4, 2018 (buffer cars) and February 12, 2019 (Atlas car) to comply with Specification S-2043 and S-401.

I was present (test witness) for the required Static Brake Force Tests and can conclude that applicable requirements of AAR Specification S-401 have been satisfactorily addressed.

The details and results of this testing is documented in the attached reports. Should you need any additional information, please do not hesitate to get in contact with me.

Sincerely,

Matt DeGeorge

Matt DeGeorge

Atlas Buffer Car Static Brake Force Test Report for December 2018

Contract Number: 89243218CNE000004
Author: Matthew DeGeorge
Date: 12/12/2018
Document RP-18-002

TEST OVERVIEW

Brake Shoe Force Test

- Testing designed to comply with AAR Standard S-401 (01/2018 Revision)
- Checklist drafted, reviewed, and finalized by project management
- Prior to testing FRA personnel reviewed the braking system on both buffer cars

Test Personnel

- Tom Sedarski (Amsted Rail; helped perform test)
- Rick Ford (Kasgro Project Manager)
- Mark Zeigler (Kasgro)
- Cory Wagner (Kasgro; performed test)
- Matt DeGeorge (TTCI observer)

Schedule

- 11/14/18 (November Visit)
  - 9:00am: testing began on buffer car IDOX 020002
  - 1:00pm: testing delayed until future date due to equipment
- 12/4/18 (December Visit)
  - 8:30am: testing began on buffer car IDOX 020002
  - 11:30am: testing concluded on buffer car IDOX 020002
  - 12:00pm – 1:00pm: Lunch (buffer cars swapped out)
  - 2:30pm: testing began on buffer car IDOX 020001
  - 4:15pm: testing concluded on buffer car IDOX 020001
- 12/5/18
  - 8:00am: Review of brake force tests on both cars
  - 9:00am – 11:00am: Overview and inspection of Atlas Cask Car

ISSUES / CONCERNS / COMMENTS

- Daily test performed on Single Car Air Brake Test Device each day before testing
- Testing on 11/14/18 was delayed until the December trip due to brake force measurement equipment issues
  - The Bluetooth connection device used to link the force sensors and the recording/readout device was broken resulting in an inability to see measured force outputs
- During the initial testing of buffer car IDOX 020002 a leak was discovered in the brake cylinder pipeline
  - The leak caused a decrease in force at each wheel over time
  - The leak was found using a soapy solution and fixed
- The piston travel on both cars was initially outside the acceptable range and was adjusted during testing
  - After the pistons were readjusted and several brake reductions were performed to stabilize the system, piston travel in both cars met the criteria
- The empty brake ratio testing was not performed due to the fact that the cars are loaded and will never be unloaded or in the empty condition
- The hand brake force measurements were performed first on buffer car IDOX 020002 with a smart hook and a load clevis pin
  - Buffer car IDOX 020001 had the hand brake force tested with the smart hook only

CONCLUSIONS

- Buffer car IDOX 020001 and IDOX 020002 met the criteria put forth in the AAR Standard S-401

Documentation Photographs

Figure B1. Atlas Buffer Railcar Isometric View

Figure B2. Brake Force Measurement System (Control Box and Readout Tablet)

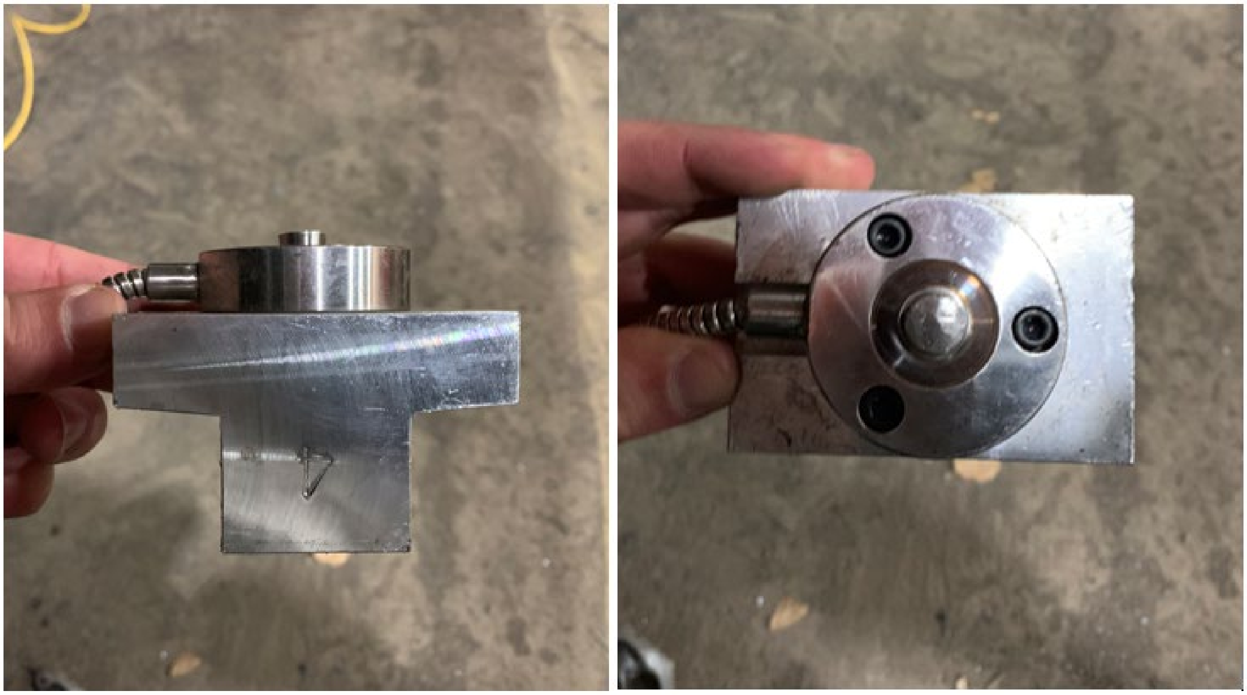


Figure B3. Force Sensor

Figure B4. Brake Force Measurement System (B-end L1, L2 Force Sensors)

Figure B5. Example Force Sensor Location

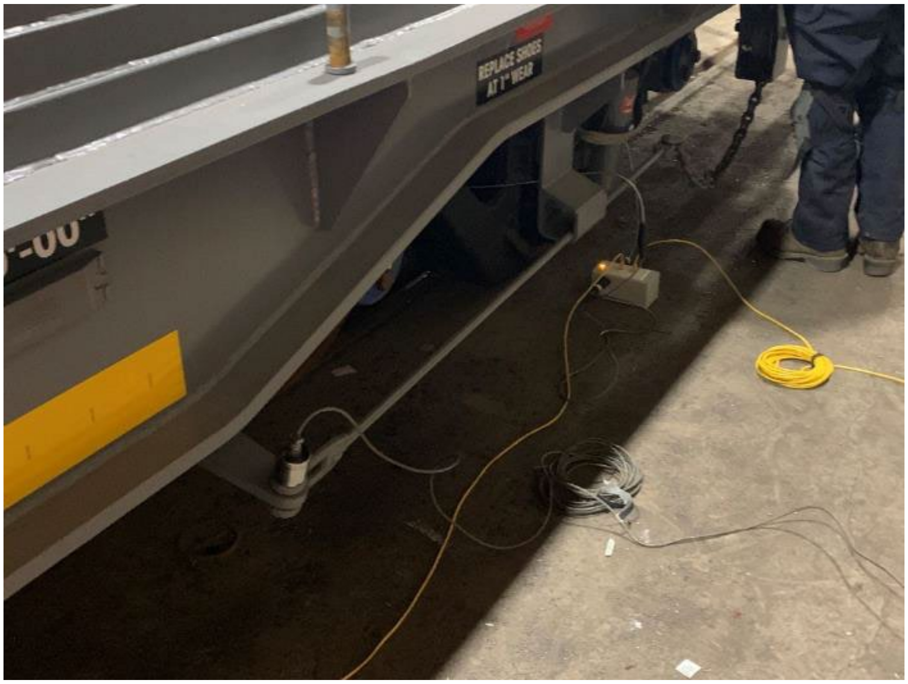


Figure B6. Brake Force Measurement System (Load Clevis Pin)

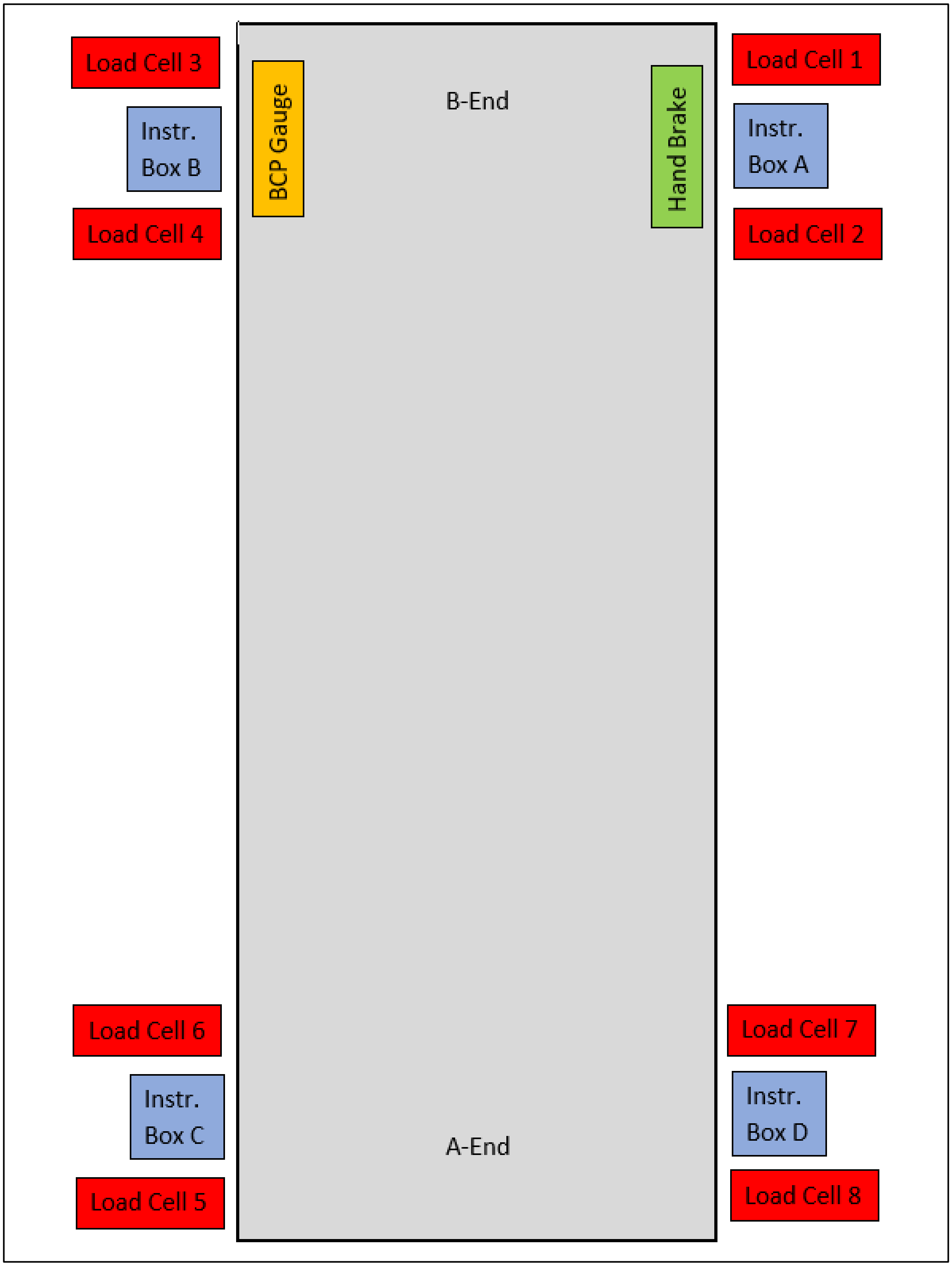


Figure B7. Buffer Railcar Instrumentation Setup Diagram (Both Cars had Identical Setup)

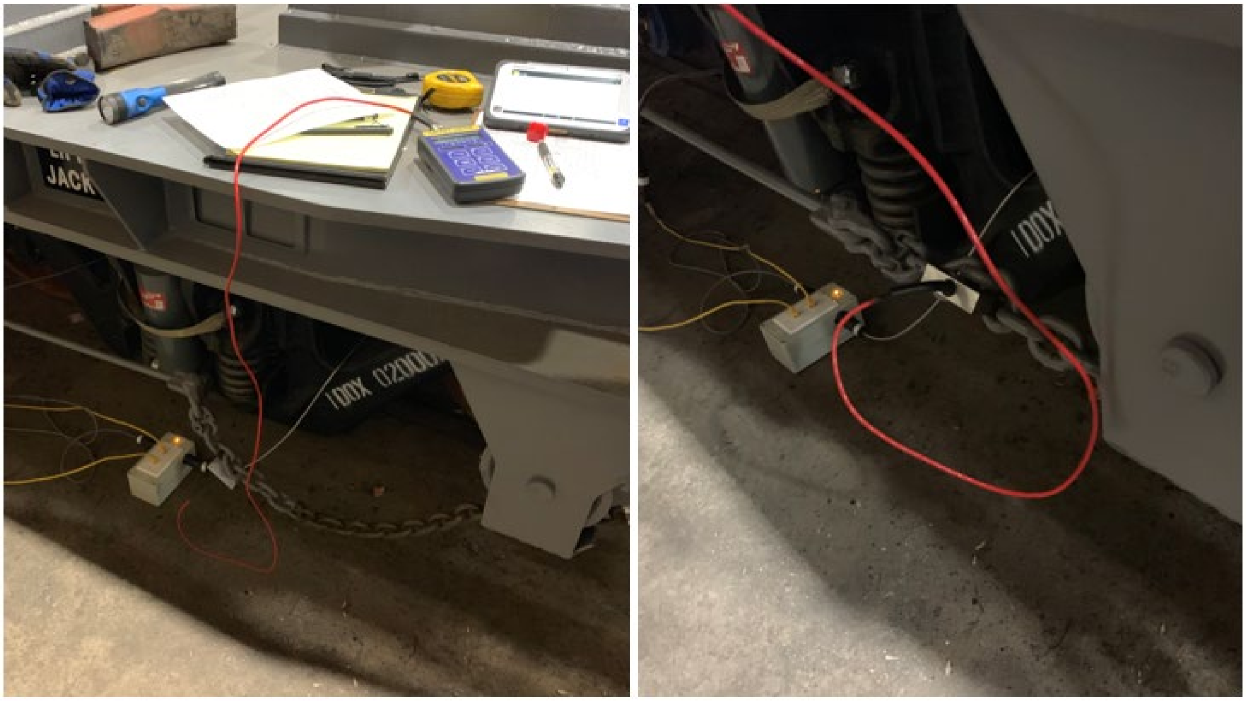


Figure B8. Smart Hook

Figure B9. Car Weight

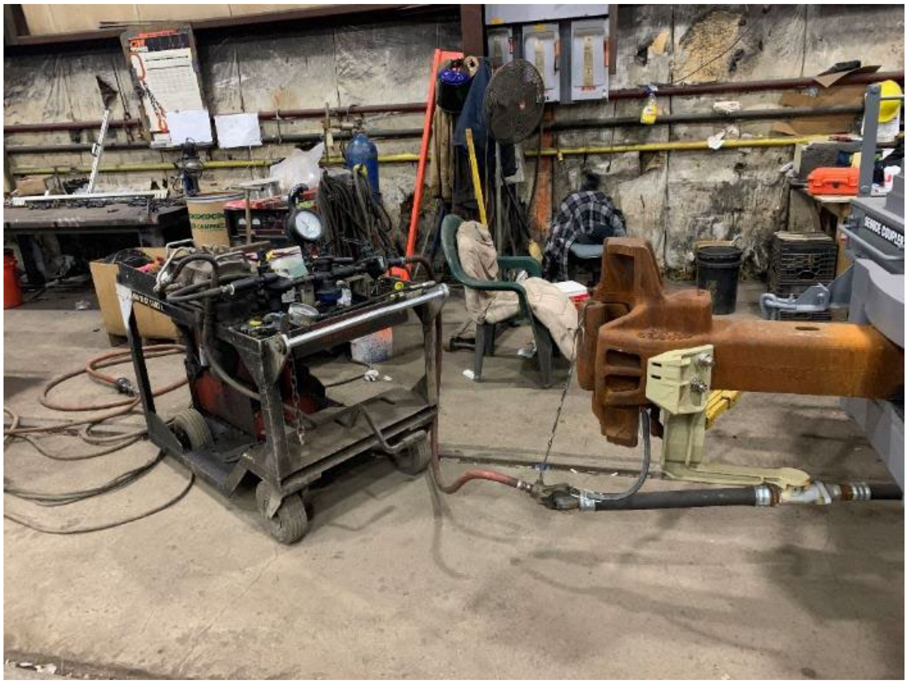


Figure B10. Single Car Air Brake Test Device

Figure B11. Test Device Gauge Calibration Information

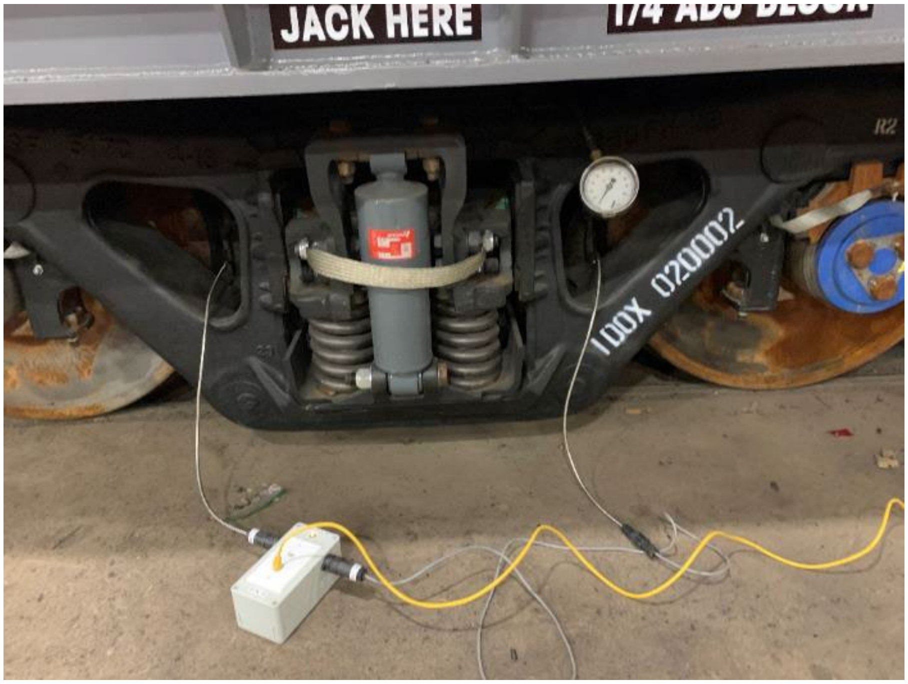


Figure B12. Brake Cylinder Gauge Location (B-end, Right Side)

Figure B13. Brake Cylinder Gauge Calibration Information

Figure B14. Rapping Hammer

PISTON TRAVEL INDICATOR
AND RANGE ON ELLCON-NATIONAL
No 8500 BRAKE SYSTEM

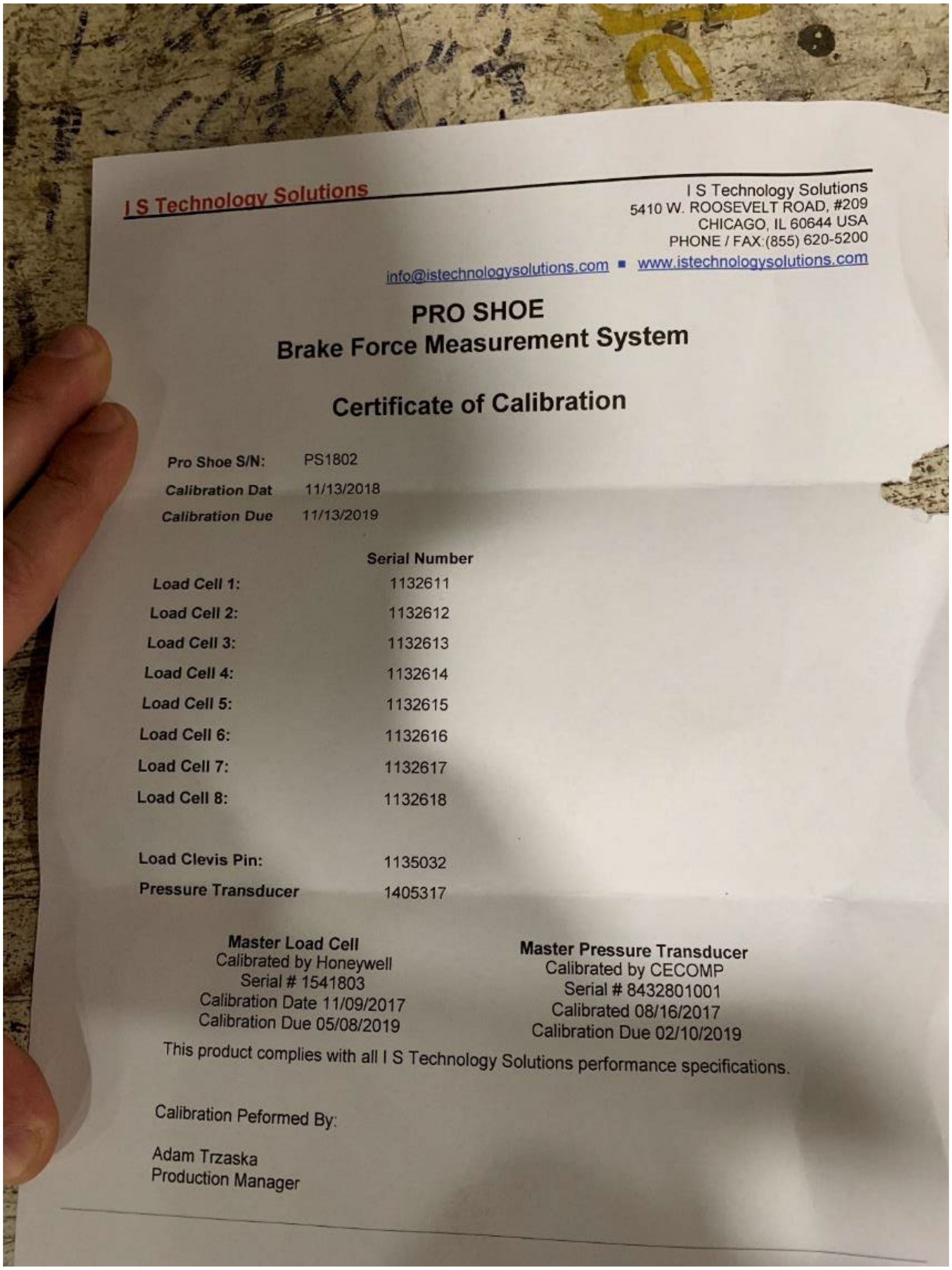
PISTON TRAVEL RANGES		
INITIAL TERMINAL	INTERMEDIATE TERMINAL	NEW OR RESET RANGE
2 1/4" MIN 3 3/4" MAX	4" MAX	2 3/4" ±1/4"

PISTON TRAVEL MEASURED FROM NON-PRESSURE HEAD TO END OF PISTON SLEEVE (IGNORE GREASE LINE)

VIEW A - A

PISTON TRAVEL OPERATING RANGE AT 50 PSI CYL. OR 20 PSI REDUCTION

Figure B15. Piston Travel Setup Information



I S Technology Solutions

I S Technology Solutions
5410 W. ROOSEVELT ROAD, #209
CHICAGO, IL 60644 USA
PHONE / FAX:(855) 620-5200
info@istechnologysolutions.com ▪ www.istechnologysolutions.com

PRO SHOE
Brake Force Measurement System

Certificate of Calibration

Pro Shoe S/N: PS1802
Calibration Dat 11/13/2018
Calibration Due 11/13/2019

	Serial Number
Load Cell 1:	1132611
Load Cell 2:	1132612
Load Cell 3:	1132613
Load Cell 4:	1132614
Load Cell 5:	1132615
Load Cell 6:	1132616
Load Cell 7:	1132617
Load Cell 8:	1132618
Load Clevis Pin:	1135032
Pressure Transducer	1405317

Master Load Cell
Calibrated by Honeywell
Serial # 1541803
Calibration Date 11/09/2017
Calibration Due 05/08/2019

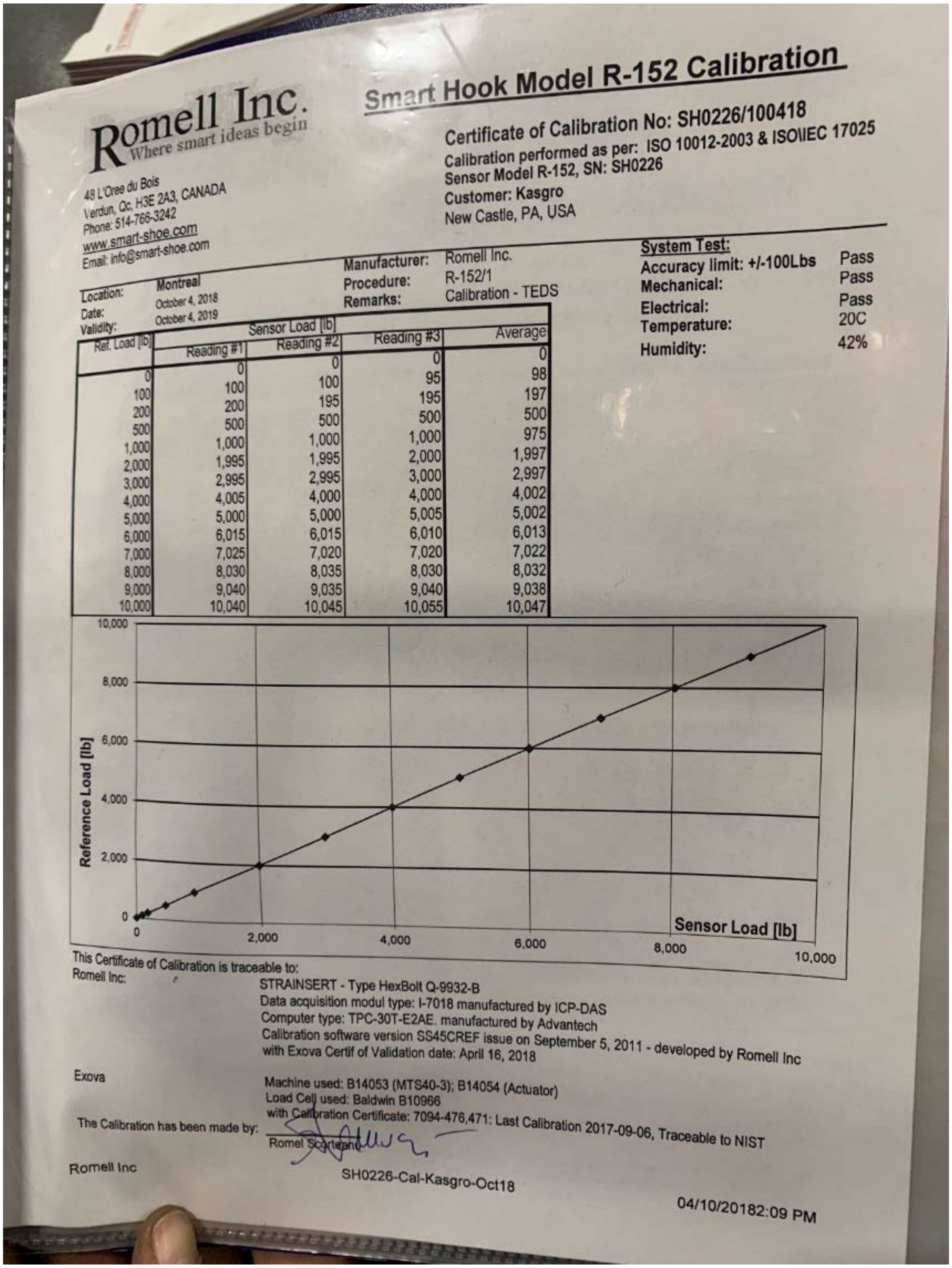
Master Pressure Transducer
Calibrated by CECOMP
Serial # 8432801001
Calibrated 08/16/2017
Calibration Due 02/10/2019

This product complies with all I S Technology Solutions performance specifications.

Calibration Peformed By:

Adam Trzaska
Production Manager

Figure B16. Brake Force Measurement System Calibration Information



Romell Inc.
Where smart ideas begin

48 L'Oree du Bois
Verdun, Qc, H3E 2A3, CANADA
Phone: 514-766-3242
www.smart-shoe.com
Email: info@smart-shoe.com

Smart Hook Model R-152 Calibration

Certificate of Calibration No: SH0226/100418
Calibration performed as per: ISO 10012-2003 & ISO\IEC 17025
Sensor Model R-152, SN: SH0226
Customer: Kasgro
New Castle, PA, USA

Location: Montreal
Date: October 4, 2018
Validity: October 4, 2019

Manufacturer: Romell Inc.
Procedure: R-152/1
Remarks: Calibration - TEDS

Ref. Load [lb]	Sensor Load [lb] Reading #1	Reading #2	Reading #3	Average
0	0	0	0	0
100	100	100	95	98
200	200	195	195	197
500	500	500	500	500
1,000	1,000	1,000	1,000	975
2,000	1,995	1,995	2,000	1,997
3,000	2,995	2,995	3,000	2,997
4,000	4,005	4,000	4,000	4,002
5,000	5,000	5,000	5,005	5,002
6,000	6,015	6,015	6,010	6,013
7,000	7,025	7,020	7,020	7,022
8,000	8,030	8,035	8,030	8,032
9,000	9,040	9,035	9,040	9,038
10,000	10,040	10,045	10,055	10,047

System Test:

Accuracy limit: +/-100Lbs	Pass
Mechanical:	Pass
Electrical:	Pass
Temperature:	20C
Humidity:	42%

This Certificate of Calibration is traceable to:

Romell Inc: STRAINSERT - Type HexBolt Q-9932-B
Data acquisition modul type: I-7018 manufactured by ICP-DAS
Computer type: TPC-30T-E2AE. manufactured by Advantech
Calibration software version SS45CREF issue on September 5, 2011 - developed by Romell Inc
with Exova Certif of Validation date: April 16, 2018

Exova: Machine used: B14053 (MTS40-3); B14054 (Actuator)
Load Cell used: Baldwin B10966
with Calibration Certificate: 7094-476,471: Last Calibration 2017-09-06, Traceable to NIST

The Calibration has been made by: Romel Scorteanu

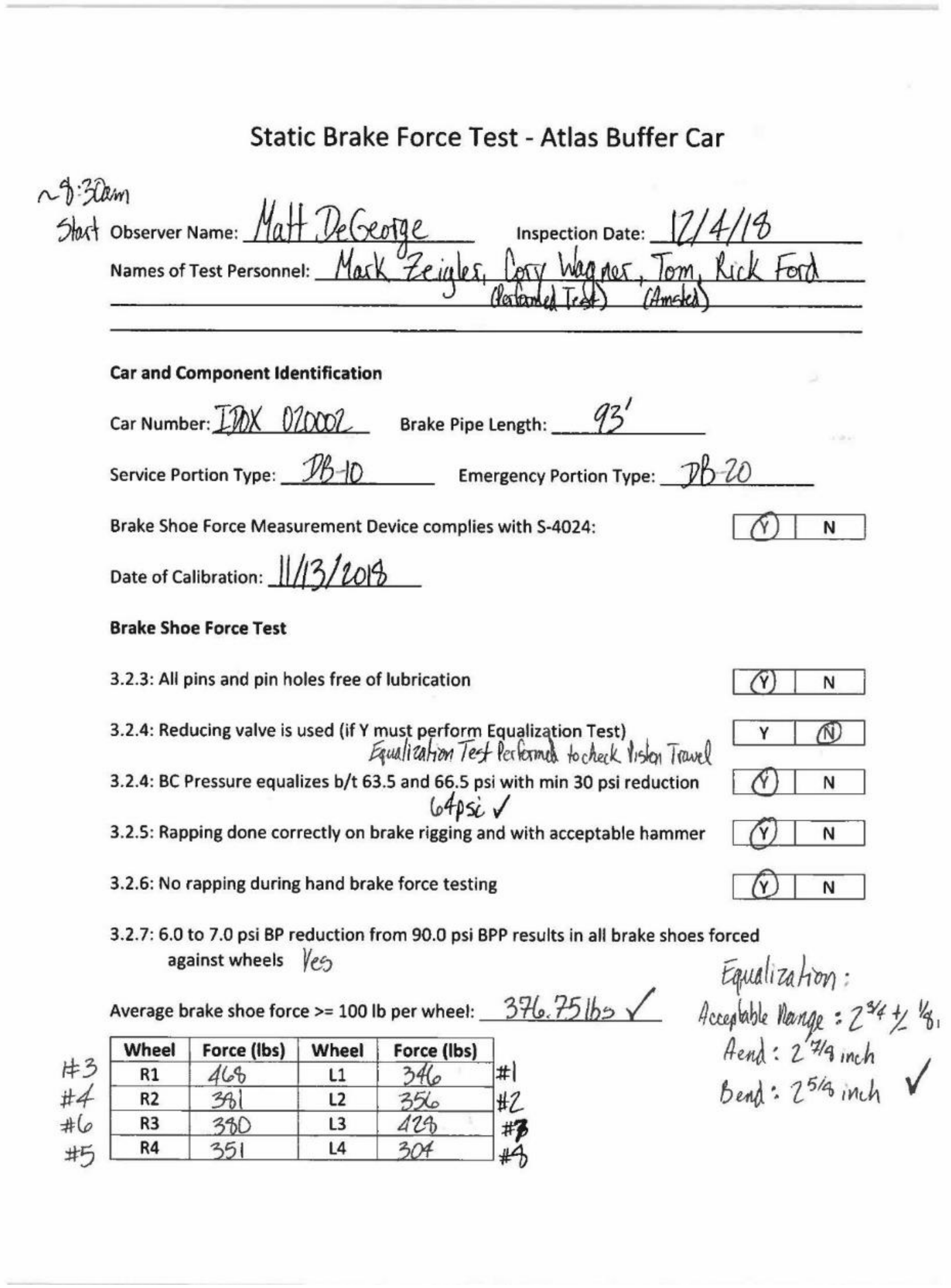
Romell Inc

SH0226-Cal-Kasgro-Oct18

04/10/20182:09 PM

Figure B17. Smart Hook Calibration Information

COMPLETED TEST CHECKLIST



Static Brake Force Test - Atlas Buffer Car

~8:30am Start

Observer Name: Matt DeGeorge

Inspection Date: 12/4/18

Names of Test Personnel: Mark Zeigler, Cory Wagner, Tom, Rick Ford (Performed Test) (Assisted)

