U.S. Department of Transportation

Federal Railroad Administration

800,000-Pound Quasi-Static End-Load Test of Crash Energy Management Equipped Car, Test 2

Office of Research and Development
Washington, DC 20590

DOT/FRA/ORD-13/04

Final Report
February 2013

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13. ABSTRACT (Maximum 200 words)

This report summarizes compressive end-load Test 2 on Budd Pioneer Car 244. The quasi-static compressive end-load test at 800,000 pounds was conducted on January 19, 2011. The test vehicle has been modified to include a crash energy management system and has been assessed in full-scale tests six times previously. Test 2 results indicate Car 244 is suitable for an additional test.

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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

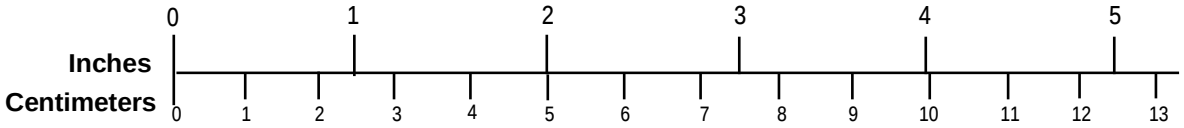
VOLUME (APPROXIMATE)

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



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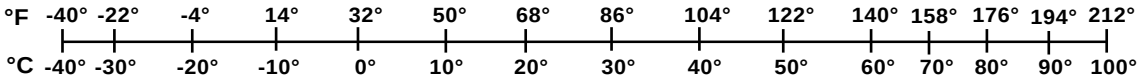

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

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

1. A quasi-static compressive end-load test at 800,000 pounds (lb), in accordance with 49 CFR 238.203, using loads applied on the line of draft.
2. A repeat of Test 1 above to determine test vehicle readiness for Test 3. Preexisting fatigue cracks were discovered in Car 244 after Test 1. The fatigue cracks were repaired, and Test 1 was repeated to ensure the integrity of the car. The test vehicle, Budd Pioneer Car 244, was determined to be suitable for Test 3.
3. A crippling load test to determine the ultimate strength of the car using loads applied through the crash energy management (CEM) system load paths.

This report summarizes Test 2, a quasi-static compressive end-load test at 800,000 lb conducted on January 19, 2011. 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 impact tests six times previously. Test 2 results indicate that Car 244 is suitable for an additional test.

1. Introduction

FRA has a continuing applied research program to provide the technical basis for rulemaking that will lead to improved crashworthiness and occupant protection for passenger railroad equipment. The program includes both conventional equipment and innovative equipment that is being introduced more frequently into U.S. service. FRA has contracted with TTCI for support of full-scale test planning, test implementation, and processing of test data for this program.

The present test, Test 2, is a repeat of Test 1. Before Test 2, the fatigue cracks that were discovered in Car 244 after Test 1 were repaired. Test 2 is being conducted to ensure that the car is acceptable for Test 3. The three-test series now planned for this car includes Tests 1 and 2, which have been conducted, and Test 3, which is scheduled for later in 2011.

1. Test 1. A static end-load test at 800,000 lb in accordance with 49 CFR 238.203 using loads applied on the line of draft.
2. Test 2. A repeat of Test 1 with repaired side sill cracks.
3. Test 3. A crippling-load test to determine the ultimate strength of the car using loads applied through the CEM system load paths.

The FRA program is currently focused on investigating alternative methods to assess the occupant volume strength of new rail cars, many of which contain CEM systems.[1] A series of tests is to be performed on Budd Pioneer Car 244. This car has been modified to include a CEM system, and it has been tested in full-scale tests six times previously. In January 2010, this car was subjected to an 800,000-pound quasi-static end-load test, Test 1, similar to the present test.[2] Figure 1 shows Car 244 in the test fixture during Test 2.

Figure 1. Budd Pioneer Car 244 in Test Fixture

During the Car 244 inspection before Test 1, a small impact deformation was noted in the decorative trim covering the right side sill. The decorative trim was removed to permit the installation of strain gages for Test 1, but it was not noted that the side sill contained a deformation from the same impact that had dented the decorative trim. Nor was it observed that the side sill contained two fatigue cracks that had been covered by the decorative trim. The fatigue cracks were located in weld-heat-affected zones where brackets had been welded to the side sill to support under-car equipment.

During Test 1, the side-sill deformation was discovered, and it was observed to enlarge during the test. The enlargement was attributed to the aforementioned preexisting deformation, so it was not considered a test failure of the vehicle.

The fatigue cracks were not discovered until after Test 1. The fatigue cracks were loaded in compression during Test 1, so they had no effect on the test outcome.

After Test 1, the impact deformation was straightened and patches were welded in place over the fatigue cracks. Then Car 244 was retested in Test 2 to assure it was suitable for the higher compressive side-sill loads expected in Test 3.

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 substantial information that has been essential in test planning and preparation.[1]

This report summarizes Test 2, the static compressive end-load test at 800,000 lb, conducted January 19, 2011.

2. Test Requirements and Method

FRA provided the test requirements document for the subject test.[3] Test requirements were developed jointly by FRA, Volpe Center, and TTCI.

2.1 Car Preparation

Two fatigue cracks were discovered in the right side sill (as viewed looking at the A-end from the B-end) after Test 1. Both cracks were adjacent to locations where supports had been welded to the inside of the sill. A patch was attached to keep the side sill in line during compression. Identical patches were applied to both sides of the car to maintain stiffness symmetry. Figure 2 shows the cracks on the side sill, and Figure 3 shows the patch in place over the cracks prior to welding. Appendix A contains a detailed drawing of the patch.

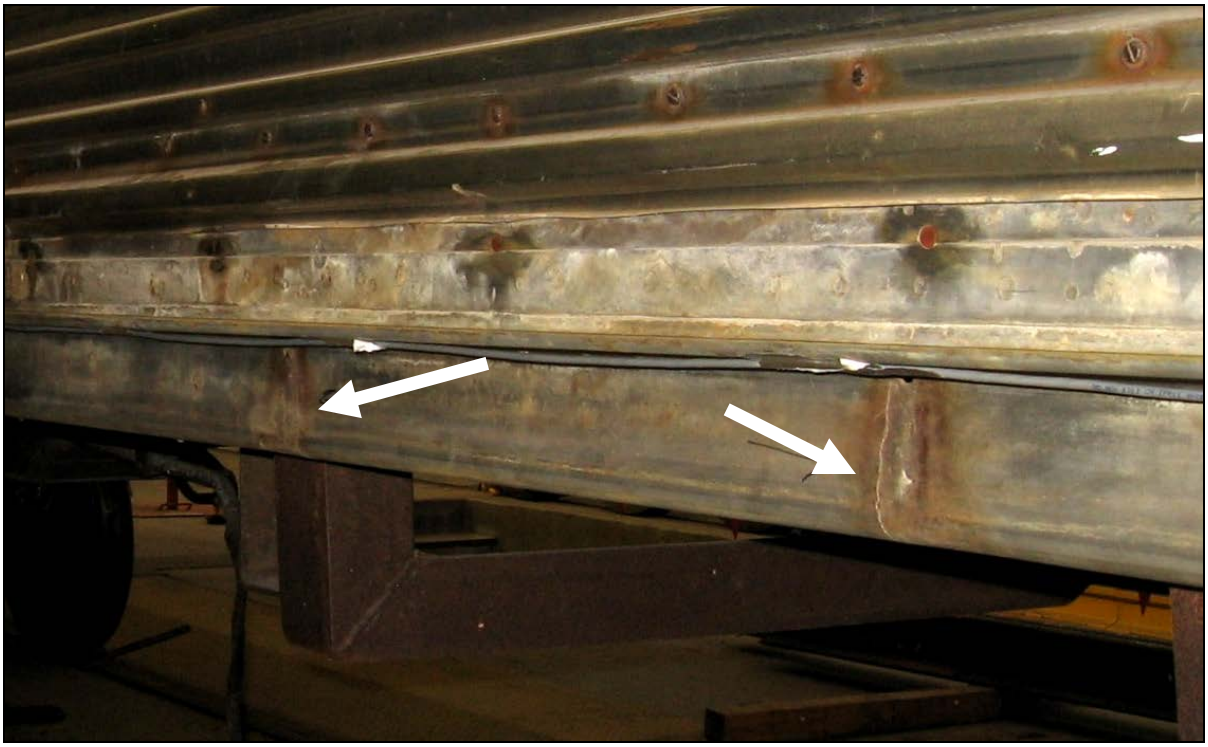


Figure 2. Fatigue Cracks in Side Sill

Figure 3. Cover Plate

The small impact deformation observed in the right side sill during Test 1 was straightened before Test 2.

