U.S. Department of Transportation
Federal Railroad Administration

Over-the-Road Testing of the Instrumented Tank Car—A Load Environment Study

Office of Research
and Development
Washington, DC 20590

DOT/FRA/ORD-10-04

Final Report
May 2010

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2010	

4. TITLE AND SUBTITLE
Over-the-Road Testing of the Instrumented Tank Car—A Load Environment Study

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
FRA/DOT/10-04

11. SUPPLEMENTARY NOTES
COTR: Program Manager Francisco González, III

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA Web site at http://www.fra.dot.gov

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

1. Fractures have been observed on stub sill tank cars for many years. Undetected and unattended, these fractures can develop into a variety of tank car failures. While tank car ruptures are relatively rare, the potential for a catastrophic HAZMAT release has made this a critical issue within the industry. The FRA contracted ENSCO, Inc., to instrument and run an instrumented tank car over the road during a special test. Testing was conducted in a special consist with the intent to collect data from the instrumented tank car, instrumented wheelsets and track geometry. The tank car used for this effort was provided by General Electric. The following key recommendations are inferred from testing and analysis:

- An autonomous test should be designed and run for the second phase of this test program.
- This would allow measurement of revenue consist forces and the actual environment that the tank car operates in. Data from this test can then be analyzed in a statistical manner as well as using correlations to associate these big events with either track geometry and/or train handling.
- Track geometry is a strong contributing factor to the load environment of the car and hence the fractures of the stub sill. The test zone selected for the autonomous measurement should be measured for track geometry either immediately prior to or immediately after the test.

14. SUBJECT TERMS	15. NUMBER OF PAGES 36
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

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

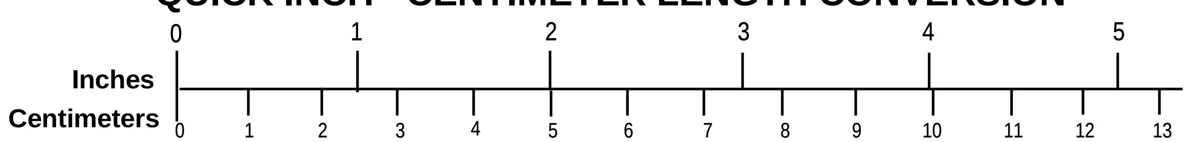
VOLUME (APPROXIMATE)

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 CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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

Updated 6/17/98

Acknowledgments

This report documents the efforts of a task force involving many people at several organizations who were brought together under the leadership of Mr. Francisco González, III, and Mr. William Schoonover of the Federal Railroad Administration (FRA).

The authors would like to express their gratitude to Mr. John Byrne and Mr. John Woodstock of General Electric Railcar Services for donating the tank car and providing it to the FRA and the industry as a research base to conduct studies on tank cars. The authors would also like to express gratitude to Mr. Arthur Clouse of FRA's Office of Safety for providing support via a geometry test under the Automatic Track Inspection Program. Although many individuals were committed to this effort, the authors would like to express gratitude to Mr. Kevin Kesler, previously with ENSCO, Inc., for his technical guidance and numerous inputs during the entire project. The authors also wish to recognize and extend special thanks to Dr. Ray Owings, previously with ENSCO, Inc., for his invaluable guidance in the data analysis efforts.

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Technical Definitions

	Definition
Instrumented Coupler	A standard coupler which is instrumented using strain gages to measure longitudinal forces acting between any two cars
Bolster	Part of a railroad carbody underneath that connects the truck's pivot to the body
Truck/Bogie	Swiveling carriage consisting of a frame, two pairs of wheels and a collection of springs used to carry and guide one end of a railroad car during navigating over railroad tracks
Cant Deficiency	For a train traveling through curved track at a given speed, the cant deficiency is the additional height that the elevated rail would have to be raised in order to produce a condition in which there is no net lateral force exerted on the rail.
°F	Temperature measured in degrees Fahrenheit
g	Acceleration of gravity
mph	Miles per hour
PSD	Power Spectral Density; describes how the variance, or power, of a time series is distributed as a function of the different frequencies that form the signal
PSI, psi	Pounds per square inch
FFT	Fast Fourier Transform; describes how the magnitude of a time series is distributed as a function of the different frequencies that form the signal
GPS	Global Positioning System
FRA	Federal Railroad Administration
TSS	Track Safety Standards
V/TI	Vehicle/Track Interaction

Executive Summary

Fractures have been observed on stub sill tank cars for many years. Undetected and unattended, these fractures can develop into a variety of tank car failures. Although tank car ruptures are relatively rare, the potential for a catastrophic hazmat release has made this a critical issue within the industry. As a result of this concern, special requirements for the construction, inspection, and repair of tank cars have been implemented.

Research into the underlying cause of stub sill tank car cracking and propagation continues. Some researchers believe that the fractures are initiated by discrete events resulting in high stresses. Multiple tests and models have focused on extreme loading events and their contribution to the development of the fatigue cracks. Furthermore, it is believed by some that the cracks are propagated by the stresses of regular over-the-road service. The Federal Railroad Administration (FRA) contracted ENSCO, Inc., to instrument and run a second instrumented tank car over the road during a special test. Testing was conducted in a special consist with the intent to collect data from the instrumented tank car, instrumented wheelsets, and track geometry. The tank car used for this effort was provided by General Electric. This report describes the instrumentation, calibration, and testing efforts conducted by ENSCO.

The tank car ran in consist with the FRA geometry car (DOTX-218) between Gettysburg, PA, and Hamlet, NC, from June 9 to June 17, 2008. The consist included the tank car, filled to capacity, with DOTX-218, an empty hopper car, and a locomotive. The train was run in the same condition as a normal service train would be, including track speed.

The following key conclusions are drawn from testing and analysis:

- The axle acceleration provides the input to the carbody and the data does not show extremely high acceleration input from the axle as measured by this test. High acceleration events were accompanied by observation of high bolster forces. These high vertical acceleration events are mostly caused by switches on the track.

- Maximum carbody accelerations in the negative direction reached about -1g which represents downward motion of the carbody on to the bolster. These accelerations represent high vertical forces to the stub sill.

- The highest vertical coupler forces were attributed to track geometry deviations specifically, a dip or bump on both rails. The speeds in which these events occurred were between 24 and 43 mph. Although track geometry seems to be the cause of these high vertical coupler forces, TSS exceptions for the respective classes were not flagged at these locations. An approximate wavelength of 100 ft seemed to be common among the top locations.

- The highest longitudinal coupler forces can be attributed to braking/acceleration of the consist resulting in a jerk in the longitudinal direction. These events generally occurred at low speeds (below 35 mph). Track geometry parameters were not found to be a contributing factor for the occurrence of high longitudinal coupler forces. Generally, high longitudinal force locations exhibited large vertical coupler forces too.

- Bolster forces were not extensively analyzed but it seems that typically axle acceleration events gave rise to changes in the bolster forces.

- The analysis of the instrumented wheelset forces showed us that not many locations exist where exceptions took place. There were four vehicle/track interactions (V/TI) exceptions for the truck side L/V ratio threshold as per the V/TI standards (in place for track class 6 and above).

- Track geometry appears to be a strong contributing factor to the load environment of the tank car especially the vertical and the longitudinal coupler forces.

The following key recommendations are inferred from testing and analysis:

- An autonomous test should be designed and run for the second phase of this test program.

- This would allow measurement of revenue consist forces and the actual environment in which the tank car operates. Data from this test can then be analyzed in a statistical manner as well as using correlations to associate these big events with either track geometry and/or train handling.