Car and Component Identification

Car Number: IDX 020002

Brake Pipe Length: 93'

Service Portion Type: DB-10

Emergency Portion Type: DB-20

Brake Shoe Force Measurement Device complies with S-4024: [✓ Y] N

Date of Calibration: 11/13/2018

Brake Shoe Force Test

3.2.3: All pins and pin holes free of lubrication [✓ Y] N

3.2.4: Reducing valve is used (if Y must perform Equalization Test) Y [✓ N]

Equalization Test Performed to check Piston Travel

3.2.4: BC Pressure equalizes b/t 63.5 and 66.5 psi with min 30 psi reduction [✓ Y] N

64psi ✓

3.2.5: Rapping done correctly on brake rigging and with acceptable hammer [✓ Y] N

3.2.6: No rapping during hand brake force testing [✓ Y] N

3.2.7: 6.0 to 7.0 psi BP reduction from 90.0 psi BPP results in all brake shoes forced against wheels Yes

Average brake shoe force >= 100 lb per wheel: 376.75lbs ✓

	Wheel	Force (lbs)	Wheel	Force (lbs)	
#3	R1	468	L1	346	#1
#4	R2	381	L2	356	#2
#6	R3	380	L3	428	#7
#5	R4	351	L4	304	#8

Equalization:

Acceptable Range: 2 3/4 +/- 1/8,

A end: 2 7/8 inch

B end: 2 5/8 inch ✓

Net Braking Ratios with 30 psi BP reduction from 90 psi BPP:

: 64psi

rapped

	Wheel	Force (lbs)	Wheel	Force (lbs)	
#3	R1	4106	L1	3751	#1
#4	R2	4288	L2	4030	#2
#6	R3	4528	L3	4516	#7
#5	R4	3882	L4	3938	#8

unrapped

#3: 4130	#1: 3749
#4: 4065	#2: 3863
#6: 4177	#7: 4253
#5: 3965	#8: 3886

Total Force: 33039lbs
Avg/wheel: 4129.88 lbs
Weight of car: 263,000lbs

Net Brake Ratio is between 11-14%: 12.56% ✓

Handbrake Force/Brake Ratio: 15.35% > 10% ✓

4.2: NBR on each wheel is within +/- 12.5% of Average NBR per wheel [✓ Y] N

Max: 4646.11 Min: 3613.65

Additional Comments: -

- Air Brake Testing Device was ran through Daily test
- Equalization Performed Several times to set correct piston travel
- multiple brake reductions performed during piston adjustments to allow system to settle
- Slow leak in Brake Cylinder Pipeline (found + repaired + test rerun)
- Empty brake ratio testing not performed (car always loaded)
- Hand brake test done with clevis pin + smart hook (tested independently of eachother)

Emergency App Test:
BCP: 64psi @ 30psi red
BCP: 76.5psi @ emergency
Falls b/t 15 + 20% higher
→ 19.53% ✓

Hand Brake Test:
Pin: #2: 11383 #4: 11966 Total Force: 43719 lbs
#1: 9805 #3: 10565 Brake Ratio: 16.62%

Smart Hook: #2: 10532 #4: 10985 Total Force: 40367 lbs
#1: 9071 #3: 9779 Brake Ratio: 15.35%

~11:30am
End of Test

Static Brake Force Test - Atlas Buffer Car

~2:30pm
Start

Observer Name: Matt DeGeorge Inspection Date: 12/4/18

Names of Test Personnel: Mark Zeigler, Cory Wagner, Tom, Rick Ford
(Performed) (Assisted)

Car and Component Identification

Car Number: IDOX 020001 Brake Pipe Length: 93'

Service Portion Type: DB-10 Emergency Portion Type: DB-20

Brake Shoe Force Measurement Device complies with S-4024: [✓ Y] N

Date of Calibration: 11/13/2018

Brake Shoe Force Test

3.2.3: All pins and pin holes free of lubrication [✓ Y] N

3.2.4: Reducing valve is used (if Y must perform Equalization Test) Y [✓ N]

3.2.4: BC Pressure equalizes b/t 63.5 and 66.5 psi with min 30 psi reduction [✓ Y] N

64psi ✓

3.2.5: Rapping done correctly on brake rigging and with acceptable hammer [✓ Y] N

3.2.6: No rapping during hand brake force testing [✓ Y] N

3.2.7: 6.0 to 7.0 psi BP reduction from 90.0 psi BPP results in all brake shoes forced against wheels Yes

Average brake shoe force >= 100 lb per wheel: 305 lbs ✓

	Wheel	Force (lbs)	Wheel	Force (lbs)	
#3	R1	307	L1	205	#1
#4	R2	268	L2	292	#2
#6	R3	369	L3	354	#7
#5	R4	364	L4	281	#8

Equalization:
Acceptable Range: 2 3/4 +/-
Aend: 2 5/8 inch
Bend: 2 5/8 inch ✓

Net Braking Ratios with 30 psi BP reduction from 90 psi BPP:

BCP: 64psi

rapped

	Wheel	Force (lbs)	Wheel	Force (lbs)	
#3	R1	4121	L1	3745	#1
#4	R2	4475	L2	4164	#2
#6	R3	4298	L3	4416	#7
#5	R4	3702	L4	4061	#8

unrapped

#3: 4006 #1: 3723
#4: 3993 #2: 3903
#6: 4055 #7: 4028
#5: 3584 #8: 3986

Total Force: 32982 lbs
Avg/Wheel: 4122.75
Weight of car: 263,000 lbs

Net Brake Ratio is between 11-14%: 12.54% ✓

Handbrake Force/Brake Ratio: 15.98% >10% ✓

4.2: NBR on each wheel is within +/- 12.5% of Average NBR per wheel [✓ Y] N

Max: 4638.09 Min: 3607.41

Additional Comments: -

- Air Brake Testing Device put through Daily Test
- Equalization Performed several times to set correct piston travel
- multiple brake reductions performed during piston adj. to allow system to settle
- empty brake ratio testing not performed (car always loaded)
- Hand brake test done with just smart hook

Emergency App Test: BCP: 64psi @ 30psi red
BCP: 76.5psi @ emergency

Falls b/t 15+20% higher → 19.53%

Hand Brake Test: Smart Hook: #2: 11097 #4: 11630
#1: 9192 #3: 10116

Total Force: 42035 lbs
Brake Ratio: 15.98%

~ 4:15pm
End of Test

TTCI
Transportation
Technology Center, Inc.

Mike Yon
Field Inspector - MID/QA Auditor
Cell: 814-515-3803

Email: Mike_yon@aar.com

March 12, 2019

File:KAS-NEWCPA-MC06-0219-MSY

Subject: Specification testing of (IDOX 20001 and 20002), Heavy Duty Flat Car

Mr. David L. Cackovic
Chief – Technical Standards & Inspections
Transportation Technology Center, Inc.
P.O. Box 11130
Pueblo, CO 81001
E-mail: David_Cackovic@aar.com

Dear Mr. Cackovic,

Specification testing of (IDOX 20001 and 20002), Heavy Duty Flat Car, specifically the Single Car Air Brake Test has been completed. Testing was done at the Kasgro Rail Corporation facility in New Castle, Pennsylvania on February 11, 2019 to comply with S-486.

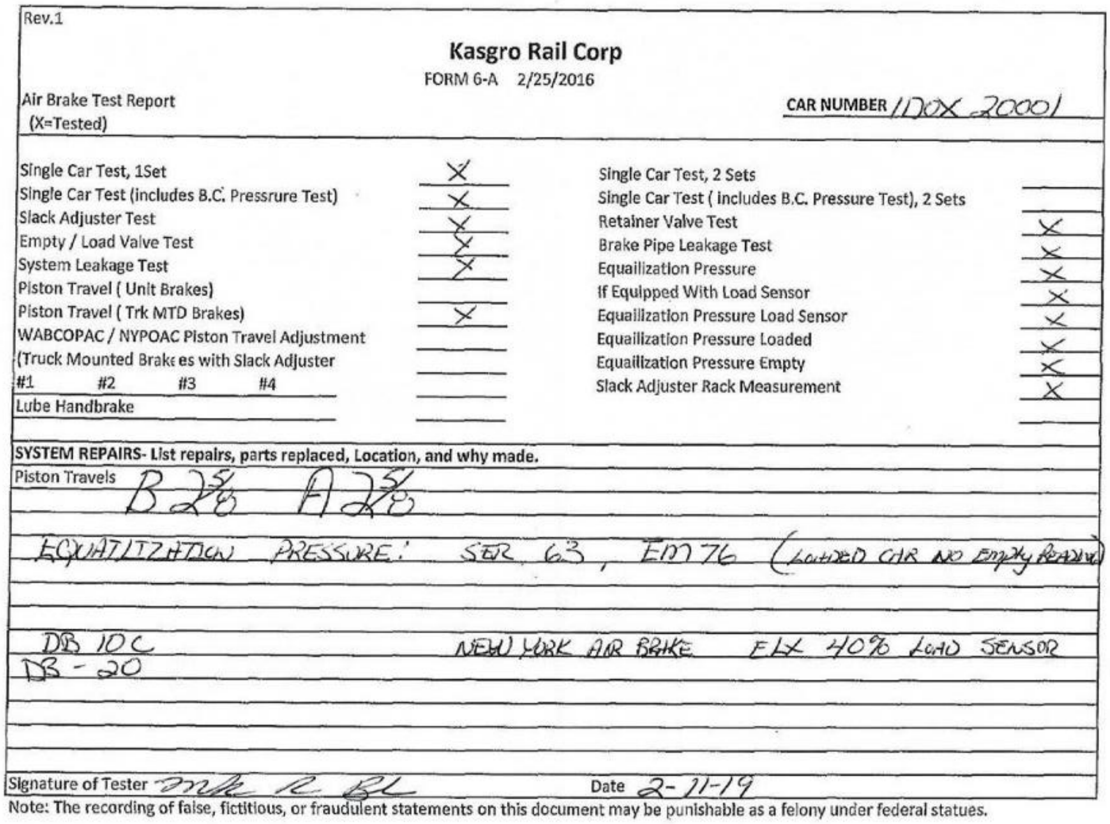
I was present (test witness) for the required Single Car Air Brake Test and can conclude that applicable requirements of AAR Specification S-486 have been satisfactorily addressed.

Attached information was supplied by the Kasgro Rail Corporation in support of the approval process. Should you need any additional information, please do not hesitate to call.

Sincerely,

Mike Yon

cc: Anna Fox, TTCI
Kasgro, mark@kasgro.com
J. Hannafious, TTCI



Rev.1

Kasgro Rail Corp

FORM 6-A 2/25/2016

Air Brake Test Report
(X=Tested)

CAR NUMBER IDOX 20001

Single Car Test, 1Set	X	Single Car Test, 2 Sets	
Single Car Test (includes B.C. Pressrure Test)	X	Single Car Test (includes B.C. Pressure Test), 2 Sets	
Slack Adjuster Test	X	Retainer Valve Test	X
Empty / Load Valve Test	X	Brake Pipe Leakage Test	X
System Leakage Test	X	Equailization Pressure	X
Piston Travel (Unit Brakes)		If Equipped With Load Sensor	X
Piston Travel (Trk MTD Brakes)	X	Equailization Pressure Load Sensor	X
WABCOPAC / NYPOAC Piston Travel Adjustment		Equailization Pressure Loaded	X
(Truck Mounted Brakε es with Slack Adjuster		Equailization Pressure Empty	X
#1 #2 #3 #4		Slack Adjuster Rack Measurement	X
Lube Handbrake			

SYSTEM REPAIRS- List repairs, parts replaced, Location, and why made.

Piston Travels B 2 5/8 A 2 5/8

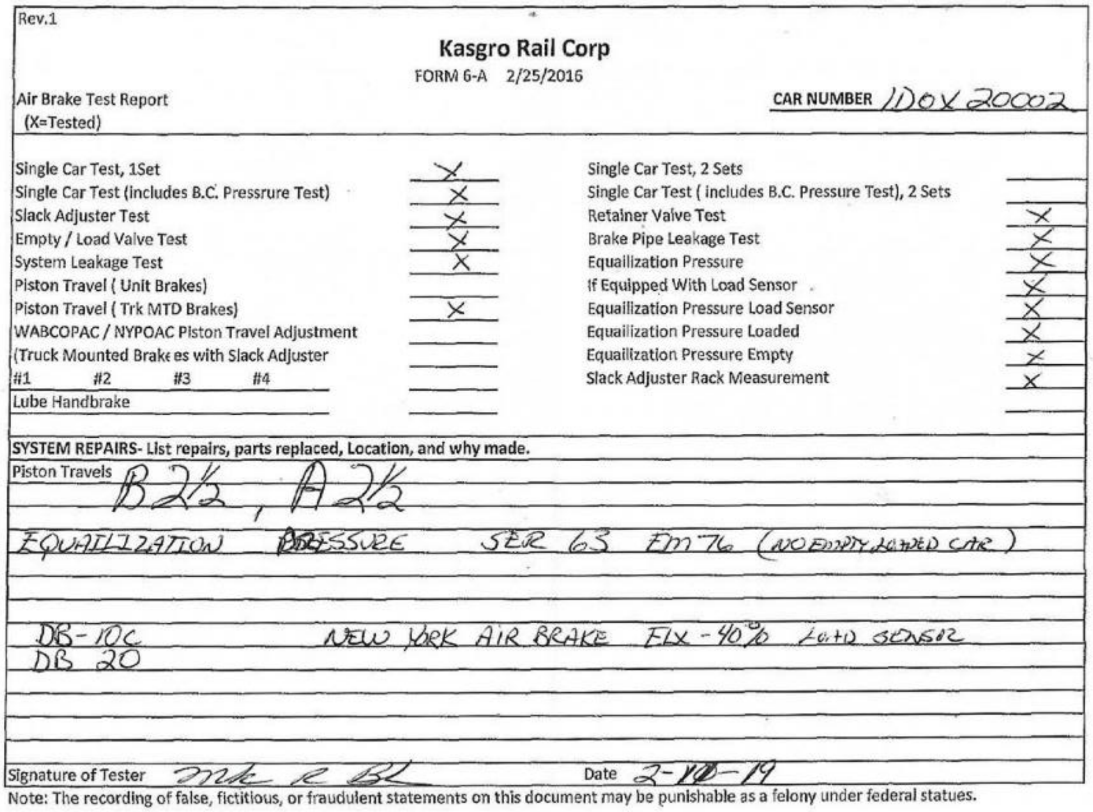
EQUALIZATION PRESSURE: SER 63, EM 76 (LOADED CAR NO Empty READING)

DB 10 C NEW YORK AIR BRAKE ELX 40% LOAD SENSOR
DB - 20

Signature of Tester

Date 2-11-19

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statues.



Rev.1

Kasgro Rail Corp

FORM 6-A 2/25/2016

Air Brake Test Report
(X=Tested)

CAR NUMBER IDOX 20002

Single Car Test, 1Set	X	Single Car Test, 2 Sets	
Single Car Test (includes B.C. Pressrure Test)	X	Single Car Test (includes B.C. Pressure Test), 2 Sets	
Slack Adjuster Test	X	Retainer Valve Test	X
Empty / Load Valve Test	X	Brake Pipe Leakage Test	X
System Leakage Test	X	Equailization Pressure	X
Piston Travel (Unit Brakes)		If Equipped With Load Sensor	X
Piston Travel (Trk MTD Brakes)	X	Equailization Pressure Load Sensor	X
WABCOPAC / NYPOAC Piston Travel Adjustment		Equailization Pressure Loaded	X
(Truck Mounted Brakε es with Slack Adjuster		Equailization Pressure Empty	X
#1 #2 #3 #4		Slack Adjuster Rack Measurement	X
Lube Handbrake			

SYSTEM REPAIRS- List repairs, parts replaced, Location, and why made.

Piston Travels B 2 1/2, A 2 1/2

EQUAILIZATION PRESSURE SER 63 EM 76 (NO EMPTY LOADED CAR)

DB-10C NEW YORK AIR BRAKE ELX - 40% LOAD SENSOR
DB 20

Signature of Tester

Date 2-10-19

Note: The recording of false, fictitious, or fraudulent statements on this document may be punishable as a felony under federal statues.

APPENDIX C: BUFFER CAR GAGE DRAWING

This appendix contains details on the location, installation, and shunt calibration of the strain gages used to measure strain on the buffer car.

All the strain gages used on the buffer car are of the same type: CEA-06-500UW-350 with the following characteristics:

- Encapsulated constantan alloy (bondable)
- Grid Length: 0.5 in
- Uniaxial type
- 350 ohm
- Gage Factor: 2.155

Installation procedures are followed from the Vishay standard protocols for bondable strain gages.

Figure C1 to Figure C4 show the locations of the strain gages. These drawing show detailed locations for gages on one quadrant of the car. The gages in the other quadrants are symmetrical.

Figure C5 to Figure C55 show photos of the installed strain gages.

Figure C56 to Figure C58 show photos of the installed thermocouples.

Figure C59 to Figure C65 show data recorded during a shunt calibration check just before the 1 million-pound squeeze test.

List of Figures

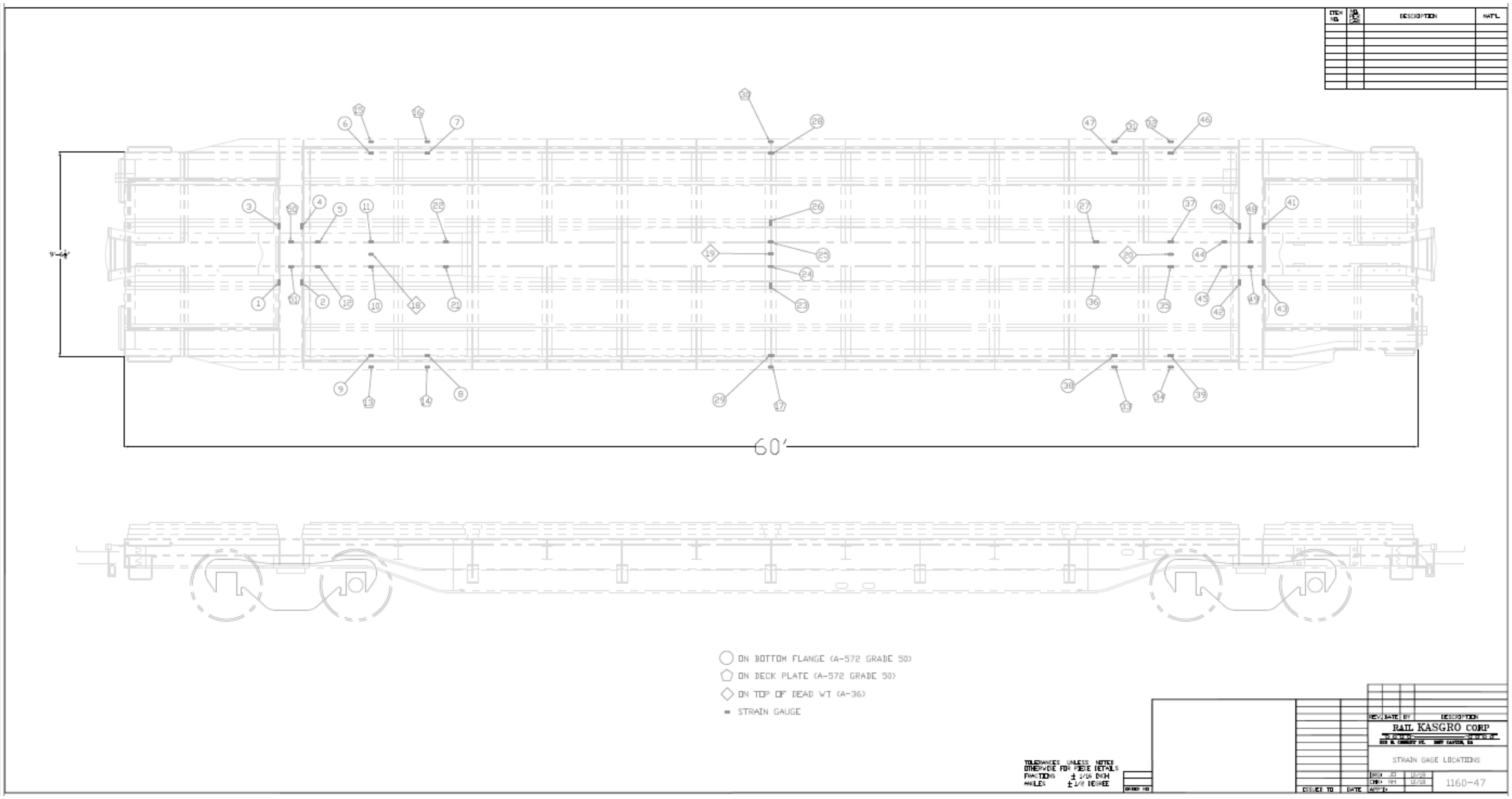
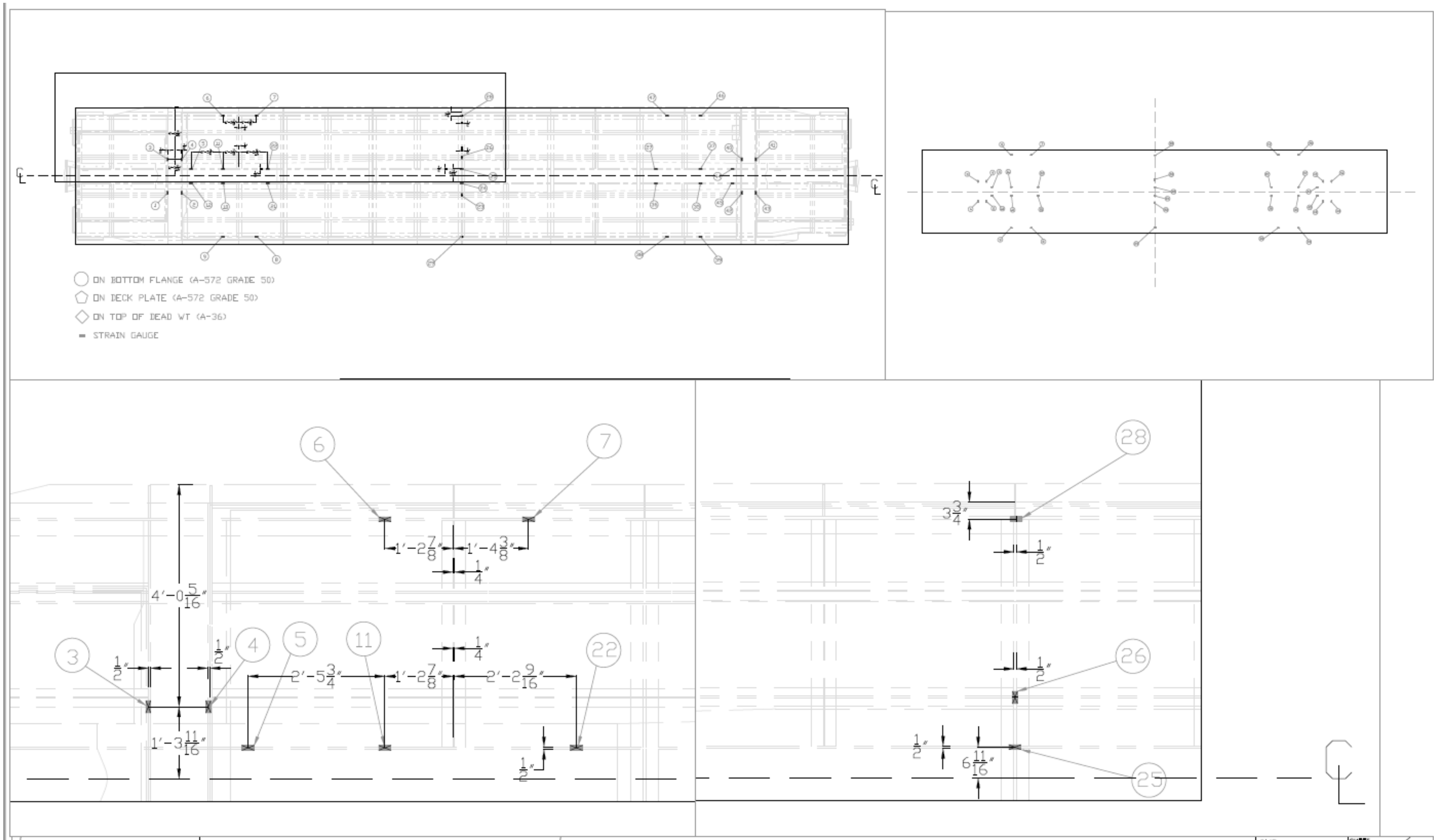


Figure C1. Strain Gage Locations



TTCI
Transportation Technology Center, Inc.

TRANSPORTATION TECHNOLOGY CENTER INC.
P.O. BOX 11130, PUEBLO CO. 81001

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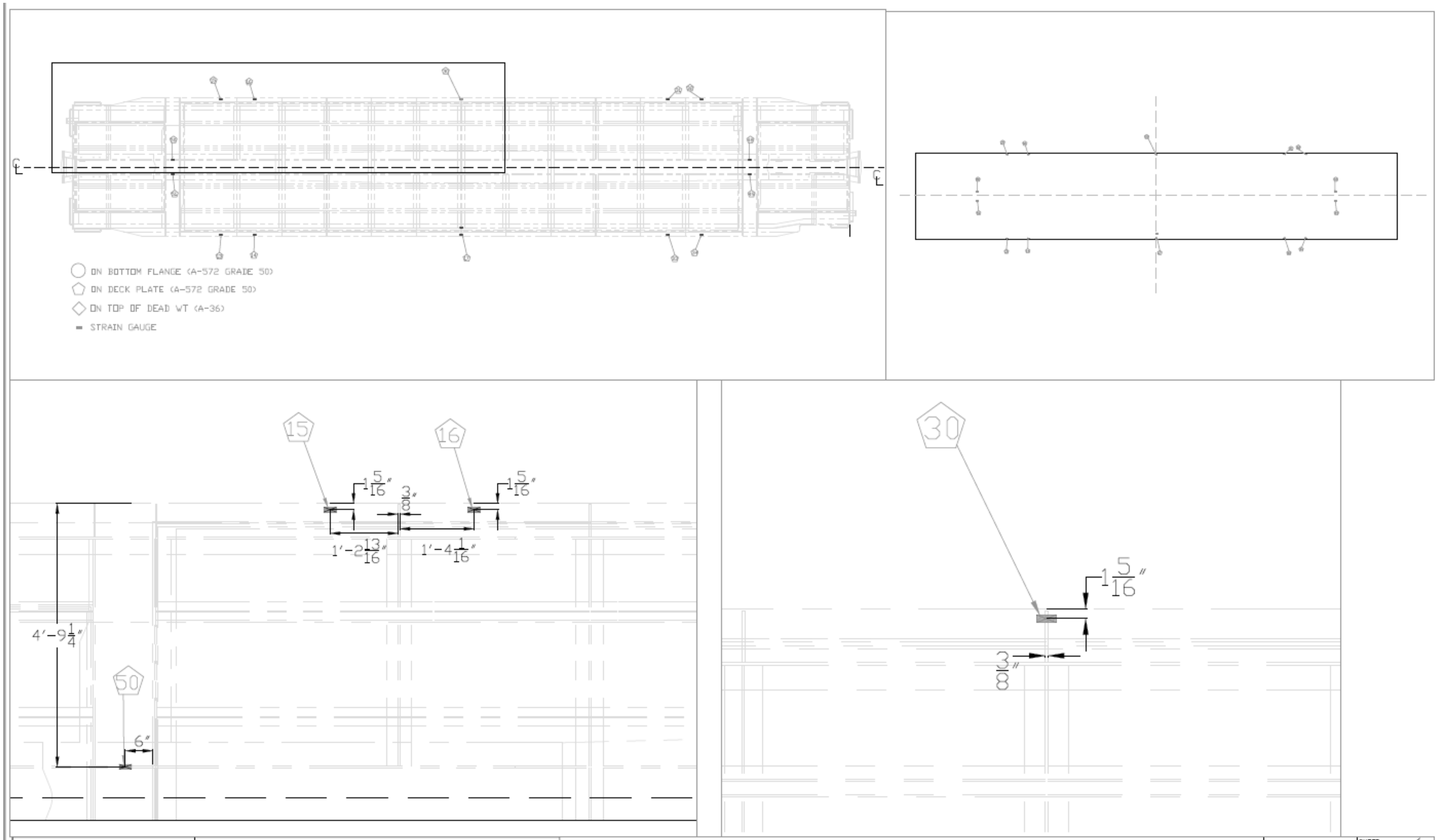
Association of American Railroads

DOE BUFFER CAR INSTRUMENTATION PLAN -
BOTTOM FLANGE STRAIN GAGES

DWN BY	DAL	CKD XXX	SHEET 1 / 3
DATE	5/9/2019	DATE XX/XX/XXXX	
PROJ.	AGH1	DWG DOE BUFFER CAR GAGE DRAWING.DWG	
PLOT RATIO	1:X	NOTE: Based on KASGRO design drawing 1160-47	

Figure C2. Detailed Strain Gage Locations, on Bottom Flange



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P.O. BOX 11130, PUEBLO CO. 81001

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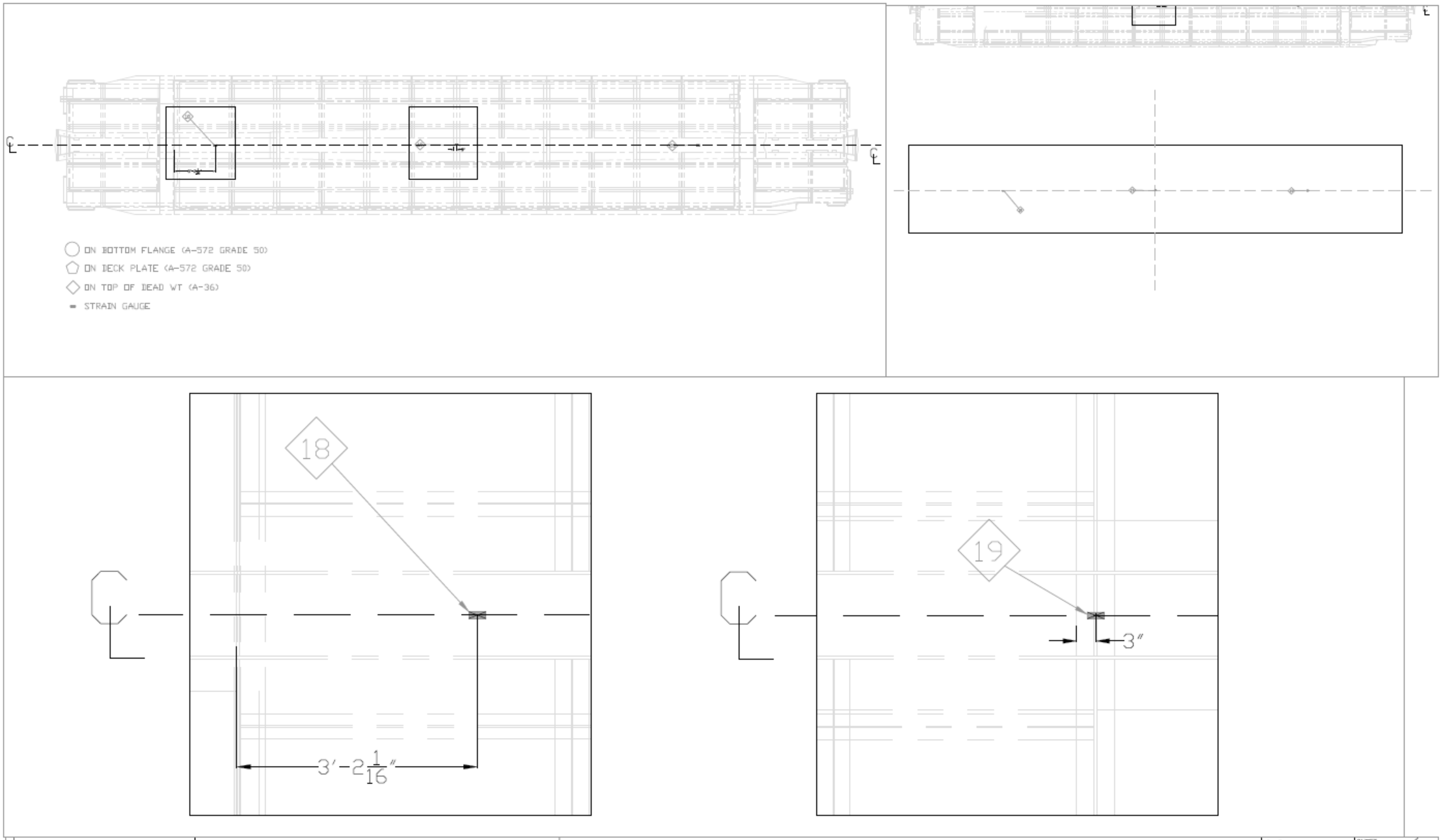
Association of American Railroads

DOE BUFFER CAR INSTRUMENTATION PLAN -
DECK PLATE STRAIN GAGES

DWN BY	DAL	CKD	XXX
DATE	5/9/2019	DATE	XX/XX/XXXX
PROJ.	AGH1	DWG	DOE BUFFER CAR GAGE DRAWING.DWG
PLOT RATIO	1:X		NOTE: Based on KASGRO design drawing 1160-47

SHEET 2/3

Figure C3. Detailed Strain Gage Locations, on Deck Plate



TTCI Transportation Technology Center, Inc.