2.2 Pass/Fail Criteria

As part of the planning activities for Test 2, Volpe Center and TTCI recommended three pass/fail criteria to assess the test results. The criteria are as follows:

1. The measurement of the overall length of the car shall return to within 0.050 inch (in) for the 800,000-pound load cycle.
2. Measured strain offsets shall remain below 1 percent, corrected for temperature.
3. There shall be no visible change in the car structure

2.3 Test Setup

Test 2 was conducted according to the load cycle and other requirements set forth in the *Test Implementation Plan for 800,000-Pound Quasi-Static End Load Test, CEM Equipped Car, Test 2*, dated January 3, 2011. A hydraulic actuator applied the longitudinal test load to one end of the car (Figure 4), and a block reacted the load at the passive end of the vehicle (Figure 5).

Figure 4. Hydraulic Actuator at Load Application End

Figure 5. Restraint System at Load Reaction End

The test load was applied incrementally, as Figure 6 illustrates. A dwell period preceded and followed each target load and gave test personnel time to approach and inspect the car, examine data, or change hydraulic power units between cycles, if necessary. After the dwell period at the 700,000-pound load, the load was reduced to slightly below 2,000 lb. After the 2,000-pound dwell period, the final 800,000-pound load cycle concluded the test sequence, as shown in Figure

6. A single deviation from the Test Implementation Plan caused the load application rate for load cycles 3 through 5 to be greater than the anticipated 0.25 in/minute. The hydraulic power supply was changed between load cycles 2 and 3 because it was not producing the expected flow rate. As a result, the flow rate of the backup power supply produced a substantially higher load application rate.

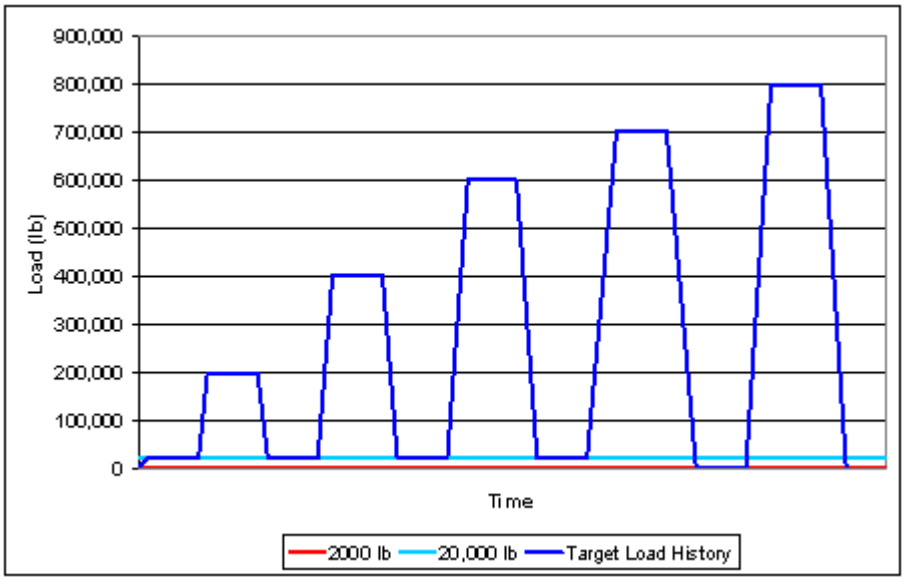


Figure 6. Target Load History

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 65 locations on longitudinal strength members provided information that indicated whether material elastic limits were exceeded during the test. Twenty-seven string potentiometers measured vehicle vertical, lateral, and longitudinal (VLL) deflections. Four high-definition video cameras and still video photography were used to document the pretest and posttest conditions of the vehicle and the conduct of the test. Table 1 summarizes the instrumentation count and types.

Table 1. Test 1 Instrumentation Summary

Type of Instrumentation	Channel Count
Strain Gages (Longitudinal)	65
Load Cell	1
String Potentiometers	27
Thermocouples	3
Total Data Channels	**92**
Digital Video	4

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 was 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 (TOR) (see Figure 7). 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 7 shows the locations of the cross sections.

Figure 8 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.