- Track geometry is a strong contributing factor to the load environment of the car and hence the fractures of the stub sill. The test zone selected for the autonomous measurement should be measured for track geometry either immediately before or immediately after the test.

- The autonomous testing to be conducted in Phase 2 should be conducted on track that has lower than average track geometry to study the relationship of the high forces and track geometry.

1. Introduction

1.1. Background

Fractures have been observed on stub sill tank cars for many years. Undetected and unattended, these fractures can develop into a variety of tank car failures. While tank car ruptures are relatively rare, the potential for a catastrophic hazardous material (hazmat) release has made this a critical issue within the industry. As a result of this concern, special requirements for the construction, inspection, and repair of tank cars have been implemented.

Research into the underlying cause of stub sill tank car cracking and propagation continues. The fractures are believed to be initiated by discrete events resulting in high stresses. Multiple tests and models have focused on extreme loading events and their contribution to the development of the fatigue cracks. Furthermore, the cracks are thought to be propagated by the stresses of regular over-the-road service. Under direction of the Tank Car Operating Environment Task Force (TCOE-TF) and the Stub Sill Working Group (SSWG), a test program was initiated to develop a methodology for both the measurement and reporting of events approaching and exceeding stub sill tank car design specifications; the TCOE-TF and the SSWG represent cooperative efforts between the Association of American Railroads (AAR), the Railway Supply Institute (RSI), the Federal Railroad Administration (FRA) and Transport Canada (TC).

Phase I of this test program addressed the development and proof of a method to record vertical and longitudinal coupler forces while employing relatively low-cost transducers and instrumentation. Phase II of the test program was established to validate the approach developed in Phase I by instrumenting several tank cars with a minimal set of sensors and instrumentation and conduct over-the-road tests. The Transportation Technology Center, Inc. (TTCI) has conducted the initial stages of Phase II on a single instrumented vehicle.

FRA contracted ENSCO, Inc., to instrument and run a second instrumented tank car over the road during a special test. Testing was conducted in a special consist with the intent to collect data from the instrumented tank car, instrumented wheelsets, and track geometry. The tank car used was for this effort was provided by General Electric (GE) and is shown in Figure 1. This report describes the instrumentation, calibration and testing efforts conducted by ENSCO.

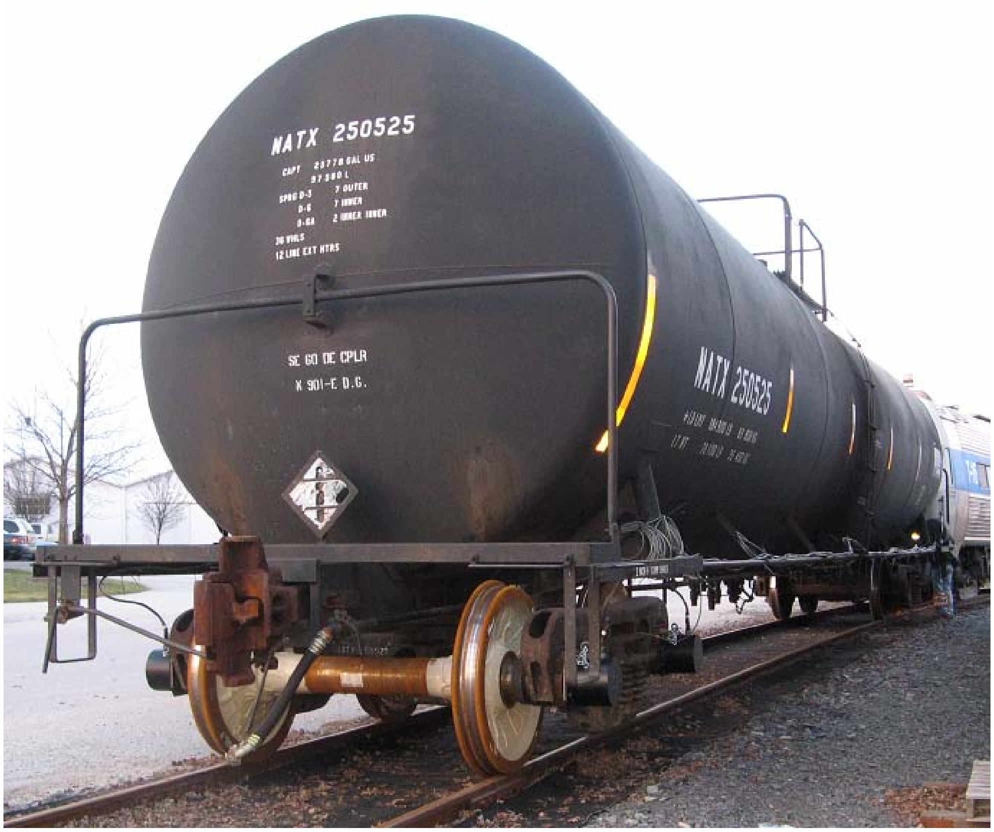

Figure 1. Tank Car Supplied by General Electric for Conducting Research

1.2. Test Objectives and Approach

The objective is to better understand the operational environment and forces exerted on tank cars in over-the-road service using methods based on results from the initial efforts conducted during Phase II of the TCOE-TF/SSWG research program. It is anticipated that the results of this test effort will either 1) confirm the industry's current understanding of fracture initiation and propagation or 2) reveal additional factors that are critical to the understanding of the phenomena. This will also make available a great deal of robust, real world ride condition data for further research in the future.

ENSCO installed six types of sensors on the tank car: accelerometers, strain gages, vertical load adapters, instrumented coupler, instrumented wheelsets, and a pressure transducer. With the tank car coupled adjacent to FRA's DOTX-218 track inspection vehicle, cables were run from the sensors to the equipment located on DOTX-218. The data acquisition equipment was synchronized to the track geometry system onboard DOTX-218, which simultaneously measured the track geometry. This dynamical testing took place over normal freight track at track speed.

1.3. Program Time Line

Key dates in the program time line are given below.

Installation on Tank Car	Dec 2006 – Nov 2007
Calibration of Sensors	Apr 2008 – May 2008
Low Speed Test Run	Jun 03 2008
Over-the-Road Testing	Jun 09 2008 – Jun 18 2008
Draft Report/Presentation	Aug 2008 to Jan 2009
Final Report	Apr 10 2009

1.4. Report Organization

The test methodology is discussed in Section 2, along with a review of the physical measurements recorded and the equipment used during testing. Section 2 also details the route on which the over-the-road testing was conducted.

Section 3 presents the results of the analysis of the collected test data; much of the information presented in Section 3 is supported by detailed analyses provided in the appendices. Section 4 presents the major observations of the test program. Conclusions based on the observations discussed in Section 4 are presented in Section 5.

Supplemental material is provided in the appendices. A list of the appendices follows:

- Appendix A: Record of Test Plan–The documentation of the test plan used in the test program.

- Appendix B: Listing of Collected Data F– Tabulated details of each data file collected during the testing.

- Appendix C: Listing of Geometry Exceptions during Testing–Tabulated details of each exception during the testing.

- Appendix D: List of IWS Exceptions from T–Tabulated details of each instrumented wheelset exception as per the vehicle/track interaction (V/TI) standards (for track class 6 and above).

2. Test Methodology

A tank car was donated by GE for conducting this research supported by the FRA. The instrumentation on the tank car, in addition to DOTX-218's geometry system, included two IWS axles, a brake pressure sensor, eight strain bridges, four vertical load adapters, five accelerometers and one instrumented coupler. Thus, the systems simultaneously collected information about the features of the track, the speed and location, the motion of the train, the dynamics of the tank car and the forces and strains on the tank car's structural parts.