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DOE BUFFER CAR INSTRUMENTATION PLAN –
DEAD WEIGHT STRAIN GAGES

DWN BY DAL
DATE 5/9/2019
PROJ. AGH1
PLOT RATIO 1:X
CKD XXX
DATE XX/XX/XXXX
SHEET 3 / 3
DWG DOE BUFFER CAR GAGE DRAWING.DWG

NOTE: Based on KASGRO design drawing 1160–47

Figure C4. Detailed Strain Gage Locations, on Top of Dead Weight

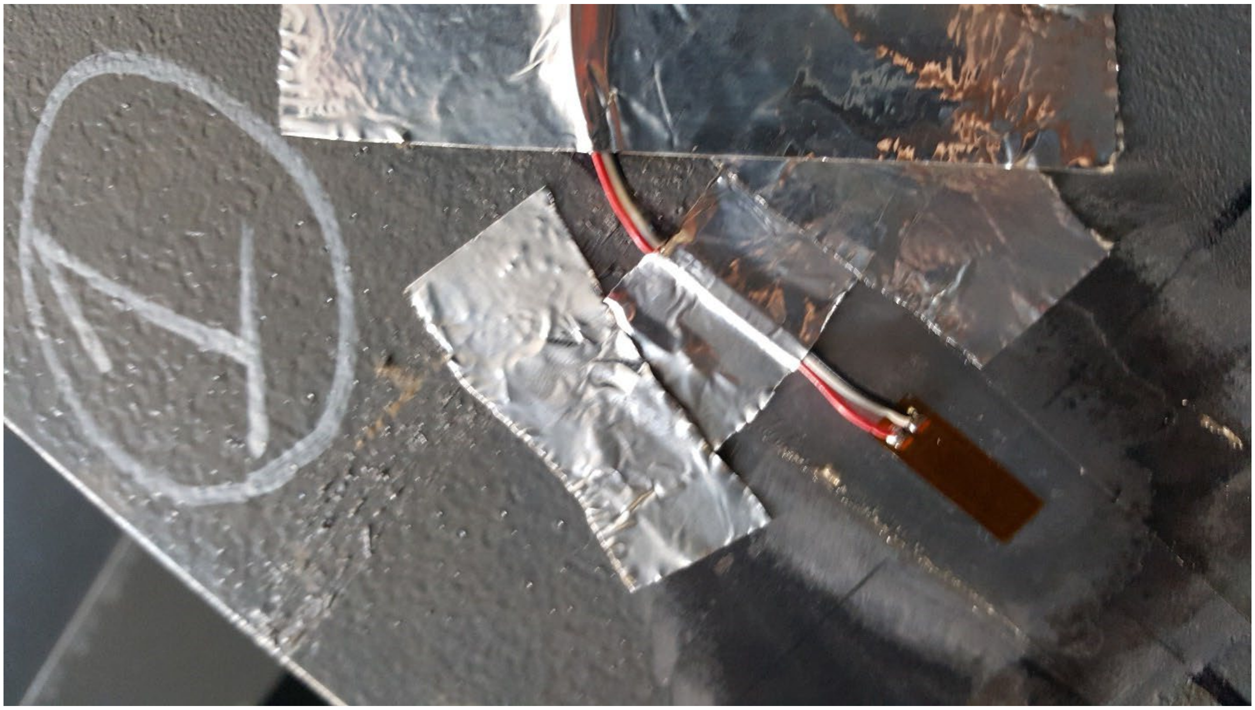


Figure C5. SGBF1 Front of Bottom Flange of A-end Body Bolster near Center Sill, LH Side

Figure C6. SGBF2 Rear of Bottom Flange of A-end Body Bolster near Center Sill, LH Side

Figure C7. SGBF3 Front of Bottom Flange of A-end Body Bolster near Center Sill, RH Side

Figure C8. SGBF4 Rear of Bottom Flange of A-end Body Bolster near Center Sill, RH Side

Figure C9. SGBF5 RH Edge of Bottom Flange of Center Sill, Aft of A-end Body Bolster

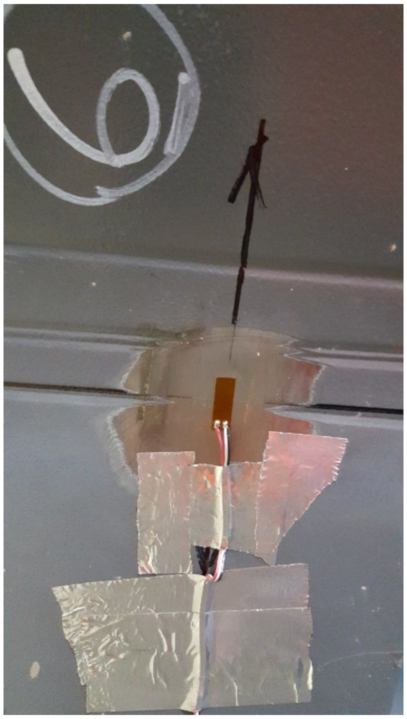


Figure C10. SGBF6 Center of Bottom Flange of RH Side Sill, Forward of Cross Bearer 7

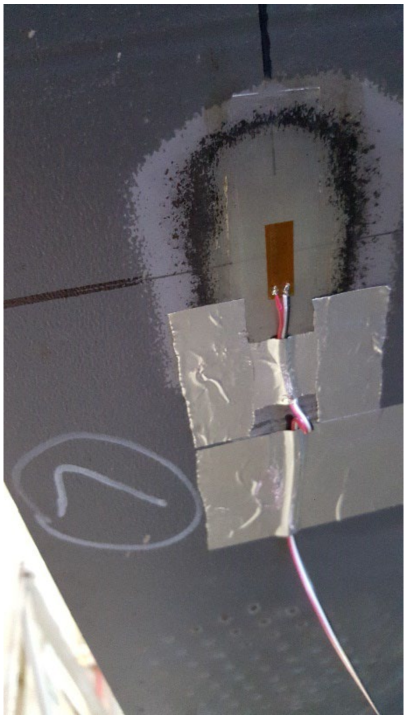


Figure C11. SGBF7 Center of Bottom Flange of RH SIDE SILL, Aft of Cross Bearer 7


Figure C12. SGBF8 Center of Bottom Flange of LH Side Sill, Aft of Cross Bearer 7

Figure C13. SGBF9 Center of Bottom Flange of LH Side Sill, forward of Cross Bearer Location 7

Figure C14. SGBF10 LH Edge of Bottom Flange of Center Sill, Forward of Cross Bearer 7

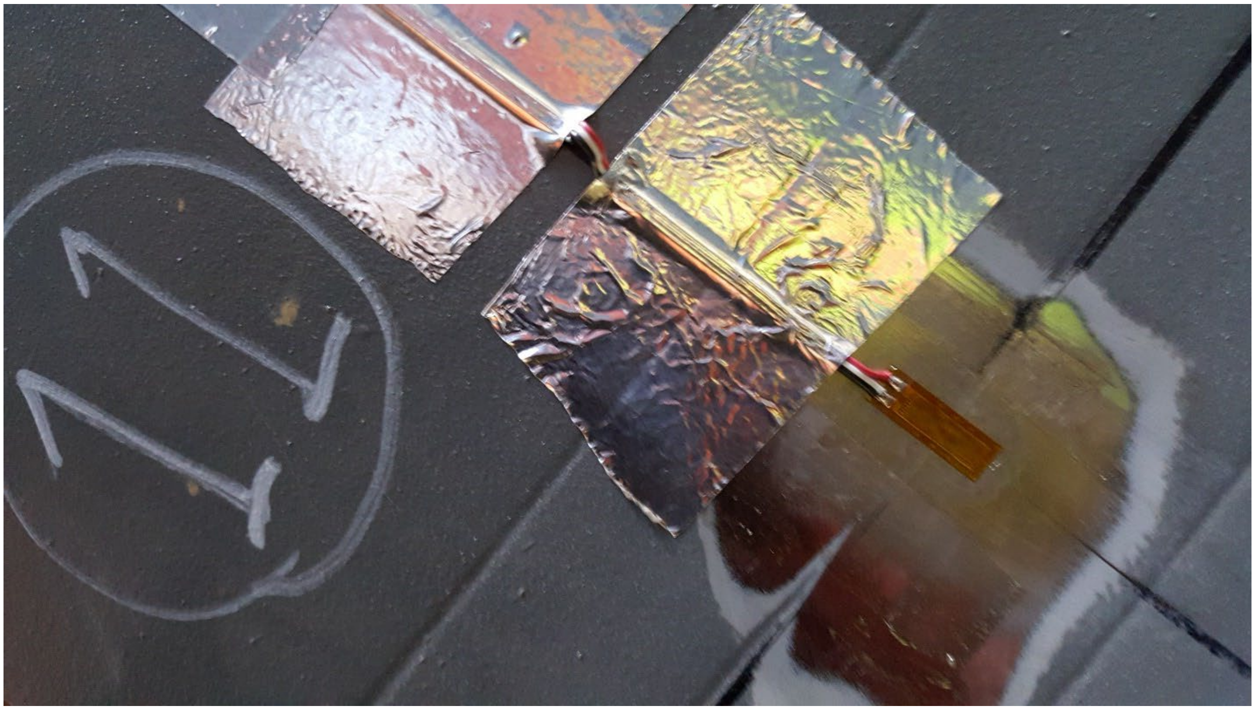


Figure C15. SGBF11 RH Edge of Bottom Flange of Center Sill, Forward of Cross Bearer 7

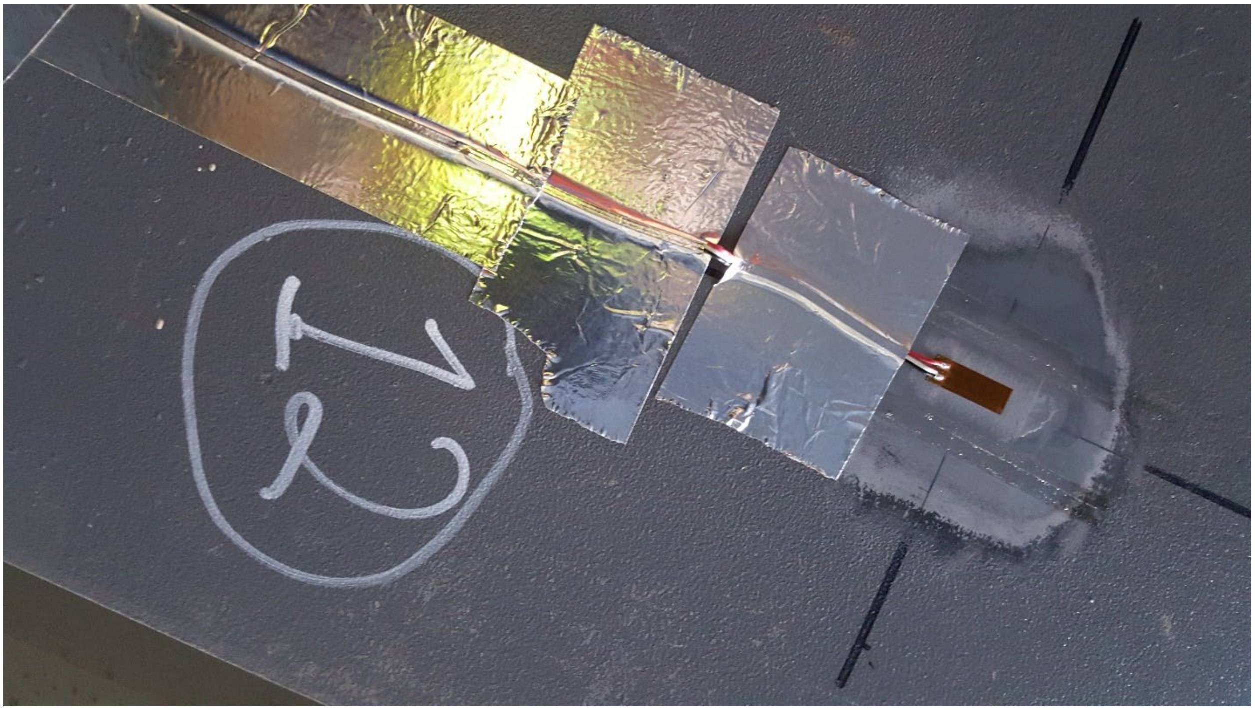


Figure C16. SGBF12 LH Edge of Bottom Flange of Center Sill, Aft of A-end Body Bolster

Figure C17. SGDP13 LH Edge of Deck Plate, Forward of Cross Bearer 7

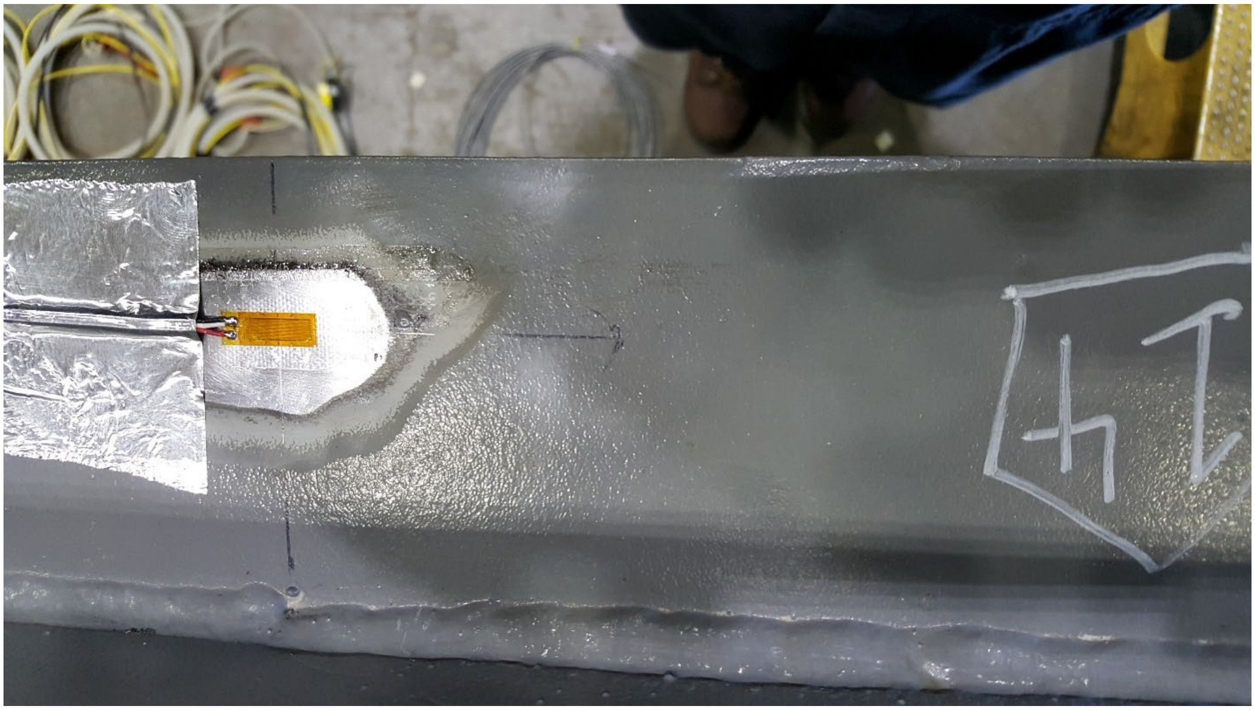


Figure C18. SGDP14 LH Edge of Deck Plate, Aft of Cross Bearer 7

Figure C19. SGDP15 RH Edge of Deck Plate, Forward of Cross Bearer 7

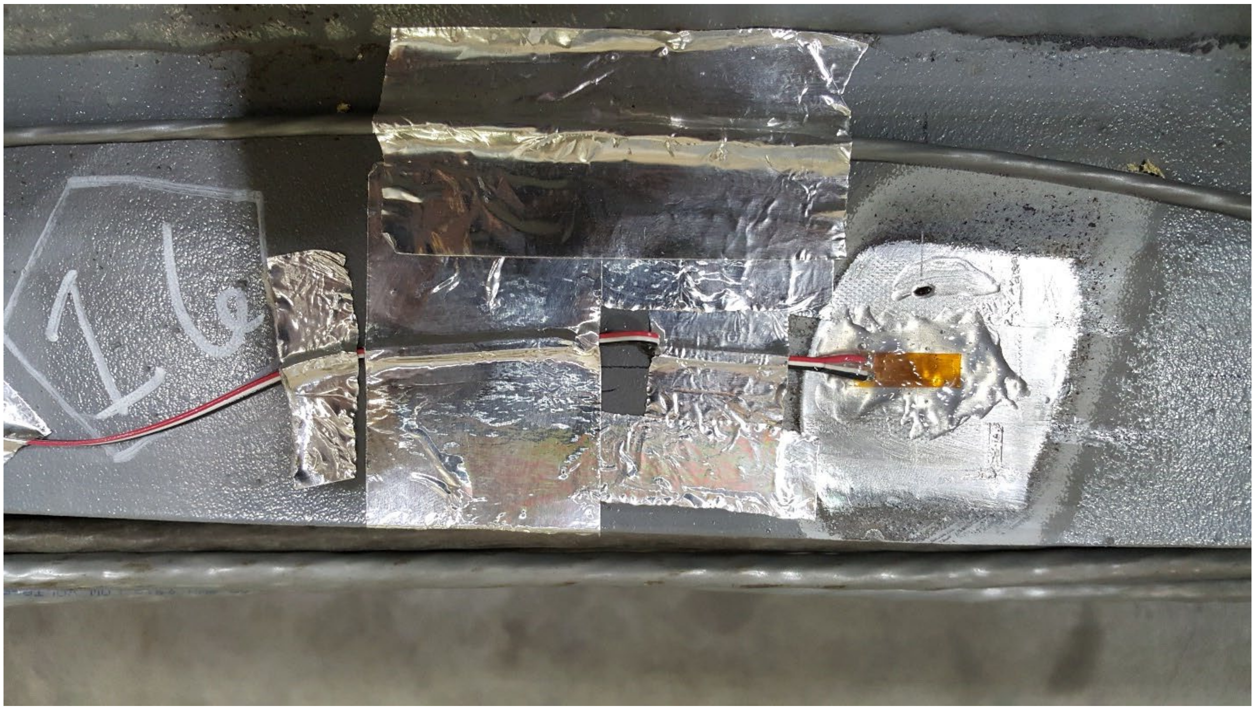


Figure C20. SGDP16 RH Edge of Deck Plate, Aft of Cross Bearer 7

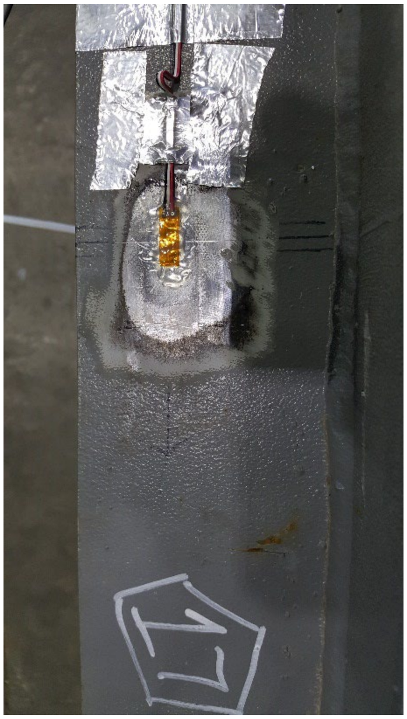


Figure C21. SGDP17 LH Edge of Deck Plate, at Longitudinal Center of Car

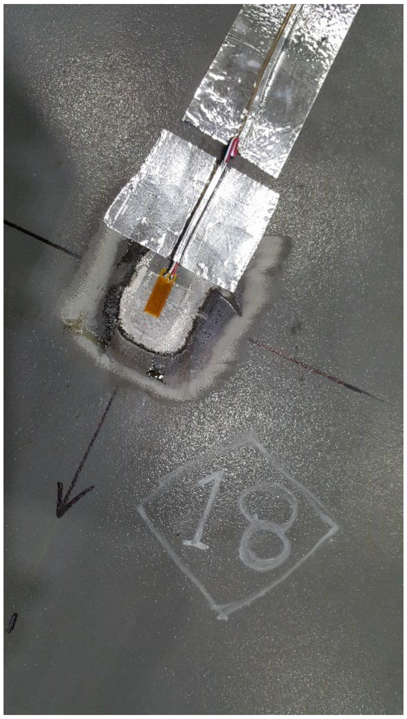


Figure C22. SGDW18 Top of Dead Weight at Lateral Center of Car, Forward of Cross Bearer 7

Figure C23. SGDW19 Top of Dead Weight, at Lateral and Longitudinal Center of Car

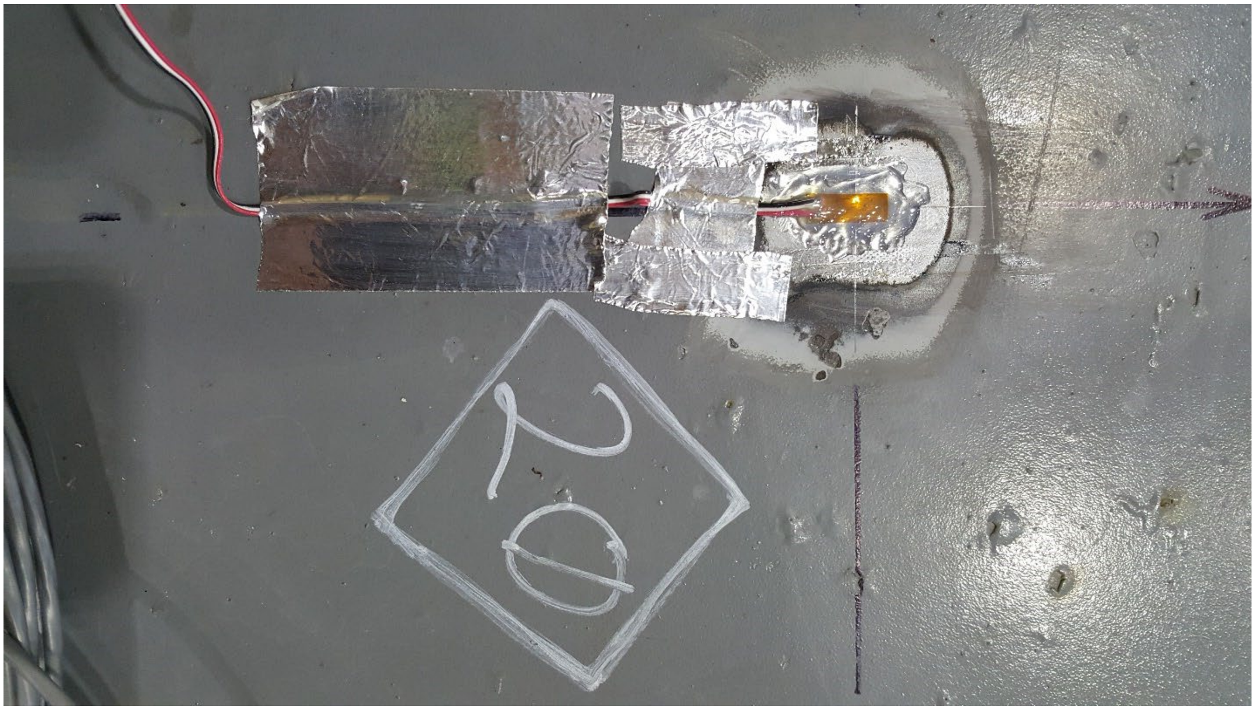


Figure C24. SGDW20 Top of Dead Weight at Lateral Center of Car, Aft of Cross Bearer 1

Figure C25. SGBF21 LH Edge of Bottom Flange of Center Sill, Forward of Cross Bearer 6

Figure C26. SGBF22 RH Edge of Bottom Flange of Center Sill, Forward of Cross Bearer 6

Figure C27. SGBF23 Bottom Flange of Cross Bearer 4, LH Side of Center Sill, at Longitudinal Center of Car

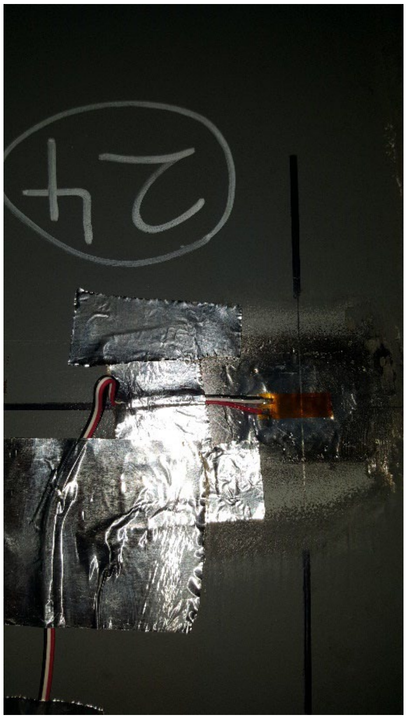


Figure C28. SGBF24 LH Edge of Bottom Flange of Center Sill, at Longitudinal Center of Car

Figure C29. SGBF25 RH Edge of Bottom Flange of Center Sill, at Longitudinal Center of Car

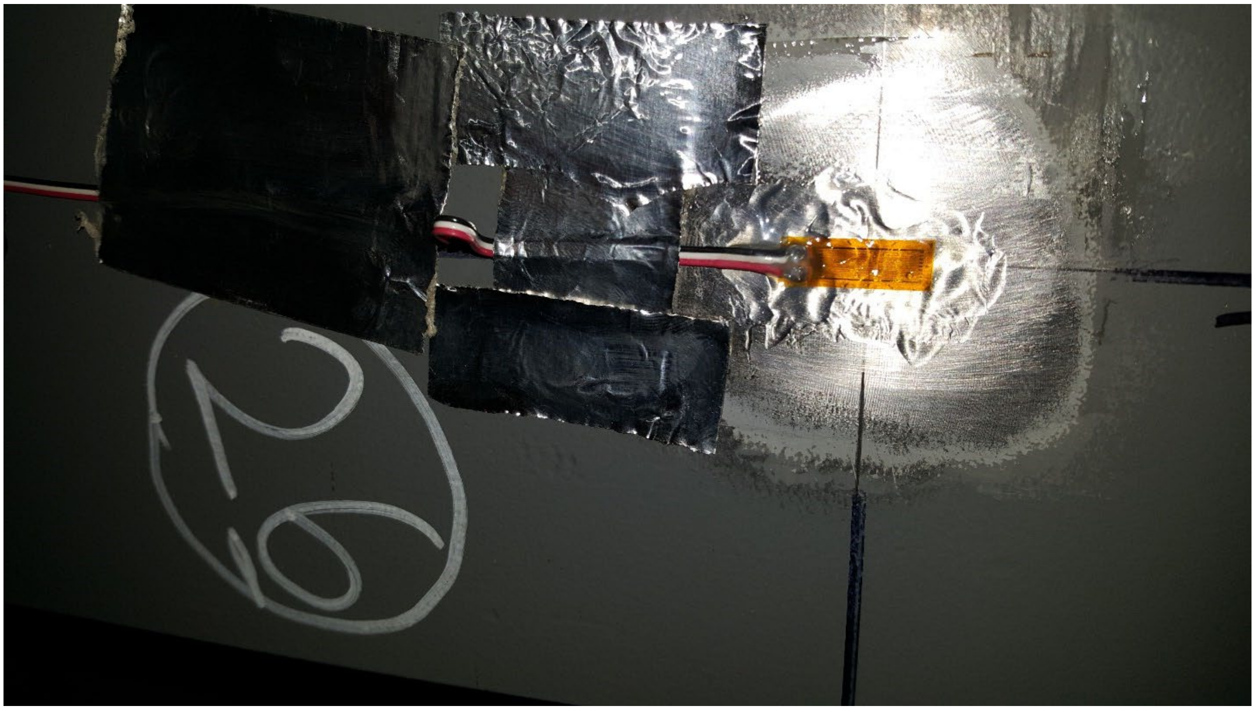


Figure C30. SGBF26 Bottom Flange of Cross Bearer 2, RH Side of Center Sill, at Longitudinal Center of Car

Figure C31. SGBF27 RH Edge of Bottom Flange of Center sill, Aft of Cross Bearer 2

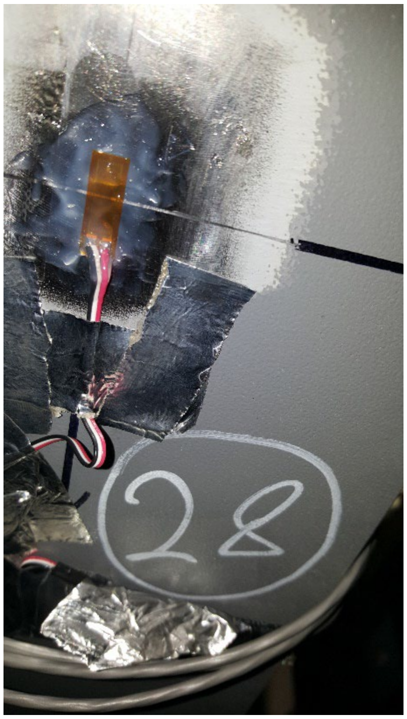


Figure C32. SGBF28 Center of Bottom Flange of RH Side Sill, at Longitudinal Center of Car

Figure C33. SGBF29 Center of Bottom Flange of LH Side Sill, at Longitudinal Center of Car

Figure C34. SGDP30 RH Edge of Deck Plate, at Longitudinal Center of Car

Figure C35. SGDP31 RH Edge of Deck Plate, Forward of Cross Bearer 2

Figure C36. SGDP32 RH Edge of Deck Plate, Aft of Cross Bearer 2

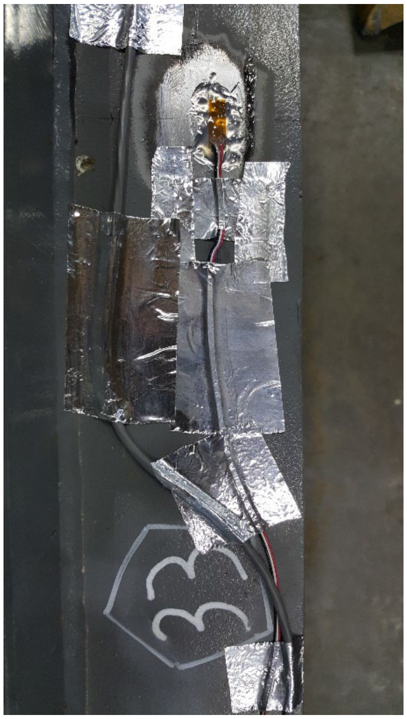


Figure C37. SGDP33 LH Edge of Deck Plate, Forward of Cross Bearer 2

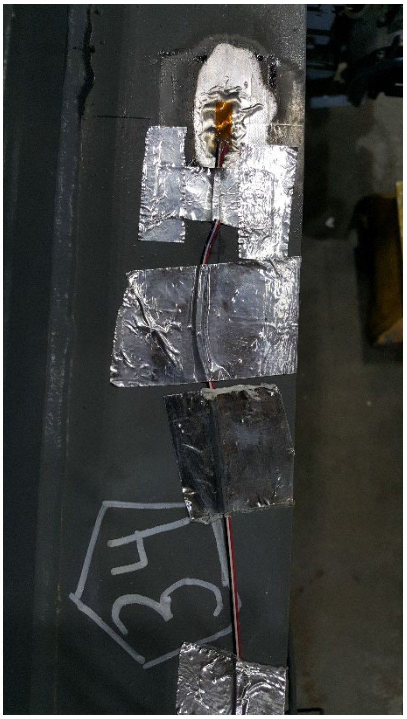


Figure C38. SGDP34 LH Edge of Deck Plate, Aft of Cross Bearer 2

Figure C39. SGBF35 LH Edge of Bottom Flange of Center Sill, Aft of Cross Bearer 1

Figure C40. SGBF36 LH Edge of Bottom Flange of Center Sill, Aft of Cross Bearer 2

Figure C41. SGBF37 RH Edge of Bottom Flange of Center Sill, Aft of Cross Bearer 1

Figure C42. SGBF38 Center of Bottom Flange of LH Side Sill, Forward of Cross Bearer 1

Figure C43. SGBF39 Center of Bottom Flange of LH Side Sill, Aft of Cross Bearer 1

Figure C44. SGBF40 Front of Bottom Flange of B-end Body Bolster near Center Sil, RH Side

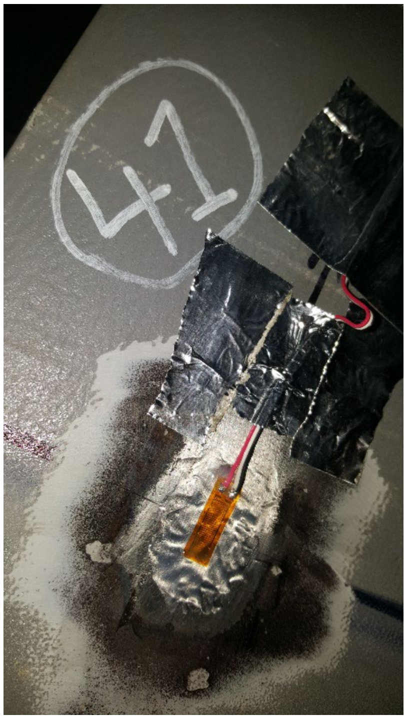


Figure C45. SGBF41 Rear of Bottom Flange of B-end Body Bolster near Center Sill, RH Side

Figure C46. SGBF42 Front of Bottom Flange of B-end Body Bolster Near Center Sill, LH Side

Figure C47. SGBF43 Rear of Bottom Flange of B-end Body Bolster near Center Sill, LH Side

Figure C48. SGBF44 RH Edge of Bottom Flange of Center Sill, Forward of B-end Body Bolster

Figure C49. SGBF45 LH edge of Bottom Flange of Center Sill, Forward of B-end Body Bolster

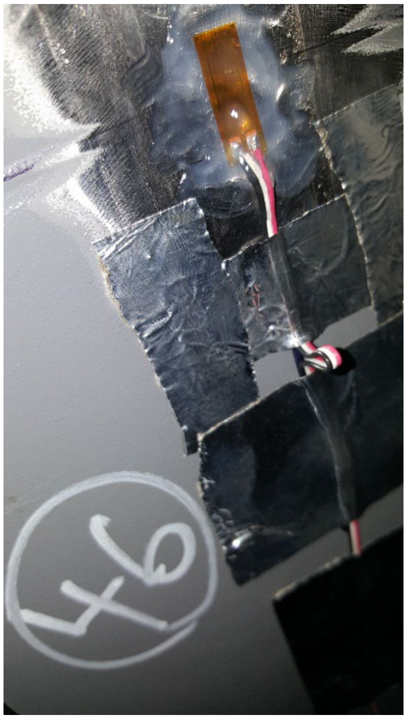


Figure C50. SGBF46 Center of Bottom Flange of RH Side Sill, Aft of Cross Bearer 1

Figure C51. SGBF47 Center of Bottom Flange of RH Side Sill, Forward of Cross Bearer 1