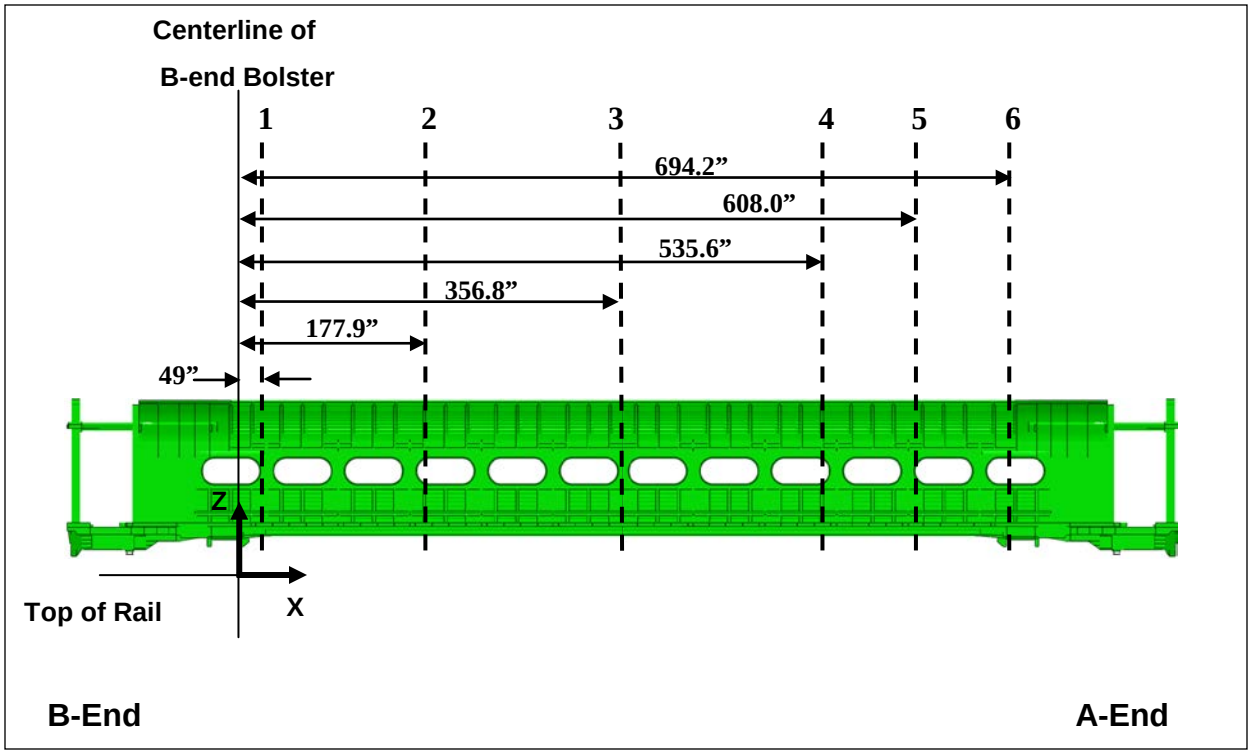


Figure 7. Longitudinal Strain Gage Cross Section Locations

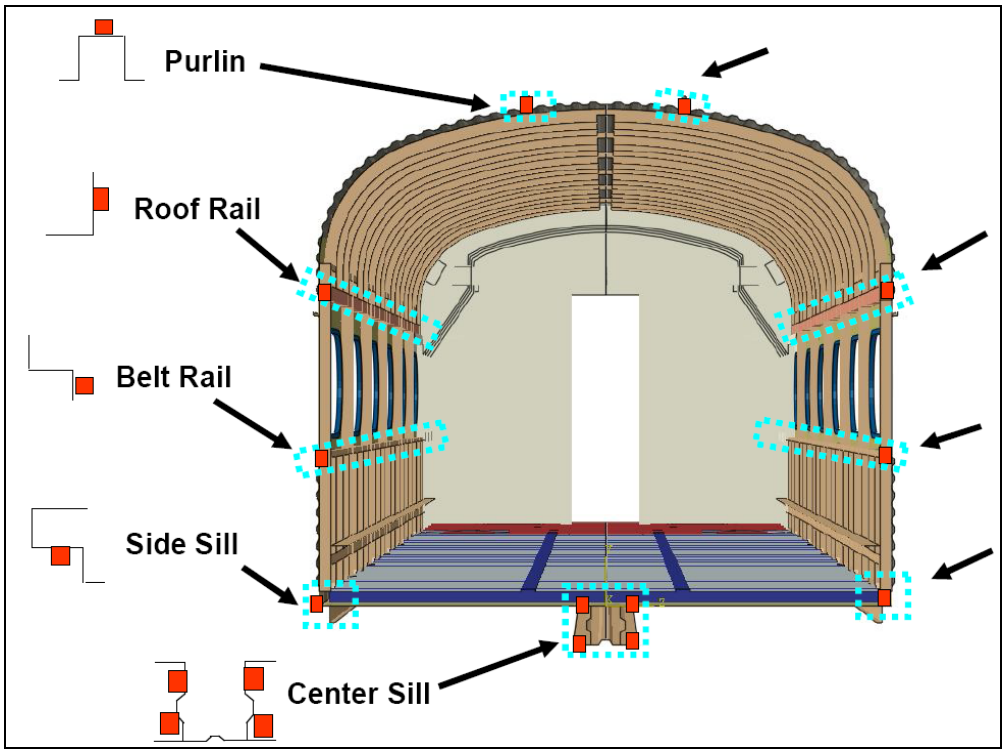


Figure 8. Strain Gage Application Locations at Cross Sections 1 through 5

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 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, Perlin Left	149.8
S1PR	Cross Section 1, Perlin 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. At this location, longitudinal gages were installed on left and right side sills and the left and right belt rails only. 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 Load Cell

A 1,000,000-pound capacity load cell (Figure 9) was mounted at the actuator end of the car to measure applied load. The channel name of this load cell was LC1.

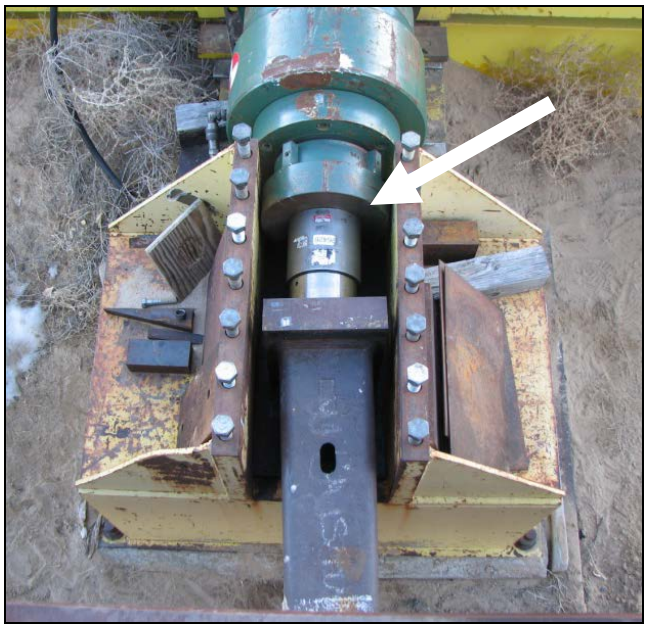


Figure 9. Load Cell

3.4 String Potentiometer Measurements

VLL string potentiometer arrays were used to measure displacements at nine locations on the car. Each VLL array was attached to the car at the same point.

Two VLL arrays were installed at the loading location on the live end and the reaction location on the fixed end, as Figure 10 shows. This required a total of six string potentiometers.

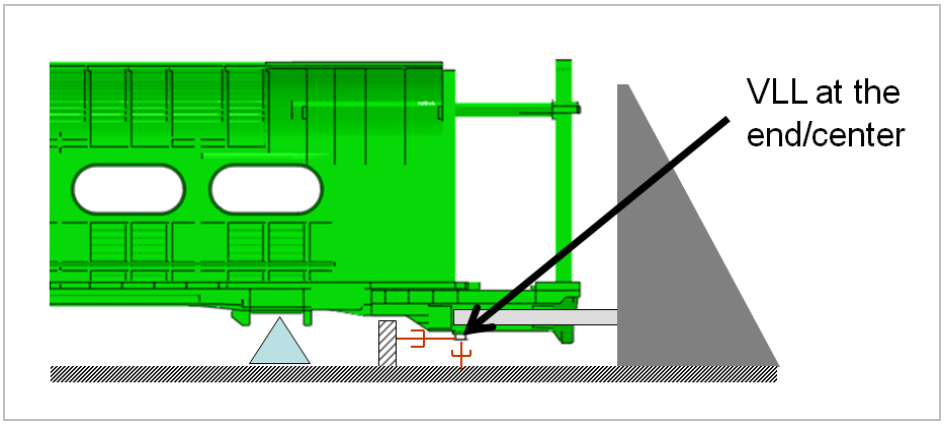


Figure 10. VLL String Potentiometers at End/Center of Car

Four VLL arrays were installed at both ends on both side sills, as Figure 11 shows. This required 12 string potentiometers. Three VLL arrays were installed on the center sill, as Figure 11 shows, and required nine string potentiometers. Table 4 contains the names of the string potentiometers and the load cell. After the Test Implementation Plan had been approved, the test team added several thermocouples and a strain gage to the vehicle's instrumentation to assist in determining

the effects of ambient temperature changes on strain gage readings. Table 5 contains the names and descriptions of the added channels.

Exposed string length of all string potentiometers was recorded before the test (Appendix B), and still photos of the attachments were taken. Positions of the sensors were recorded using the coordinate system in this report.