Car Manufacturer	–Union Tank Car
Under Frame Design	–UTLZBG Stub Sill w/ Head brace
Coupler Design	–A End & B End: SE60DE
Draft Gear Design	–E/F Top & Bottom Shelf

2.1. Instrumentation for Testing

The overall instrumentation layout is shown in Figure 2. Details for the sensors are provided in the following few paragraphs.

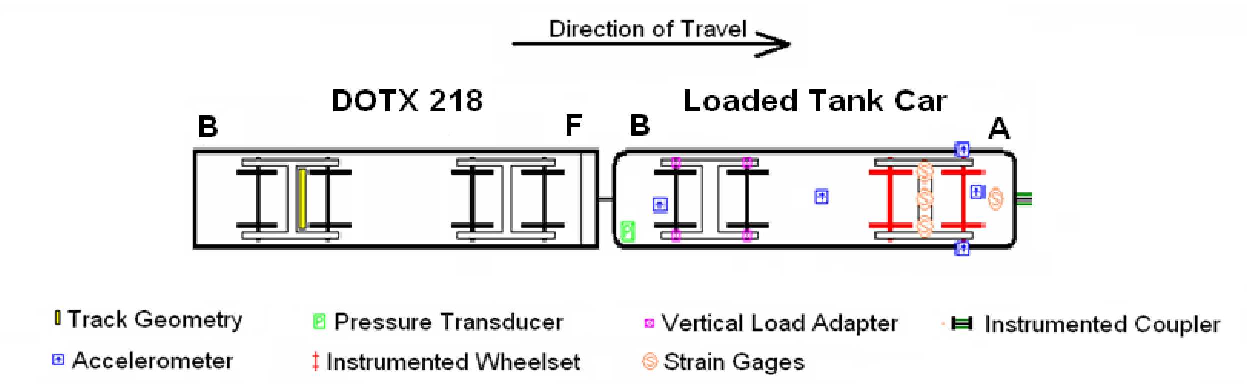

Figure 2. Instrumentation Layout for the Over-the-Road Testing

The tank car was filled to its weight capacity with water for the test—22,000 gal (184 kips). The weight of the car with an empty tank is 78 kips. The filling was done in five steps using tanker trucks of approximately a 6,000-gallon capacity—these steps are shown in Table 1. The filling was monitored and strains on the bolster were measured before filling, halfway through the first tanker truck, and before the second tanker truck. Because the capacity is weight-based, the tank car's tank was not filled to the very top or 100 percent of the tank's volume. Table 1 provides the filling schedule used for the tank car loading from empty to full on basis of the gauge table provided by GE.

Table 1. Tank Car Filling Schedule from Tank Trucks

Halfway through first tanker truck	3,238 gal
After first tanker	6,018 gal
After second tanker	12,210 gal
After third tanker	18,253 gal
After partial fourth tanker	22,132 gal

To more accurately measure the strains caused by loading at each point, steel blocks were used to control the load path of the carbody's weight to the truck. Blocks would, for example, be set on the left side of the bolster such that the carbody was not touching the center or right contact point. A load cell placed in the load path between the carbody and truck at left, right, or center contact point, measured the force.

The coupler vertical strains were tested using a device with a hydraulic ram and a load cell, which applied upward and downward loads to the coupler. This test correlated the vertical loading on the coupler to the strains measured in the vertical coupler load channel.

2.1.1 Coupler Forces

Coupler forces were measured between the tank car (A-end) and the rest of the consist. A special coupler instrumented with strain bridges was used to measure the longitudinal forces. The instrumented coupler was provided by FRA for the purpose of this test. To measure vertical forces a pair of shear gages is mounted on each side of the coupler channel as shown in Figure 3. These gages are wired using a completion card to form a full bridge. A second set of gages are mounted next to the original set as a spare (total eight gages, four on each side). The mounting process included grinding the surface to provide a smooth area to which the strain gages could adhere. To increase resolution after unsatisfactory initial testing, new gages were applied at a location closer to the end of the car but not beyond the points on contact between the coupler channel and the coupler.

Figure 3. Shear Gages Measuring Vertical Coupler Force. Left: Close up of installation. Right: New gages on the right replace gages (covered with sealant) on the left which were then disconnected

2.1.2 Bolster Forces

A second set of strain gages were mounted on the truck bolster underneath the side bearing as shown in Figure 4. One gage is mounted on each side to form a half bridge. Bridge completion resistors were used to complete the bridge. A spare set of gages were mounted adjacent to the main gages. An identical set of gages were mounted on the truck bolster on the other side of the vehicle. These gages were used to measure the side bearing loads.

Figure 4. Strain Gages Measuring Bolster Side Bearing Loads

A third set of strain gages are mounted on the each side of the bottom center of the bolster as shown in Figure 5. One gage is mounted on each side to form a half bridge. Bridge completion resistors are used to complete the bridge. A spare set of gages are mounted adjacent to the main gages. These gages are used to measure the bolster center bowl load.

Figure 5. Strain Gages Measuring Bolster Center Bowl Load

2.1.3 Carbody and Axle Accelerations

Accelerometers are installed at several locations on the tank car. The first is a triaxial accelerometer mounted on top of the carbody as shown in Figure 6. The second and third accelerometers are mounted on the stub sill at each end of the car as shown in Figure 7. These measure accelerations in the vertical direction only. The fourth and fifth accelerometers are on the bearing adapter on both sides of the first axle as shown in Figure 8. These measure accelerations on the axle in the vertical direction.

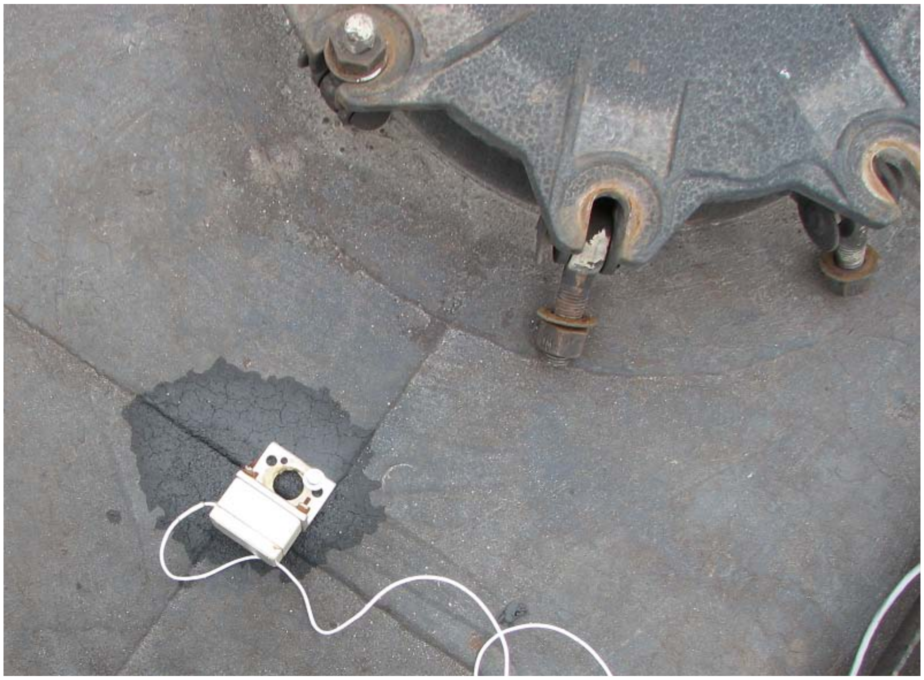

Figure 6. Triaxial Accelerometer Mounted on Top of Carbody

Figure 7. Vertical Accelerometer Mounted on the Stub Sill and Each End of the Car

