U.S. Department of
Transportation

**Federal Railroad
Administration**

800,000-Pound Quasi-Static End-Load Test of Crash Energy Management-Equipped Car, Test 1

Office of Research
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This report summarizes the quasi-static compressive end-load test at 800,000 pounds performed on Budd Pioneer Car 244. The car complies with 49 CFR 238.203 because it resisted the test loads with no significant permanent deformations of the body structure. All measured strains were below the yield strains of the materials on which strain gages were installed.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

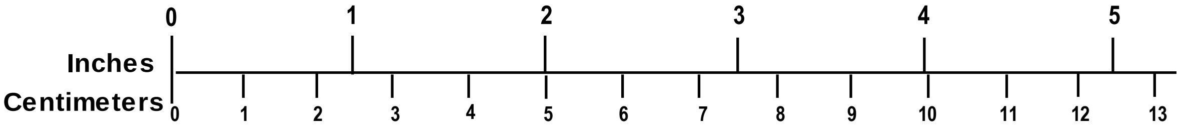
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

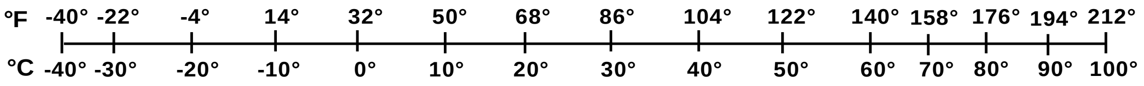
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

The Federal Railroad Administration (FRA) has contracted with Transportation Technology Center, Inc. (TTCI) to perform a series of three full-scale tests to provide the technical basis for rule making that will lead to improved crashworthiness and occupant protection for passenger railroad equipment. The three-test series comprises:

1. A quasi-static compressive end-load test at 800,000 pounds, in accordance with Code of Federal Regulations 49 CFR 238.203, using loads applied on the line of draft
2. An elastic-limit test using loads applied through the crash energy management (CEM) system load paths
3. A crippling load test to determine the ultimate strength of the car using loads applied through the CEM system load paths

This report summarizes Test 1, the quasi-static compressive end-load test at 800,000 pounds conducted on January 20, 2010. The test was performed on Budd Pioneer Car 244, which has been modified to include a CEM system and has been assessed in full-scale tests five times previously.

The car complies with 49 CFR 238.203 and APTA-CS-034-99-Rev 2 because it resisted the test loads with no significant permanent deformation of the body structure. All measured strains were below the yield strains of the materials on which strain gages were installed.

1. Introduction

FRA funds and administers a Passenger Car Crash Testing program to provide the technical basis for rule making that will lead to improved crashworthiness and occupant protection for passenger railroad equipment. The program includes both conventional equipment and innovative equipment that is quickly being introduced into U.S. service. FRA has contracted with TTCI for full-scale test planning, test implementation, and processing of test data in support of this program.

The program is investigating alternative methods to assess the occupant volume strength of innovative rail cars, many of which contain CEM systems. A series of three tests will be performed on Budd Pioneer Car 244 (Figure 1). This car has been modified to include a CEM system, and has previously undergone five full-scale tests. The three new tests planned for this car include:

1. A static compressive end-load test at 800,000 pounds in accordance with Code of Federal Regulations 49 CFR 238.203 using loads applied on the line of draft

2. An elastic-limit test using loads applied through the CEM system load paths

3. A crippling load test to determine the ultimate strength of the car using loads applied through the CEM system load paths

This report summarizes Test 1, which was performed on January 20, 2010. The results will determine whether Car 244 is suitable for the remaining tests.

Companion computational work performed by the John A. Volpe National Transportation Systems Center (Volpe Center) for the three-test series has provided predictions of the vehicle's response in the tests and additional information that has been essential in test planning and preparation (1).

Figure 1. Budd Pioneer Car 244

1.1 Objectives

The objective of the subject test was to demonstrate whether or not modified Budd Pioneer Car 244 meets the current 800,000-pound static compressive end-load strength requirement and is suitable for the remaining tests planned for the car. The car complies with 49 CFR 238.203 and APTA-CS-034-99-Rev 2 if it resists the test compressive load without permanent deformation of the body structure.

2. Test Requirements and Method

FRA provided the Test Requirements Document for the subject test (2). Test requirements were developed jointly by FRA, the Volpe Center, and TTCI.

Test vehicle preparation included a thorough inspection to determine suitability for testing. The inspection included assessing straightness of the longitudinal strength members and vehicle skin. Preparation also included replacement of 12 shear bolts (1-inch Grade 8/UNC, ASTM A490) in the push-back coupler systems on each end of the car (Figure 2) and straightening of any minor damage in the end frame structure and coupler areas. The end frames were removed to provide access for modifications to the draft pockets for load application and reaction hardware. End frames were replaced so that the upper slide tubes were secured by Huck® fasteners in the proper locations. An access plate in the floor at each end was removed and replaced after new shear bolts were installed.

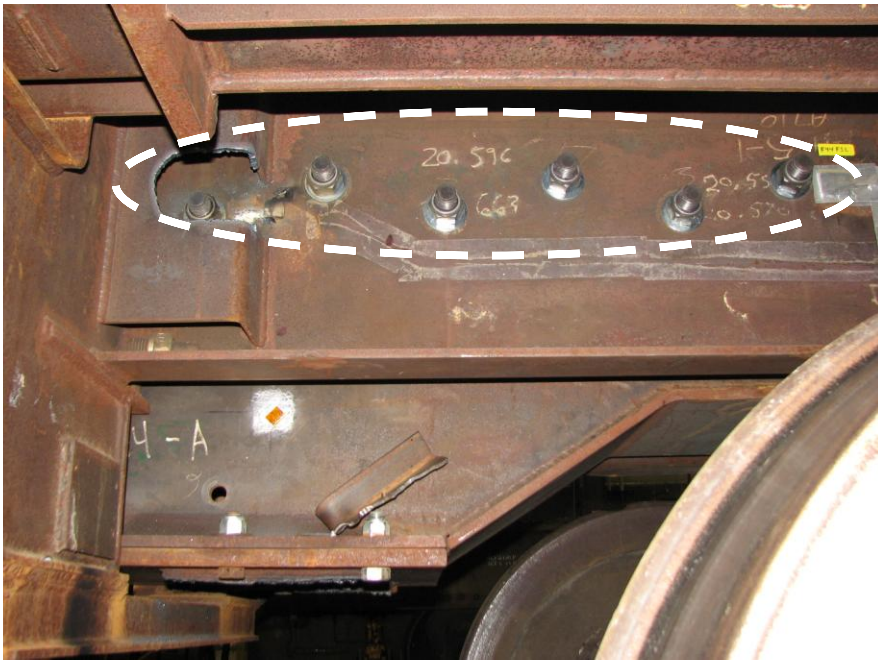

Figure 2. Shear Bolts

The test vehicle was installed in TTCI's full-scale quasi-static compressive strength test fixture where it was loaded in compression incrementally along the draft line to 800,000 pounds. The car's trucks were in place and on rails that run the length of the test fixture. The trucks provided vertical support for the car body without longitudinal restraints. Couplers and draft gears were removed. A hydraulic actuator applied the longitudinal test load to one end of the car (Figure 3), and a block reacted to the load at the passive end of the vehicle (Figure 4).

Figure 3. Test Setup at Load Application End

Figure 4. Test Setup at Load Reaction End

The test load was applied incrementally as Figure 5 shows. A dwell period preceded and followed each target load. After the dwell period at the 700,000-pound load, the load was reduced to slightly below 2,000 pounds and, after a further dwell period, was increased to the full test load of 800,000 pounds. Dwell periods allowed time to examine data and the test car.