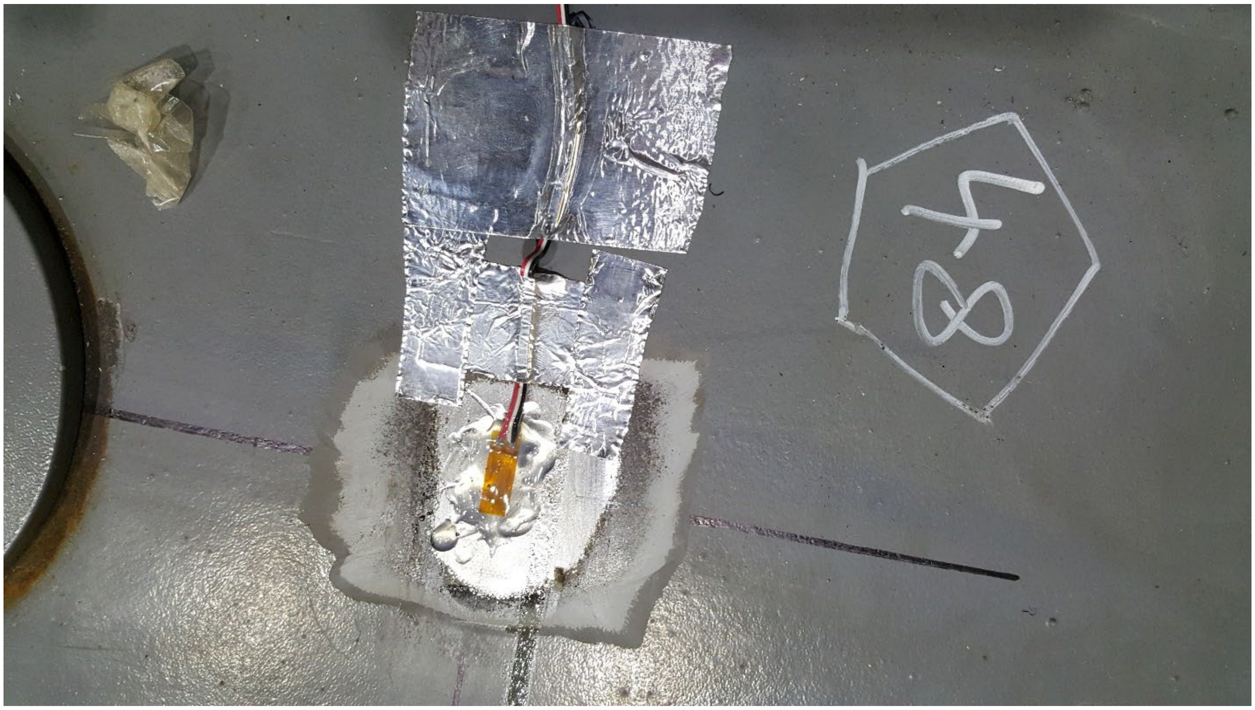


Figure C52. SGDP48 Top of Deck Plate, Longitudinally Centered over B-End Body Bolster, Above RH Edge of Center Sill

Figure C53. SGDP49 Top of Deck Plate, Longitudinally Centered over B-end Body Bolster, above LH Edge of Center Sill

Figure C54. SGDP50 Top of Deck Plate, Longitudinally Centered over A-End Body Bolster, above RH Edge of Center Sill

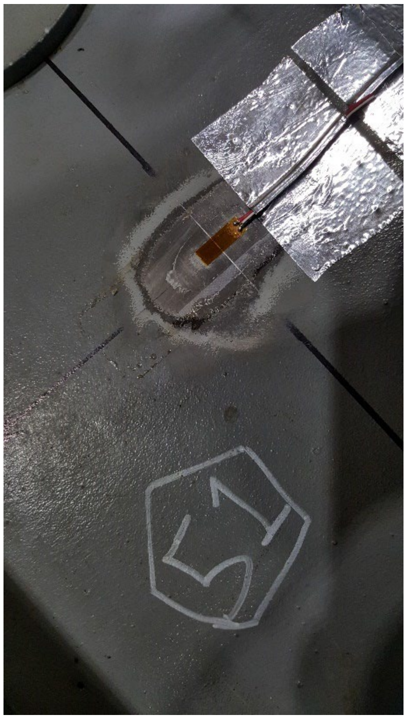


Figure C55. SGDP52 Top of Deck Plate, Longitudinally Centered over A-End Body Bolster, above LH Edge of Center Sill

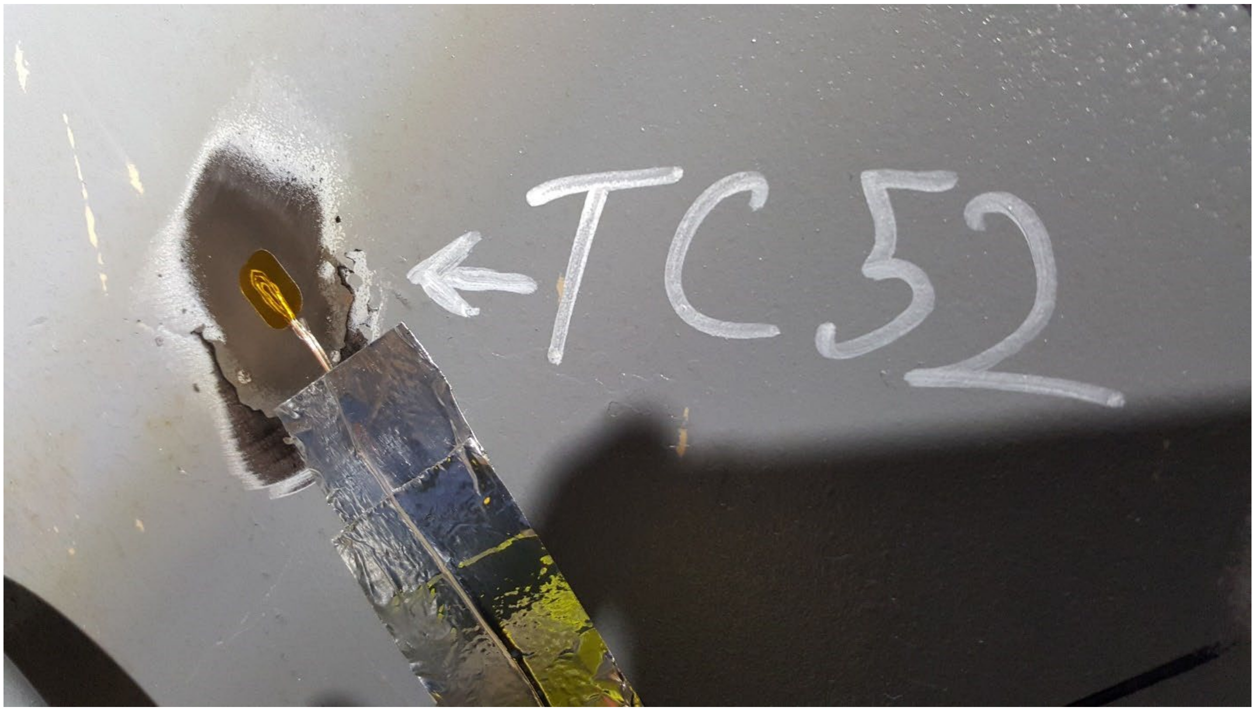


Figure C56. TC52 Laterally and Longitudinally Centered on Top of Deck Plate Forward of A-end Body Bolster

Figure C57. TC53 Laterally and Longitudinally Centered on top of Deck Plate Forward of A-End Body Bolster

Figure C58. TC54 Bottom Flange of Cross Bearer 4 at Lateral and Longitudinal Center of Car

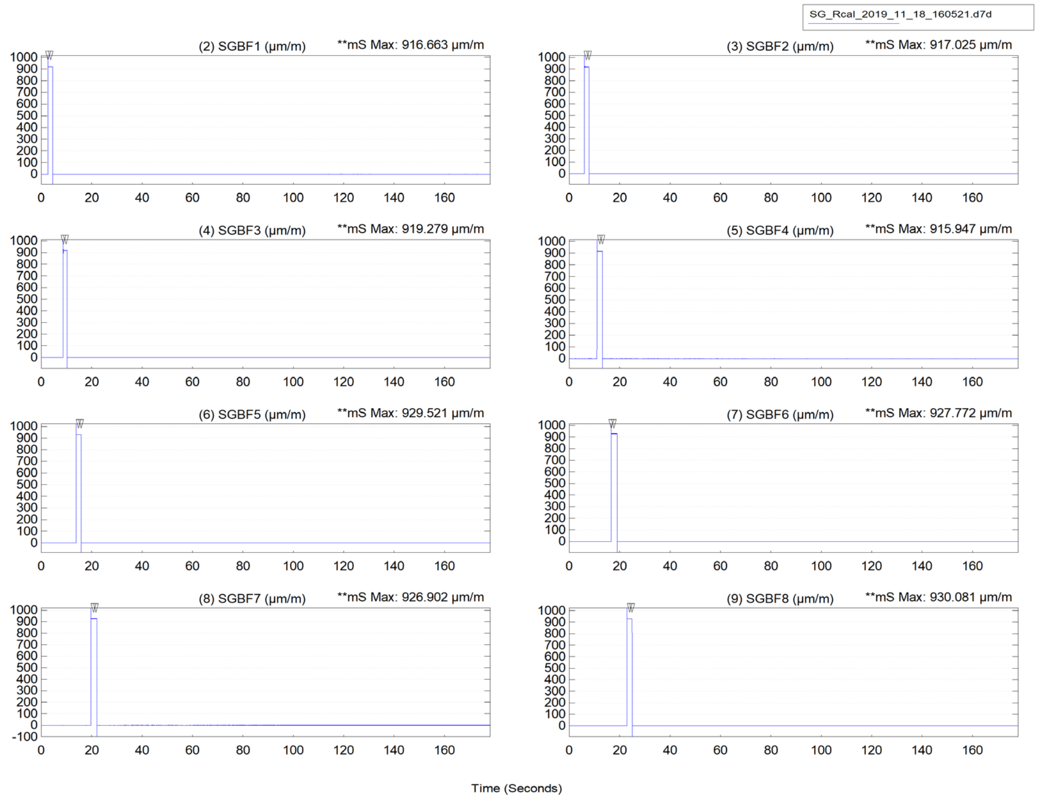


Figure C59. Shunt Calibration of Gages 1-8 with a High Precision 174.650 kΩ Resistor

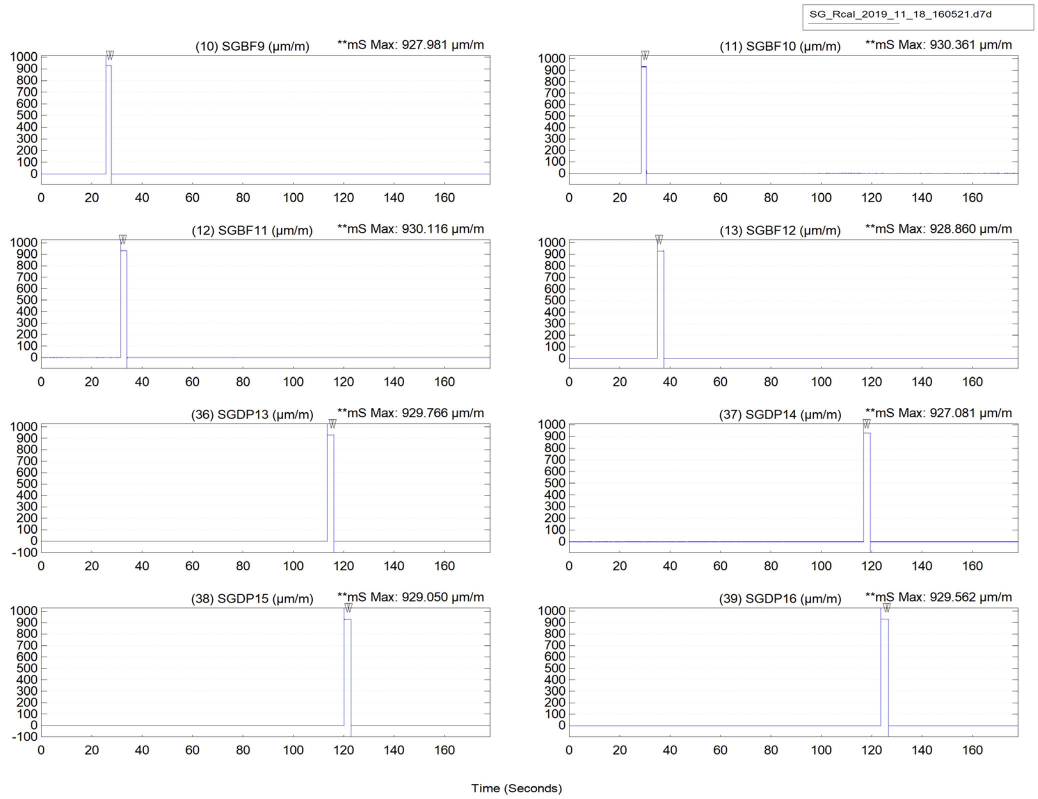


Figure C60. Shunt Calibration of gages 9-16 with a High Precision 174.650 kΩ Resistor

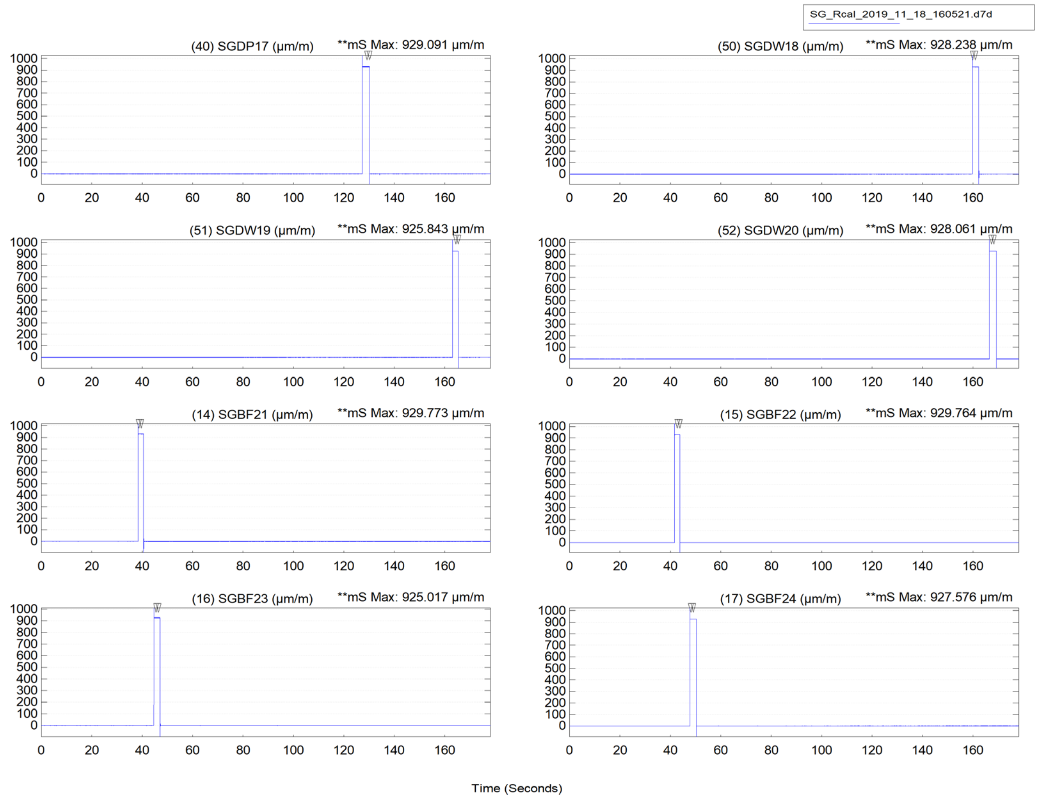


Figure C61. Shunt Calibration of Gages 17-24 with a High Precision 174.650 kΩ Resistor

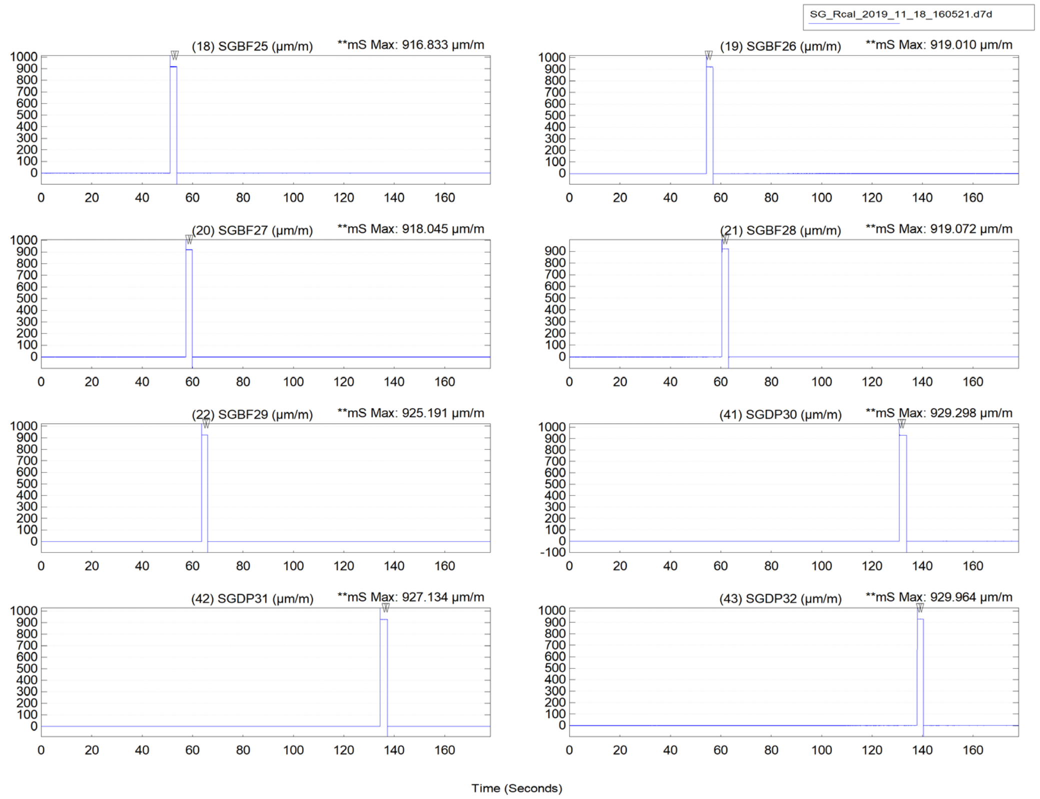


Figure C62. Shunt Calibration of Gages 25-32 with a High Precision 174.650 kΩ Resistor

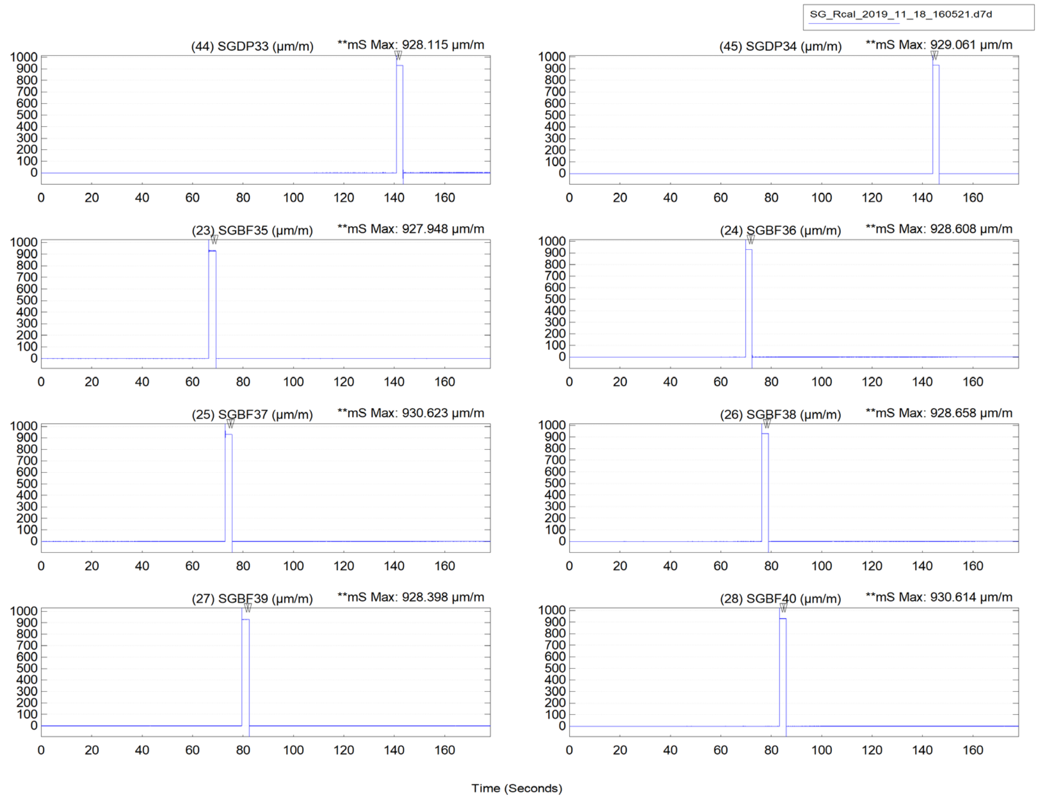


Figure C63. Shunt Calibration of Gages 33-40 with a High Precision 174.650 kΩ Resistor

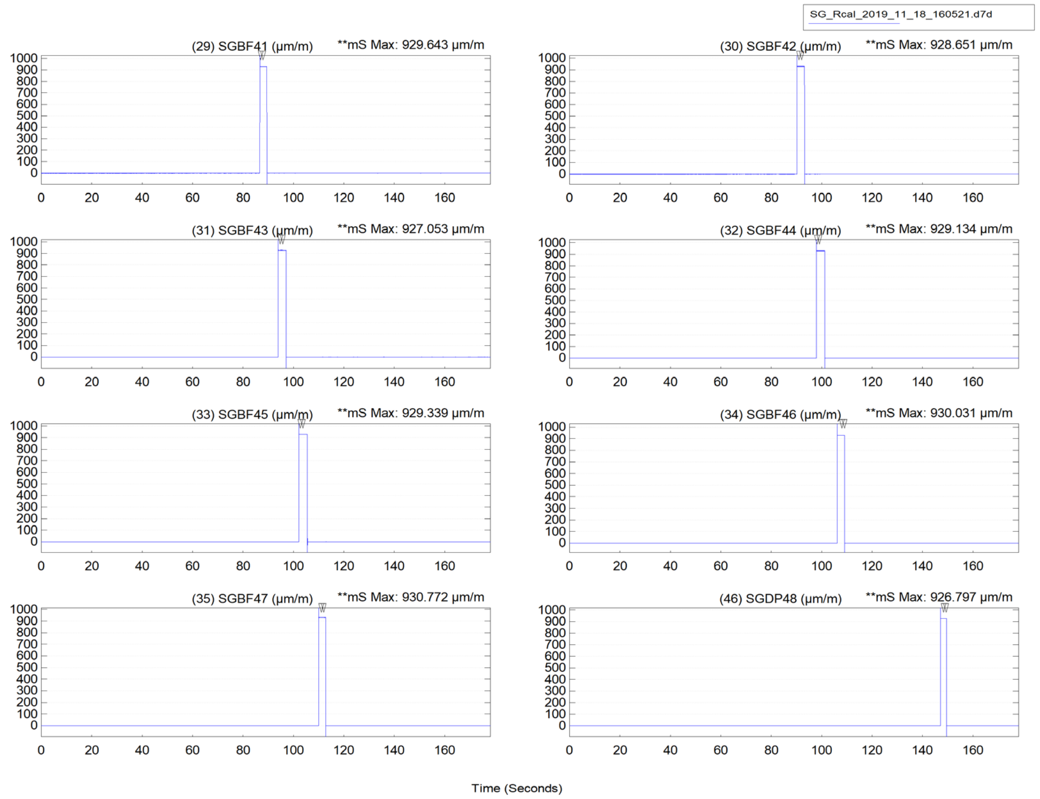


Figure C64. Shunt Calibration of Gages 41-48 with a High Precision 174.650 kΩ Resistor

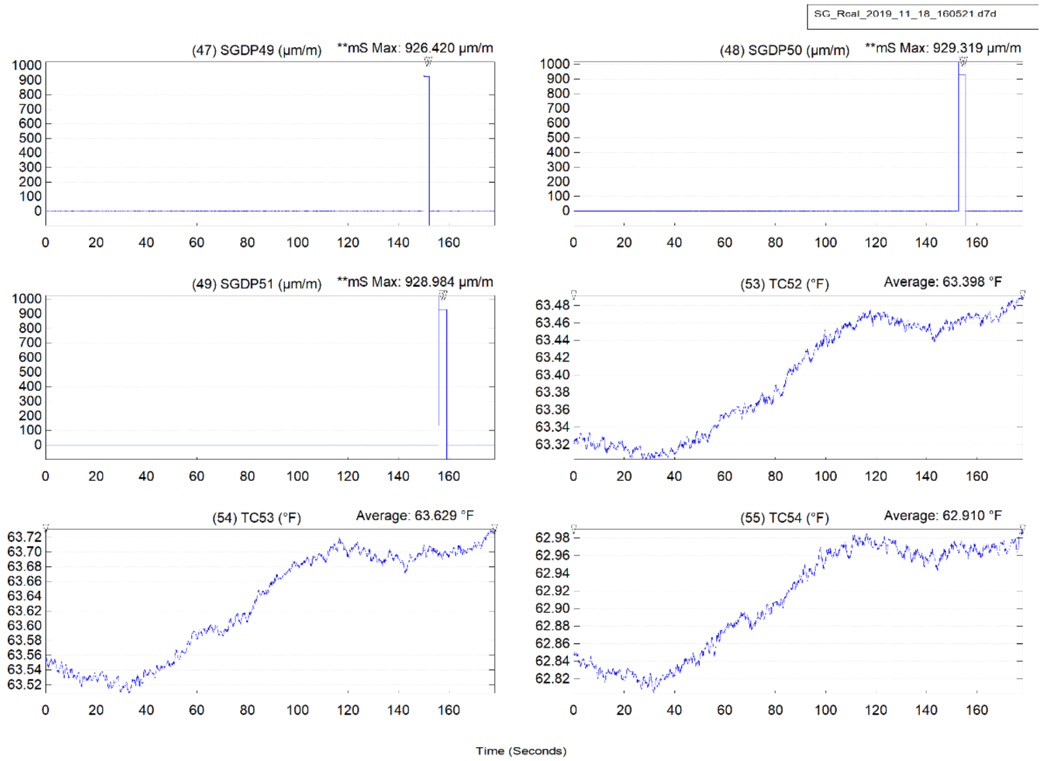


Figure C65. Shunt calibration of Gages 49-51 with a High Precision 174.650 kΩ Resistor, and Plot of the Three Thermocouples. The TTC Weather station showed ambient temperature was 63°F on November 18, 2019, at 4:00 pm when this file was recorded

APPENDIX D: KASGRO BUCKLING ANALYSIS

S-2043 Critical Buckling Analysis

March 2021

Prepared by: Kasgro Engineering

At the request of the TTCI reviewer, Kasgro was asked to look for the critical buckling stress of the structure. Although this is a requirement in the S-2043 specification, when building railcars to AAR specification M1001, Chapter 11, we have not had to consider critical buckling stress except in compression members of Schnabel cars and Schnabel carload fixtures that contained long compression elements. These compression members have a continuous cross section which a theoretical buckling stress could be defined. Unlike the Schnabel compression members, the Atlas car bodies do not have continuous cross sections. Both cars have multiple cross sections and will not behave like a continuous column with a constant cross section. The following analysis is an approximation.

The critical buckling conditions have been re-evaluated to apply a C value of 1.0 (M-1001 4.2.2.11) to represent simple supports on both ends of the car. This is believed to be the most accurate way to represent the critical buckling condition. The linear buckling analysis now shows an EIGV value of 2.13E+7 before a member of the Buffer Car, Figure A, were to buckle. The linear buckling analysis also now shows an EIGV value of 1.03E+7 before a member of the Cask Car, Figure B, were to buckle. The EIGV values well exceed the designed squeeze load for both cars. In other words, it would take EIGV times a (1 lbf.) Squeeze load for the first buckling failure to occur. Since this would be the start of any buckling, the minimum margin of safety against buckling is something greater than one. The figures below show the deformations of the cars under the buckling load. Local buckling at the applied loads can occur prior to a primary structural member.

Figure A (side view of Buffer Car):

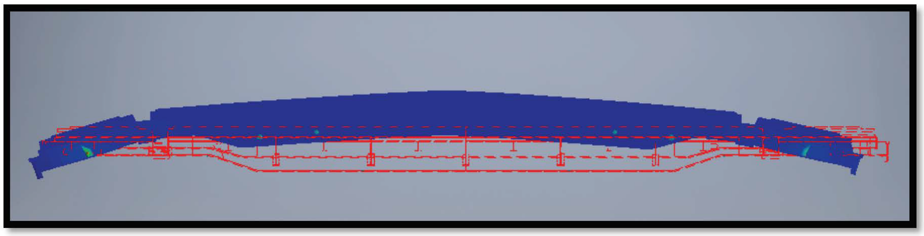
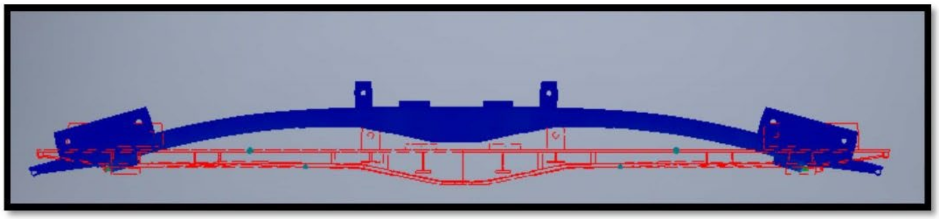


Figure B (side view of Cask Car):



APPENDIX E: COMPRESSIVE END LOAD TEST

Additional results of stresses measured for each strain gauge location during the 1-million-pound compression load test are shown in Figure E1 and Figure E2. Figure E3 shows the maximum stress at the location of highest stress

List of Figures

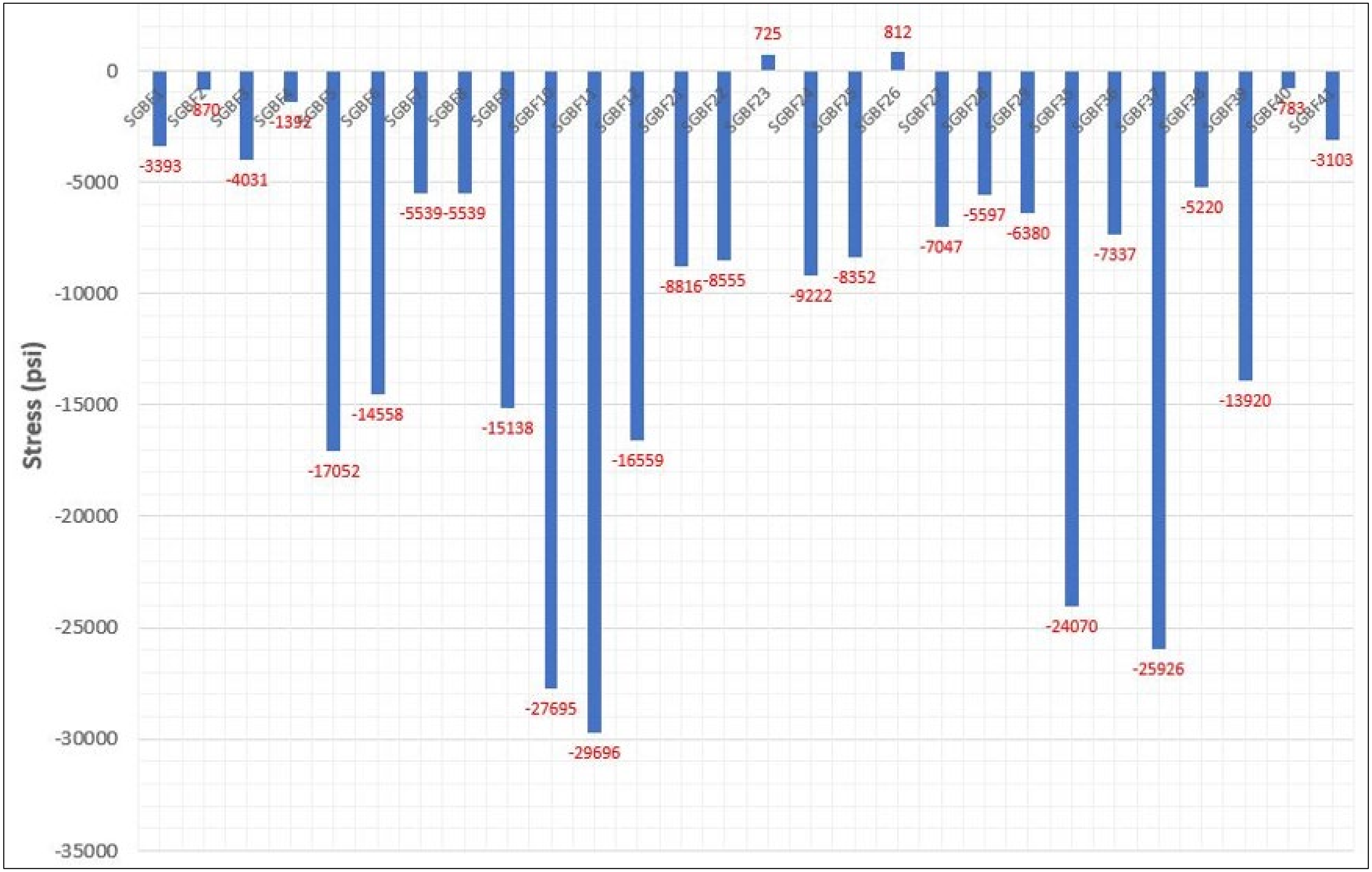


Figure E1. Stresses Under 1 Million Pounds Compression Load 1 of 2 (first group of gauges)

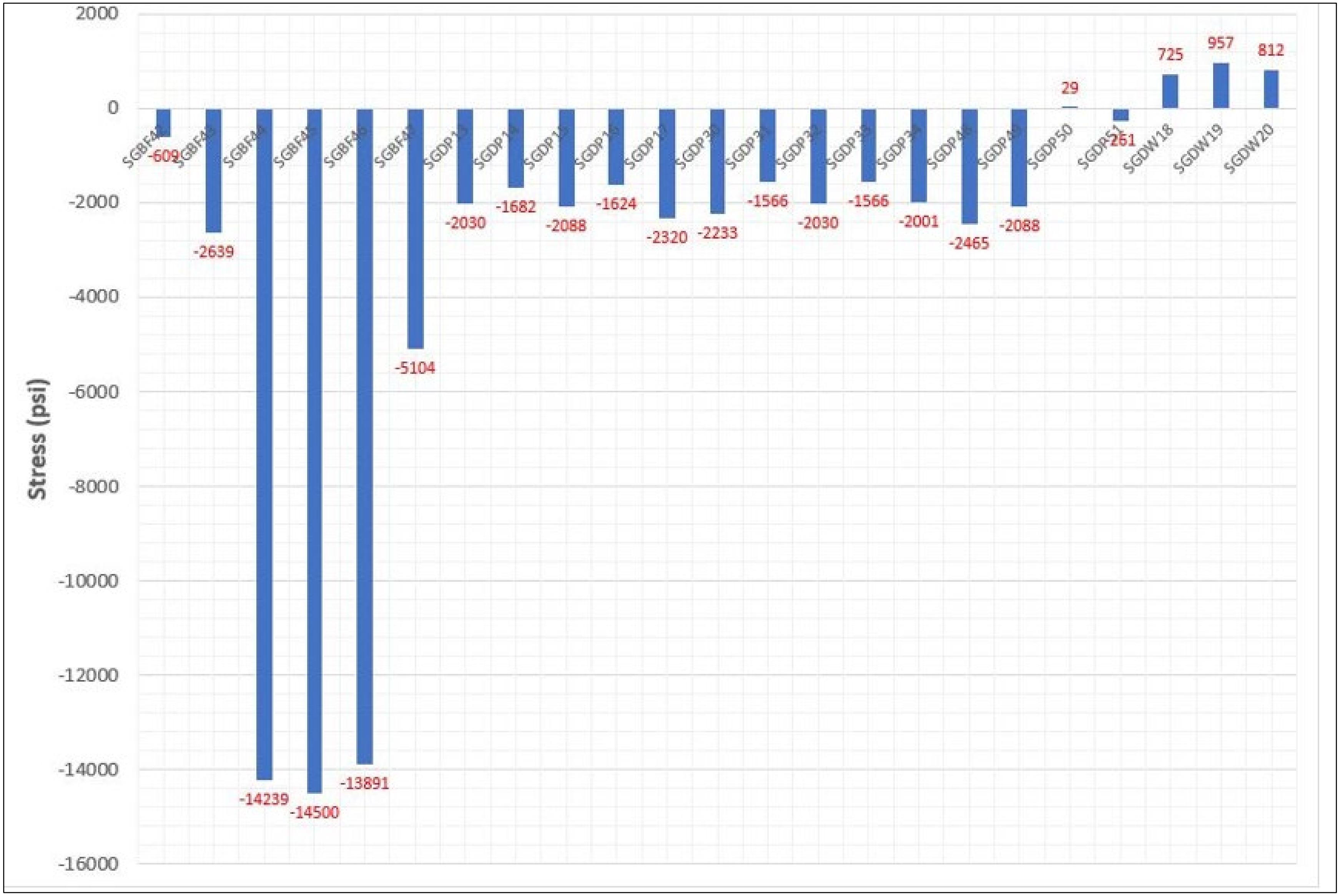


Figure E2. Stresses Under 1 Million Pounds Compression Load 2 of 2 (second group of gauges)