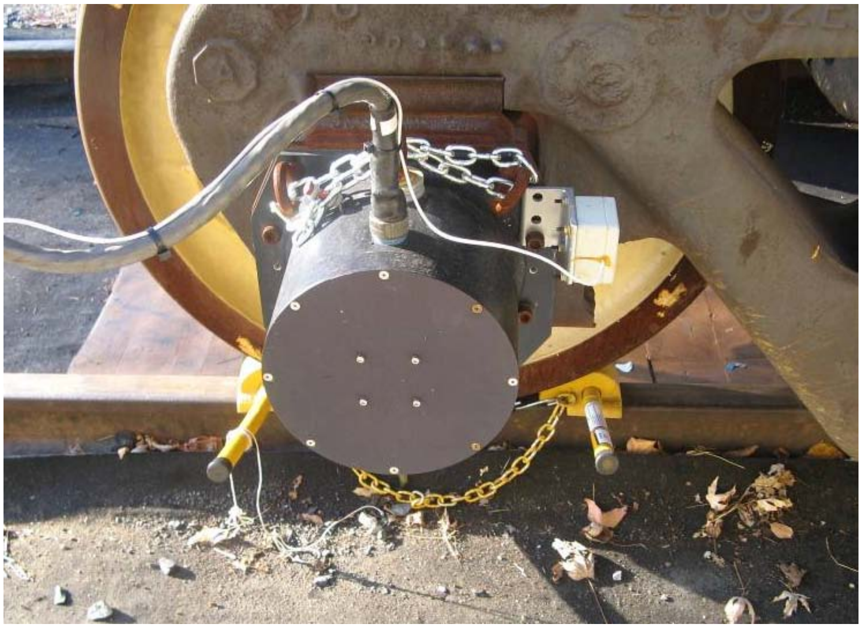

Figure 8. Vertical Accelerometer Mounted on the Axle on Both Sides of the Car

2.1.4 Vertical Loads

Vertical load adapters are modified bearing adapters used to measure the vertical wheel forces. The vertical load adapters are made using strain gages. After they are calibrated, they are used like any other load cells. Figure 9 shows a vertical load adapter mounted on the tank car. Four of these were mounted on the B-End of the tank car, opposite to most of the instrumentation.

Figure 9. Vertical Load Adapter

2.1.5 Brake Pressure

Brake application data was gathered to correlate the force and strain data to the operation of the car. This measurement was achieved by using a pressure transducer to measure the brake cylinder pressure. Only one pressure transducer is needed for the entire vehicle. Figure 10 shows the installation of the brake pressure transducer with the wires disconnected and protected from moisture before the test.

Figure 10. Brake Pressure Transducer

2.1.6 Instrumented Wheel/Rail Forces

One of the most sophisticated and useful tools to measure the vehicle dynamics is to use instrumented wheelsets. Each wheel and axle of one truck is instrumented with strain gages in several configurations. Once calibrated, these are used to measure the vertical, lateral, and longitudinal forces at the wheel/rail interface. They are also used to measure the contact position on the wheel. Figure 11 shows the instrumented wheelsets mounted on the A-end of the tank car. The instrumented wheelsets have their own signal conditioning units and computers. There are fully synchronized with DOTX-218’s track geometry system.

Figure 11. Instrumented Wheelsets

2.1.7 Data Acquisition and Hardware Settings

Data Acquisition was performed using two separate systems: one for IWS and one for all other tank car sensors. The IWS system consists of 32 channels using Ectron transducer conditioner amplifiers and Michigan Scientific resolver electronics. Twenty-four channels of strain, four rotation resolver channels, and four IWS-specific acceleration channels exist. Details for these channels are provided in Table 3. These provided input to a QNX computer which used custom software to monitor the system, perform calculations and record 64 channel binary files. An additional computer was used to display the data in real time. Both computers were monitored during the test.

The (non-IWS) data acquisition system (DAQ), which acquired the tank car sensor data, consisted of two sixteen-channel signal conditioning units (SCUs) and a portable computer. Of the 32 available channels, only 21 were used—1 instrumented coupler channel, 7 acceleration channels, 8 strain channels, 4 vertical load channels, and 1 brake pressure channel. Details of these channels are provided in Table 2. The output from the SCUs was passed through a filter card and into a data acquisition card, both of which were in the computer. LabVIEW based software then acquired, recorded and displayed the data in real time. The SCU also provided GPS data using an antenna which was affixed to the roof of DOTX-218.

The DOTX-218 track geometry inspection vehicle served two primary functions. It provided a location for the signal conditioning equipment, computers, and personnel for the dynamic testing. DOTX-218 also collected the track geometry measurements as well as all associated data such as GPS location. The track geometry system will provide synchronization signals, including milepost, feet-after-milepost, sync count, and sync foot to the tank car (DAQ) system and the IWS system.

2.1.8 Channel Assignments

Channel assignments and the respective descriptions for the DAQ system and the IWS system are provided in Table 2 and Table 3.

Table 2. Input Channels for DAQ System

Serial Num	Type	Channel Name
1	Full bridge strain	Coupler Longitudinal Force
2	Acceleration	Acceleration Carbody Longitudinal
3	Acceleration	Acceleration Carbody Lateral
4	Acceleration	Acceleration Carbody Vertical
5	Acceleration	Stub Sill Vertical A
6	Acceleration	Stub Sill Vertical B
7	Acceleration	Axle Left Vertical
8	Acceleration	Axle Right Vertical
9	1/2 bridge strain	Coupler Vertical
10	1/2 bridge strain	Coupler Vertical (spare)
11	1/2 bridge strain	Bolster Left
12	1/2 bridge strain	Bolster Center
13	1/2 bridge strain	Bolster Right
14	1/2 bridge strain	Bolster Left (spare)
15	1/2 bridge strain	Bolster Center (spare)
16	1/2 bridge strain	Bolster Right (spare)
17	Full bridge strain	Vertical Load Adapter Left Axle 3
18	Full bridge strain	Vertical Load Adapter Right Axle 3
19	Full bridge strain	Vertical Load Adapter Left Axle 4
20	Full bridge strain	Vertical Load Adapter Right Axle 4
21	Pressure	Brake Pressure

Table 3. Input Channels for the IWS System

	Type	Full Name
1	Resolver	Resolver, SIN Θ
2	Resolver	Resolver, COS Θ
3	Strain	Vertical "a" Bridge, Field Side
4	Strain	Vertical "a" Bridge, Gauge Side
5	Strain	Vertical "b" Bridge, 8 gauges, both sides
6	Strain	Lateral "a" Bridge
7	Strain	Lateral "b" Bridge
8	Strain	Torque Bridge (Longitudinal)
9	Strain	Vertical "a" Bridge, Field Side
10	Strain	Vertical "a" Bridge, Gauge Side
11	Strain	Vertical "b" Bridge, 8 gauges, both sides
12	Strain	Lateral "a" Bridge

13	Strain	Lateral "b" Bridge
14	Strain	Torque Bridge (Longitudinal)
15	Resolver	Resolver, SIN Θ
16	Resolver	Resolver, COS Θ
17	Strain	Vertical "a" Bridge, Field Side
18	Strain	Vertical "a" Bridge, Gauge Side
19	Strain	Vertical "b" Bridge, 8 gauges, both sides
20	Strain	Lateral "a" Bridge
21	Strain	Lateral "b" Bridge
22	Strain	Torque Bridge (Longitudinal)
23	Strain	Vertical "a" Bridge, Field Side
24	Strain	Vertical "a" Bridge, Gauge Side
25	Strain	Vertical "b" Bridge, 8 gauges, both sides
26	Strain	Lateral "a" Bridge
27	Strain	Lateral "b" Bridge
28	Strain	Torque Bridge (Longitudinal)
29	Acceleration	Vertical acceleration, carbody
30	Acceleration	Lateral acceleration, carbody
31	Acceleration	Vertical acceleration, truck frame
32	Acceleration	Lateral acceleration, truck frame

2.2. Test Logistics

The test was conducted between Gettysburg, PA, and Hamlet, NC, on CSX track with an additional short run between Biglerville, PA, and Gettysburg on GET track, from June 9 to June 18, 2008. This route was chosen over a previous plan to test in New England or in the Midwest for several reasons. Cold weather was a great concern because of the negative effect snow has on the geometry car's laser sensors. Though the test occurred in June, it was not clear initially that this was to be the timeframe. Second, keeping the test in the mid-Atlantic region, specifically around Washington, DC, reduced travel costs and greatly increased access to ENSCO equipment and personnel in the event of a problem.