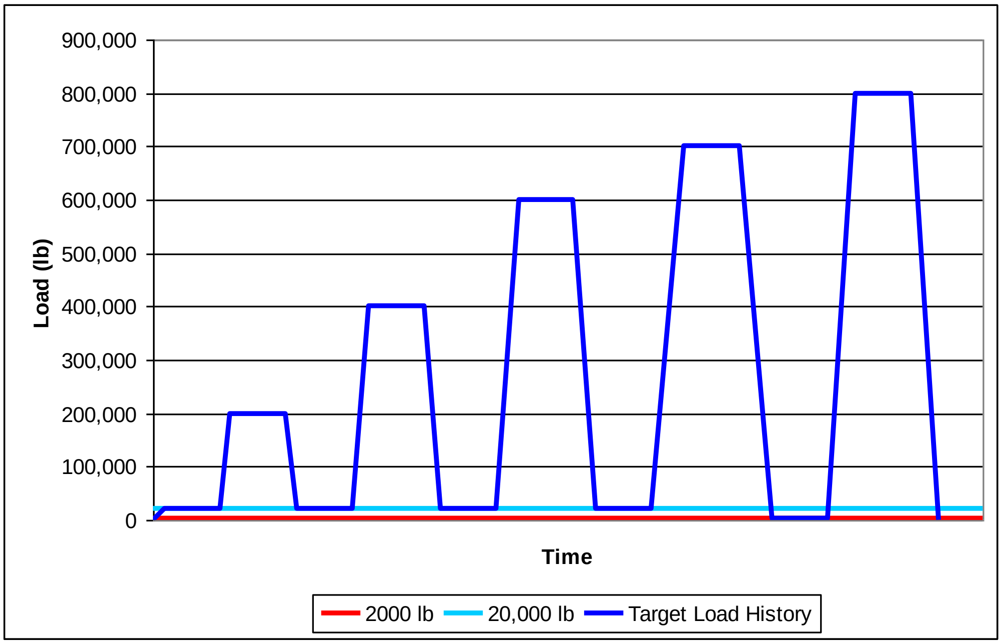

Figure 5. Target Load History

3. Instrumentation and Video

The car was extensively instrumented in this test. A load cell was placed between the actuator and the test car to measure the applied longitudinal load. Strain gages at 64 locations on longitudinal strength members provided information on whether or not material elastic limits were exceeded during the test. Strain gage rosettes at eight locations near the load application and load restraint locations provided information on material behavior near the application points. Seven string potentiometers measured vehicle vertical deflections. They documented the static mode shape of the loaded car. Two string potentiometers at the ends of the car measured longitudinal displacements. They measured vehicle compression under loading and indicated if the vehicle acquired permanent compression set during the test. Most instrumentation from the current test was left on the car for the subsequent tests. Testers used still and video photography to documented pre- and post-test conditions of the vehicle and the testing procedure. Table 1 summarizes the instrumentation count and types.

Table 1. Test 1 Instrumentation Summary

Type of Instrumentation	**Channel Count**
Strain Gages (Longitudinal)	64
Three-Element Rosettes	24 (8 Rosettes)
Load Cell	1
String Potentiometers	9
Actuator Pressure	1
Ambient Temperature	1
Total Data Channels	**100**
Digital Video	5 Cameras

3.1 Definition of Coordinate Axes

Positive **x** direction is longitudinal from the B-end toward the A-end of Car 244. Positive **y** direction is left when the car is viewed from the B-end toward the A-end, and positive **z** is up. The origin of the reference frame is defined by x = 0 at the centerline of the B-end bolster, y = 0 at car centerline, and z = 0 at top of rail. See Figure 6. Locations of strain gages and string potentiometers were measured relative to these coordinate axes.

3.2 Longitudinal Strain Gage Locations

Longitudinal single-element strain gages were installed at six car cross sections. The cross sections are numbered 1 through 6 starting near the center of the B-end bolster. Figure 6 shows the locations of the cross sections.

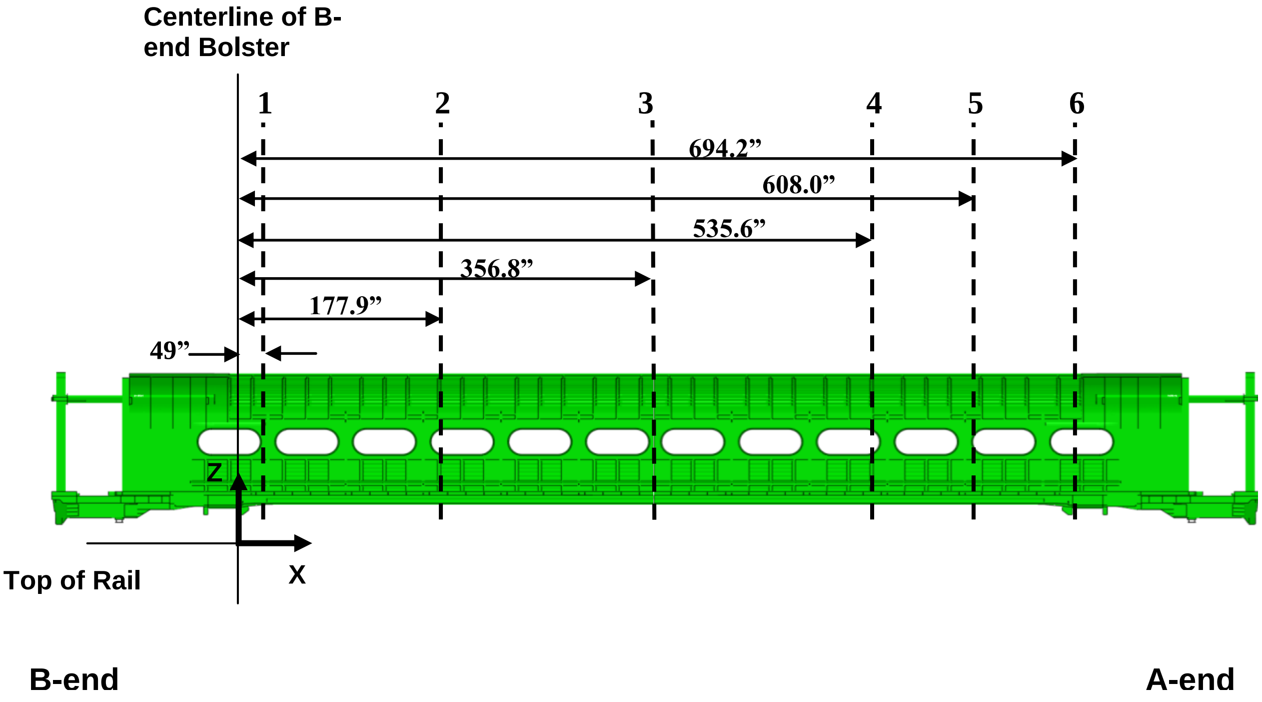

Figure 6. Longitudinal Strain Gage Cross Section Locations

Figure 7 shows how the gages were applied at cross sections 1 through 5. At cross section 6 only the belt line and side sill gages were applied.

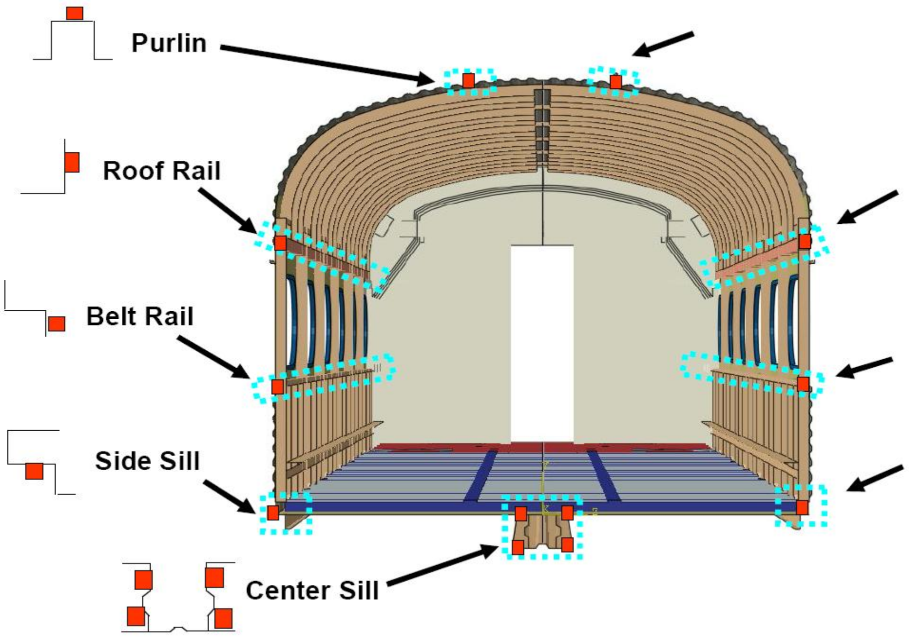

Figure 7. Strain Gage Application Locations at Cross Sections 1 through 5

Table 2 contains the names and descriptions of strain gages mounted on longitudinal strength members at cross section 1. Strain gage names are similar at the remaining cross sections using numbers 2 through 5. For example Gage S2SSL is located at cross section 2 Side Sill Left. Table 2 also shows the gage heights above top of rail (TOR).