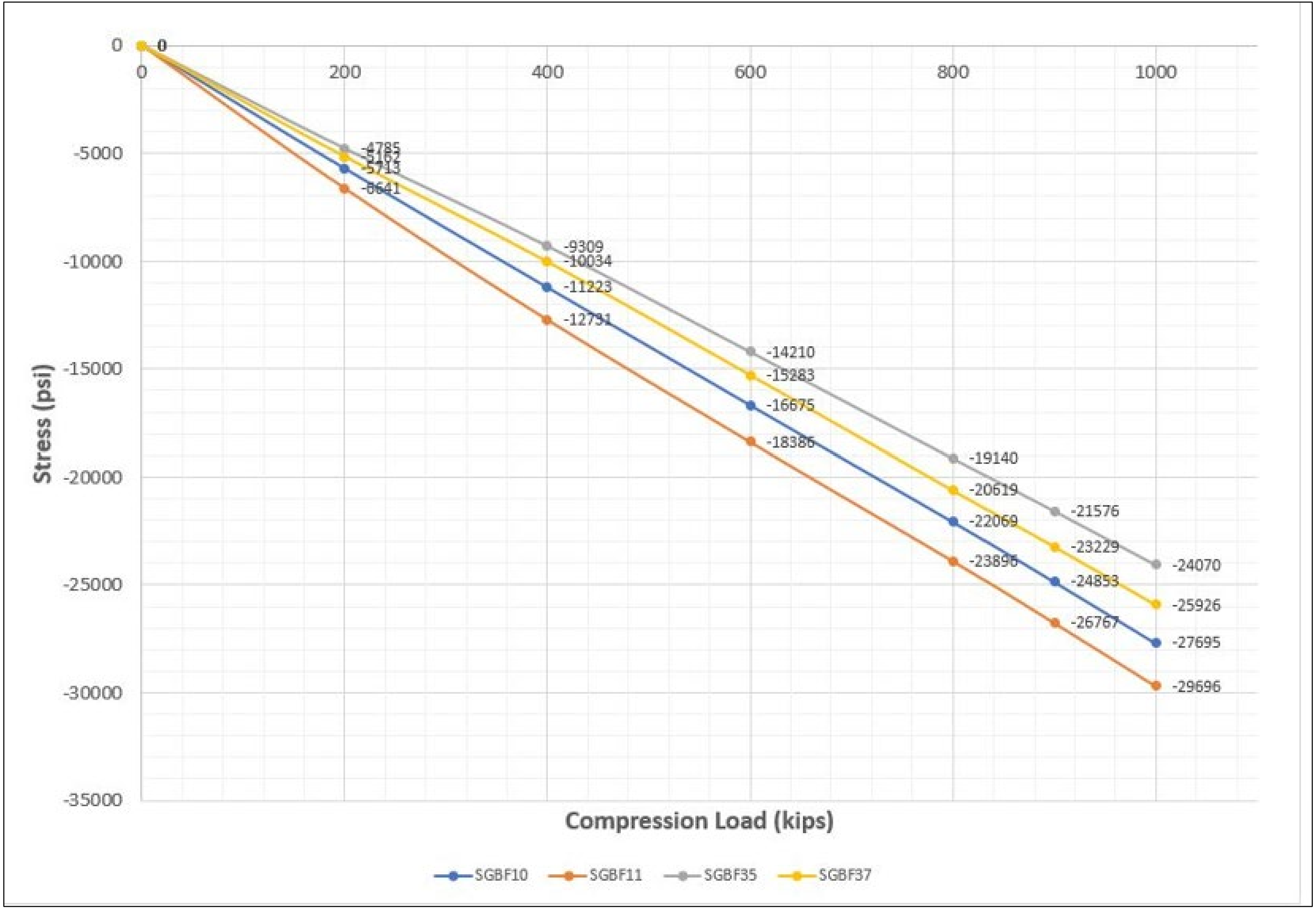


Figure E3. Maximum Stresses at Highest Stress Locations

The following figure shows the full squeeze test up to 1 million pounds for the four highest strained locations. The load was cycled, increasing in 200,000-pound increments until 1 million pounds was reached. After the initial load application, the load was not dropped back to zero until 1 million pounds was reached to prevent shifting of the test fixtures. No re-zero of the gages was done during the whole test after the initial zero before the beginning of the test. It is evident that no permanent deformation was created at these areas.

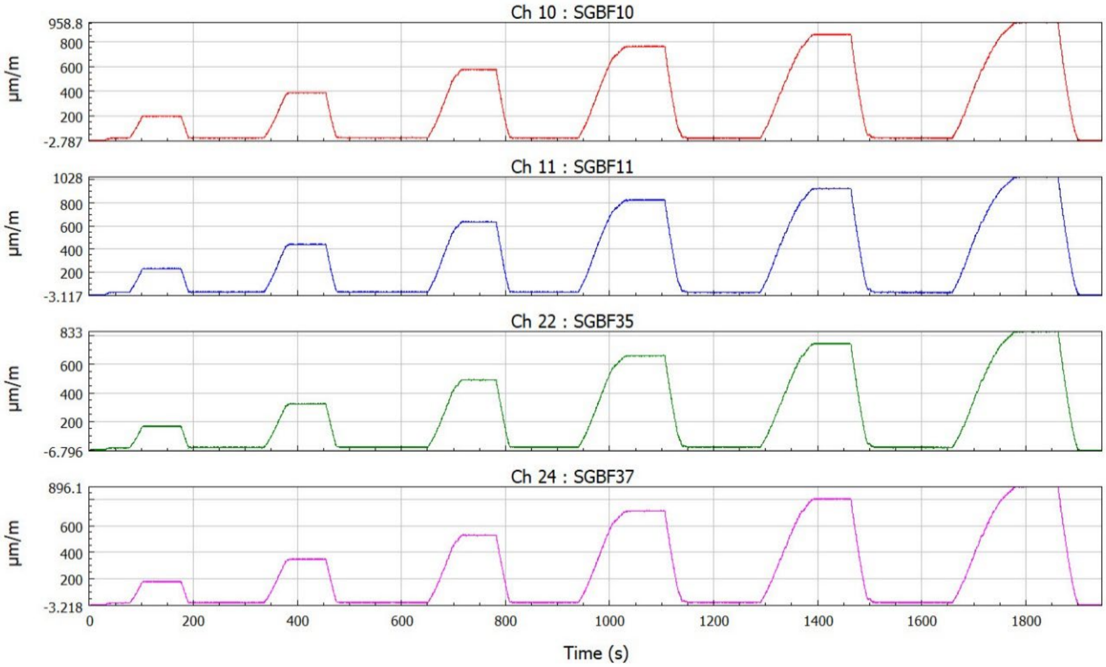
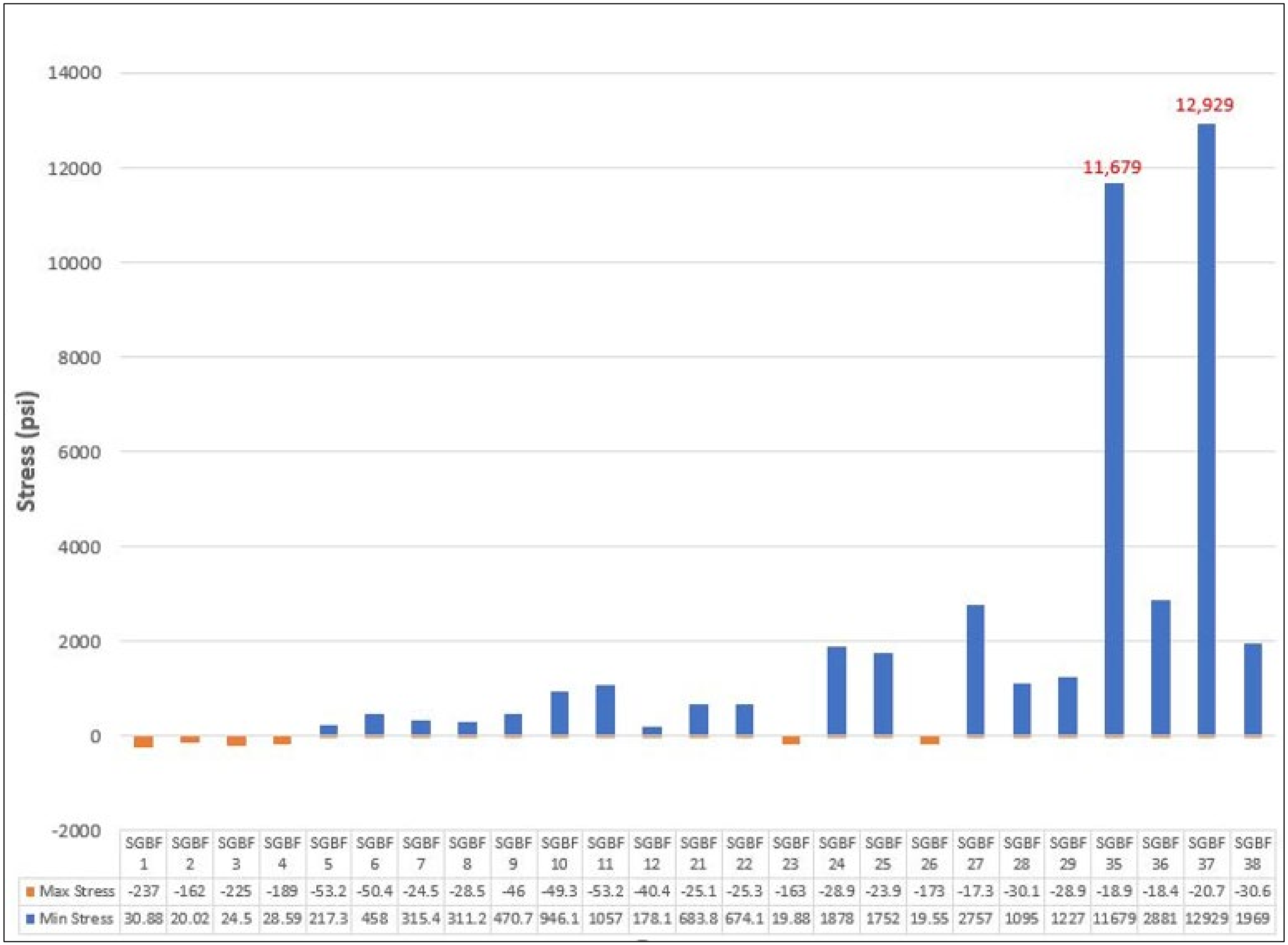


Figure E4. Time History of Strain on Four Critical Gages showing that the Strain Returned to Zero at the End of the Test

APPENDIX F: COUPLER VERTICAL LOADS

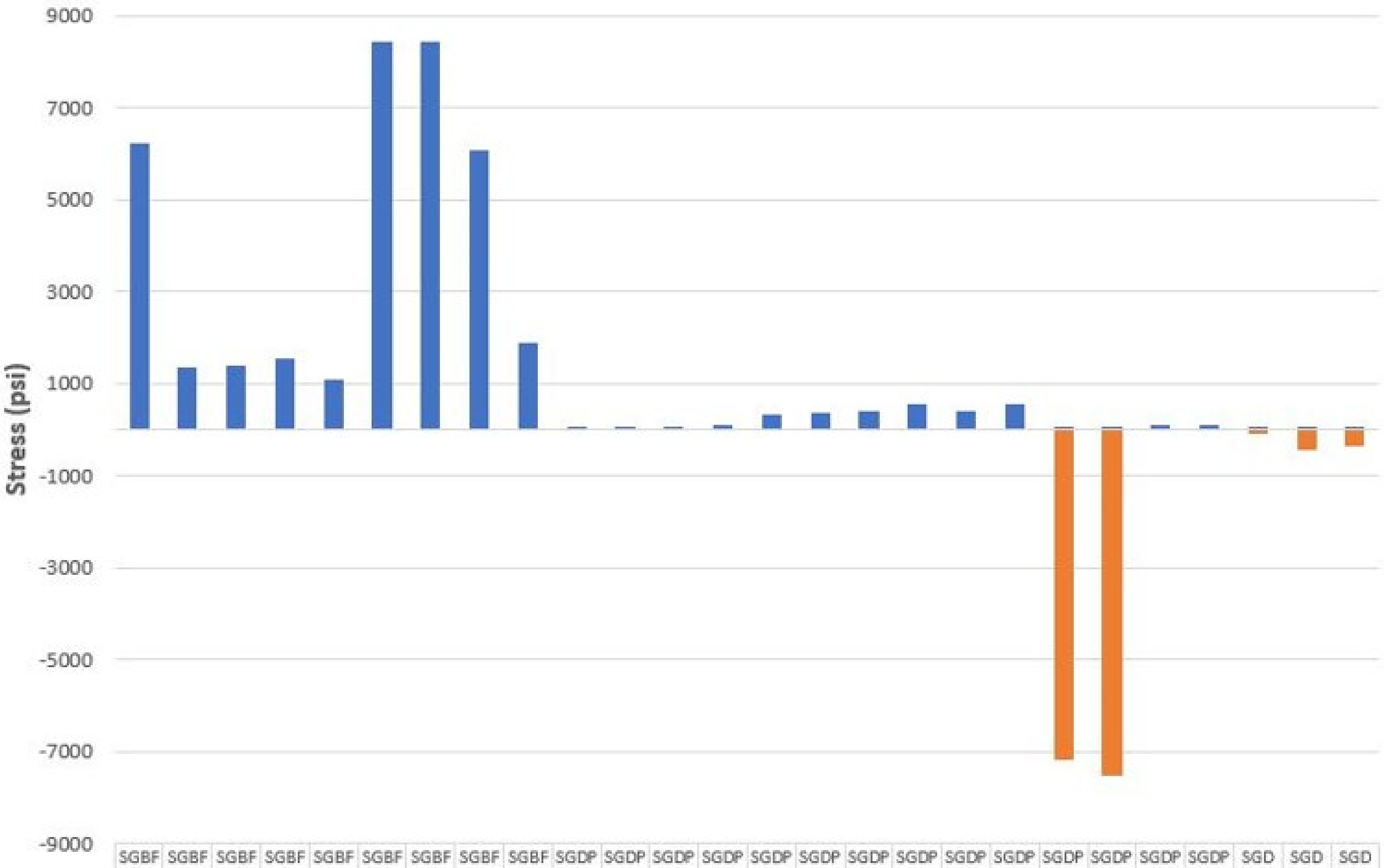
Additional results for individual strain gauges during the coupler vertical load test are shown in Figure F1 through Figure F4. The results are presented with stresses under vertical force upward and with stresses under vertical force downward.

List of Figures



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
🟧 Max Stress	-237	-162	-225	-189	-53.2	-50.4	-24.5	-28.5	-46	-49.3	-53.2	-40.4	-25.1	-25.3	-163	-28.9	-23.9	-173	-17.3	-30.1	-28.9	-18.9	-18.4	-20.7	-30.6
🟦 Min Stress	30.88	20.02	24.5	28.59	217.3	458	315.4	311.2	470.7	946.1	1057	178.1	683.8	674.1	19.88	1878	1752	19.55	2757	1095	1227	11679	2881	12929	1969

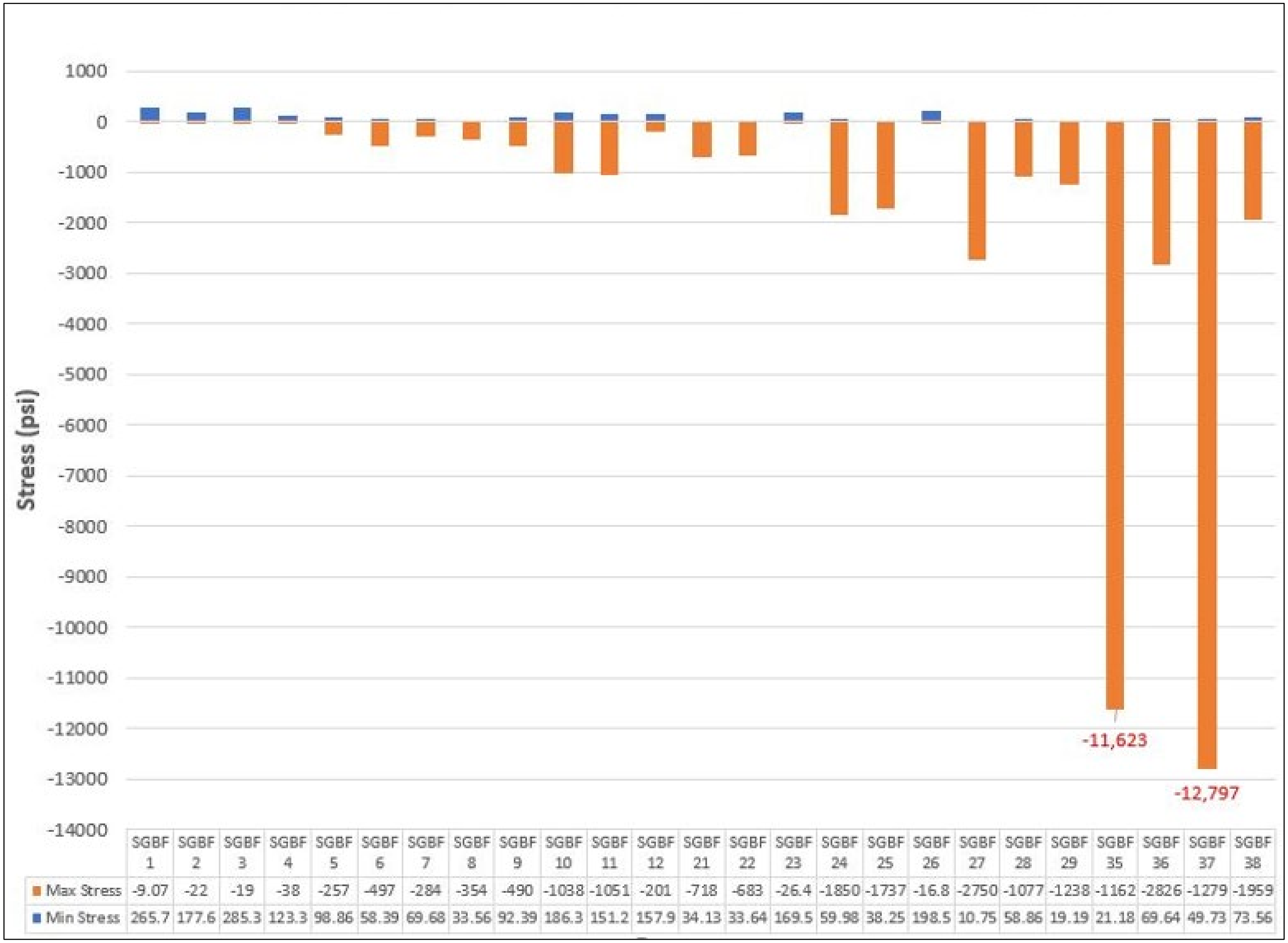
Figure F1. Stresses Under 50 kips Vertical Force (Force Applied Upward) (1 of 2)



	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16
🟧 Series2	-22.8	-33.7	-17.2	-22.8	-36.1	-22.3	-24.2	-23.3	-18.1	-23.4	-29.1	-30.5	-24.2
🟦 Series1	6232	1337	1386	1553	1070	8436	8422	6081	1877	48.89	71.98	59.78	82.58

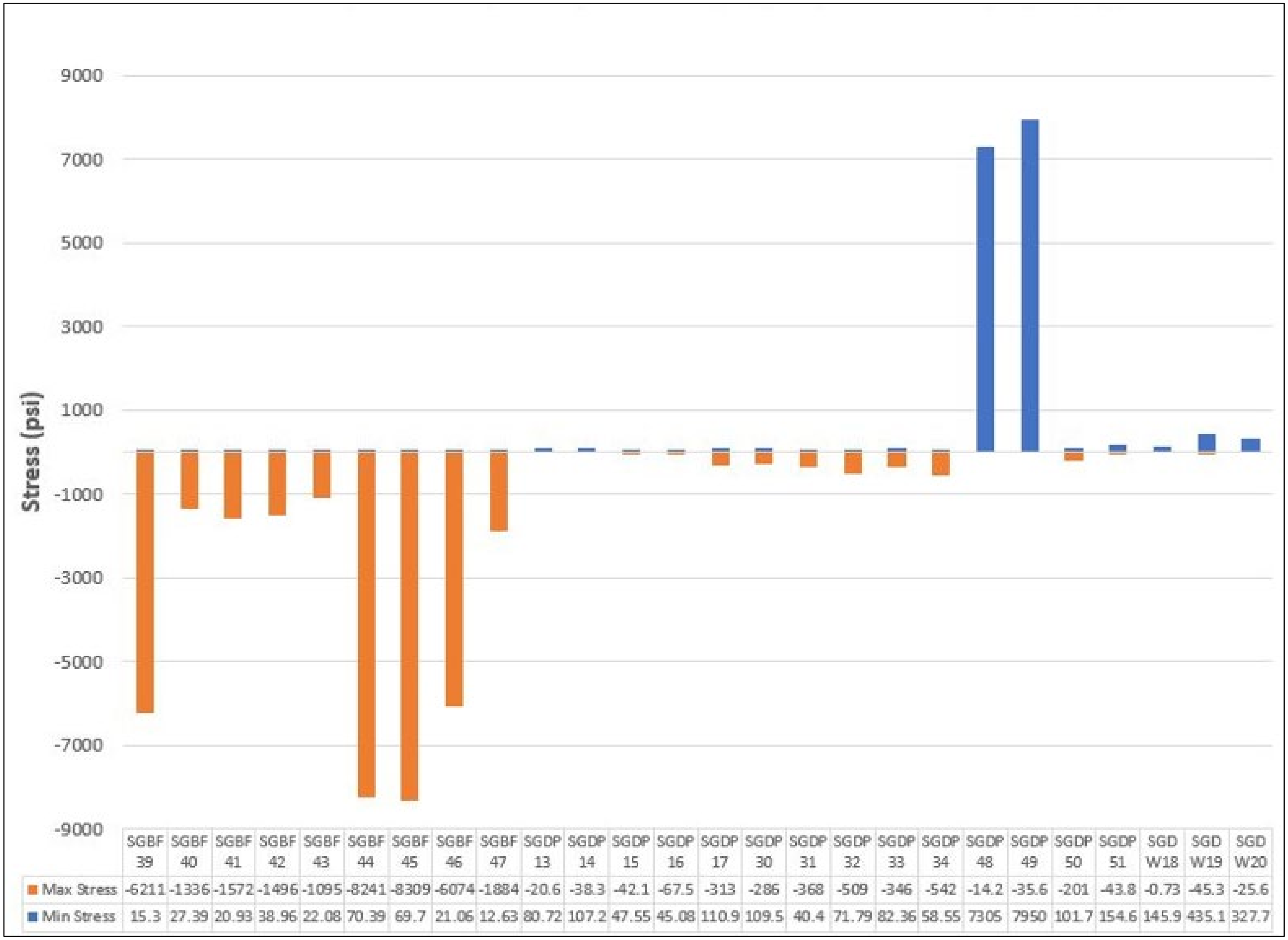
	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
🟧 Series2	-29.4	-19.9	-25.7	-37.8	-25.2	-22.8	-7197	-7534	-37.8	-28.1	-112	-430	-372
🟦 Series1	339.8	346.6	381	535.9	401.3	563	25.88	30.39	107.2	80.33	22.31	17.79	20.94

Figure F2. Stresses Under 50 kips Vertical Force (Force Applied Upward) (2 of 2)



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
■ Max Stress	-9.07	-22	-19	-38	-257	-497	-284	-354	-490	-1038	-1051	-201	-718	-683	-26.4	-1850	-1737	-16.8	-2750	-1077	-1238	-1162	-2826	-1279	-1959
■ Min Stress	265.7	177.6	285.3	123.3	98.86	58.39	69.68	33.56	92.39	186.3	151.2	157.9	34.13	33.64	169.5	59.98	38.25	198.5	10.75	58.86	19.19	21.18	69.64	49.73	73.56

Figure F3. Stresses Under 50 kips Vertical Force (Force Applied Downward) (1 of 2)



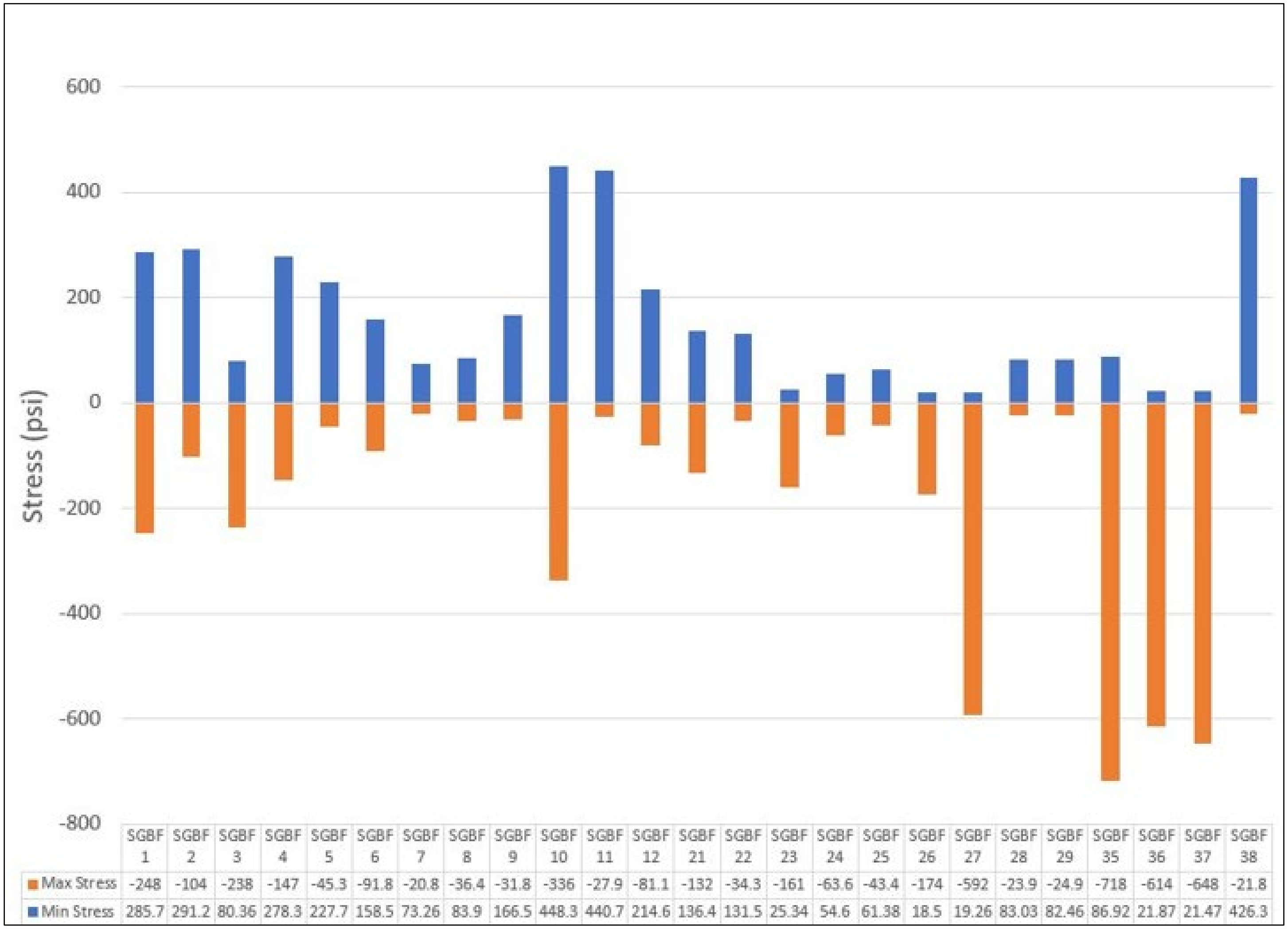
	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16
🟧 Max Stress	-6211	-1336	-1572	-1496	-1095	-8241	-8309	-6074	-1884	-20.6	-38.3	-42.1	-67.5
🟦 Min Stress	15.3	27.39	20.93	38.96	22.08	70.39	69.7	21.06	12.63	80.72	107.2	47.55	45.08

	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
🟧 Max Stress	-313	-286	-368	-509	-346	-542	-14.2	-35.6	-201	-43.8	-0.73	-45.3	-25.6
🟦 Min Stress	110.9	109.5	40.4	71.79	82.36	58.55	7305	7950	101.7	154.6	145.9	435.1	327.7

Figure F4. Stresses Under 50 kips Vertical Force (Force Applied Downward) (2 of 2)

APPENDIX G: JACKING TEST RESULTS

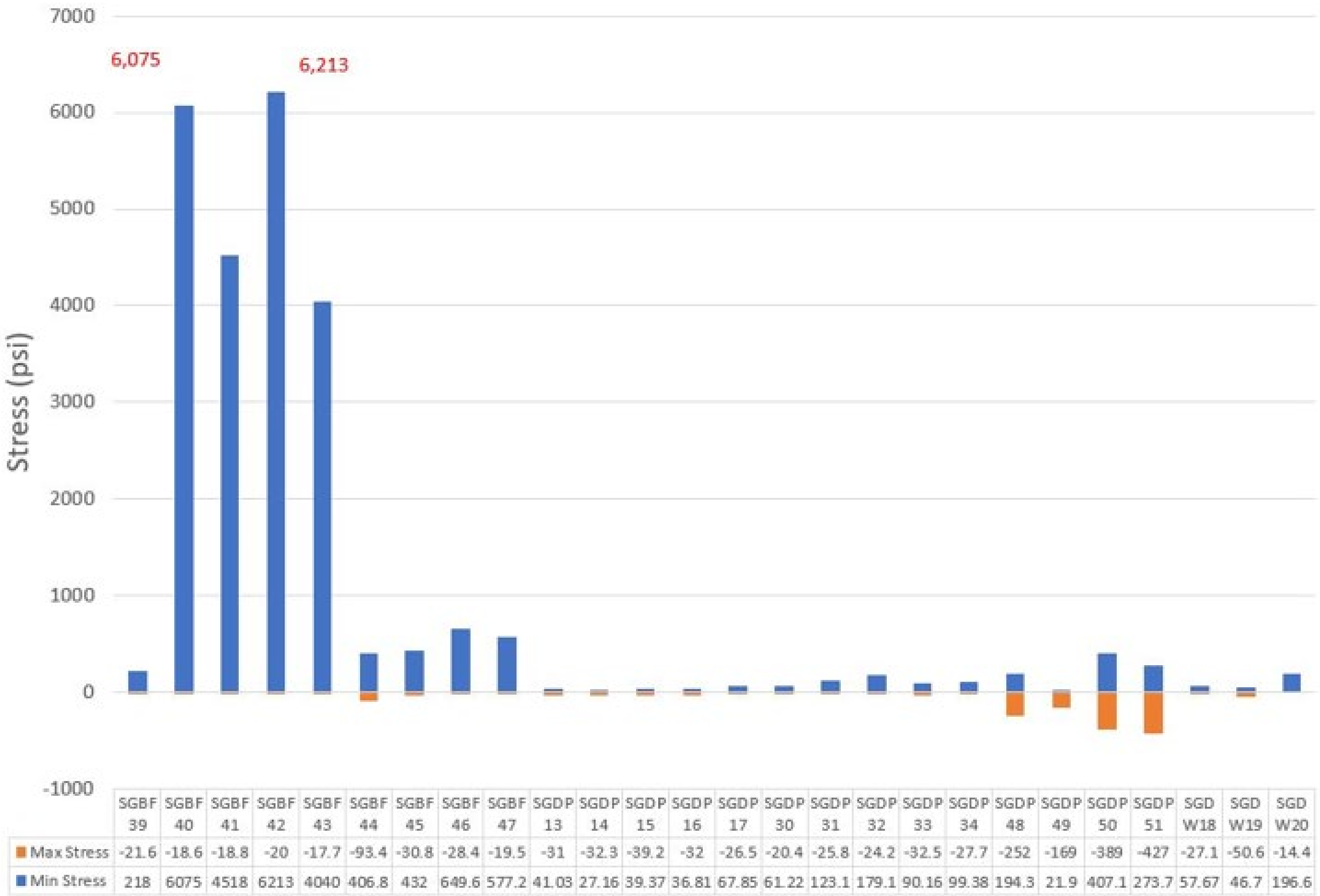
List of Figures



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12
🟧 Max Stress	-248	-104	-238	-147	-45.3	-91.8	-20.8	-36.4	-31.8	-336	-27.9	-81.1
🟦 Min Stress	285.7	291.2	80.36	278.3	227.7	158.5	73.26	83.9	166.5	448.3	440.7	214.6

	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
🟧 Max Stress	-132	-34.3	-161	-63.6	-43.4	-174	-592	-23.9	-24.9	-718	-614	-648	-21.8
🟦 Min Stress	136.4	131.5	25.34	54.6	61.38	18.5	19.26	83.03	82.46	86.92	21.87	21.47	426.3

Figure G1. Jacking Test Stresses (1 of 2)



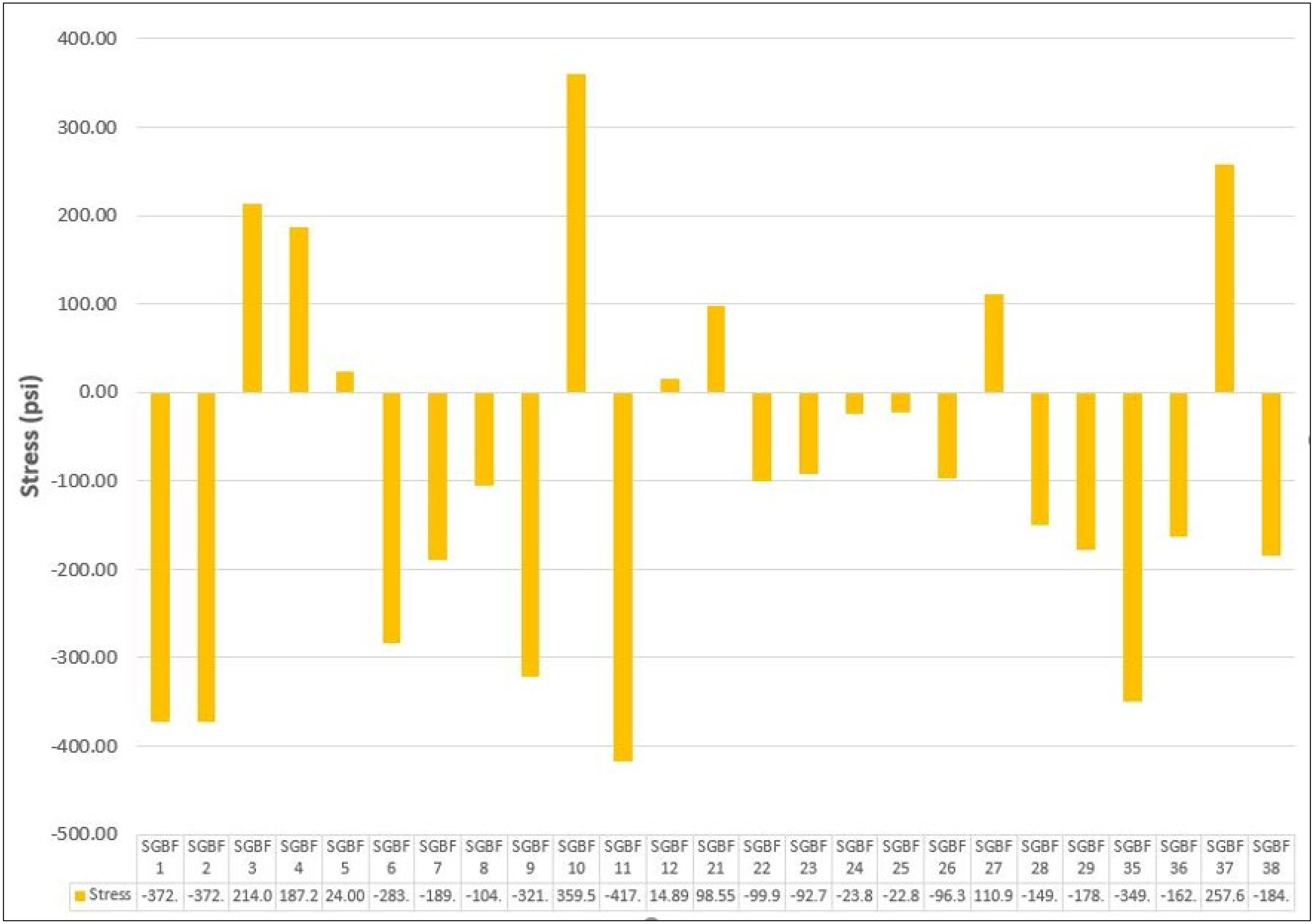
	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
🟧 Max Stress	-21.6	-18.6	-18.8	-20	-17.7	-93.4	-30.8	-28.4	-19.5	-31	-32.3	-39.2	-32	-26.5	-20.4	-25.8	-24.2	-32.5	-27.7	-252	-169	-389	-427	-27.1	-50.6	-14.4
🟦 Min Stress	218	6075	4518	6213	4040	406.8	432	649.6	577.2	41.03	27.16	39.37	36.81	67.85	61.22	123.1	179.1	90.16	99.38	194.3	21.9	407.1	273.7	57.67	46.7	196.6

Figure G2. Jacking Test Stresses (2 of 2)

APPENDIX H: CARBODY TWIST RESULTS

Additional results in the form of stresses from individual strain gauges from the carbody twist test are presented.