The consist, shown in Figure 12, included four cars: DOTX-218, the instrumented tank car, the locomotive and an empty hopper. One of the requirements of instrumented wheelsets is that the brakes on those wheels/axles need to be removed or disabled. This is to ensure accurate measurements and to prevent damage to the wheelsets. This required that there be at least four vehicles in the train consist to ensure that there is at least 85 percent braking. The consist shown below was used for most of the testing except the move from Biglerville to Gettysburg. The consist used for this short move was Locomotive 1, Locomotive 2, tank car, DOTX-218, and the empty hopper.

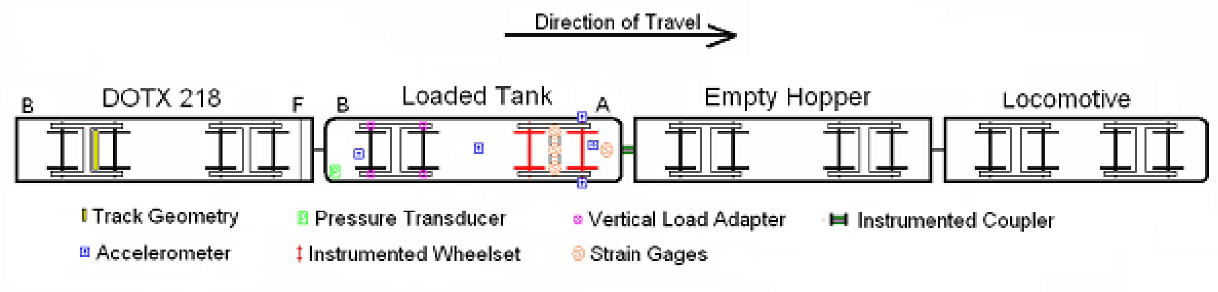

Figure 12. Consist with Instrumentation

2.3. Test Route and Collected Data

The data were collected over 8 days, between June 9, 2008, and June 18, 2008, on CSX track from Gettysburg, PA, to Hamlet, NC, and back as provided in Table 4. Details of the files and number of seconds of data collected are provided in Appendix B. A map of route tested is shown in Figure 13.

Table 4. Testing Schedule used for the Tank Car

Day	Railroad	From	To	Distance
6/03/2008	GET	Biglerville, PA	Gettysburg, PA	8
6/09/2008	CSX	Gettysburg, PA	Baltimore, MD	72
6/10/2008	CSX	Baltimore, MD	Richmond, VA	155
6/11/2008	CSX	Richmond, VA	Rocky Mount, NC	105
6/12/2008	CSX	Rocky Mount, NC	Hamlet, NC	154
6/13/2008	CSX	Hamlet, NC	Rocky Mount, NC	154
6/16/2008	CSX	Rocky Mount, NC	Richmond, VA	105
6/17/2008	CSX	Richmond, VA	Baltimore, MD	155
6/18/2008	CSX	Baltimore, MD	Gettysburg, PA	72

Figure 13. Route Map Used for Testing of the Tank Car is Highlighted in Green

2.3.1. Data Collection and On-Board Analysis

The data collection system and the IWS data were monitored in real time for any events of interest during the entire test. Log sheets were created to note down any problems with any channels and also to keep track of files and associated start and end locations.

2.3.2. Data Processing Methods

General statistical methods were used to find the maximum, minimum and other relevant parameters for each tank car channel. The geometry data was processed against the FRA Track Safety Standards (TSS) for the relevant class of track. The instrumented wheelset forces were also processed against the relevant FRA TSS. Data was also analyzed for a few important parameters to provide insight into the cause of high vertical and longitudinal coupler forces.

2.4. Issues Encountered During Testing

2.4.1. Accelerometer on the carbody

The carbody accelerometer, which was mounted on the top of the car, had a significant magnitude of high frequency vibrations and the suspicion was these vibrations could be localized and do not represent rigid body motion. The stub sill accelerometers do not show this behavior and are more indicative of the rigid body motion.

2.4.2. Synchronization problems for IWS

The instrumented wheelset system lost synchronization pulses from the TGMS occasionally. This did not affect the overall synchronization because IWS still received the sync foot pulses, which continued to increment to 4,000 or 6,000 instead of the usual 2,000. The next sync count pulse received was automatically updated with the correct value. Therefore, during data processing, this was considered and the right synchronized locations were used for analysis.

3. Test Results

This section provides an overview of the results determined from analysis of the data collected and events observed during this test program. More detailed results, as well as the original data sets, are contained in the various appendices to this report.

Each section below provides information of the various parameters studied during the over-the-road testing. Results obtained using general statistical analysis are presented in Section 3.1, results from the acceleration data are presented in Section 3.1.1, results from the force analysis are presented in Section 3.1.2, results from the geometry data analyses are presented in Section 3.2, and results from the instrumented wheelset analysis are presented in Section 3.3. Section 3.4 covers the analysis of the important parameters by using examples.

3.1. General Statistical Analysis

As described in Section 2.1.8, measurements were made at multiple locations on the tank car with the forces being collected on one of the lead truck of the tank car. The following sections present the results obtained from analyses that were conducted on the recorded data by using statistical methods.

3.1.1. Accelerations

Acceleration measurements were made on the carbody, truck and the axle on the tank car. The specific locations of these force measurements were previously described in Section 2.1. Acceleration data processing was conducted with a digital filter frequency of 10 Hz. The highest vertical acceleration observed on the axle during this testing was 21g, measured on the right end of the axle. The highest vertical acceleration observed on the left end of the axle was 13g. Highest carbody vertical accelerations were observed on the sensor placed on the top of the carbody in the center of the car. Maximum positive acceleration observed was 0.9g and maximum negative acceleration was -1.1g. Due to the placement of the carbody accelerometer, as desired by GE, the accelerations observed at this location might be localized vibration. One of the causes might be the proximity to the manway cover at the top of the tank car as show in Figure 6. The RMS value for this carbody acceleration was higher than the stub sill accelerations recorded indicating sustained localized vibrations.

Table 5 provides the summary of the statistical methods used for the acceleration measurements made on the tank car.