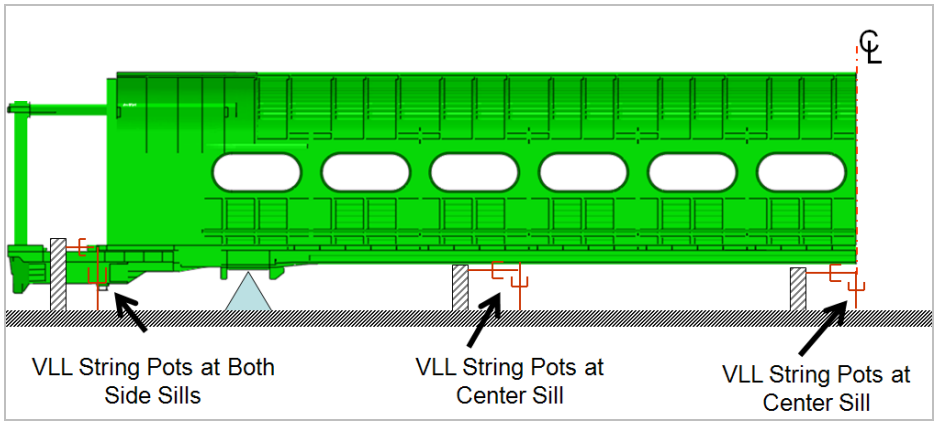


Figure 11. VLL String Potentiometers at Side Sills and Center Sill

Table 4. String Potentiometers and Load Cell

Channel Name	Sensor Description
SPAX	Loading End/Center – Longitudinal
SPAY	Loading End/Center – Lateral
SPAZ	Loading End/Center – Vertical
SPBX	Reaction End/Center – Longitudinal
SPBY	Reaction End/Center – Lateral
SPBZ	Reaction End/Center – Vertical
SPSSALX	Side Sill/Loading End/Left – Longitudinal
SPSSALY	Side Sill/Loading End/Left – Lateral
SPSSALZ	Side Sill/Loading End/Left – Vertical
SPSSARX	Side Sill/Loading End/Right – Longitudinal
SPSSARY	Side Sill/Loading End/Right – Lateral
SPSSARZ	Side Sill/Loading End/Right – Vertical
SPSSBLX	Side Sill/Reaction End/Left – Longitudinal
SPSSBLY	Side Sill/Reaction End/Left – Lateral
SPSSBLZ	Side Sill/Reaction End/Left – Vertical
SPSSBRX	Side Sill/Reaction End/Right – Longitudinal
SPSSBRY	Side Sill/Reaction End/Right – Lateral
SPSSBRZ	Side Sill/Reaction End/Right – Vertical
SPCSAX	Center Sill/Loading End – Longitudinal
SPCSAY	Center Sill/Loading End – Lateral
SPCSAZ	Center Sill/Loading End – Vertical
SPCSCX	Center Sill/Center – Longitudinal
SPCSCY	Center Sill/Center – Lateral
SPCSCZ	Center Sill/Center – Vertical
SPCSBX	Center Sill/Reaction End – Longitudinal
SPCSBY	Center Sill/Reaction End – Lateral
SPCSBZ	Center Sill/ Reaction End – Vertical
LC1	Load Cell

Additional channels are as follows:

Table 5. Additional Channel Descriptions

Channel Name	Sensor Description
PR1	Pressure
THIGH	Temperature on the car in high position
TLOW	Temperature on the car in low position
TSPEC	Temperature on the specimen
TAMB	Temperature on the car in an ambient position
SSPEC	Strain on the specimen

3.5 Supplemental Measurements

Thermocouples were installed on the roof, the side sill, and under the test car. Before the test, TTCI monitored strain gage and thermocouple responses on the unloaded car to determine strain gage response to temperature changes. Table 6 provides the names of the thermocouples.

Table 6. Thermocouples

Camera	Location
TC1	Roof near S1PL
TC2	Side sill near S6SSR
TC3	Under test car

3.6 Real-Time Photography

Four high-definition video cameras recorded the test conduct. Table 7 provides the camera names and views.

Table 7. Video Cameras and Views

Camera	View
HD camera 1	Isometric view of loading end
HD camera 2	Longitudinal view of car side to show camber deflection
HD camera 3	Isometric view of reaction end
HD camera 4	Side view of entire car

Figure 12 shows a schematic of the camera setup.

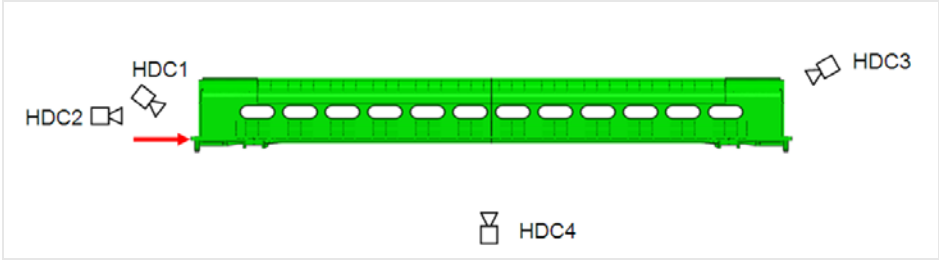


Figure 12. Camera Setup

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 is a 16-bit system with user defined sample rates; the signal conditioning provides anti-aliasing filters, differential inputs, and resister calibrations to verify data integrity before and after testing.

Data was anti-alias filtered at 10 hertz (Hz) and recorded at 64 Hz. An uninterruptable power system 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.

All channels of data recorded by the MEGADAC acquisition system were decimated by a factor of 8 in postprocessing to reduce file size. The decimation resulted in an effective sample rate of 8 Hz. Postprocessed data was stored digitally in engineering units and provided to FRA and Volpe Center on external USB hard drives.

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

4. Test Results

Figure 13 shows the load history during the 800,000-pound cycle, which included a 4-minute dwell period. The maximum recorded load was approximately 820,000 lb. The load relaxed slightly and stabilized at approximately 800,000 lb toward the end of the dwell period.

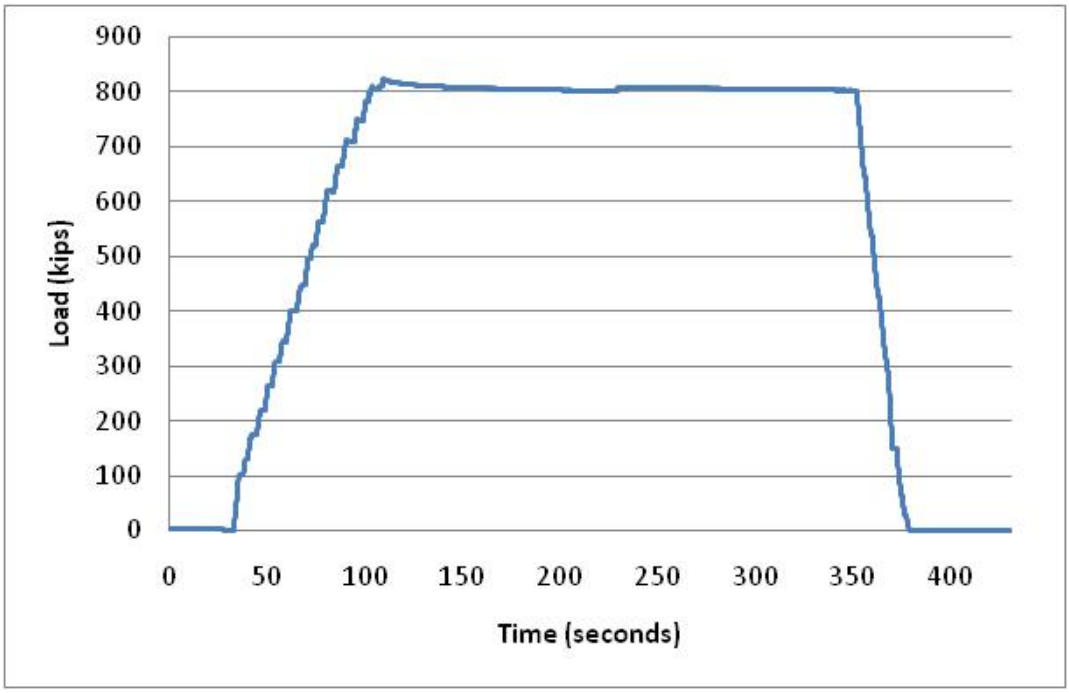


Figure 13. Load History during 800,000-Pound Load Cycle

Figure 14 shows the test car during the dwell period at 800,000 lb. 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 photograph. The waves appear as the alternating light and dark vertical bands under the windows.