List of Figures



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
■ Stress	-372.	-372.	214.0	187.2	24.00	-283.	-189.	-104.	-321.	359.5	-417.	14.89	98.55	-99.9	-92.7	-23.8	-22.8	-96.3	110.9	-149.	-178.	-349.	-162.	257.6	-184.

Figure H1. Twist Stresses, A-End Left Side (1 of 2)

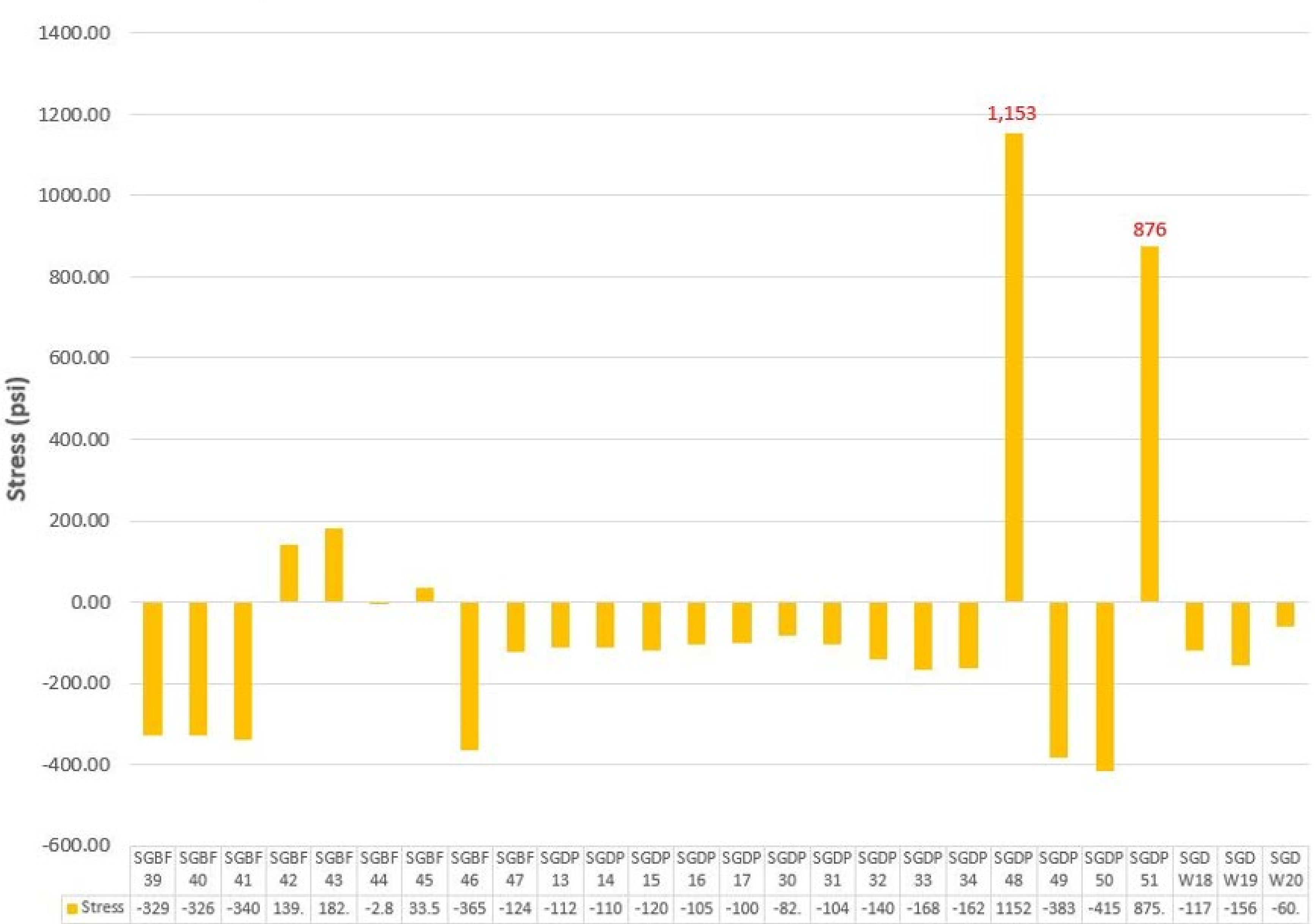


Figure H2. Twist Stresses, A-End Left Side (2 of 2)

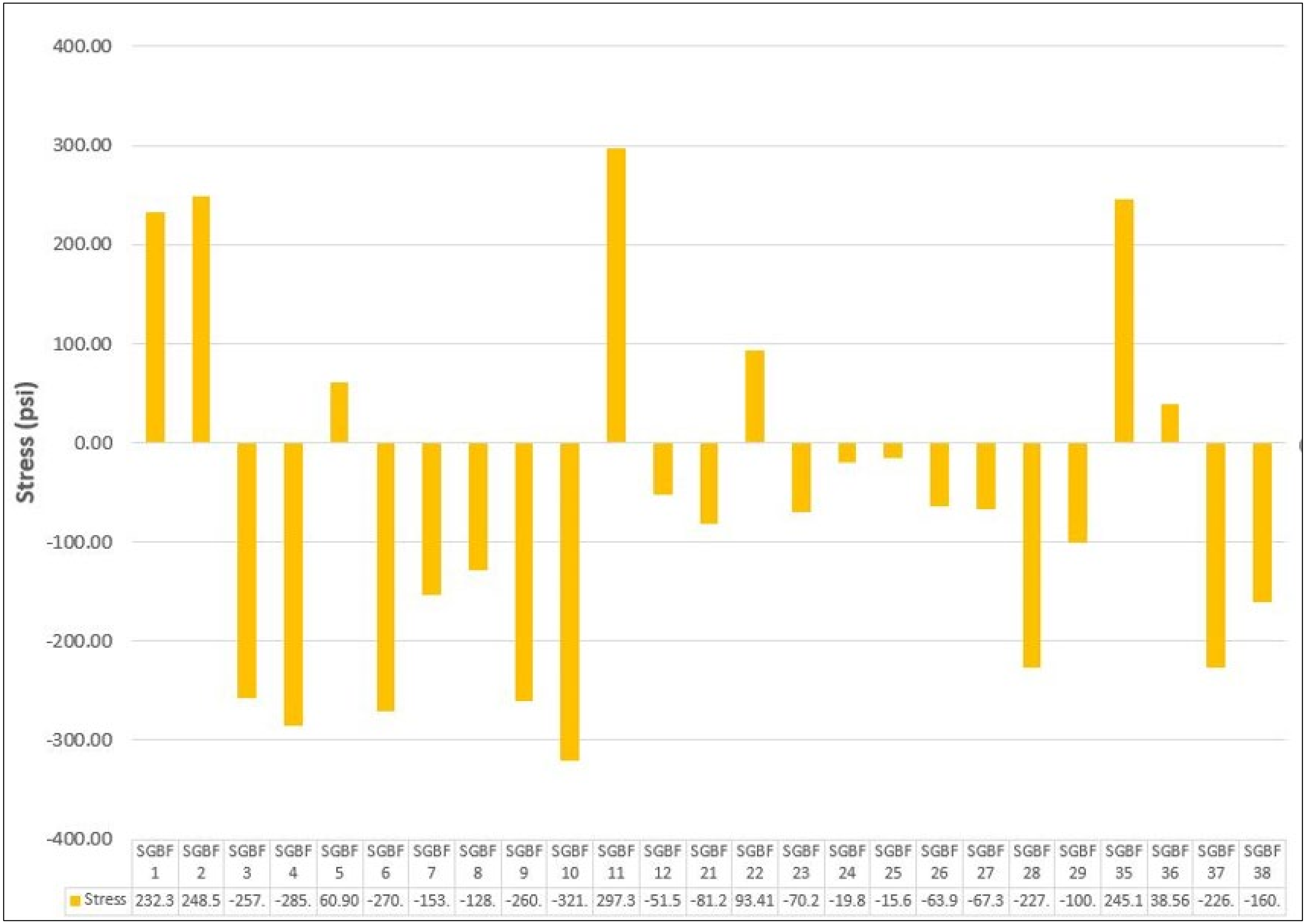


Figure H3. Twist Stresses, A-End Right Side (1 of 2)

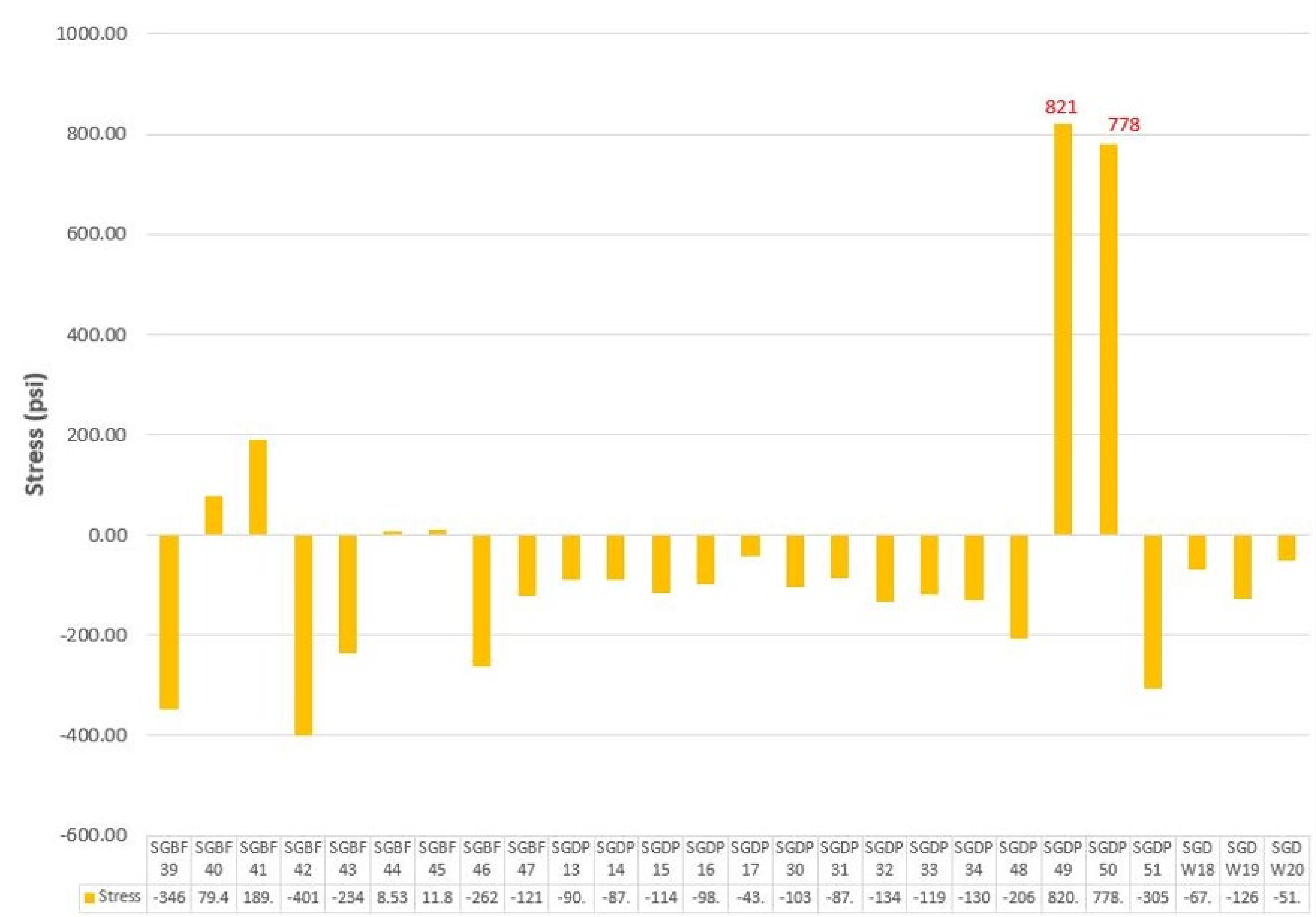
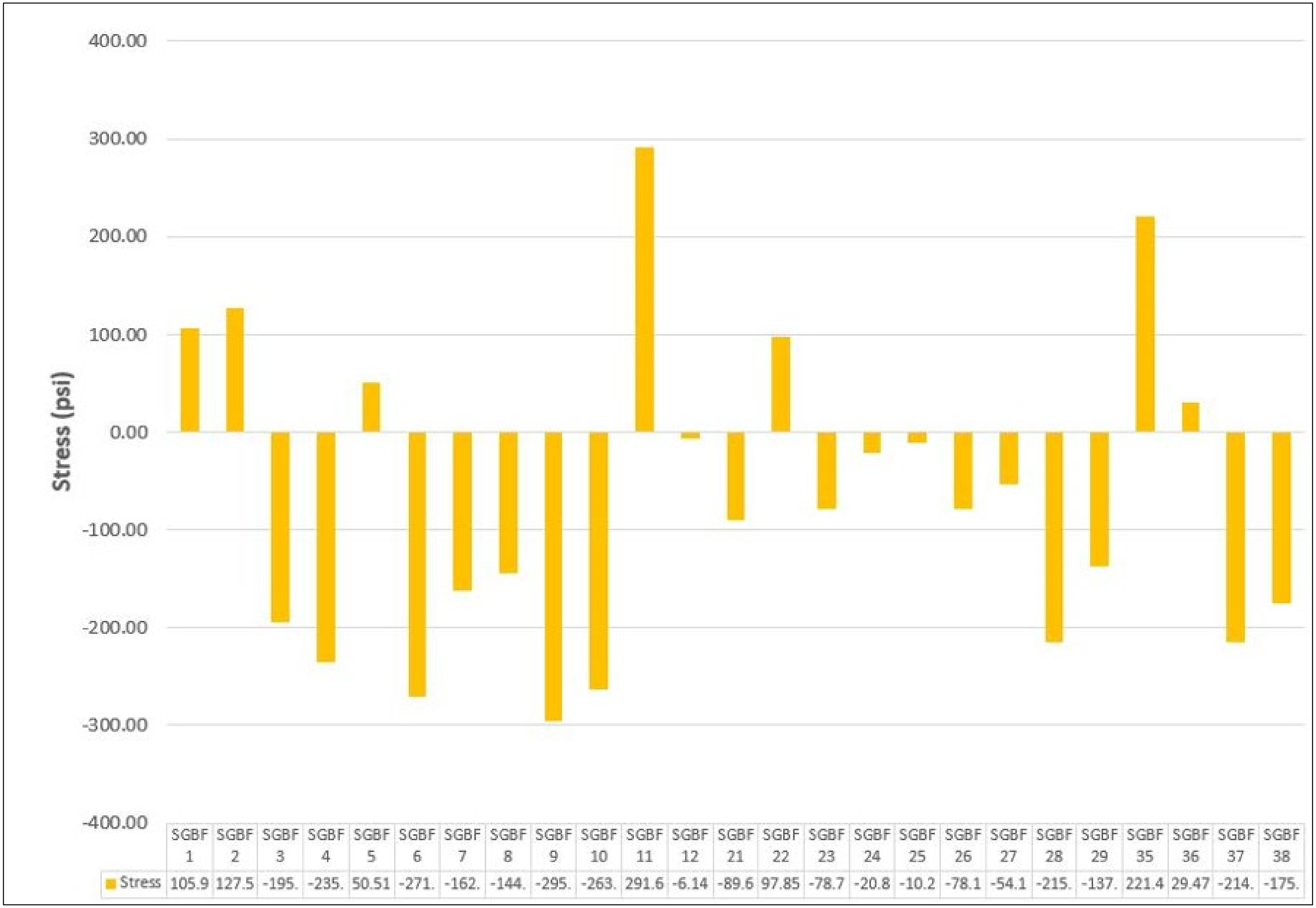


Figure H4. Twist Stresses, A-End Right Side (2 of 2)



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
■ Stress	105.9	127.5	-195.	-235.	50.51	-271.	-162.	-144.	-295.	-263.	291.6	-6.14	-89.6	97.85	-78.7	-20.8	-10.2	-78.1	-54.1	-215.	-137.	221.4	29.47	-214.	-175.

Figure H5. Twist Stresses, B-End Left Side (1 of 2)

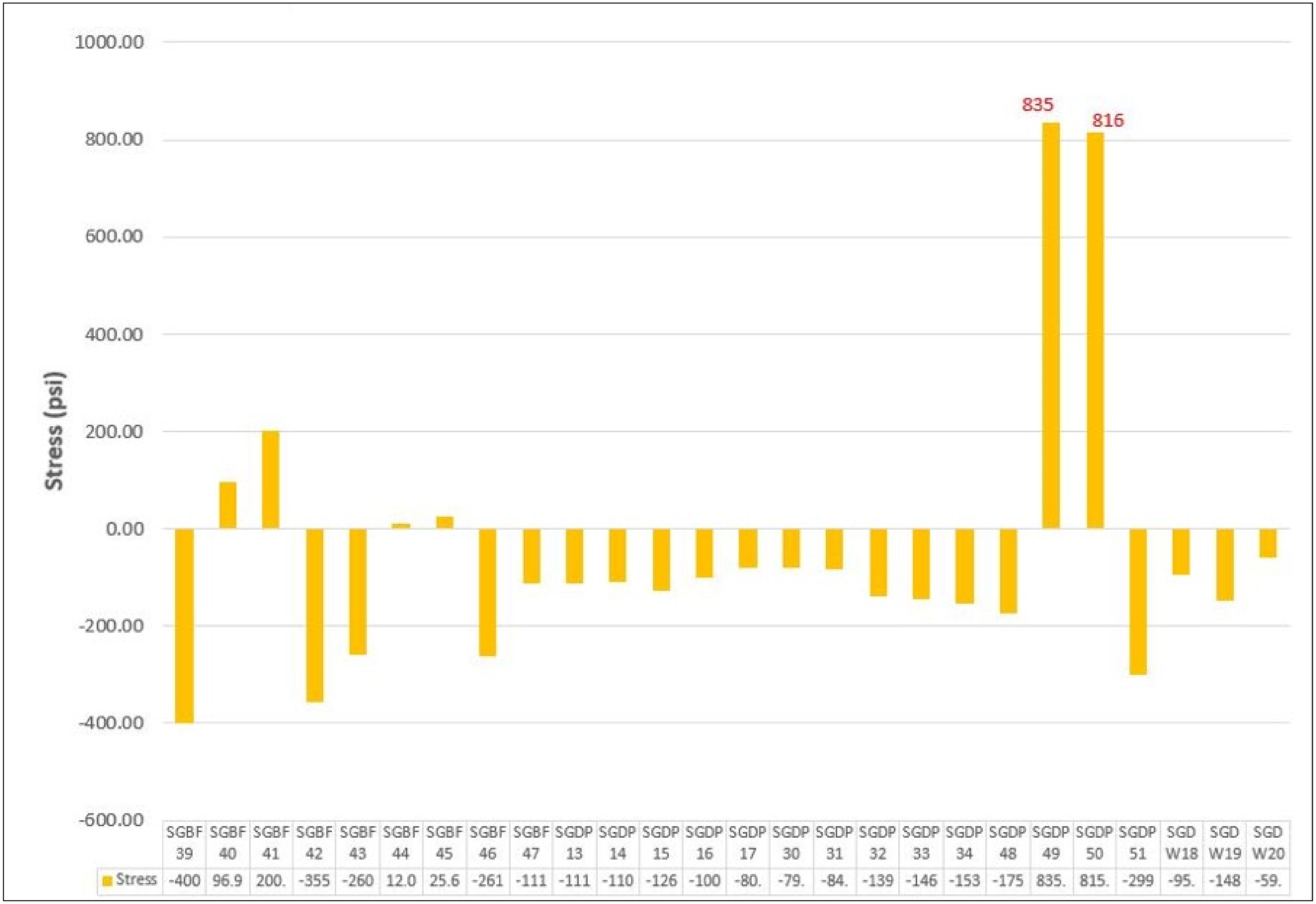
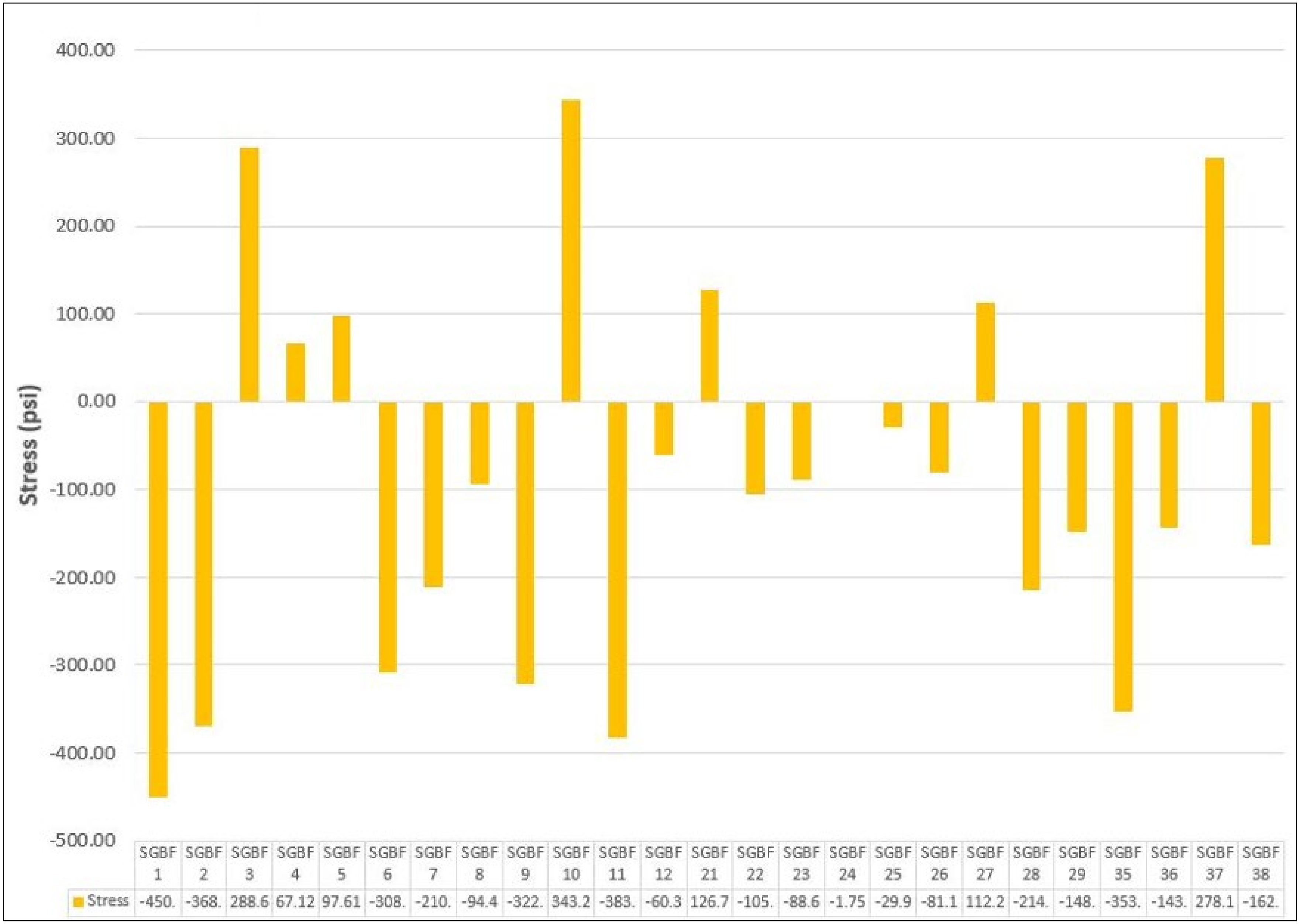
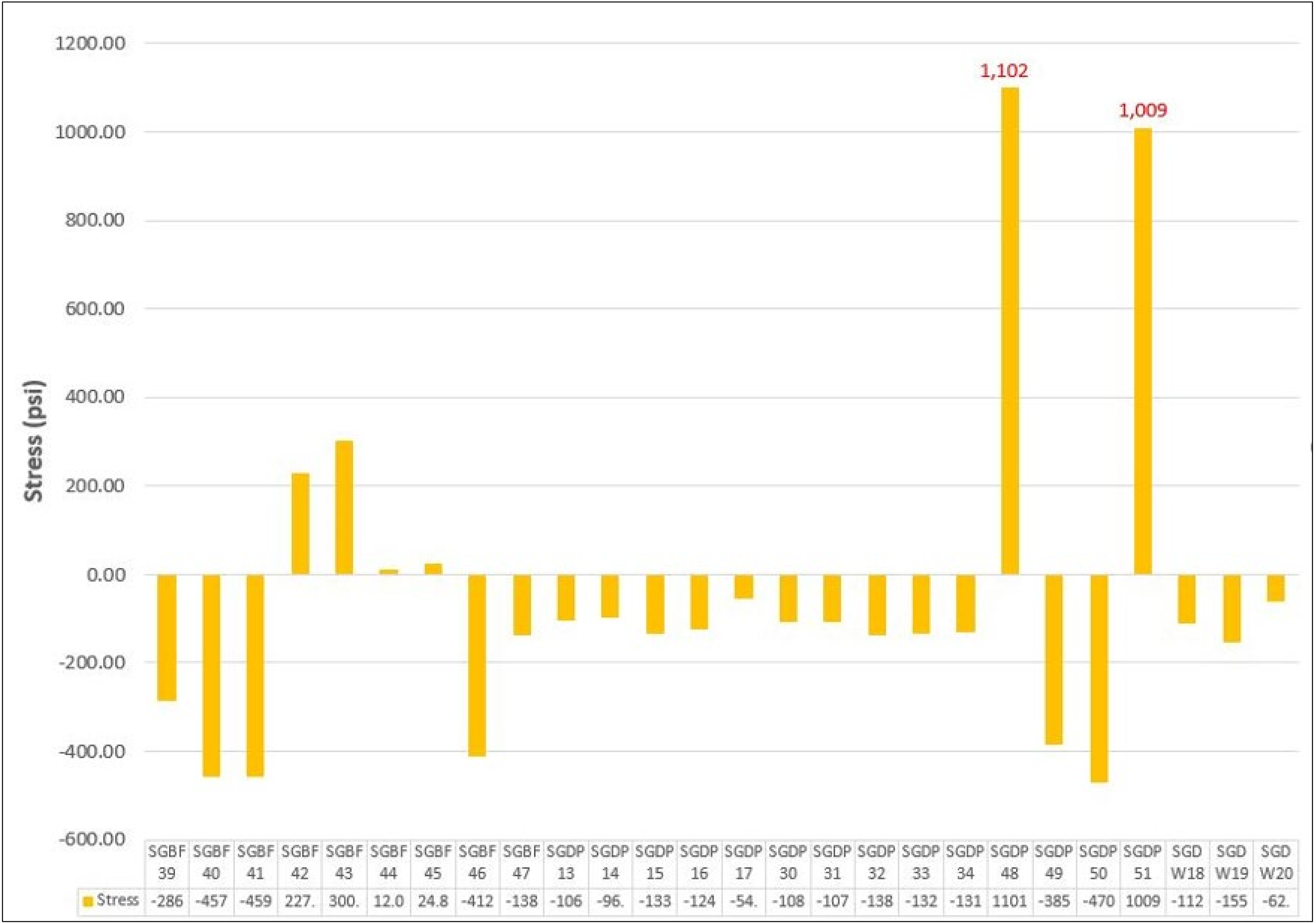


Figure H6. Twist Stresses. B-End Left Side (2 of 2)



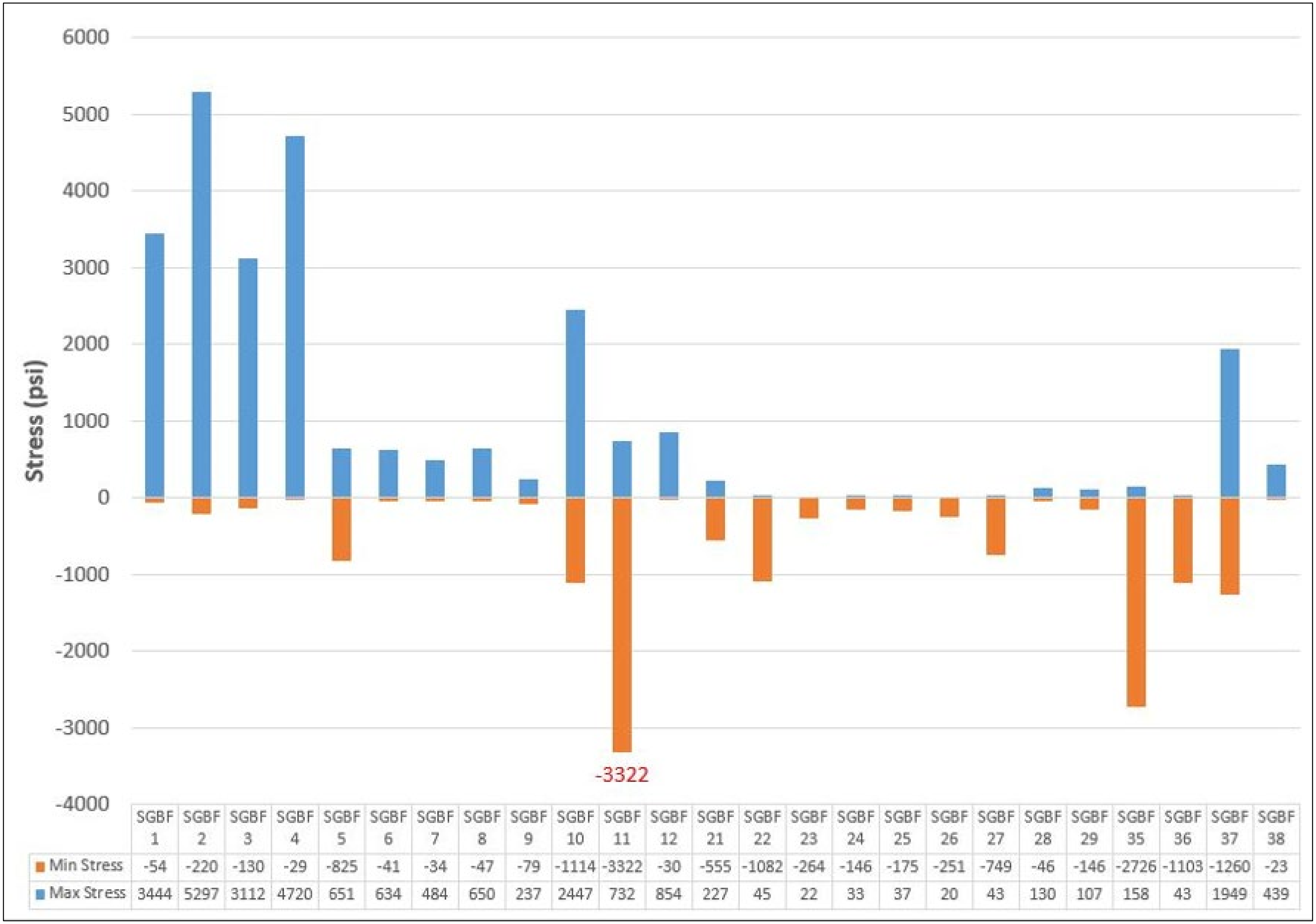
	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
■ Stress	-450.	-368.	288.6	67.12	97.61	-308.	-210.	-94.4	-322.	343.2	-383.	-60.3	126.7	-105.	-88.6	-1.75	-29.9	-81.1	112.2	-214.	-148.	-353.	-143.	278.1	-162.