Table 2. Longitudinal Strain Gage Names at Cross Section 1

Channel Name	Sensor Description	Sensor Height from Top of Rail (inches)
S1SSL	Cross Section 1, Side Sill Left	47.6
S1BRL	Cross Section 1, Belt Rail Left	78.0
S1RRL	Cross Section 1, Roof Rail Left	111.5
S1PL	Cross Section 1, Purlin Left	149.8
S1PR	Cross Section 1, Purlin Right	149.8
S1RRR	Cross Section 1, Roof Rail Right	111.5
S1BRR	Cross Section 1, Belt Rail Right	78.0
S1SSR	Cross Section 1, Side Sill Right	47.6
S1CSBL	Cross Section 1, Center Sill Bottom Left	40.5
S1CSTL	Cross Section 1, Center Sill Top Left	45.0
S1CSTR	Cross Section 1, Center Sill Top Right	45.0
S1CSBR	Cross Section 1, Center Sill Bottom Right	40.5

Cross section 6 is located 694.2 in from the B-end bolster centerline. Longitudinal gages were installed on the left and right side sills and the left and right belt rails only at this location. Table 3 contains the names of the gages at cross section 6 and their heights above TOR.

Table 3. Longitudinal Strain Gage Names at Cross Section 6

Channel Name	Sensor Description	Sensor Height from Top of Rail (inches)
S6SSL	Cross Section 6, Side Sill Left	47.6
S6BRL	Cross Section 6, Belt Rail Left	78.0
S6BRR	Cross Section 6, Belt Rail Right	78.0
S6SSR	Cross Section 6, Side Sill Right	47.6

3.3 Strain Gage Rosette Locations

Eight strain gage rosettes were installed at highly stressed locations on the sliding sills and fixed sills. One leg of each rosette was installed in the longitudinal or horizontal direction. Another leg was installed vertically, and the third leg makes a 45-degree angle to the other legs. Figure 8 and 9 show the locations of the rosettes and the measurements of the locations. Table 4 contains the gage names. Figure 10 illustrates the rosette orientations that were used to calculate the principal strains, stresses, and directions.

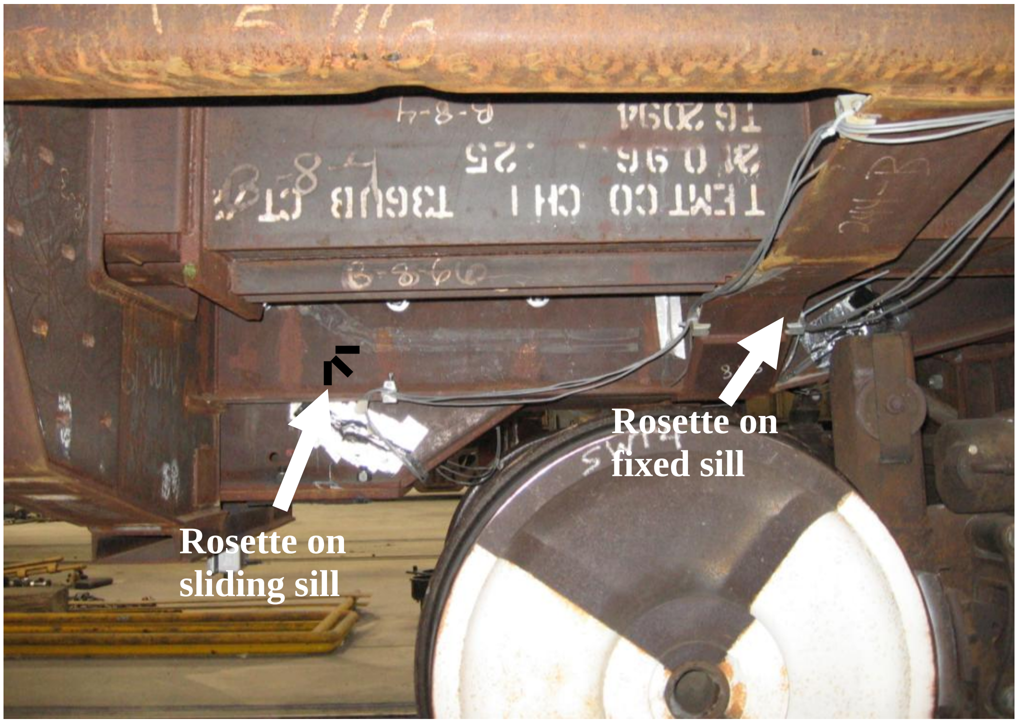

Figure 8. Locations of Strain Gage Rosettes, Right Side at B-end

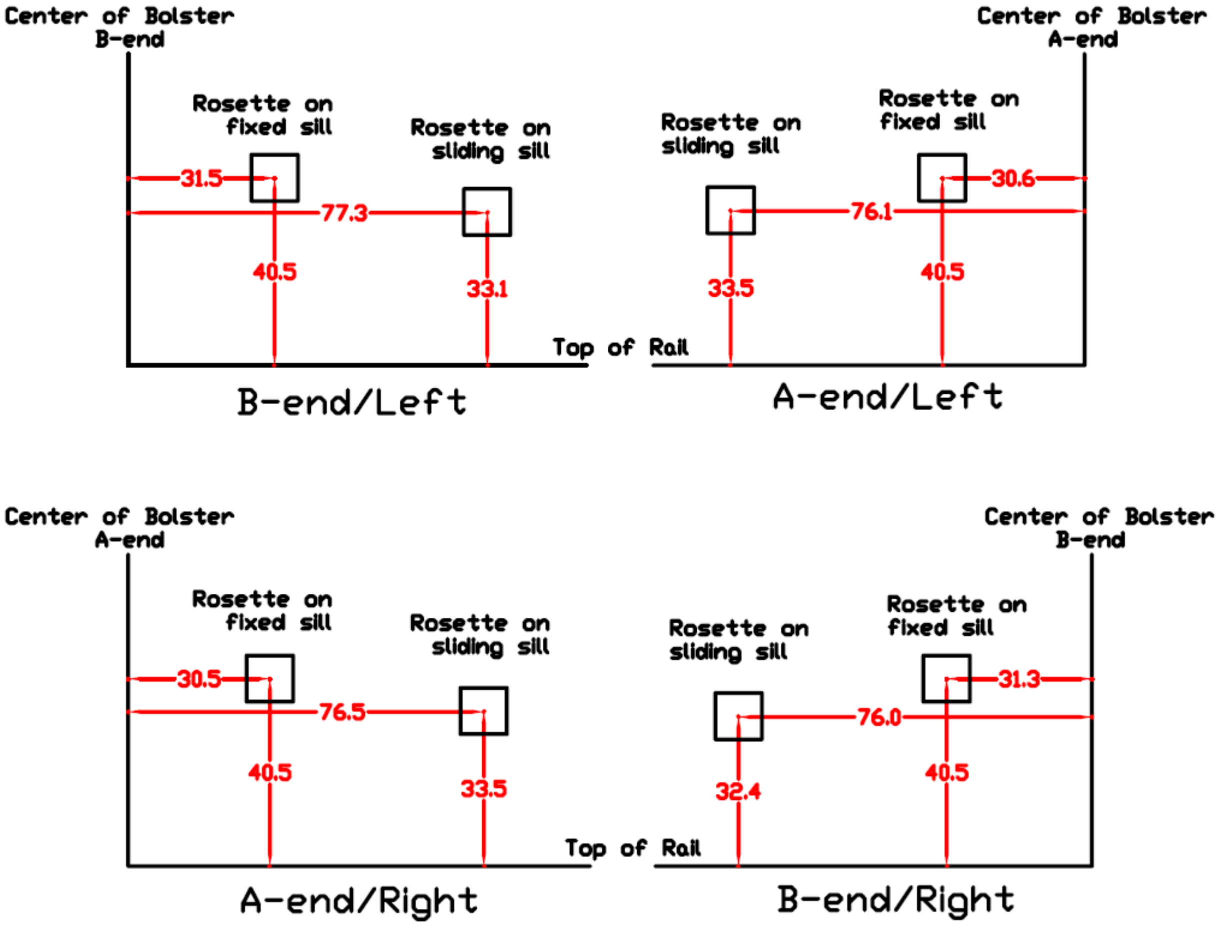

Figure 9. Measurements of the Strain Gage Rosette Locations

Table 4. Strain Gage Rosette Names

Channel Name	Sensor Description
SBFSLH	B-end Fixed Sill Left Horizontal
SBFSLA	B-end Fixed Sill Left Angled at 45 degrees
SBFSLV	B-end Fixed Sill Left Vertical
SBSSLH	B-end Sliding Sill Left Horizontal
SBSSLA	B-end Sliding Sill Left Angled at 45 degrees
SBSSLV	B-end Sliding Sill Left Vertical
SBFSRH	B-end Fixed Sill Right Horizontal
SBFSRA	B-end Fixed Sill Right Angled at 45 degrees
SBFSRV	B-end Fixed Sill Right Vertical
SBSSRH	B-end Sliding Sill Right Horizontal
SBSSRA	B-end Sliding Sill Right Angled at 45 degrees
SBSSRV	B-end Sliding Sill Right Vertical
SAFSLH	A-end Fixed Sill Left Horizontal
SAFSLA	A-end Fixed Sill Left Angled at 45 degrees
SAFSLV	A-end Fixed Sill Left Vertical
SASSLH	A-end Sliding Sill Left Horizontal
SASSLA	A-end Sliding Sill Left Angled at 45 degrees
SASSLV	A-end Sliding Sill Left Vertical
SAFSRH	A-end Fixed Sill Right Horizontal
SAFSRA	A-end Fixed Sill Right Angled at 45 degrees
SAFSRV	A-end Fixed Sill Right Vertical
SASSRH	A-end Sliding Sill Right Horizontal
SASSRA	A-end Sliding Sill Right Angled at 45 degrees
SASSRV	A-end Sliding Sill Right Vertical