Figure 14. Test Car under 800,000-Pound Compressive Load

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 perlins were tensile. To visualize the strain variations in the car from bottom (compression) to top (tension), TTCI engineers plotted the maximum values of strains in all the carbody gages versus percentage of car height, where the zero height datum is at the lowest gages on the center sill. Figure 15 shows peak strains during the 800,000-pound load cycle. The peak strains cluster fairly well along a straight line, except for those at belt rail, where the scatter is substantial. The linear approximation crosses the zero-strain axis near the roof rail, where all strain gages registered small values.

The strain plotted in Figure 15 for gage S2BRL having a value of approximately –3,100 microstrain shows as the outlying brown square at cross section 2. Becausee Figure 15 shows data from all the carbody strain gages during the peak loading cycle, it is clear that all other peak strains are substantially smaller.

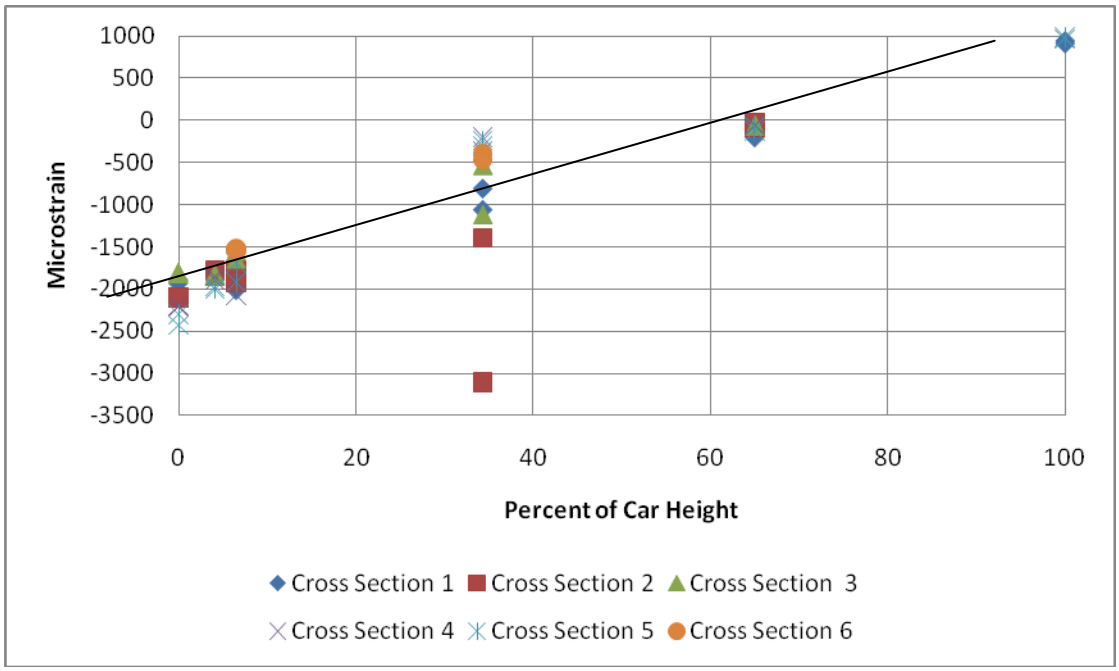


Figure 15. Peak Strains versus Height on Car during the 800,000-Pound Load Cycle

The –3,100 microstrain corresponds to a stress of approximately –90,000 pounds per square inch (psi), which TTCI understands to be below the minimum yield strength of the stainless steel belt rail material. The strain readings from gage S2BRL were substantially higher than other strains recorded during the test. Gage S2BRL is on the belt rail adjacent to a section that is bent inward toward the center of the car. When the car compresses under load, that section deflects inward and puts the gage into additional compression. Figure 16 shows the strain gage inside the car. (Note: The gage label shows the name from a previous designation. The photograph shows gage S2BRL covered with black protective material). The mounting location of this strain gage near a bent section on the belt rail accounts for the uncharacteristically high strain readings.

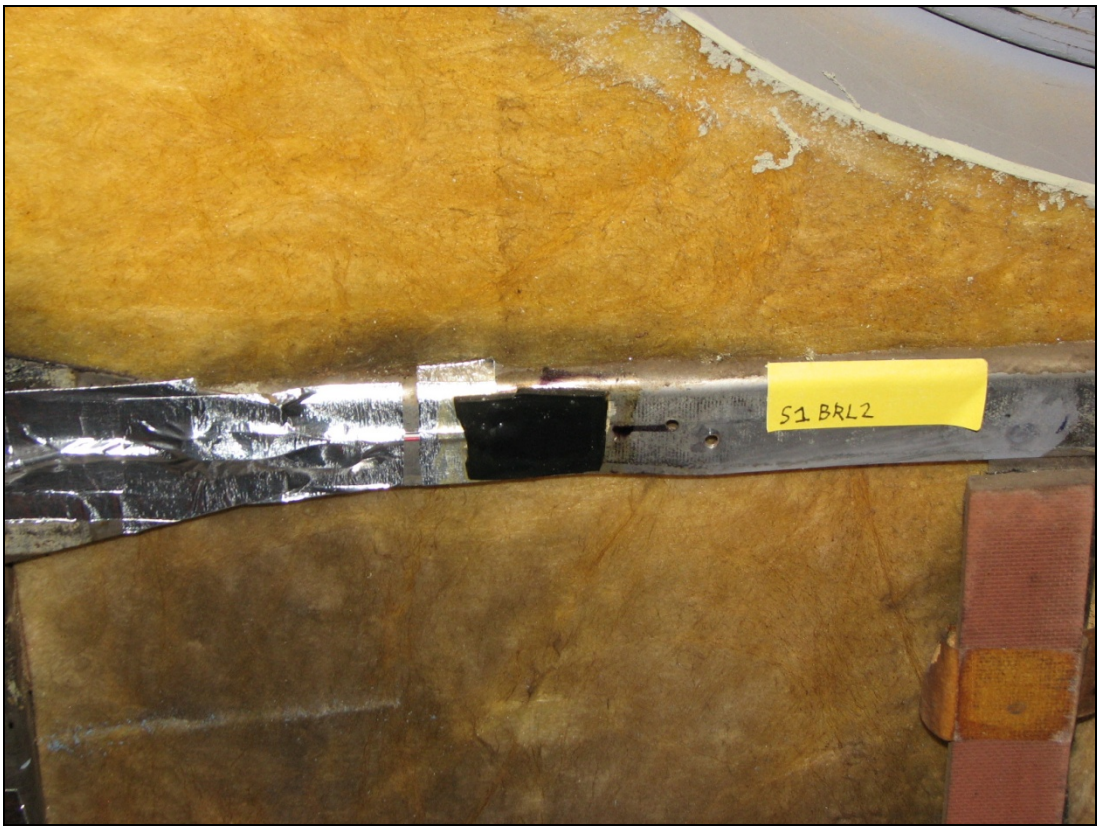


Figure 16. Location of Gage S2BRL inside the Test Car

The following subsections discuss test results in relation to the pass/fail criteria in subsection 2.2.

4.1 Overall Length Criterion

Figure 17 shows car-length reduction versus applied load for load cycles 1 and 5, the 200,000- and 800,000-pound load cycles. In load cycle 5, substantial hysteresis separates the loading and unloading portions of the cycle. At the beginning of the unloading cycle, the order of 20,000 lb of load change occurs before appreciable change in car length occurs. Both the hysteresis and the varying slope of the length versus load curves constitute nonlinear behavior of the load-elongation response of the car.