Figure H7. Twist Stresses. B-End Right Side (1 of 2)



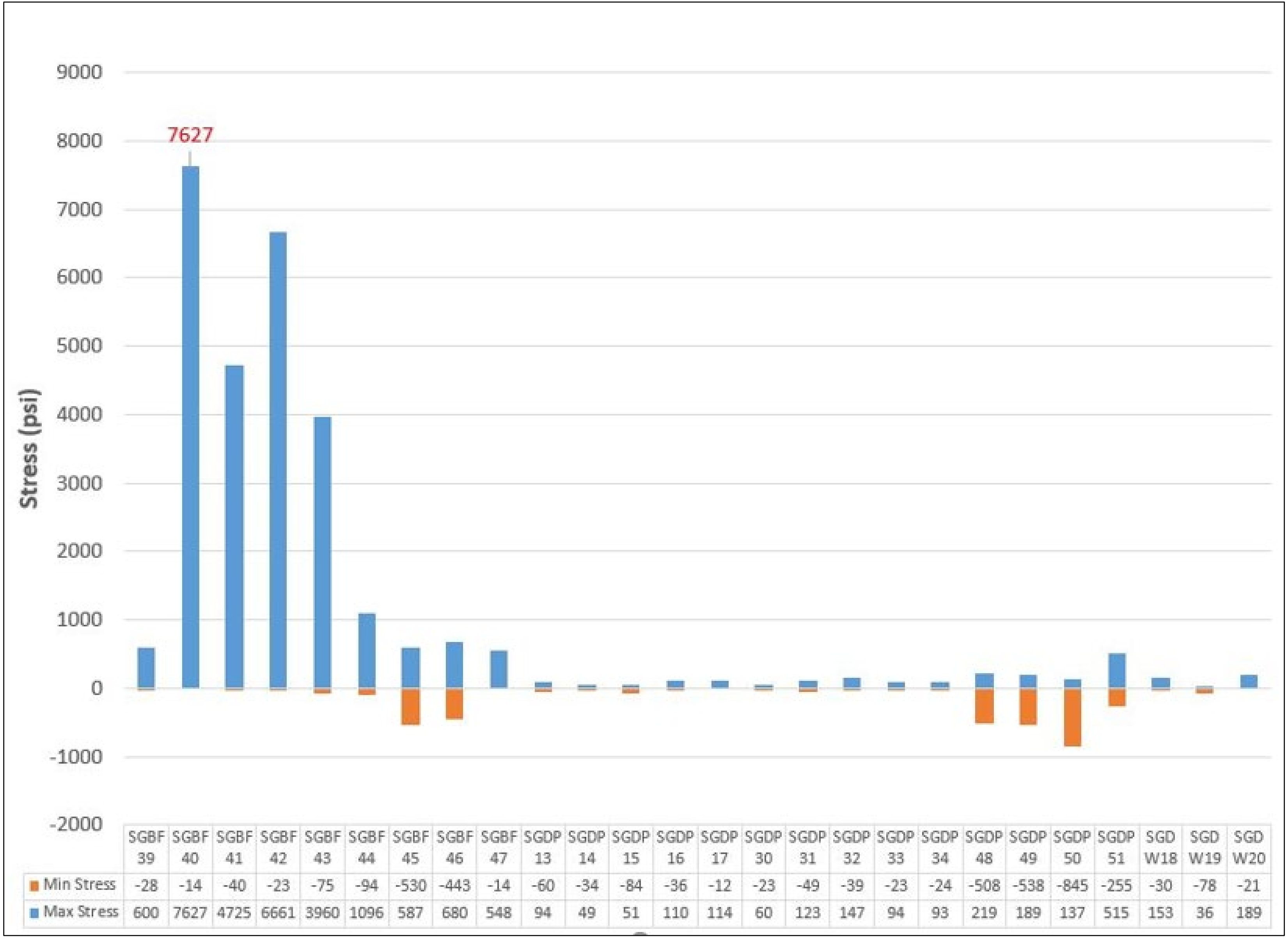
	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
■ Stress	-286	-457	-459	227.	300.	12.0	24.8	-412	-138	-106	-96.	-133	-124	-54.	-108	-107	-138	-132	-131	1101	-385	-470	1009	-112	-155	-62.

Figure H8. Twist Stresses. B-End Right Side (2 of 2)



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
■ Min Stress	-54	-220	-130	-29	-825	-41	-34	-47	-79	-1114	-3322	-30	-555	-1082	-264	-146	-175	-251	-749	-46	-146	-2726	-1103	-1260	-23
■ Max Stress	3444	5297	3112	4720	651	634	484	650	237	2447	732	854	227	45	22	33	37	20	43	130	107	158	43	1949	439

Figure H9. Twist Stresses Part 2 (1 of 2)



	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
■ Min Stress	-28	-14	-40	-23	-75	-94	-530	-443	-14	-60	-34	-84	-36	-12	-23	-49	-39	-23	-24	-508	-538	-845	-255	-30	-78	-21
■ Max Stress	600	7627	4725	6661	3960	1096	587	680	548	94	49	51	110	114	60	123	147	94	93	219	189	137	515	153	36	189

Figure H10. Twist Stresses Part 2 (2 of 2)

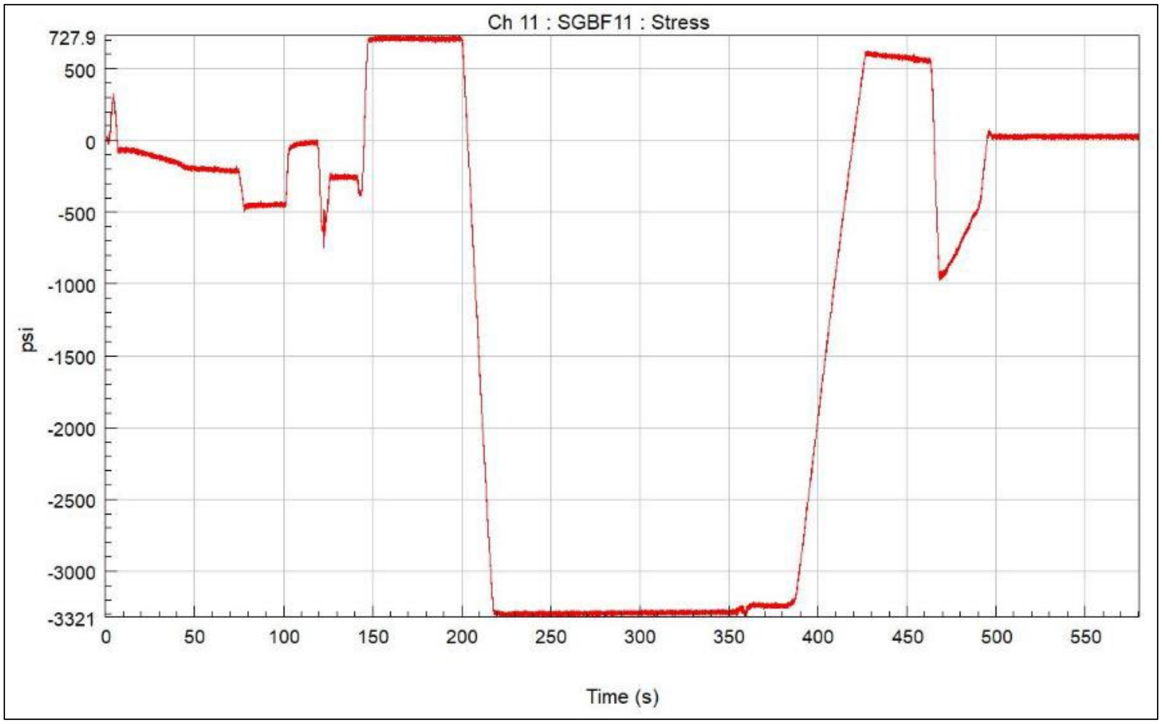


Figure H11. Twist Stresses Part 2 SGBF11

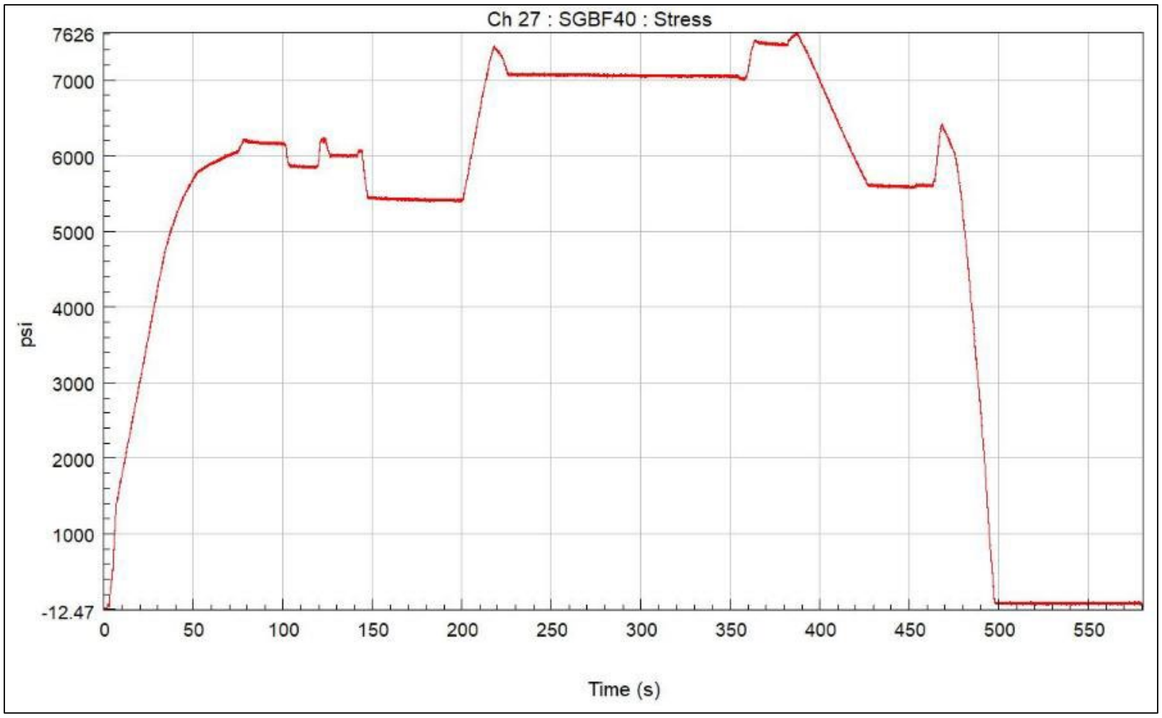
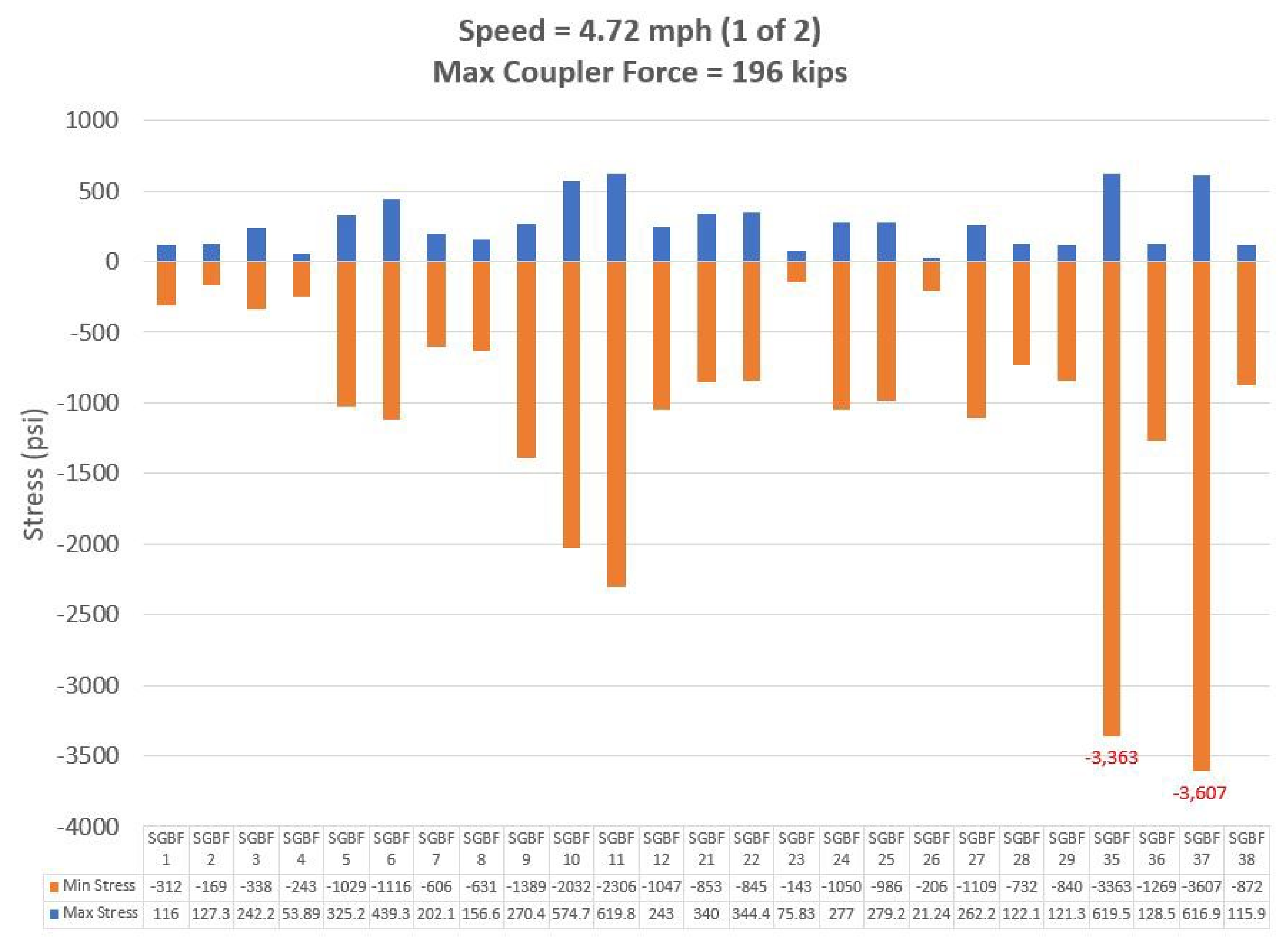


Figure H12. Twist Stresses Part 2 SGBF40

APPENDIX I: IMPACT TESTS

Additional results for individual strain gauges during the impact test are presented in Figures I1 through I16.

List of Figures



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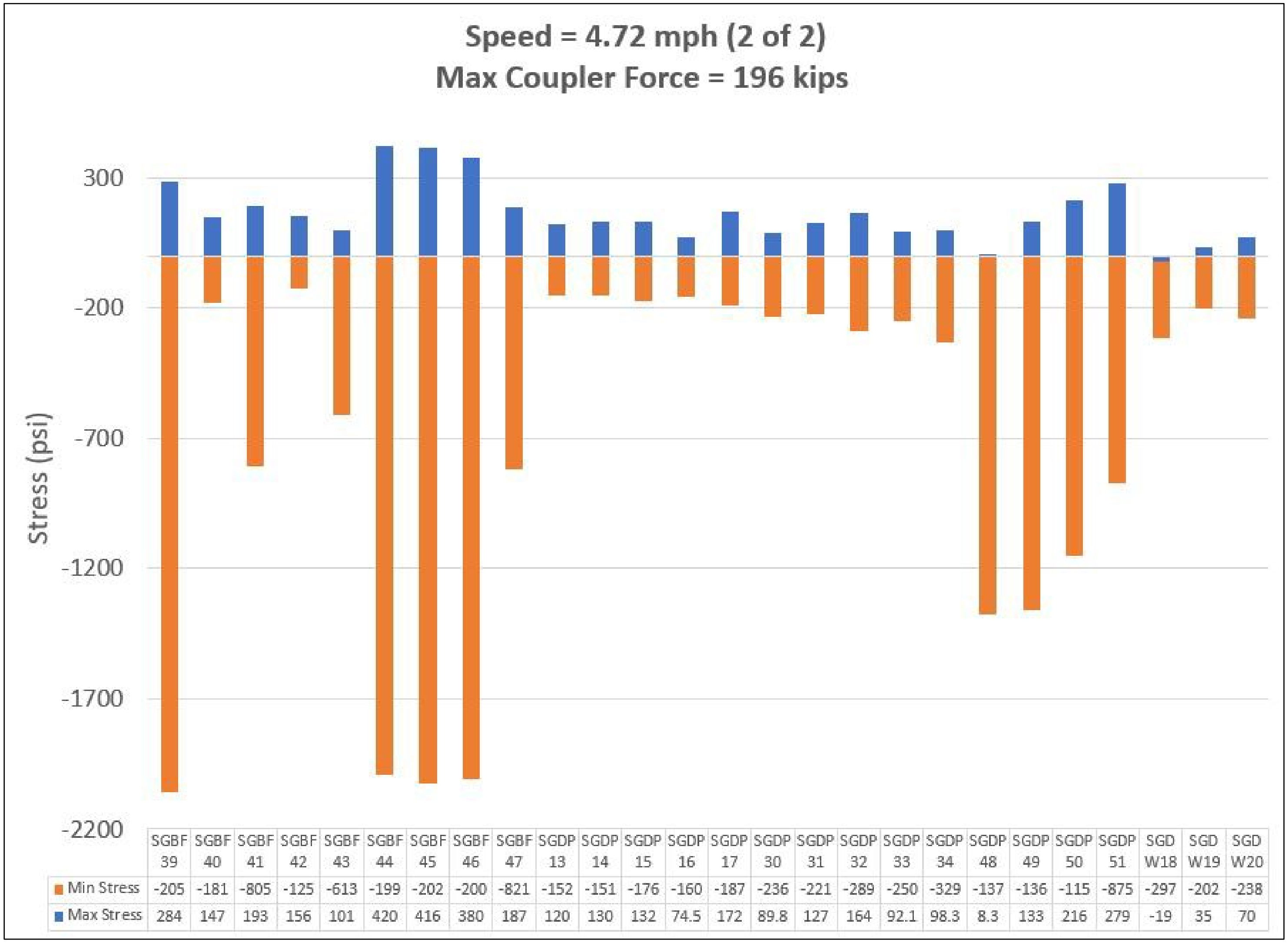
🟧 Min Stress	-312	-169	-338	-243	-1029	-1116	-606	-631	-1389	-2032	-2306	-1047	-853	-845	-143	-1050	-986	-206	-1109	-732	-840	-3363	-1269	-3607	-872
🟦 Max Stress	116	127.3	242.2	53.89	325.2	439.3	202.1	156.6	270.4	574.7	619.8	243	340	344.4	75.83	277	279.2	21.24	262.2	122.1	121.3	619.5	128.5	616.9	115.9

Figure I1. Stresses at 4 mph Nominal Test Speed. (1 of 2)



	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
■ Min Stress	-205	-181	-805	-125	-613	-199	-202	-200	-821	-152	-151	-176	-160	-187	-236	-221	-289	-250	-329	-137	-136	-115	-875	-297	-202	-238
■ Max Stress	284	147	193	156	101	420	416	380	187	120	130	132	74.5	172	89.8	127	164	92.1	98.3	8.3	133	216	279	-19	35	70

Figure I2. Stresses at 4 mph Nominal Test Speed. (2 of 2)

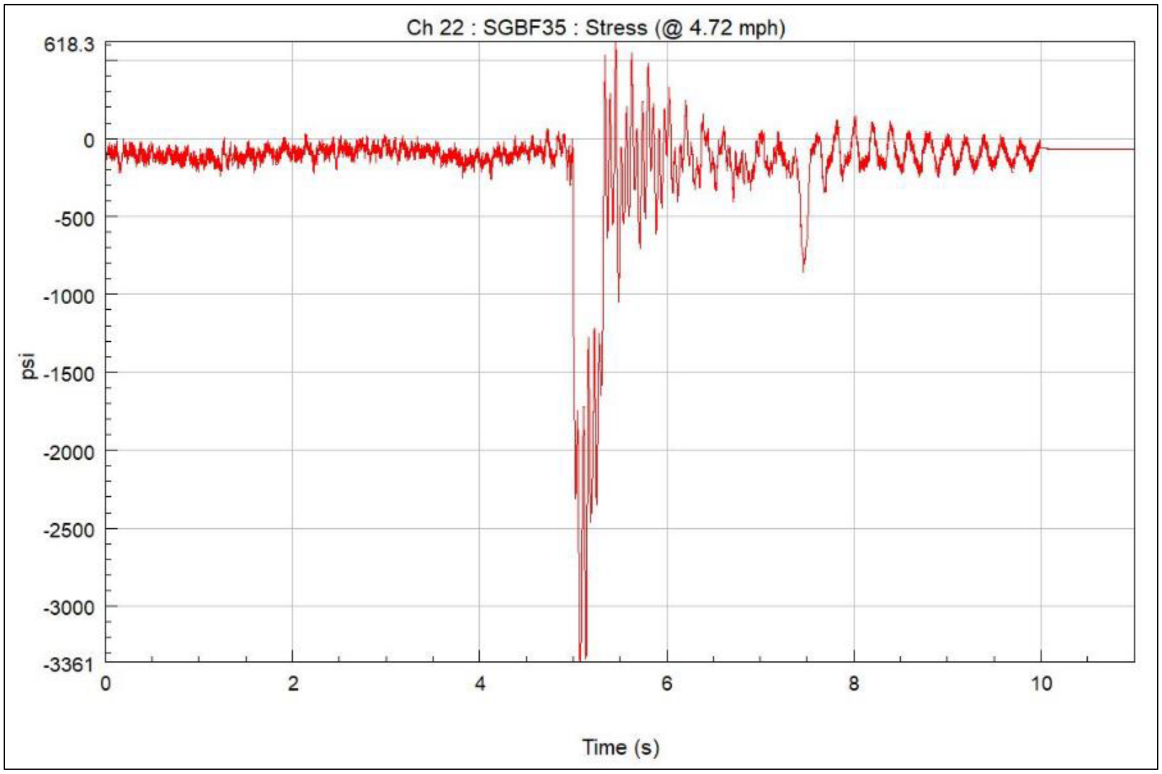


Figure I3. Dynamic Stresses, SGBF35, 4mph Nominal Speed

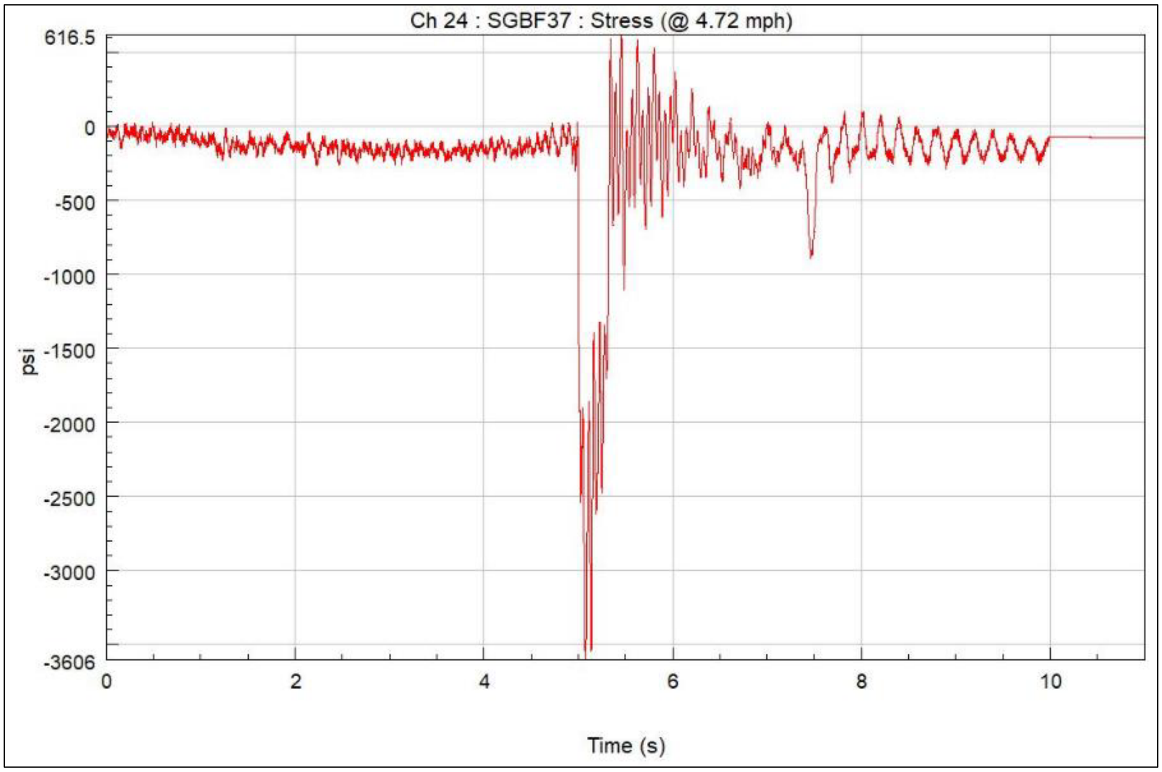
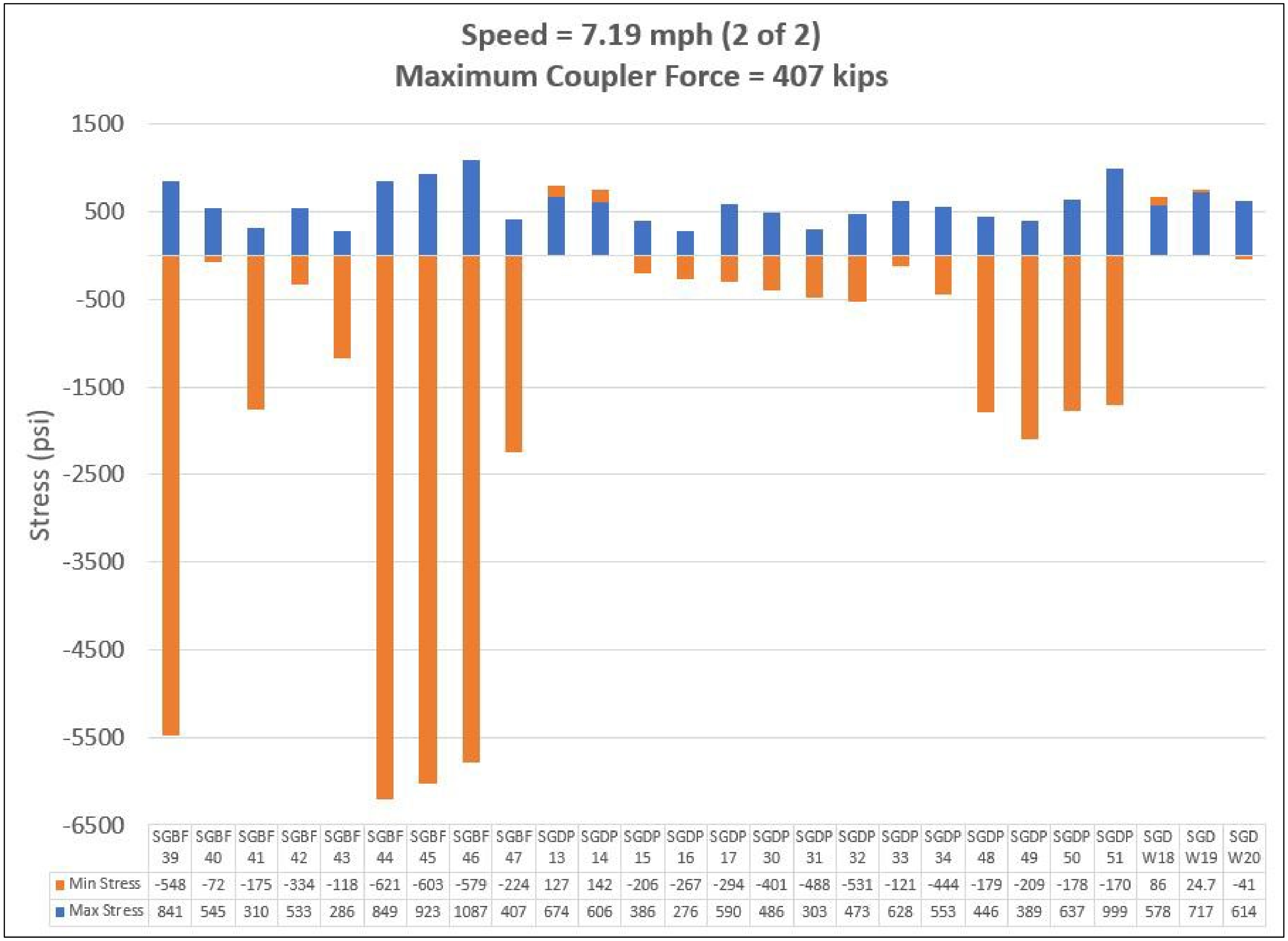


Figure I4. Dynamic Stresses. SGBF37, 4 mph Nominal Speed

	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
🟧 Min Stress	-58.4	-254	-96.3	-379	-2496	-3242	-1403	-1271	-2874	-4579	-5125	-2333	-1980	-1914	-72.7	-3015	-2831	-43.5	-2927	-1881	-2433	-9732	-2889	-1063	-1795
🟦 Max Stress	593.7	301.4	509.6	295	1260	1399	632.6	449.3	1330	2322	2513	1198	829.1	877.8	445.9	734.8	619	425.3	652.5	589.8	598.3	1728	830	1779	666.7

Figure I5. Stresses at 6 mph Nominal Test Speed. (1 of 2)



	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
🟧 Min Stress	-548	-72	-175	-334	-118	-621	-603	-579	-224	127	142	-206	-267	-294	-401	-488	-531	-121	-444	-179	-209	-178	-170	86	24.7	-41
🟦 Max Stress	841	545	310	533	286	849	923	1087	407	674	606	386	276	590	486	303	473	628	553	446	389	637	999	578	717	614

Figure I6. Stresses at 6 mph Nominal Test Speed. (2 of 2)