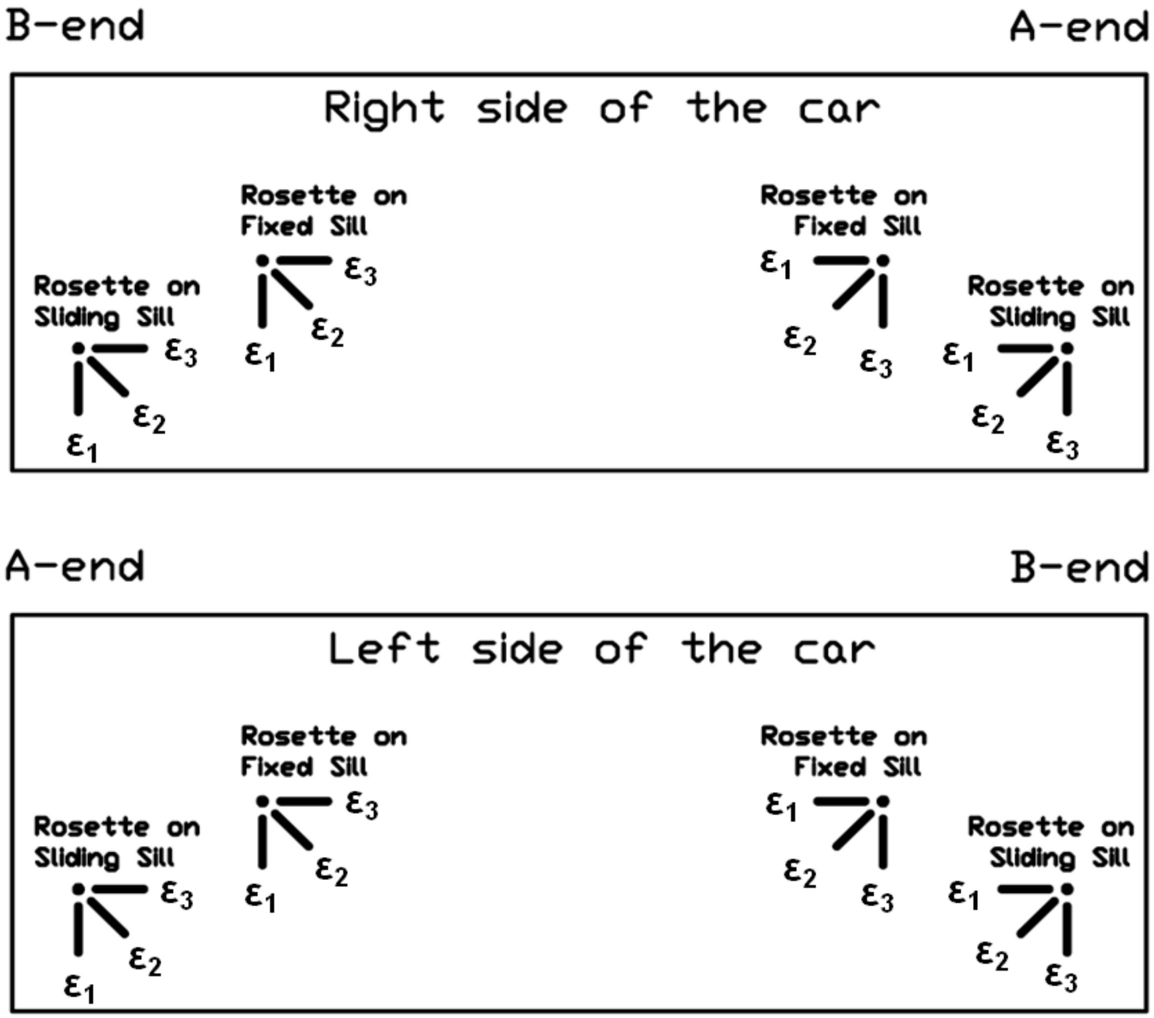

Figure 10. Strain Gage Rosette Orientation

3.4 Load Cell

A 1,000,000-pound capacity load cell (Figure 11) was mounted at the actuator end of the car to measure applied load. The channel name of this load cell was LC1.

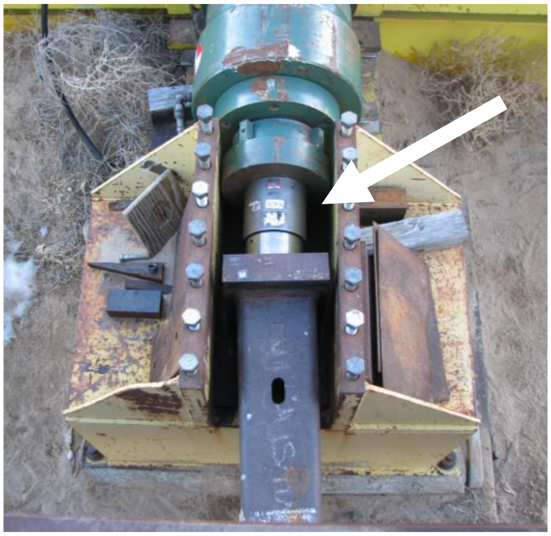

Figure 11. Load Cell LC1

3.5 String Potentiometer Measurements

Seven string potentiometers measured vertical deflections of the carbody. Figure 12 illustrates the locations of the string potentiometers on half of the car. Table 5 contains the names, descriptions, and locations of the string potentiometers.

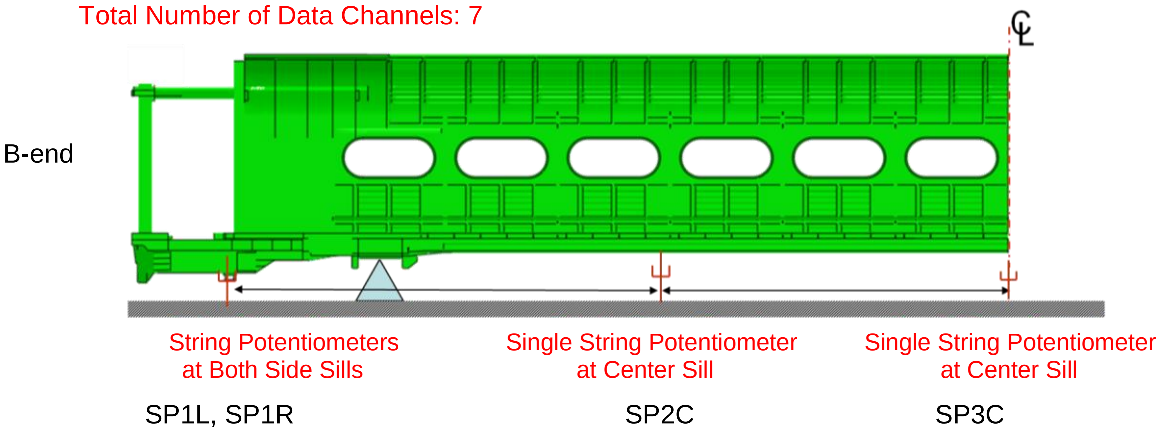

Figure 12. Vertical String Potentiometer Locations

Two string potentiometers measured carbody longitudinal displacement. Figure 13 shows one measurement was made at each car end relative to ground. The longitudinal string potentiometers were attached to the draft gear cover plates as near as practical to the car ends. Vertical string potentiometers were set up to measure at least 2 in of car deflection. Longitudinal string potentiometers were set up to measure at least 4 in of car deflection.