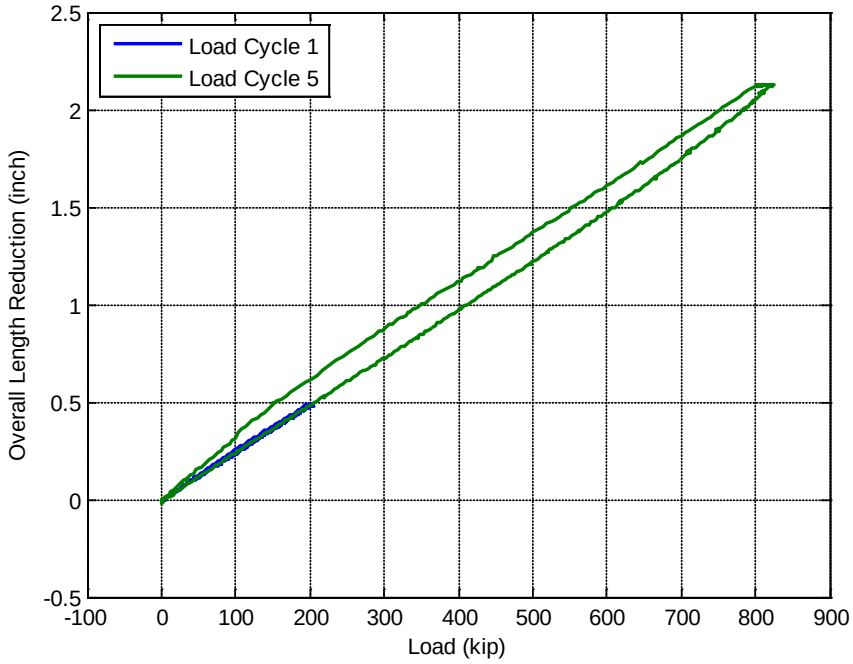


Figure 17. Car 244 Length Reduction versus Applied Load

The overall length criterion was evaluated for the entire test period rather than for the 800,000-pound load cycle, as required by criterion 1. The load at the beginning of the 800,000-pound load cycle was not the same as the load at the end of the cycle, so any change in length would have partially resulted from the change in load.

The test duration includes the zero load condition before application of the first load cycle through the zero load condition after conclusion of the load cycle 5. Figure 18 shows another view of Figure 17 with expanded scales near the origin. In Figure 18, it is clear that the overall change in car length is less than 0.05 in. The recorded value of car-length reduction over the test is 0.0045 in, which is well within the pass/fail criterion.

In Test 1, on January 20, 2010, the car-length reduction was 0.011 in, which is also within the overall length pass/fail criterion limit.

In Figure 18, the nonconstant slopes of the load-elongation curves are apparent. Car 244 emitted sounds that could be described as creeks, groans, and pops during both loading and unloading. The acoustic emissions are consistent with localized stick-slip behavior within the car structure. The car structure includes both welded and riveted connections.

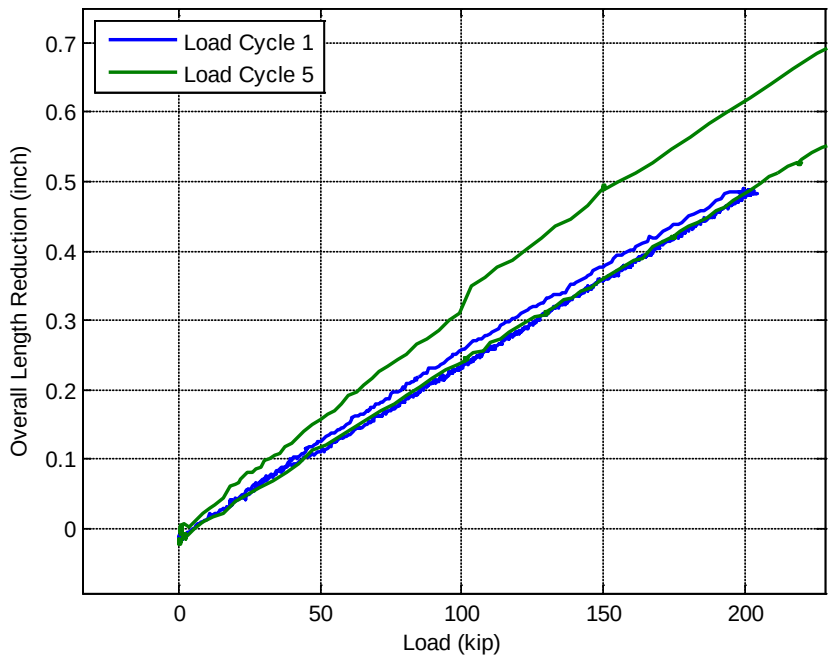


Figure 18. Car 244 Length Reduction on Expanded Scales

4.2 Strain Offset Criterion

Pass/fail criterion No. 2 requires the readings of all strain gages to exhibit no greater indicated strain change than 1 percent of the yield strain of the materials on which the gages are installed from the beginning to the end of the test. The beginning to the end of the test is taken to include the zero load condition before application of the first load cycle through the zero load condition after conclusion of the fifth load cycle.

All structural materials on Car 244 have a yield strength of at least 75,000 psi. The yield strain in a tensile test is related to the yield stress by

$$\varepsilon_y = \frac{\sigma_y}{E}$$

For 75,000 psi yield strength and 29×10^6 psi elastic modulus, the yield strain is

$$\varepsilon_y = \frac{75{,}000}{29 \times 10^6} \cong 2{,}600 \times 10^{-6}$$

So, 1 percent of the yield strain is approximately 26 microstrain. Figure 19 shows the temperature-induced changes of indicated strain on an unstressed sample of side sill material suspended under the center of the car during the test. The temperature of the sample dropped by approximately 2 ºF during the test.

The total change in indicated strain between the beginning of the first load cycle and the end of the last load cycle was –9 microstrain. The lower limit of strain offset is therefore $-26 - 9 = -35$ microstrain. The upper limit of strain offset is $26 - 9 = 17$ microstrain.

Figure 20 shows offsets for all 64 strain channels during Test 2. Nearly half the strain offsets fall below the lower limit of 1 percent, corrected for temperature. The minimum strain offset is –66 microstrain. This strain offset occurred on channel 20, S2BRR. The name code translates to strain at cross section 2, belt rail, and right side of car as described in the Test Implementation Plan. The maximum magnitude strain was approximately –1,400 microstrain, which corresponds to a compressive stress of approximately 42,000 psi, well below the minimum yield strength of instrumented members. The –66 microstrain offset corresponds to a compressive stress of approximately 1,900 psi. The belt rail has a cross-sectional area of approximately 0.25 in^2, so the corresponding compressive force is approximately 500 lb if the strain is uniform.

For comparison purposes, Figure 21 shows strain offsets for the same 64 strain channels during Test 1, which was conducted a year earlier. These strain offsets are not temperature compensated because the zero-strain material reference sample was not used in that test. Ambient temperature increased during Test 1 by approximately 5 ºF. Test 1 strain offsets meet a strain offset criterion set at 4 percent of yield strain without temperature compensation. Temperature compensation is important when judgments are being made based on small changes in strain levels because indicated strain levels change with both ambient temperature and actual strain.