Table 5. General Statistics of Acceleration Measurements on the Tank Car

	Min	Max	Average	RMS	Units
Parameter	Accelerations in G's				
Carbody Longitudinal	-0.464	0.273	-0.074	0.017	g
Carbody Lateral	-0.287	0.454	0.062	0.051	g
Carbody Vertical	-1.142	0.873	-0.066	0.103	g
Stub Sill Vertical A End	-1.05	0.529	-0.007	0.058	g
Stub Sill Vertical B End	-0.472	0.557	0.033	0.059	g
Axle Vertical Left	-5.18	13.86	-0.106	0.079	g
Axle Vertical Right	-5.01	21.7	0.21	0.082	g

3.1.2. Forces

In addition to the acceleration measurements, force measurements were also made on the bolster, vertical bearing, and coupler in the longitudinal and vertical directions. The specific locations of these force measurements were previously described in Section 2.1. Force data processing was conducted with a digital filter frequency of 25 Hz. A summary of the statistical numbers for the forces thus measured is provided in Table 6. The two most important forces considered part of the tank car operating environment are the longitudinal and vertical coupler forces. The coupler vertical force is the force that is exerted on the stub sill from the ends of the car and is believed to be major cause of cracking of the stub sills. During the 1,000 mi of testing conducted, a maximum force of 11,860 lbs was observed. This value is lower than the value TTCI has reported (approximately 25 kips) and is attributed to the consist being a shorter consist and not being a regular freight consist. A maximum longitudinal coupler force of 185 kips was observed during this test. A maximum unloading of 37 percent was observed by using the vertical bearing load measurements made on the trailing truck. The instrumented wheelsets data will provide a better measure of unloading of the wheels.

Table 6. General Statistics of Force measurements on the Tank Car

	Min	Max	Average
Parameter	Force in Pounds		
Longitudinal Coupler Force	-115695	185779	
Coupler Vertical Force	-10489	11857	
Vertical Load Axle 3 Left	19062	56580	31374
Vertical Load Axle 3 Right	19961	52240	31377

Vertical Load Axle 4 Left	18295	57140	31381
Vertical Load Axle 4 Right	18768	53530	31383
Bolster Left Load	-10441	114947	19594
Bolster Center Load	11230	141313	85353
Bolster Right Load	-3350	57270	19530

3.2. Geometry Data

The collected geometry report was assimilated and a combined exception report was put together. Table 7 provides a summary of the number of exceptions found by DOTX-218. More details for the exceptions flagged as per FRA TSS are provided in Appendix C. Most of the exceptions are narrow gage exceptions and a few vertical surface exceptions. Details of a few exceptions including the effect on the tank car are analyzed in Section 3.4.6.

Table 7. Summary of Geometry Exceptions during the Over-the-road testing from DOTX-218

Type of Exception	Number of Exceptions
Narrow Gage	149
Wide Gage	2
Profile 62' Left	2
Profile 62' Right	2
Runoff Left	1
Runoff Right	1
Warp 62'	3
Twist 31'	3

3.3. Instrumented Wheelset Forces

The IWS forces were analyzed by using the V/TI standards as specified in the FRA TSS for classes 6 and above. Although the tank car usually runs at lower speeds and lower classes than Class 6, the instrumented wheelset data provide important information in determining the safety of the tank cars at locations of interest.

The data was analyzed by using a software program and the number of locations where thresholds were exceeded is tabulated below in Table 8. It is observed that only one type of exception was triggered during the entire testing route. Four locations were found which exceeded the current V/TI thresholds and the rest of the locations were triggered based on an 80 percent threshold level of the V/TI standards. Calculations of these exceptions were based on a digital filter of 25 Hz for the force data. Details for these exception locations are provided in Appendix D.

Table 8. Number of Locations which triggered IWS exceptions

	Number of Exceptions	
Type	Safety	Maintenance
Truck Side L/V Left	4	74
Truck Side L/V Right	-	50

3.4. Analysis of Important Parameters

A few important parameters were analyzed in depth by using examples of each force case. These cases are presented in the following subsections.

3.4.1. Positive Longitudinal Coupler Force

Positive longitudinal coupler force locations were chosen based on the highest positive values determined during the entire testing and by using a filter of 25 Hz. Three locations were analyzed in depth by using the array of data collected to see which parameters make the most impact on the longitudinal coupler force. The highest location with a longitudinal coupler force of 185 kips is presented with Figure 14–16. All the locations analyzed depicted the following characteristics:

- They can be attributed to braking, resulting in a jerk in the longitudinal direction.
- The speeds in which these events occurred were between 1–35 miles per hour (mph).
- Track geometry parameters were not found to be a contributing factor for the occurrence of high longitudinal coupler forces.
- Each of these locations had large vertical coupler forces.