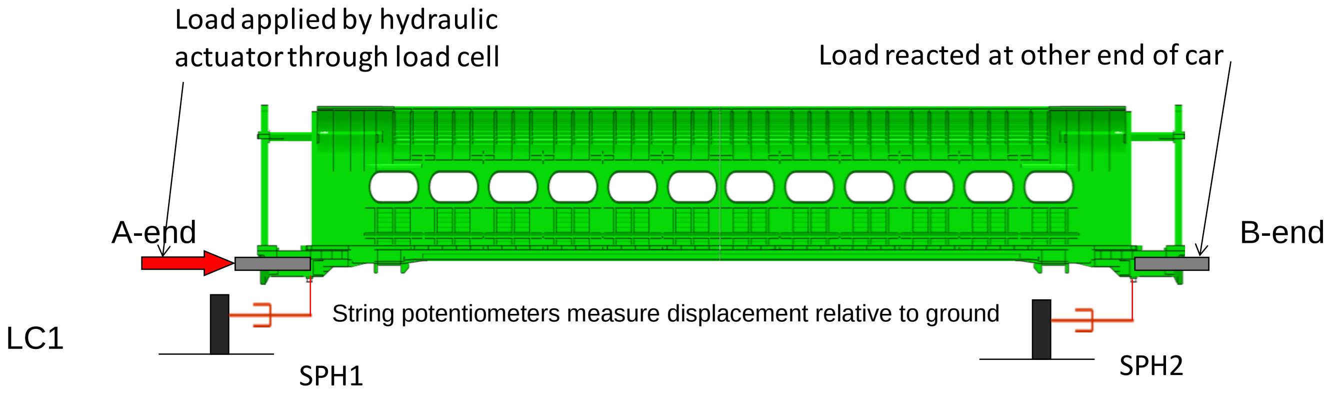

Figure 13. Longitudinal String Potentiometer Locations

Table 5. String Potentiometers and Load Cell

Channel Name	Sensor Description	Locations (inch)		
		x	y	z
SP1L	Vertical, B-end Left	-86.5	57.1	38.0
SP1R	Vertical, B-end Right	-86.5	-57.1	38.0
SP2C	Vertical, Section 2 Center	177.3	0.25	35.9
SP3C	Vertical, Section 3 Center	357.4	0	31.4
SP4C	Vertical, Section 4 Center	536.2	0.75	36.4
SP5L	Vertical, A-end Left	800.2	57.1	40.0
SP5R	Vertical, A-end Right	800.2	-57.1	40.0
SPH1	Horizontal at load application end (A-end)	797.3	0	20.6
SPH2	Horizontal at load restraint end (B-end)	-86.0	0	18.4
LC1	Load Cell	A-end		

3.6 Real-Time Photography

Table 6 lists the cameras and views. Five digital video cameras recorded the test. High-speed cameras 1 and 3 were triggered externally to expose one frame of video for each 0.01 in of car compression as measured by SPH1-SPH2. Due to a technical problem during the test, high-speed camera 2 was manually triggered at 30 frames per second (fps) during the fourth load cycle (700,000-pound target load) and at 10 fps during the fifth load cycle (800,000-pound target load). The 0.01-in trigger signal was derived from a processed output of the stroke data taken from the Megadac data acquisition system. The remaining two cameras recorded high-definition (HD) images in real time.

Table 6. Video Cameras and Views

Camera	View
High-speed camera 1	Load application point
High-speed camera 2	Load reaction point
High-speed camera 3	Bottom of center sill, mid body
HD camera 1	Overall view of car A-end showing load application point
HD camera 2	Elevation view of the entire car

3.7 Data Acquisition and Processing

A Megadac 5414AC data acquisition system provided the analog to digital conversion, recording capability, and signal conditioning needed for the load cell, strains, and displacement transducers. The Megadac data acquisition system is a 16-bit system with user defined sample rates; the signal conditioning provides anti-aliasing filters, differential inputs, and resistor calibrations to verify data integrity before and after testing.

Data was anti-alias filtered at 10 Hz, recorded at 64 Hz, and synchronized with a time reference to the application of the load on the car. An uninterruptable power source was used in the event of power failure to ensure data integrity during the test. Strain gage channels were zeroed prior to initial load application.

The appendix contains a list of all recorded channels, their units, and their polarities.

Five channels of processed data were computed from each strain gage rosette:

- Maximum and minimum principal strains
- Maximum and minimum principal stresses
- Angles of maximum principal stresses

Formulas contained in Vishay Tech Note TN-515 (3) were used for the computations. Rosettes were mounted on carbon steel for which a Poisson ratio of 0.3 and an elastic modulus of 30,000,000 pounds per square inch (psi) were used in the computations.

All channels of data recorded by the Megadac acquisition system were post processed to reduce file size. Post-processed data was stored digitally in engineering units and provided to FRA and Volpe on external USB hard drives.

All recorded video files were transferred to external hard drives and provided to FRA and Volpe. Video data were supplied in native uncompressed formats. The high-speed cameras used .cine format. The HD video cameras used proprietary Sony® .m2t format. In addition to native formats, high-speed camera videos were converted to .avi format, and HD videos were converted to .wmv format. One USB hard drive was provided to FRA and one to Volpe.

4. Test Results

Figure 14 shows the load history during the 800,000-pound cycle, which included an 8-minute dwell. The maximum recorded load was 820,000 pounds. The load stabilized at 800,000 pounds toward the end of the dwell period.

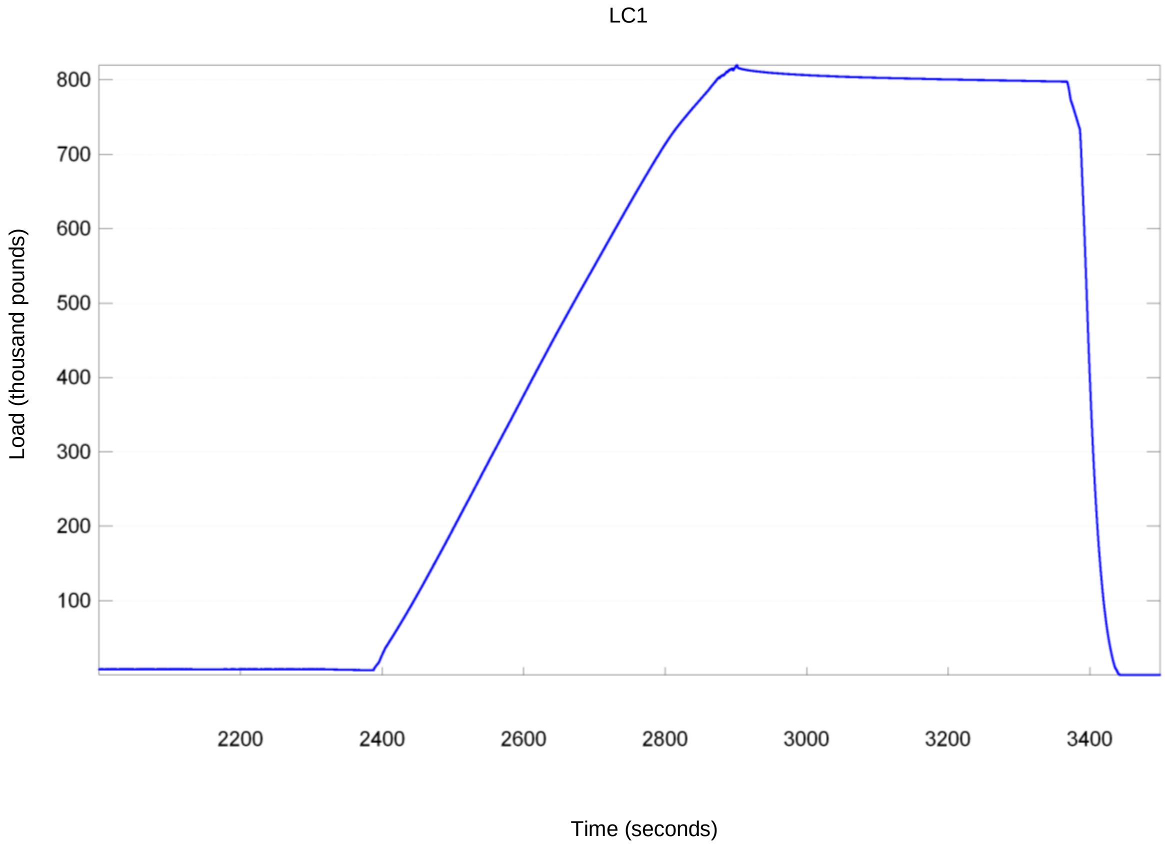

Figure 14. Load History during 800,000-Pound Load Cycle

Figure 15 shows the test car during the dwell period at 800,000 pounds. The camber of the car under load shows clearly relative to the red reference line. Waves that formed in the skin of the car are apparent in the photo.