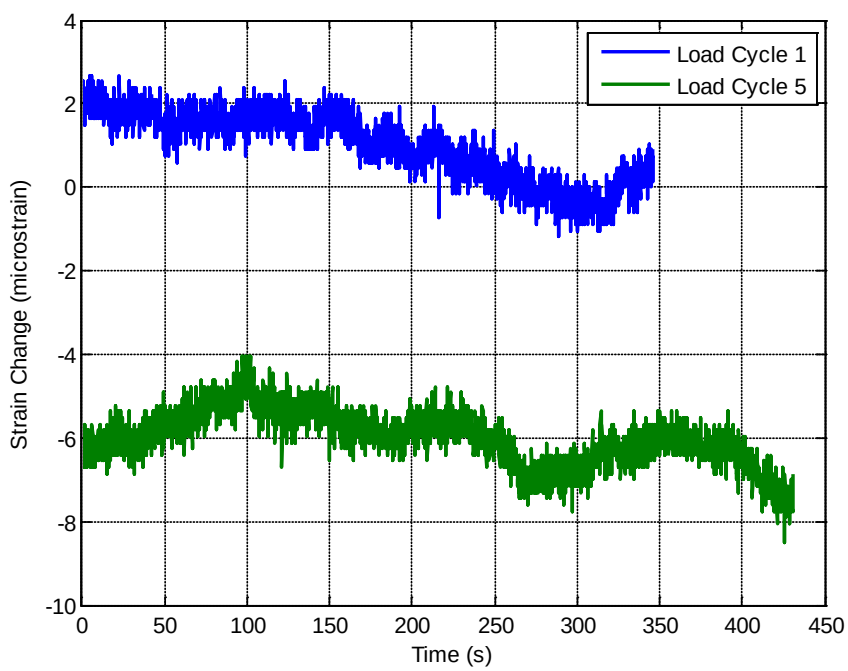


Figure 19. Temperature-Induced Strain Change of Unstrained Sample

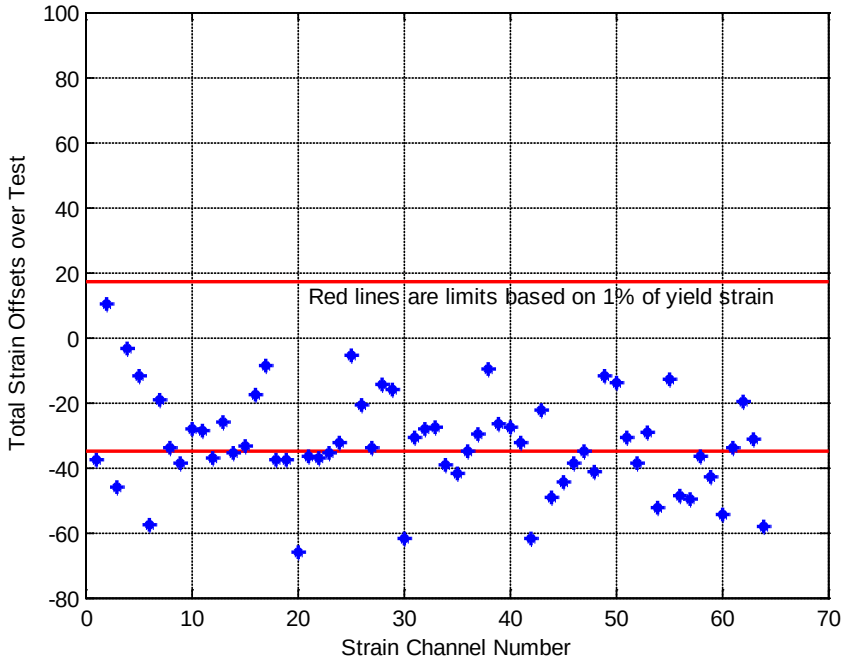


Figure 20. Strain Offset versus Temperature-Corrected Limits in Test 2

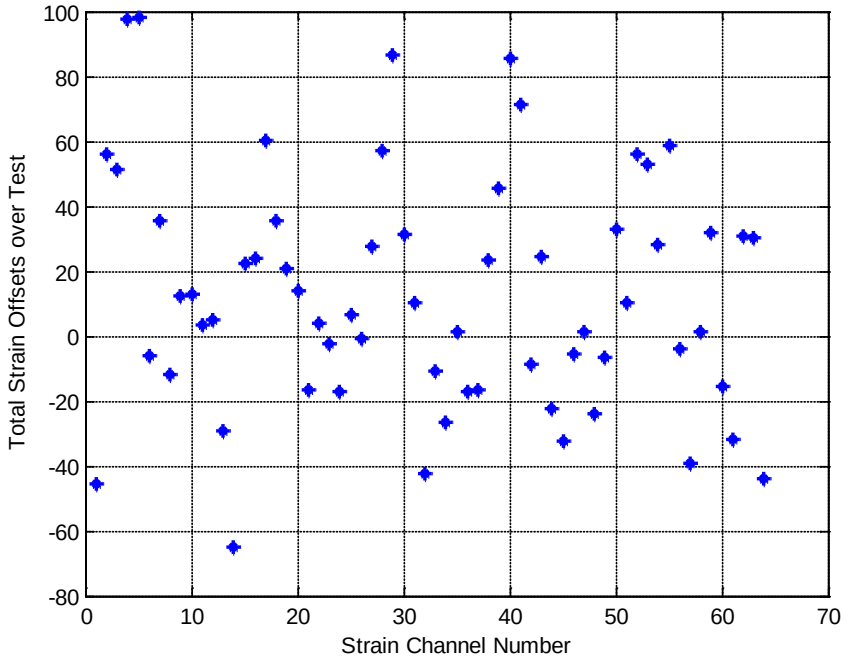


Figure 21. Non-Temperature-Corrected Strain Offsets in Test 1

4.3 Visual Observation Criterion

Car 244 was inspected visually at the test site immediately after the test and again the following day when the car was positioned over a pit to facilitate inspection of the center sill and side sills. No permanent deformation was observed.

5. Conclusions and Recommendations

Car 244 passed the overall length and visual inspection criteria established prior to Test 2. It did not pass the strain offset criterion. The maximum strain reading on the strain gage having the greatest strain offset shows that the corresponding stress was below the yield stress of the belt rail material.

Test data shows that strain offsets observed in the test do not correlate well with the magnitude of strain for a given strain gage location. Strain offsets over each load cycle do not correlate well with the magnitude of the applied loads.

Based upon these test results, TTCI recommends the following:

- The overall length criterion of 0.05-inch change in car length demonstrated that the car had a negligibly small change in length over both Test 1 and Test 2. The overall length criterion should be retained. For general use, the allowable length change should be expressed as a percentage of car length.
- Visual inspection of the car revealed no changes in car structure. Visual inspection is important because not all areas on the car are monitored by instrumentation. The visual inspection criterion should be retained.
- The strain offset criterion did not prove to be effective when applied to Test 1 or Test 2. Instead, it is recommended that the yield criterion require the maximum magnitude of measured strain to be less than the yield strain of the material. It is noted that this criterion already appears in Option A of the occupant volume integrity compliance criteria discussed in the September 2010 Draft Rail Safety Advisory Committee Report titled *Technical Criteria and Procedures for Evaluating the Crashworthiness and Occupant Protection Performance of Alternatively Designed Passenger Rail Equipment for Use in Tier I Service*.[4]
- When the maximum strain criterion above replaces the strain offset criterion, Car 244 passes the acceptance criteria. TTCI concludes that the vehicle is acceptable for the crippling load test, Test 3.