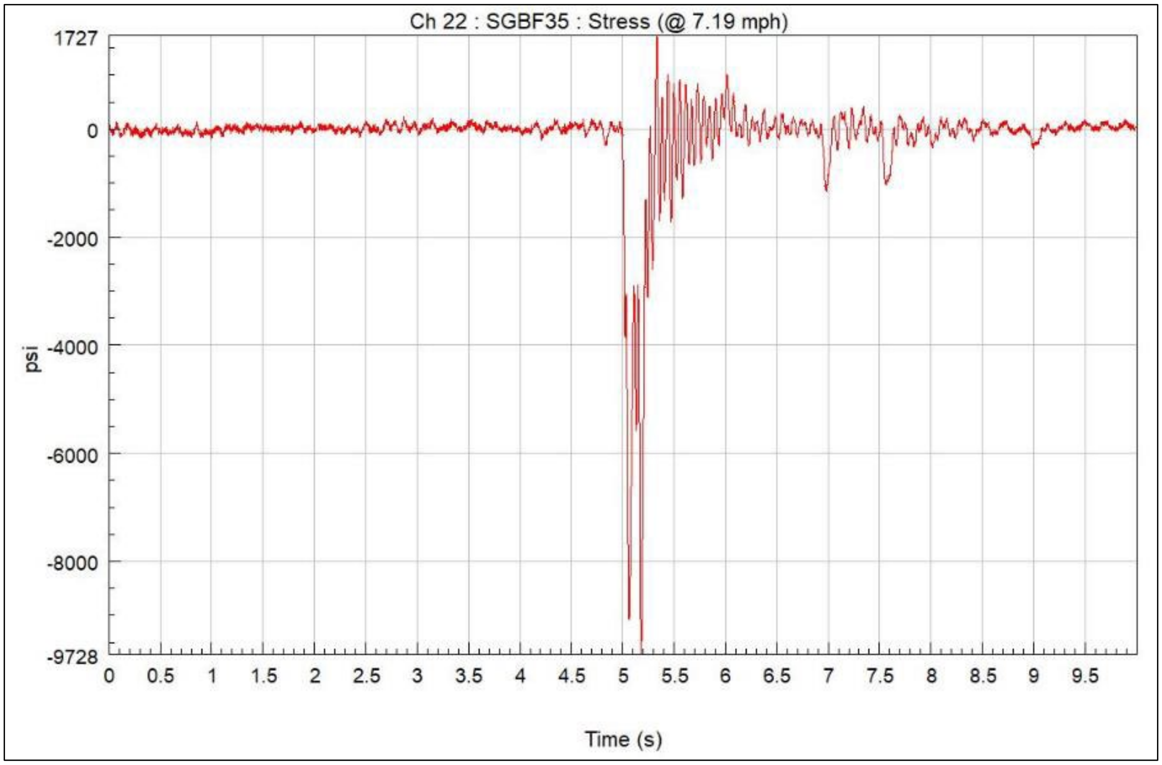


Figure I7. Dynamic Stresses, SGBF35, 6 mph Nominal Speed

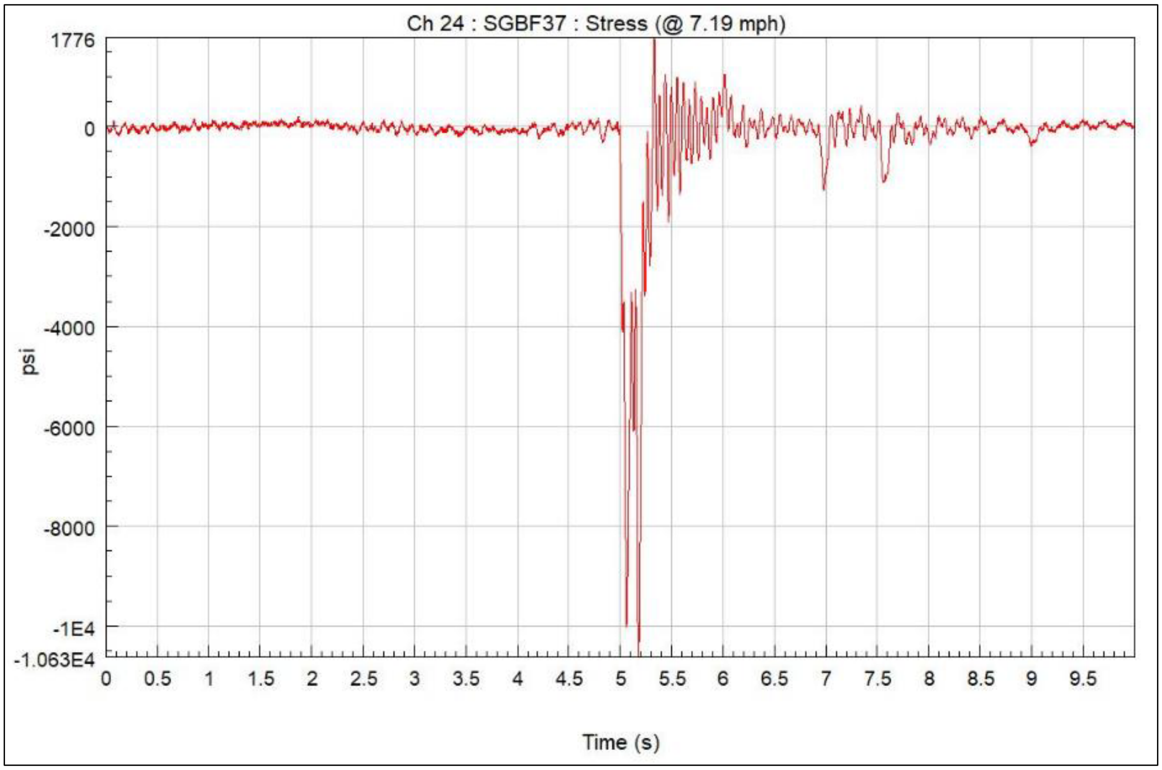
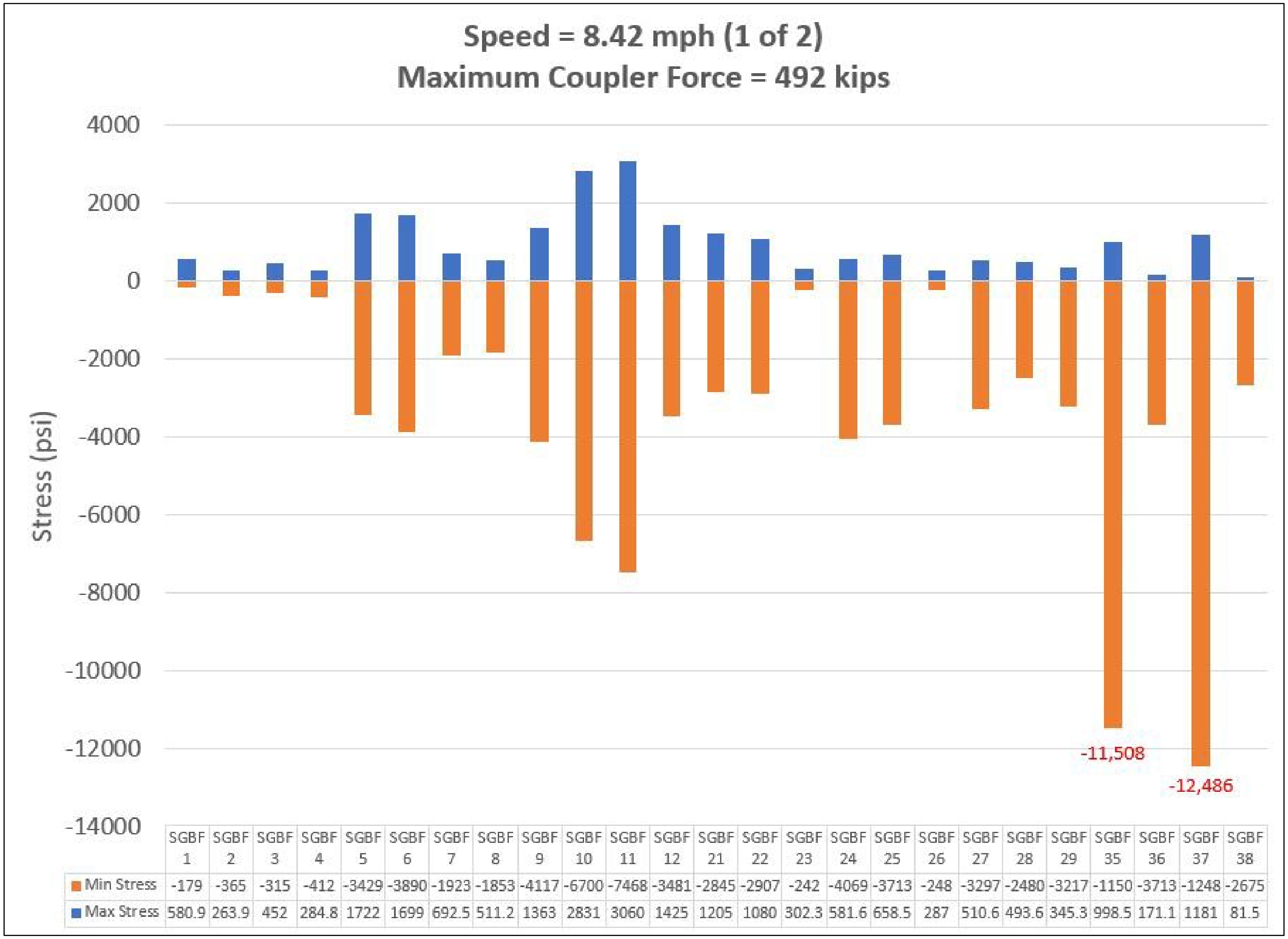
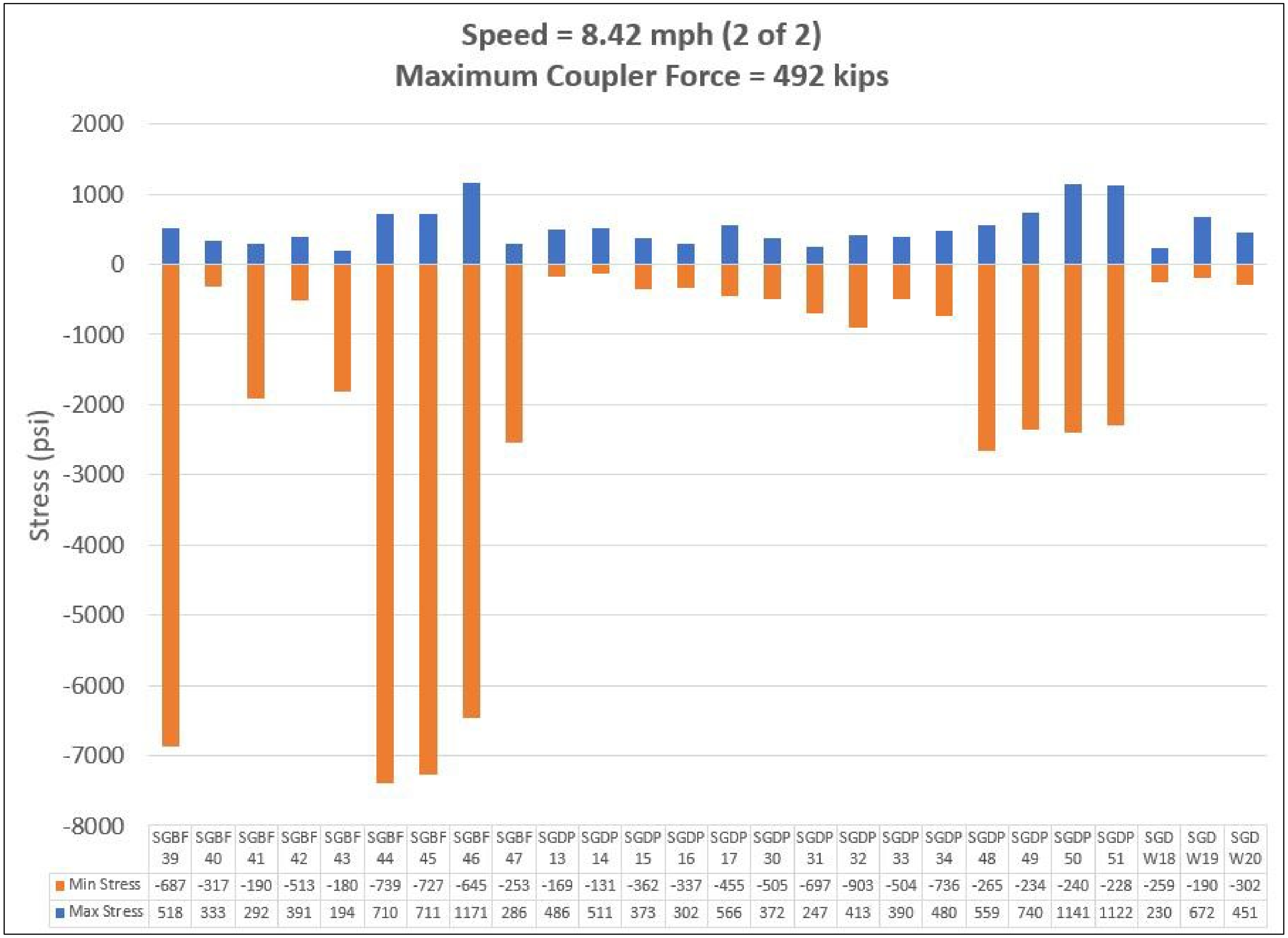


Figure I8. Dynamic Stresses. SGBF37, 6 mph Nominal Speed



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
■ Min Stress	-179	-365	-315	-412	-3429	-3890	-1923	-1853	-4117	-6700	-7468	-3481	-2845	-2907	-242	-4069	-3713	-248	-3297	-2480	-3217	-1150	-3713	-1248	-2675
■ Max Stress	580.9	263.9	452	284.8	1722	1699	692.5	511.2	1363	2831	3060	1425	1205	1080	302.3	581.6	658.5	287	510.6	493.6	345.3	998.5	171.1	1181	81.5

Figure I9. Stresses at 8 mph Nominal Test Speed. (1 of 2)



	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGDP 13	SGDP 14	SGDP 15	SGDP 16	SGDP 17	SGDP 30	SGDP 31	SGDP 32	SGDP 33	SGDP 34	SGDP 48	SGDP 49	SGDP 50	SGDP 51	SGD W18	SGD W19	SGD W20
🟧 Min Stress	-687	-317	-190	-513	-180	-739	-727	-645	-253	-169	-131	-362	-337	-455	-505	-697	-903	-504	-736	-265	-234	-240	-228	-259	-190	-302
🟦 Max Stress	518	333	292	391	194	710	711	1171	286	486	511	373	302	566	372	247	413	390	480	559	740	1141	1122	230	672	451

Figure I10. Stresses at 8 mph Nominal Test Speed. (2 of 2)

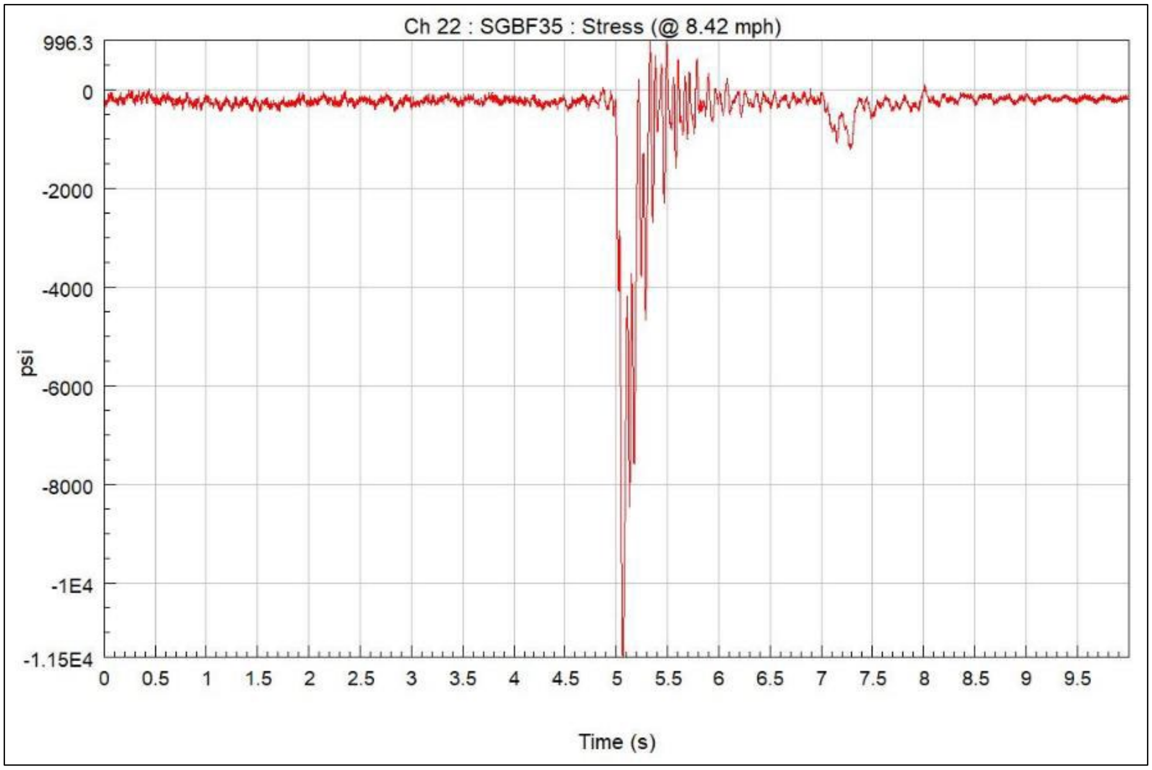


Figure I11. Dynamic Stresses. SGBF35, 8 mph Nominal Speed

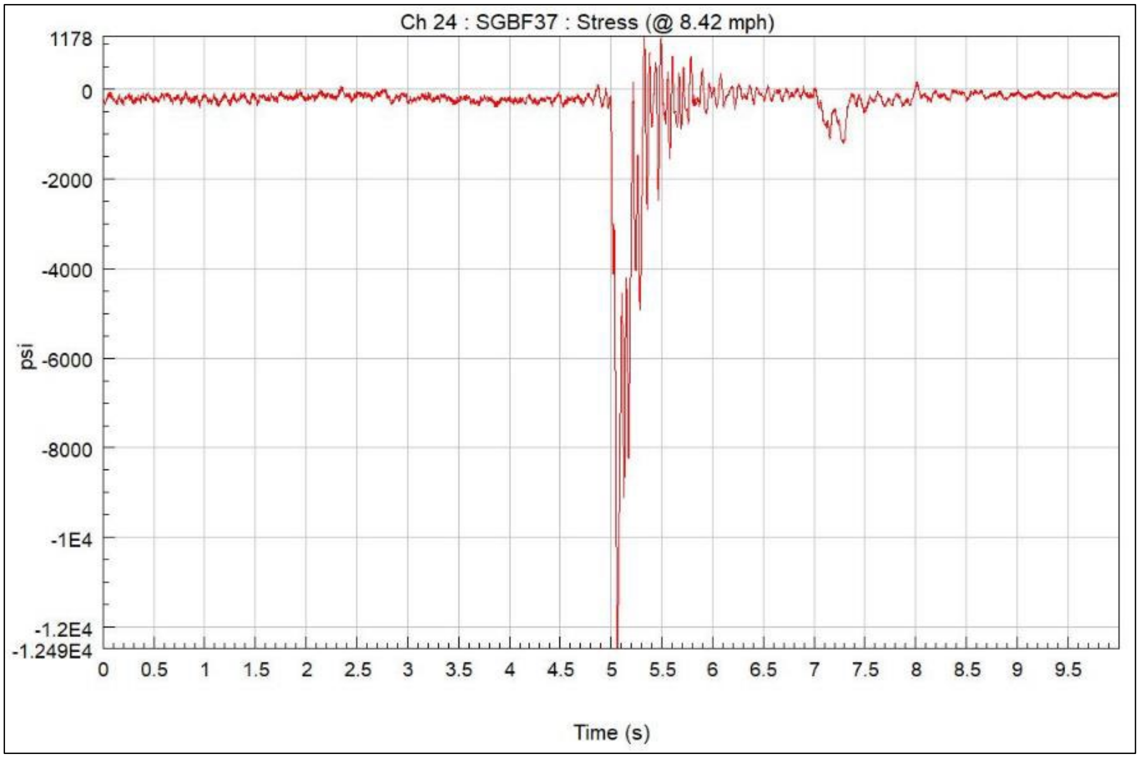
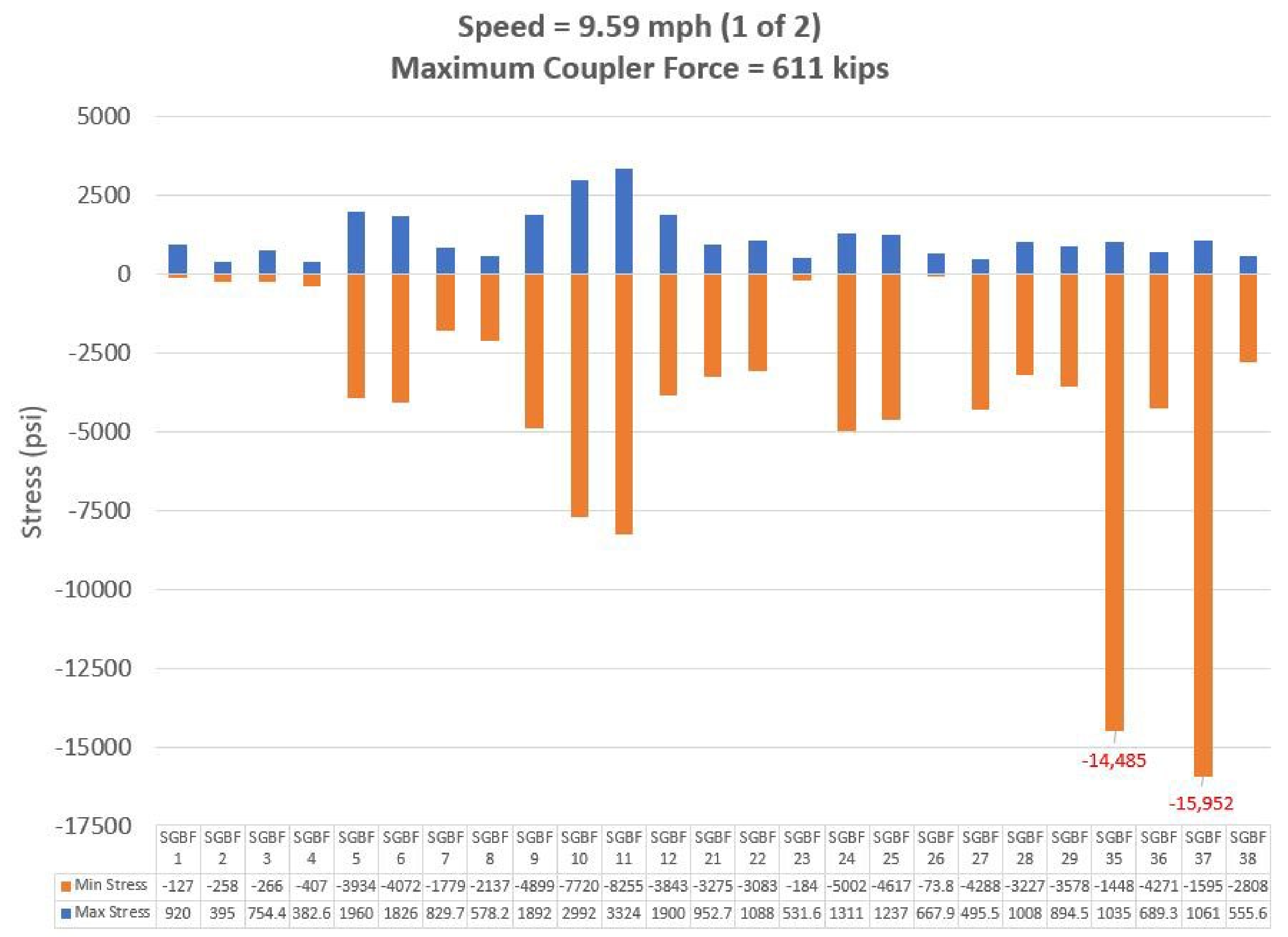
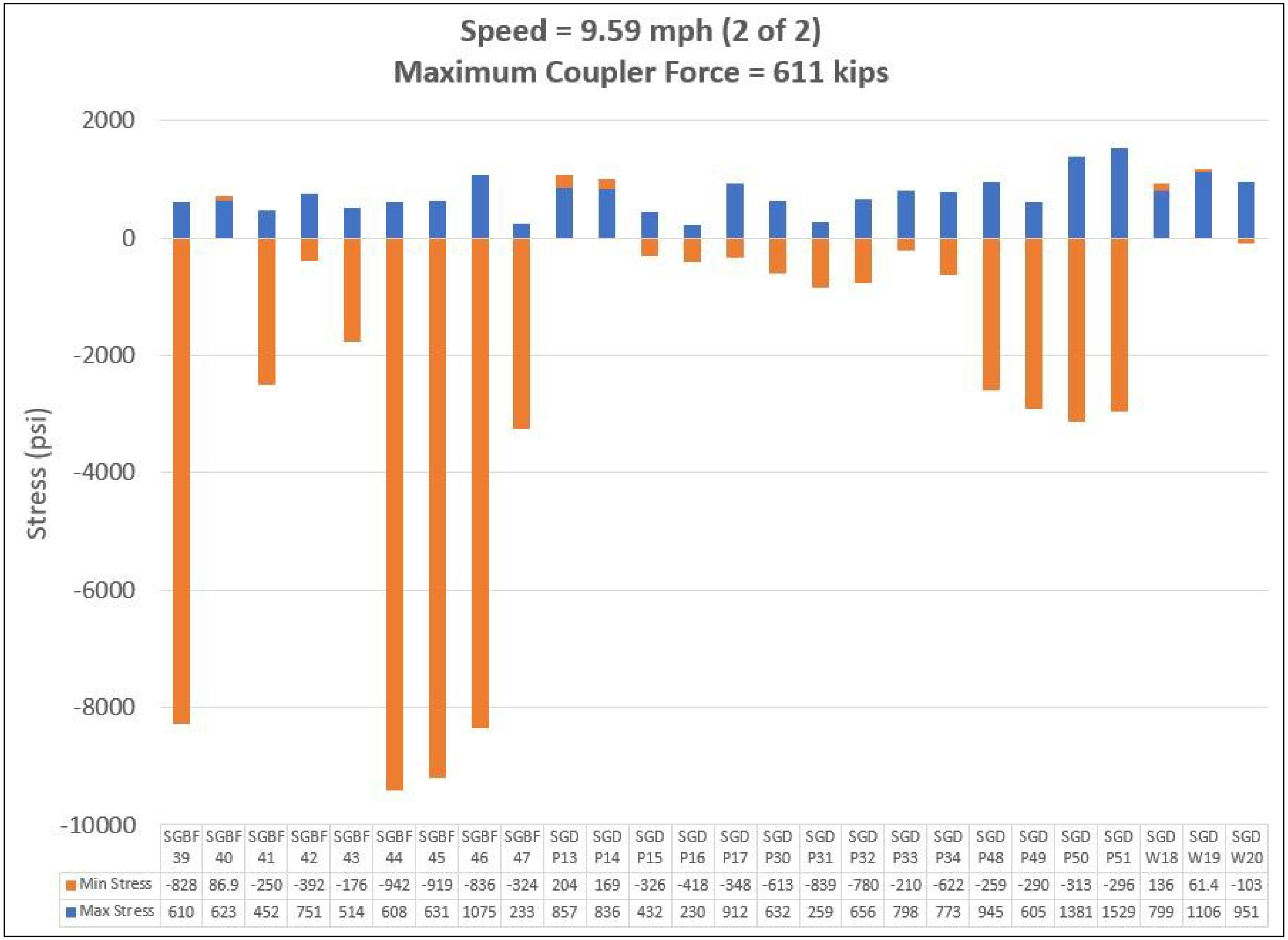


Figure I12. Dynamic Stresses. SGBF37, 8 mph Nominal Speed



	SGBF 1	SGBF 2	SGBF 3	SGBF 4	SGBF 5	SGBF 6	SGBF 7	SGBF 8	SGBF 9	SGBF 10	SGBF 11	SGBF 12	SGBF 21	SGBF 22	SGBF 23	SGBF 24	SGBF 25	SGBF 26	SGBF 27	SGBF 28	SGBF 29	SGBF 35	SGBF 36	SGBF 37	SGBF 38
🟧 Min Stress	-127	-258	-266	-407	-3934	-4072	-1779	-2137	-4899	-7720	-8255	-3843	-3275	-3083	-184	-5002	-4617	-73.8	-4288	-3227	-3578	-1448	-4271	-1595	-2808
🟦 Max Stress	920	395	754.4	382.6	1960	1826	829.7	578.2	1892	2992	3324	1900	952.7	1088	531.6	1311	1237	667.9	495.5	1008	894.5	1035	689.3	1061	555.6

Figure I13. Stresses at 9 mph Nominal Test Speed (1 of 2)



	SGBF 39	SGBF 40	SGBF 41	SGBF 42	SGBF 43	SGBF 44	SGBF 45	SGBF 46	SGBF 47	SGD P13	SGD P14	SGD P15	SGD P16	SGD P17	SGD P30	SGD P31	SGD P32	SGD P33	SGD P34	SGD P48	SGD P49	SGD P50	SGD P51	SGD W18	SGD W19	SGD W20
🟧 Min Stress	-828	86.9	-250	-392	-176	-942	-919	-836	-324	204	169	-326	-418	-348	-613	-839	-780	-210	-622	-259	-290	-313	-296	136	61.4	-103
🟦 Max Stress	610	623	452	751	514	608	631	1075	233	857	836	432	230	912	632	259	656	798	773	945	605	1381	1529	799	1106	951

Figure I14. Stresses at 9 mph Nominal Test Speed. (2 of 2)

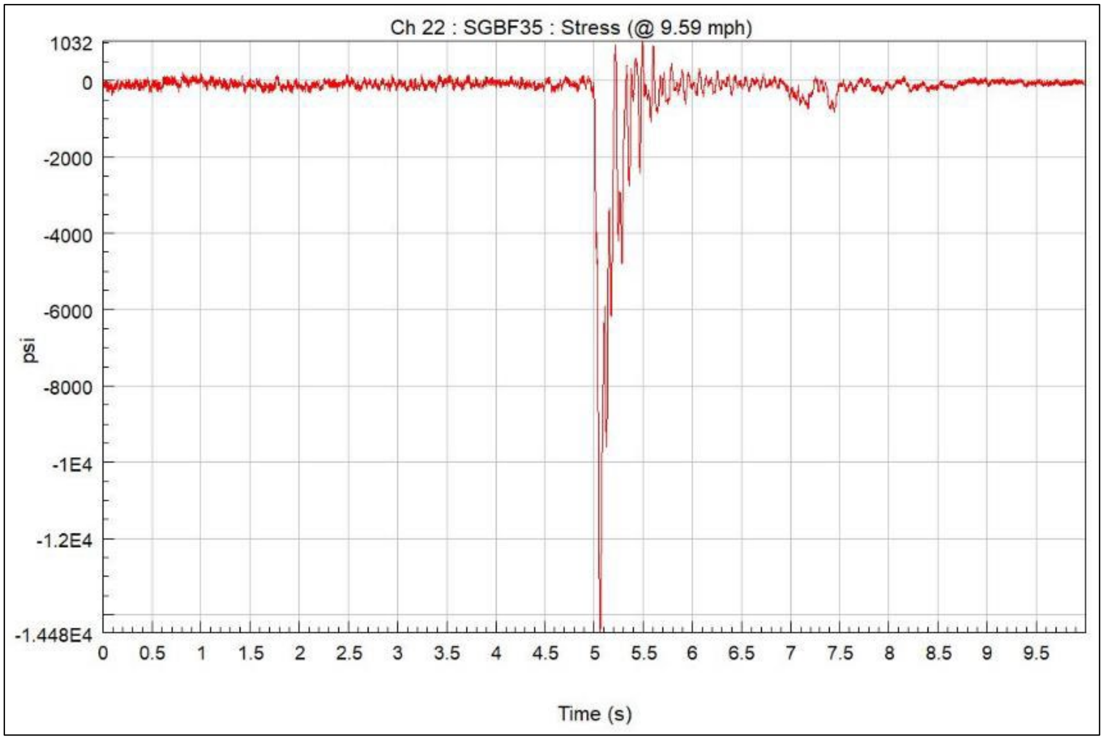


Figure I15. Dynamic Stresses, SGBF35, 9 mph Nominal Speed

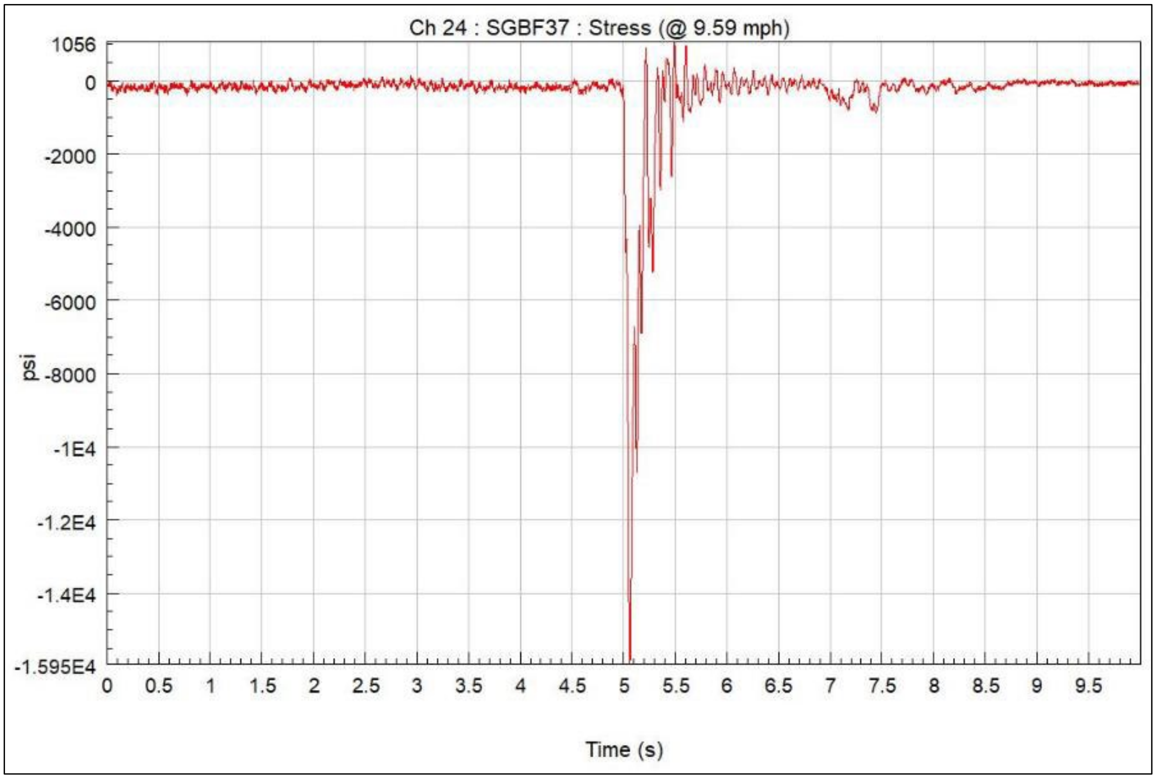


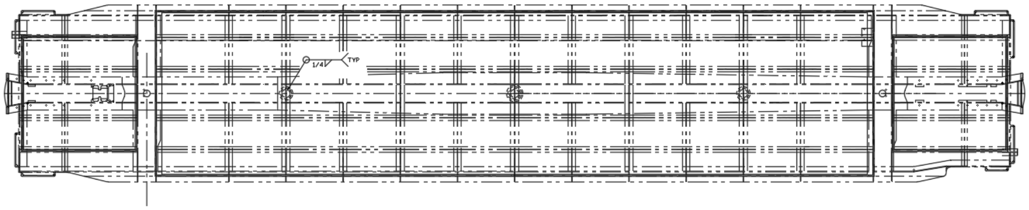
Figure I16. Dynamic Stresses, SGBF37, 9 mph Nominal Speed

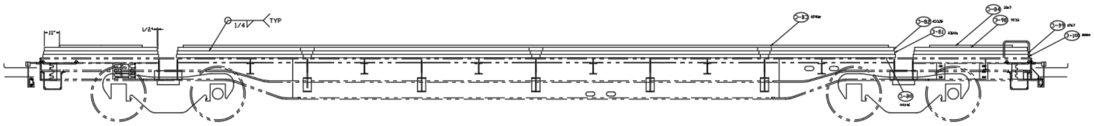
APPENDIX J: KASGRO SECUREMENT ANALYSIS

KASGRO RAIL

Atlas Buffer Car OTLR

May 26, 2021
Prepared by:
Kasgro Engineering





The loads will be secured on all sides with a single sided 1/4-inch fillet weld. Each load that is attached to the car will be analyzed individually. The car light weight is estimated at 73 k.

- Estimated center load weight: 157,000 lbs.
- Weld size = 0.25 in.
- Effective throat angle = 0.707
- Allowable design stress per AWS D15.1 Table C4 Class 1. = 29 ksi
- (0.25 in) (0.707) (29,000 psi) = 5125.75 lbs./in
- Longitudinal Requirement = (157,000 lbs. (6) / 5125.75 lbs./in) = 183.78 in of weld
- Lateral Requirement = (157,000 lbs. (4) / 5125.75 lbs./in) = 122.52 in of weld
- Vertical Requirement = (73,000 lbs. / 5125.75 lbs./in) = 14.24 in of weld
- Existing securement weld total length = 1,284 in
- Estimated outboard load weight (one per end): 16,500 lbs./weight
- Weld size = 0.25 in.
- Effective Throat Angle = 0.707
- Allowable design stress per AWS D15.1 Table C4 Class 1. = 29 ksi
- (0.25 in) (0.707) (29,000 psi) = 5125.75 lbs./in
- Longitudinal Requirement = (16,500 lbs. (6) / 5125.75 lbs./in) = 19.31 in of weld
- Lateral Requirement = (16,500 lbs. (4) / 5125.75 lbs./in) = 12.88 in of weld
- Vertical Requirement = (73,000 lbs. / 5125.75 lbs./in) = 14.24 in of weld
- Existing securement weld total length = 336 in

Overall, these numbers are conservative considering that all four sides of each load are welded. Each welded connection is reacting to all three directions of force (lateral, longitudinal and vertical.)