Figure 16 plots the final two load-compression cycles of the car. Some hysteresis appears between loading and unloading curves. No significant permanent compression of the car occurred.

Figure 15. The Test Car under 800,000-Pound Compressive Load

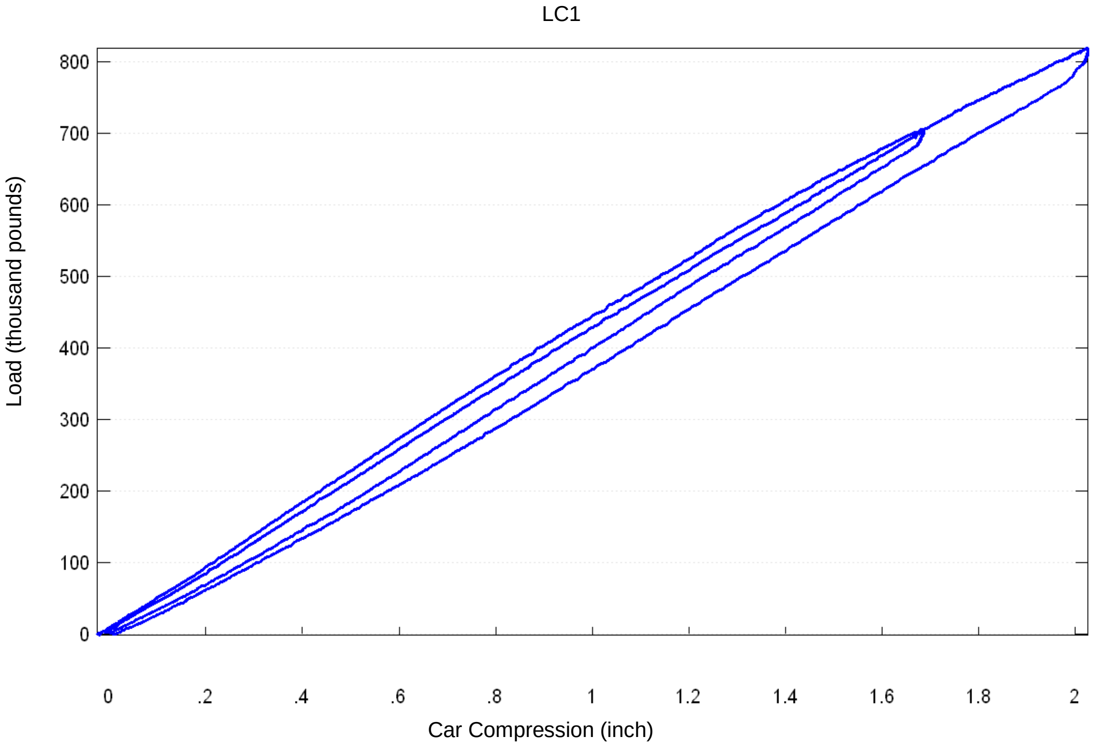

Figure 16. Load versus Car Compression for the Last Two Load Cycles

All strain gage channels outputs returned to near their initial strain values during the last two load cycles. The highest recorded strain magnitude was approximatley -3,250 microstrain in location S2BRL, which is the left side belt rail at cross section 2. See Figure 17. This strain corresponds to a stress of approximatley -98,000 psi, which is below the reported minimum yield strength of the stainless steel belt rail beam. The strain readings from gage S2BRL were substantially higher than other strains recorded during the test. Gage S2BRL is located in close proximity to a window on the car. Figure 7 shows the proximity of the car windows to the belt rail.

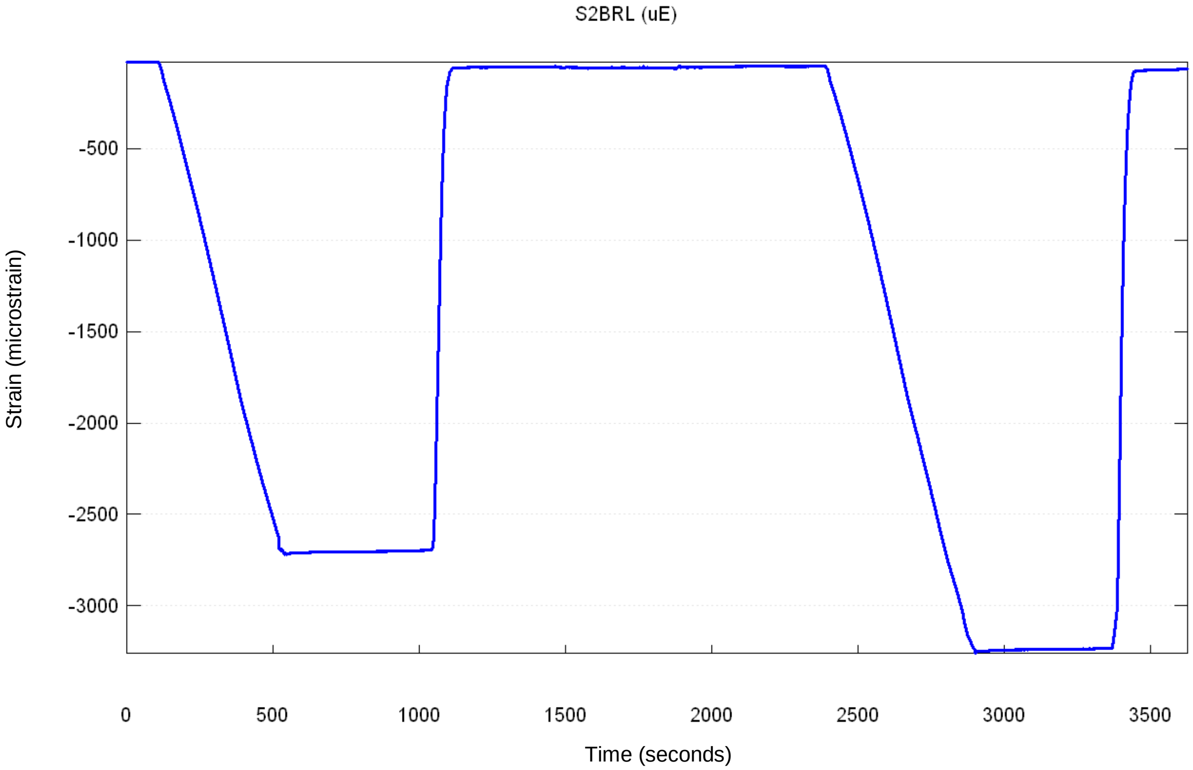

Figure 17. Gage S2BRL Strains during the Last Two Load Cycles

When the car was loaded in compression, strains in the center sill and other lower areas of the car were compressive. Strains in the roof purlins were tensile. To understand the strain variations in the car from bottom (compression) to top (tension), TTCI plotted the maximum values of strains in all the carbody gages versus percent of car height, where the zero height datum is at the lowest gages on the center sill. The plot shown in Figure 18 applies for the 800,000-pound load cycle. The peak strains cluster fairly well along a straight line except for those at belt rail, where some of the gages were located near windows. The linear approximation crosses the zero-strain axis near the roof rail, where all strain gages registered small values.

The strain plotted in Figure 17 for gage S2BRL having magnitude of approximately -3,250 microstrain shows as the outlying brown square in Figure 18 at cross section 2. Because

Figure 18 shows data from all the carbody strain gages during the peak loading cycle, it can be seen that all other peak strains are substantially smaller.