6. References

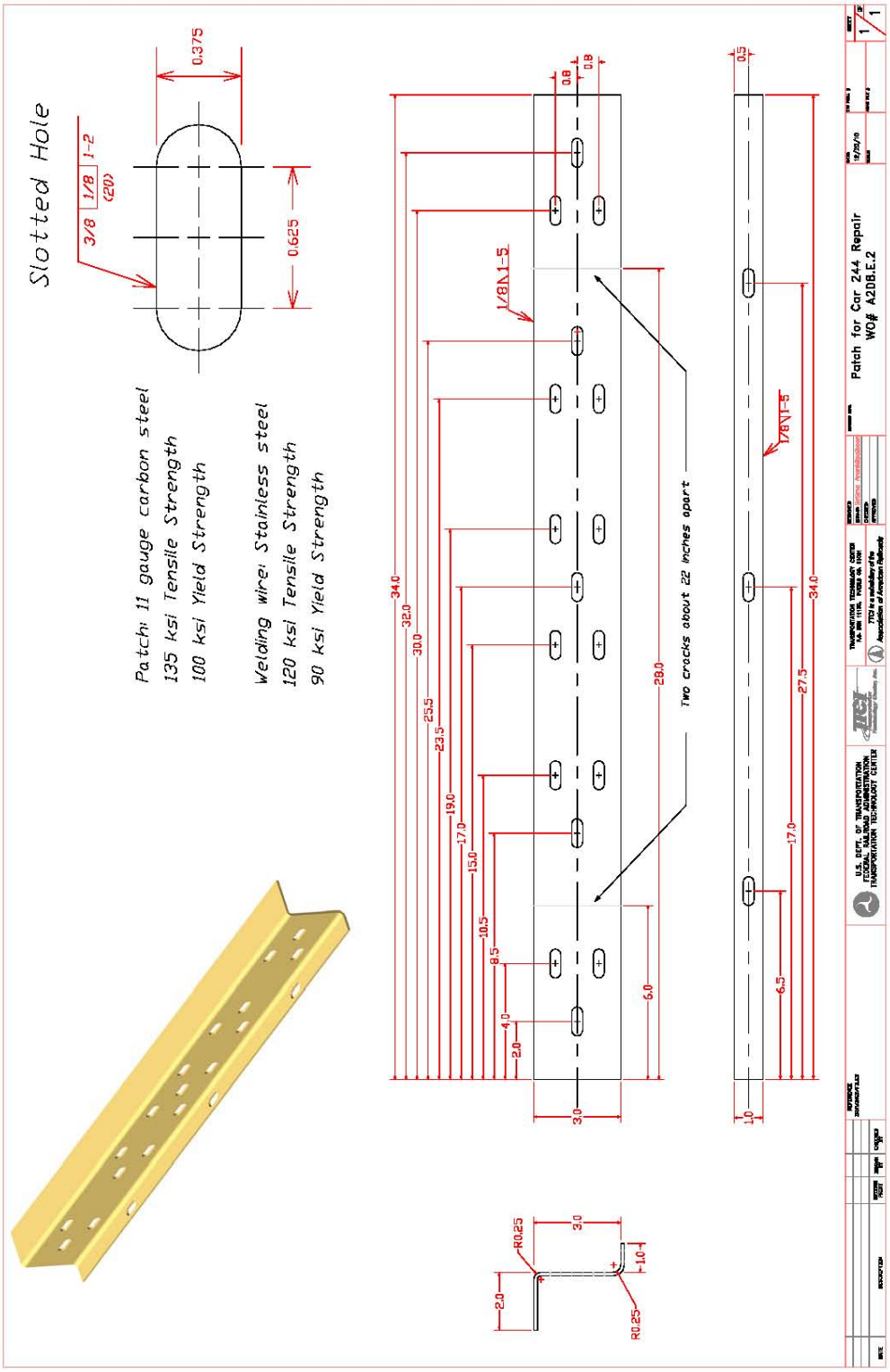
1. Carolan, M., and Muhlanger, M. P. "Strategy for alternative occupant volume testing." In proceedings of the ASME 2009 Rail Transportation Division Fall Conference. 20–21 Oct. 2009, Fort Worth, TX. New York, NY: American Society of Mechanical Engineers.

2. Fries, R. H., and Anankitpaiboon, S. "800,000-Pound quasi-static end-load test of crash energy management equipped car, test 1." U.S. Department of Transportation Report No. DOT/FRA/ORD-10/12. 2010 Nov. Washington, DC: Office of Railroad Policy and Development, Federal Railroad Administration. http://www.fra.dot.gov/rpd/downloads/TR_800K_pound_test_102910.pdf.

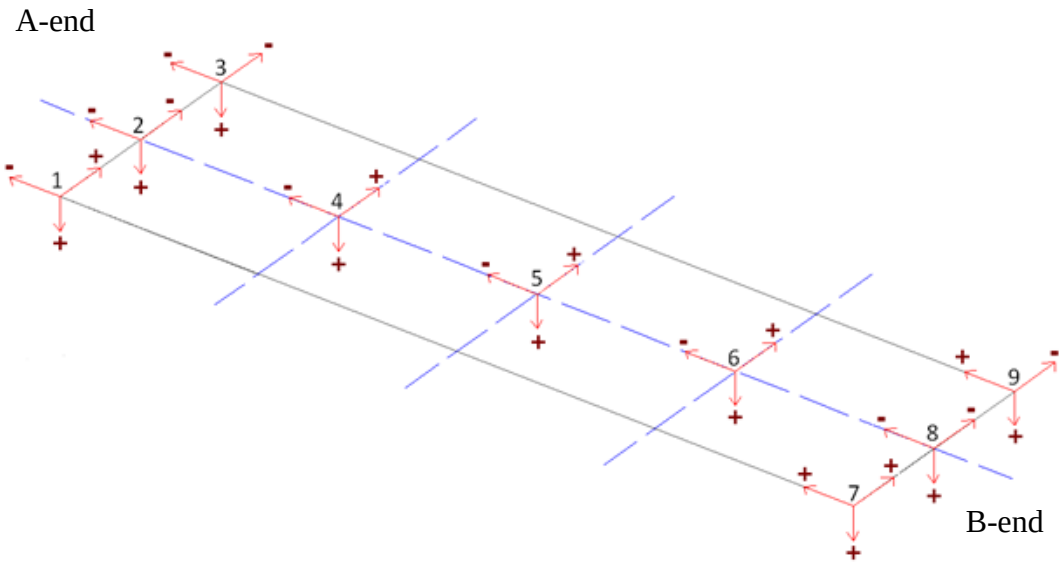
3. Muhlanger, M., and Carolan, M. "Test requirements: 800 kip Occupant Volume Strength Tests." Prepared for Federal Railroad Administration Equipment Safety Research Program. 2009 Oct. and revisions. Washington, DC: U.S. Department of Transportation.

4. Carolan, M., Llana, P., and Tyrell, D. "Technical criteria and procedures for evaluating the crashworthiness and occupant protection performance of alternatively designed passenger rail equipment for use in tier I service." DOT/FRA/ORD draft report. 2010 Sept. 16. Washington, DC: Railroad Safety Advisory Committee/Passenger Safety Working Group/Engineering Task Force. U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development.

Appendix A.
Patch Details



Appendix B.
String Potentiometer Locations, Polarities, and Exposed String Lengths



String Potentiometer Sign Conventions

Location	String Potentiometer	Exposed String Length (inches)
1	Vertical	28 1/2
1	Lateral	38 3/16
1	Longitudinal	47 13/16
2	Vertical	15 1/8
2	Lateral	54
2	Longitudinal	56 3/8
3	Vertical	29 1/2
3	Lateral	39 5/8
3	Longitudinal	56 1/4
4	Vertical	16 1/2
4	Lateral	82 3/16
4	Longitudinal	48 3/16
5	Vertical	15 1/16
5	Lateral	80 3/8
5	Longitudinal	64 13/16
6	Vertical	20 13/16
6	Lateral	81 9/16
6	Longitudinal	53 1/8
7	Vertical	33 1/8
7	Lateral	36 15/16
7	Longitudinal	42 3/8
8	Vertical	18 15/16
8	Lateral	60 1/2
8	Longitudinal	22 3/8
9	Vertical	32 7/16
9	Lateral	40 1/8
9	Longitudinal	46 3/16

Abbreviations and Acronyms

ºF	degrees Fahrenheit
CEM	crash energy management
FRA	Federal Railroad Administration
TOR	top of rail
TTCI	Transportation Technology Center, Inc.
VLL	vertical, lateral, and longitudinal