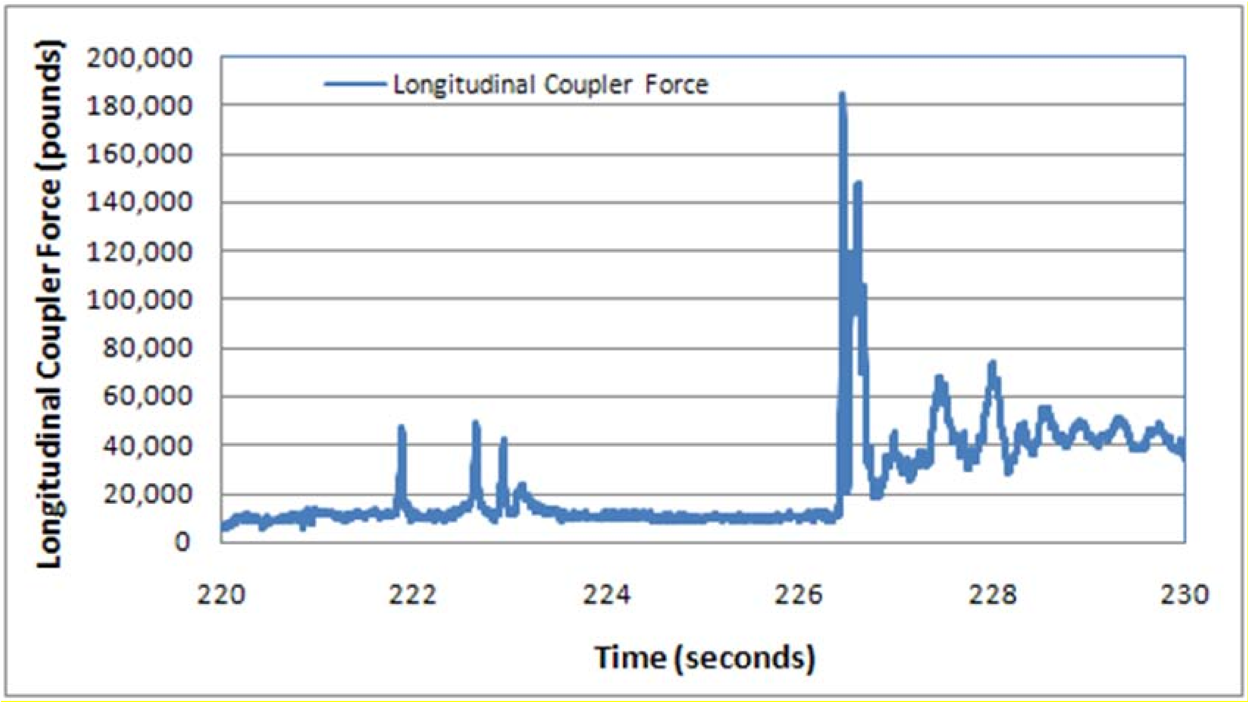

Figure 14. Highest Positive Longitudinal Coupler Force Observed During Testing

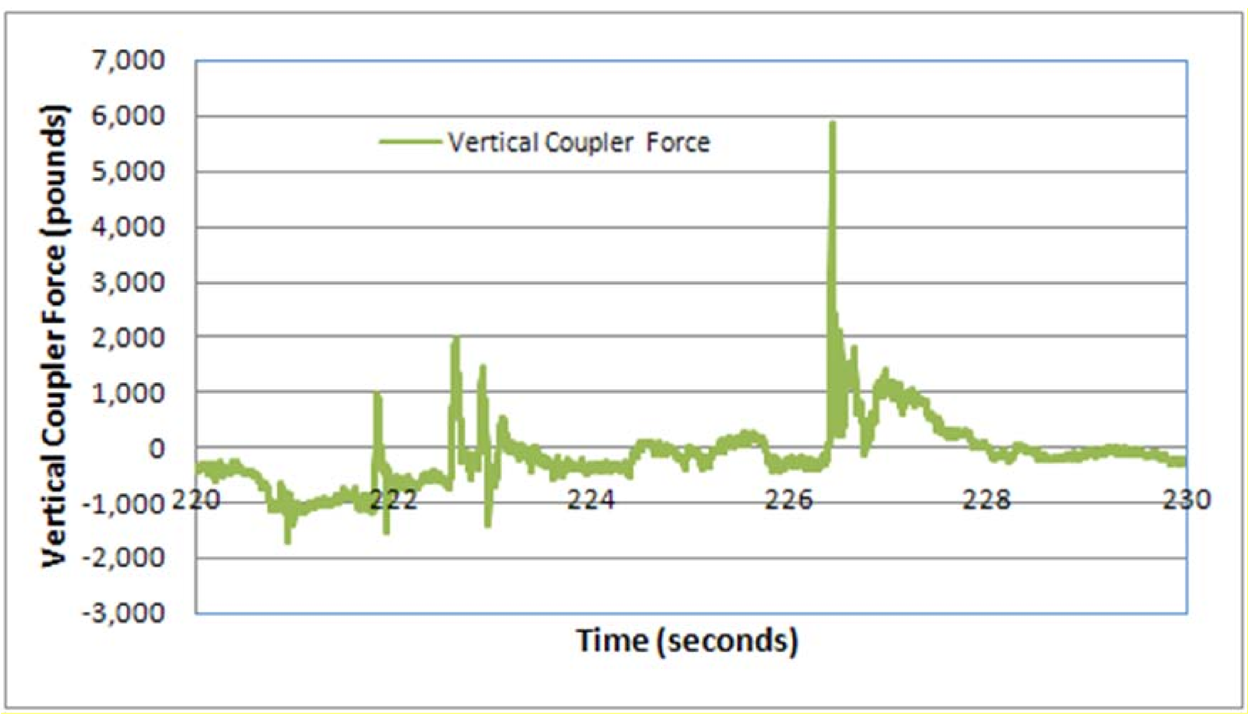

Figure 15. Corresponding Vertical Coupler Force for this Event

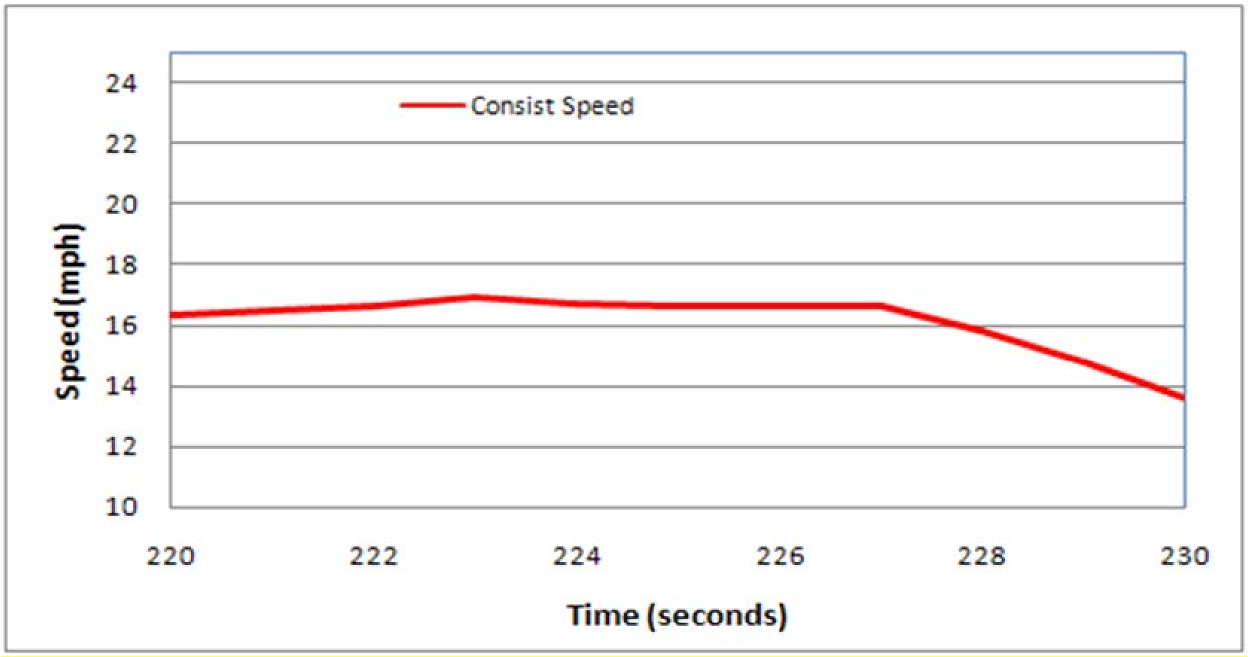

Figure 16. Deceleration of the Consist causes High Positive Longitudinal Coupler Forces

3.4.2. Negative Longitudinal Coupler Force

Negative longitudinal coupler force locations were chosen based on the highest negative values determined during the entire testing and by using a filter of 25 Hz. Three locations were analyzed in depth using the array of data collected to see which parameters make the most impact on these events. The highest location with a longitudinal coupler force of 130 kips is presented using Figure 17–Figure 19. All the locations analyzed depicted the following characteristics:

- They can be attributed to train acceleration.
- The speeds these events occurred were near or at 0 mph speed.
- Speed was too slow to measure track geometry.
- Each of these locations had large vertical coupler forces.
- Water movement inside the tank may be attributed to cyclic force level change in the longitudinal direction after the initial jerk.