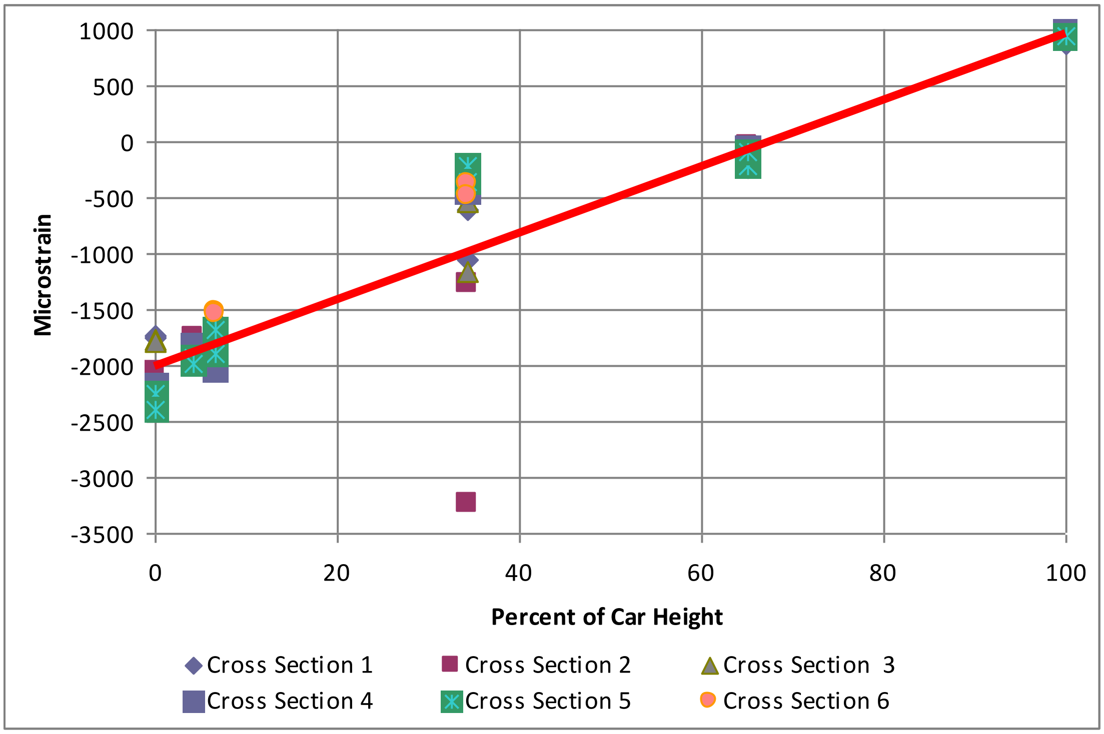

Figure 18. Peak Strains versus Height on Car during the 800,000-Pound Load Cycle

A uniform beam having a linear strain gradient deflects into the shape of a circular arc. Figure 19 shows a comparison between the actual car vertical deflections as measured by string potentiometers and the deflection of a beam having the strain gradient of the straight line in Figure 18, adjusted to match the boundary conditions at the car end. The comparison shows the deflected vertical shape of the car closely matches the circular arc computed from the strain gradient at the measurement locations.

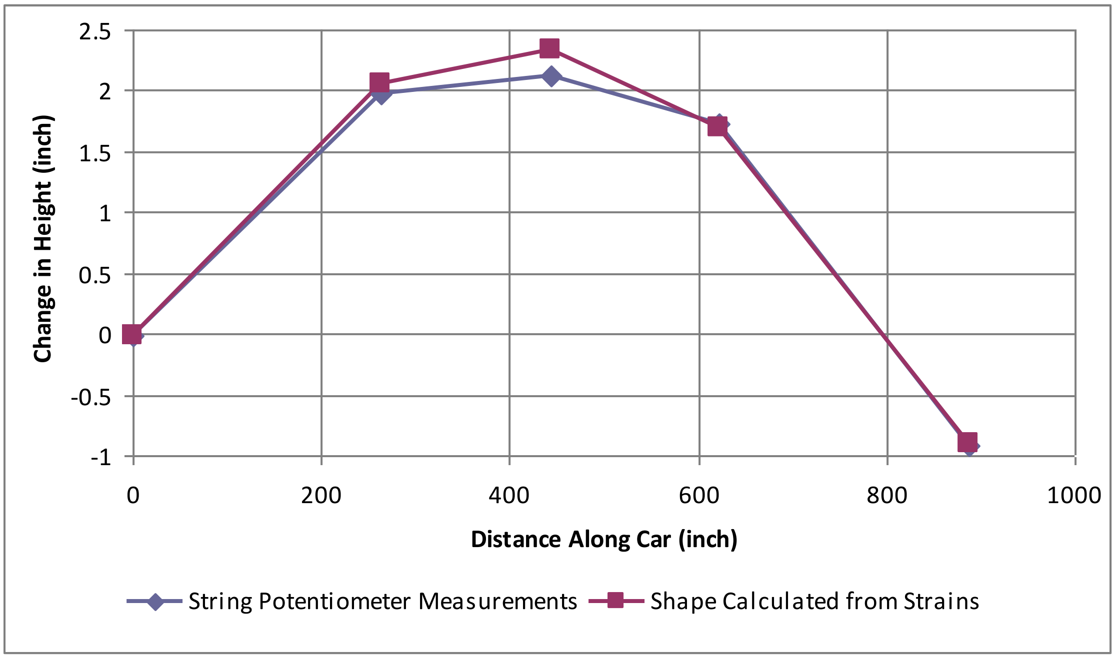

Figure 19. Vertical Mode Shape of Car 244 during 800,000-Pound Load

Two cracks were discovered in the right side sill after the test. Figure 20 shows photographs of the cracks. Both cracks are adjacent to locations where supports have been welded to the inside of the sill. Both cracks appear to have existed for a substantial period of time, because the crack surfaces are well soiled. TTCI believes these cracks existed prior to the test.

Figure 20. Cracks in Right Side Sill

5. Conclusions

Budd Pioneer Car 244 was subjected to a quasi-static compressive end-load test at a maximum load of slightly greater than 800,000 pounds in accordance with 49 CFR 238.203 using loads applied on the line of draft. The car complies with 49 CFR 238.203 and APTA-CS-034-99-Rev 2, because it resisted the test loads with no significant permanent deformation of the body structure. All measured strains were below the yield strains of the materials on which the gages were installed.

6. References

1. Carolan, Michael and Michelle Priante Muhlanger, October 2009, “Strategy for Alternative Occupant Volume Testing,” *Proceedings of ASME 2009 Rail Transportation Division Fall Conference,* Fort Worth, TX.

2. Muhlanger, Michelle and Michael Carolan, October 2009 and revisions, “Test Requirements: 800 Kip Occupant Volume Strength Tests,” prepared for Federal Railroad Administration Equipment Safety Research Program.

3. Vishay Tech Note TN-515, Revision 22-Jan-10, Document Number: 11065, available from www.vishaypg.com.

Appendix.
Test Data Channel List

Channel No.	Channel Name	Sensor Type	Sensor Description	Unit	Positive Indicates
1	TIME		Time	seconds	-
2	S1SSL	Strain Gage	Cross Section 1, Side Sill Left	microstrain	Tension
3	S1BRL	Strain Gage	Cross Section 1, Belt Rail Left	microstrain	Tension
4	S1RRL	Strain Gage	Cross Section 1, Roof Rail Left	microstrain	Tension
5	S1PL	Strain Gage	Cross Section 1, Purlin Left	microstrain	Tension
6	S1PR	Strain Gage	Cross Section 1, Purlin Right	microstrain	Tension
7	S1RRR	Strain Gage	Cross Section 1, Roof Rail Right	microstrain	Tension
8	S1BRR	Strain Gage	Cross Section 1, Belt Rail Right	microstrain	Tension
9	S1SSR	Strain Gage	Cross Section 1, Side Sill Right	microstrain	Tension
10	S1CSBL	Strain Gage	Cross Section 1, Center Sill Bottom Left	microstrain	Tension
11	S1CSTL	Strain Gage	Cross Section 1, Center Sill Top Left	microstrain	Tension
12	S1CSTR	Strain Gage	Cross Section 1, Center Sill Top Right	microstrain	Tension
13	S1CSBR	Strain Gage	Cross Section 1, Center Sill Bottom Right	microstrain	Tension
14	S2SSL	Strain Gage	Cross Section 2, Side Sill Left	microstrain	Tension
15	S2BRL	Strain Gage	Cross Section 2, Belt Rail Left	microstrain	Tension
16	S2RRL	Strain Gage	Cross Section 2, Roof Rail Left	microstrain	Tension
17	S2PL	Strain Gage	Cross Section 2, Purlin Left	microstrain	Tension
18	S2PR	Strain Gage	Cross Section 2, Purlin Right	microstrain	Tension
19	S2RRR	Strain Gage	Cross Section 2, Roof Rail Right	microstrain	Tension
20	S2BRR	Strain Gage	Cross Section 2, Belt Rail Right	microstrain	Tension
21	S2SSR	Strain Gage	Cross Section 2, Side Sill Right	microstrain	Tension
22	S2CSBL	Strain Gage	Cross Section 2, Center Sill Bottom Left	microstrain	Tension
23	S2CSTL	Strain Gage	Cross Section 2, Center Sill Top Left	microstrain	Tension
24	S2CSTR	Strain Gage	Cross Section 2, Center Sill Top Right	microstrain	Tension
25	S2CSBR	Strain Gage	Cross Section 2, Center Sill Bottom Right	microstrain	Tension
26	S3SSL	Strain Gage	Cross Section 3, Side Sill Left	microstrain	Tension
27	S3BRL	Strain Gage	Cross Section 3, Belt Rail Left	microstrain	Tension
28	S3RRL	Strain Gage	Cross Section 3, Roof Rail Left	microstrain	Tension
29	S3PL	Strain Gage	Cross Section 3, Purlin Left	microstrain	Tension
30	S3PR	Strain Gage	Cross Section 3, Purlin Right	microstrain	Tension
31	S3RRR	Strain Gage	Cross Section 3, Roof Rail Right	microstrain	Tension
32	S3BRR	Strain Gage	Cross Section 3, Belt Rail Right	microstrain	Tension
33	S3SSR	Strain Gage	Cross Section 3, Side Sill Right	microstrain	Tension
34	S3CSBL	Strain Gage	Cross Section 3, Center Sill Bottom Left	microstrain	Tension
35	S3CSTL	Strain Gage	Cross Section 3, Center Sill Top Left	microstrain	Tension
36	S3CSTR	Strain Gage	Cross Section 3, Center Sill Top Right	microstrain	Tension
37	S3CSBR	Strain Gage	Cross Section 3, Center Sill Bottom Right	microstrain	Tension
38	S4SSL	Strain Gage	Cross Section 4, Side Sill Left	microstrain	Tension
39	S4BRL	Strain Gage	Cross Section 4, Belt Rail Left	microstrain	Tension
40	S4RRL	Strain Gage	Cross Section 4, Roof Rail Left	microstrain	Tension

Channel No.	Channel Name	Sensor Type	Sensor Description	Unit	Positive Indicates
41	S4PL	Strain Gage	Cross Section 4, Purlin Left	microstrain	Tension
42	S4PR	Strain Gage	Cross Section 4, Purlin Right	microstrain	Tension
43	S4RRR	Strain Gage	Cross Section 4, Roof Rail Right	microstrain	Tension
44	S4BRR	Strain Gage	Cross Section 4, Belt Rail Right	microstrain	Tension
45	S4SSR	Strain Gage	Cross Section 4, Side Sill Right	microstrain	Tension
46	S4CSBL	Strain Gage	Cross Section 4, Center Sill Bottom Left	microstrain	Tension
47	S4CSTL	Strain Gage	Cross Section 4, Center Sill Top Left	microstrain	Tension
48	S4CSTR	Strain Gage	Cross Section 4, Center Sill Top Right	microstrain	Tension
49	S4CSBR	Strain Gage	Cross Section 4, Center Sill Bottom Right	microstrain	Tension
50	S5SSL	Strain Gage	Cross Section 5, Side Sill Left	microstrain	Tension
51	S5BRL	Strain Gage	Cross Section 5, Belt Rail Left	microstrain	Tension
52	S5RRL	Strain Gage	Cross Section 5, Roof Rail Left	microstrain	Tension
53	S5PL	Strain Gage	Cross Section 5, Purlin Left	microstrain	Tension
54	S5PR	Strain Gage	Cross Section 5, Purlin Right	microstrain	Tension
55	S5RRR	Strain Gage	Cross Section 5, Roof Rail Right	microstrain	Tension
56	S5BRR	Strain Gage	Cross Section 5, Belt Rail Right	microstrain	Tension
57	S5SSR	Strain Gage	Cross Section 5, Side Sill Right	microstrain	Tension
58	S5CSBL	Strain Gage	Cross Section 5, Center Sill Bottom Left	microstrain	Tension
59	S5CSTL	Strain Gage	Cross Section 5, Center Sill Top Left	microstrain	Tension
60	S5CSTR	Strain Gage	Cross Section 5, Center Sill Top Right	microstrain	Tension
61	S5CSBR	Strain Gage	Cross Section 5, Center Sill Bottom Right	microstrain	Tension
62	S6SSL	Strain Gage	Cross Section 6, Side Sill Left	microstrain	Tension
63	S6BRL	Strain Gage	Cross Section 6, Belt Rail Left	microstrain	Tension
64	S6BRR	Strain Gage	Cross Section 6, Belt Rail Right	microstrain	Tension
65	S6SSR	Strain Gage	Cross Section 6, Side Sill Right	microstrain	Tension
66	SBFSLH	Strain Gage Rosette	B-end Fixed Sill Left Horizontal	microstrain	Tension
67	SBFSLA	Strain Gage Rosette	B-end Fixed Sill Left Angled at 45 degrees	microstrain	Tension
68	SBFSLV	Strain Gage Rosette	B-end Fixed Sill Left Vertical	microstrain	Tension
69	SBSSLH	Strain Gage Rosette	B-end Sliding Sill Left Horizontal	microstrain	Tension
70	SBSSLA	Strain Gage Rosette	B-end Sliding Sill Left Angled at 45 degrees	microstrain	Tension
71	SBSSLV	Strain Gage Rosette	B-end Sliding Sill Left Vertical	microstrain	Tension
72	SBFSRH	Strain Gage Rosette	B-end Fixed Sill Right Horizontal	microstrain	Tension
73	SBFSRA	Strain Gage Rosette	B-end Fixed Sill Right Angled at 45 degrees	microstrain	Tension
74	SBFSRV	Strain Gage Rosette	B-end Fixed Sill Right Vertical	microstrain	Tension
75	SBSSRH	Strain Gage Rosette	B-end Sliding Sill Right Horizontal	microstrain	Tension
76	SBSSRA	Strain Gage Rosette	B-end Sliding Sill Right Angled at 45 degrees	microstrain	Tension
77	SBSSRV	Strain Gage Rosette	B-end Sliding Sill Right Vertical	microstrain	Tension
78	SAFSLH	Strain Gage Rosette	A-end Fixed Sill Left Horizontal	microstrain	Tension
79	SAFSLA	Strain Gage Rosette	A-end Fixed Sill Left Angled at 45 degrees	microstrain	Tension
80	SAFSLV	Strain Gage Rosette	A-end Fixed Sill Left Vertical	microstrain	Tension

Channel No.	Channel Name	Sensor Type	Sensor Description	Unit	Positive Indicates
81	SASSLH	Strain Gage Rosette	A-end Sliding Sill Left Horizontal	microstrain	Tension
82	SASSLA	Strain Gage Rosette	A-end Sliding Sill Left Angled at 45 degrees	microstrain	Tension
83	SASSLV	Strain Gage Rosette	A-end Sliding Sill Left Vertical	microstrain	Tension
84	SAFSRH	Strain Gage Rosette	A-end Fixed Sill Right Horizontal	microstrain	Tension
85	SAFSRA	Strain Gage Rosette	A-end Fixed Sill Right Angled at 45 degrees	microstrain	Tension
86	SAFSRV	Strain Gage Rosette	A-end Fixed Sill Right Vertical	microstrain	Tension
87	SASSRH	Strain Gage Rosette	A-end Sliding Sill Right Horizontal	microstrain	Tension
88	SASSRA	Strain Gage Rosette	A-end Sliding Sill Right Angled at 45 degrees	microstrain	Tension
89	SASSRV	Strain Gage Rosette	A-end Sliding Sill Right Vertical	microstrain	Tension
90	SP1L	String Potentiometer	Vertical, B-end Left	inch	Extension
91	SP1R	String Potentiometer	Vertical, B-end Right	inch	Extension
92	SP2C	String Potentiometer	Vertical, Section 2 Center	inch	Extension
93	SP3C	String Potentiometer	Vertical, Section 3 Center	inch	Extension
94	SP4C	String Potentiometer	Vertical, Section 4 Center	inch	Extension
95	SP5L	String Potentiometer	Vertical, A-end Left	inch	Extension
96	SP5R	String Potentiometer	Vertical, A-end Right	inch	Extension
97	SPH1	String Potentiometer	Horizontal at load application end (A-end)	inch	Extension
98	SPH2	String Potentiometer	Horizontal at load restraint end (B-end)	inch	Extension
99	LC1	Load Cell	A-end	kips	Compression
100	PR1	Pressure Gage	Actuator Pressure	psi	-
101	TAMB	Temperature	Ambient Temperature	F	-

Abbreviations and Acronyms

FRA	Federal Railroad Administration
CEM	crash energy management
fps	frames per second
HD	high-definition
psi	pounds per square inch
TOR	top of rail
TTCI	Transportation Technology Center, Inc.