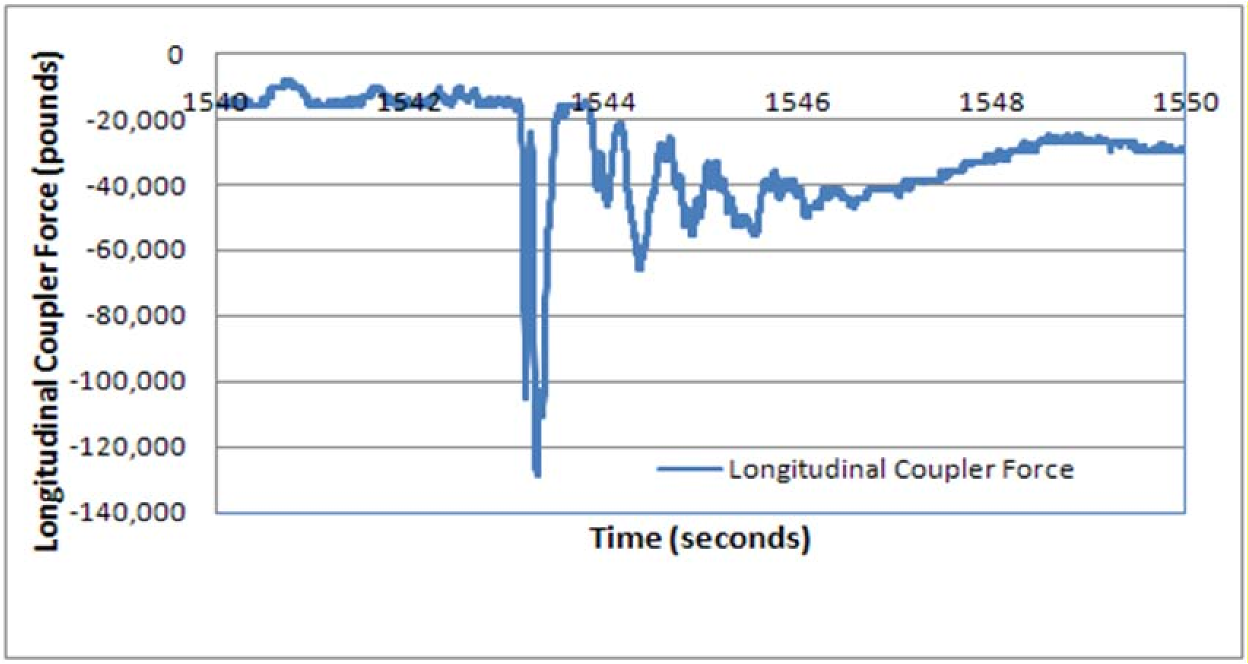

Figure 17. Highest Negative Longitudinal Coupler Force Observed During Testing

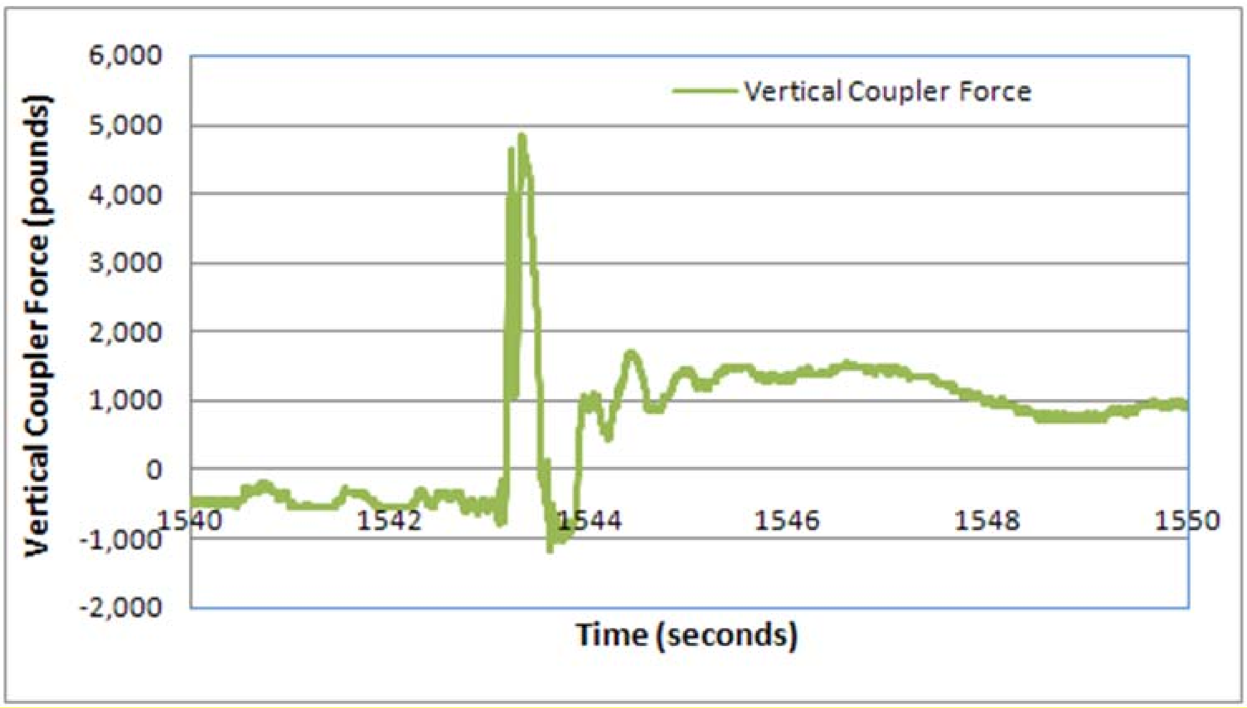

Figure 18. Corresponding Vertical Coupler Force for this Event

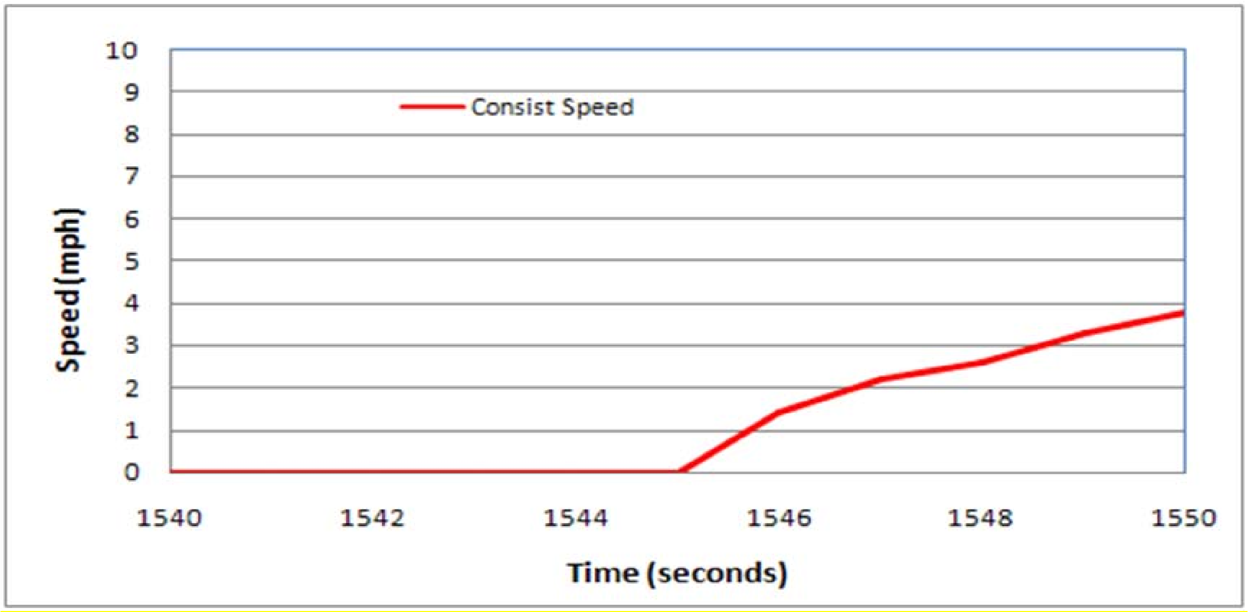

Figure 19. Acceleration of the Consist causes High Negative Longitudinal Coupler Forces

3.4.3. Positive Vertical Coupler Force

Positive vertical coupler force locations were chosen based on the highest positive values determined during the entire testing and by using a filter of 25 Hz. Three locations were analyzed in depth by using the array of data collected to see which parameters make the most impact on these events. The highest location with a vertical coupler force of 10.8 kips is presented by using Figure 20–22. All the locations analyzed depicted the following characteristics:

- They can be attributed to track geometry specifically, a dip or bump on both rails.
- The speeds these events occurred were between 24 and 43 mph.
- Although track geometry seems to be the cause of these high vertical coupler forces, TSS exceptions for the respective classes were not flagged at these locations.
- An approximate wavelength of 100 ft seemed to be common among the top locations.
- These locations conversely resulted in longitudinal coupler forces at approximately 60 percent of the highest.
- Speed of the train consist was not found to be a contributing factor.

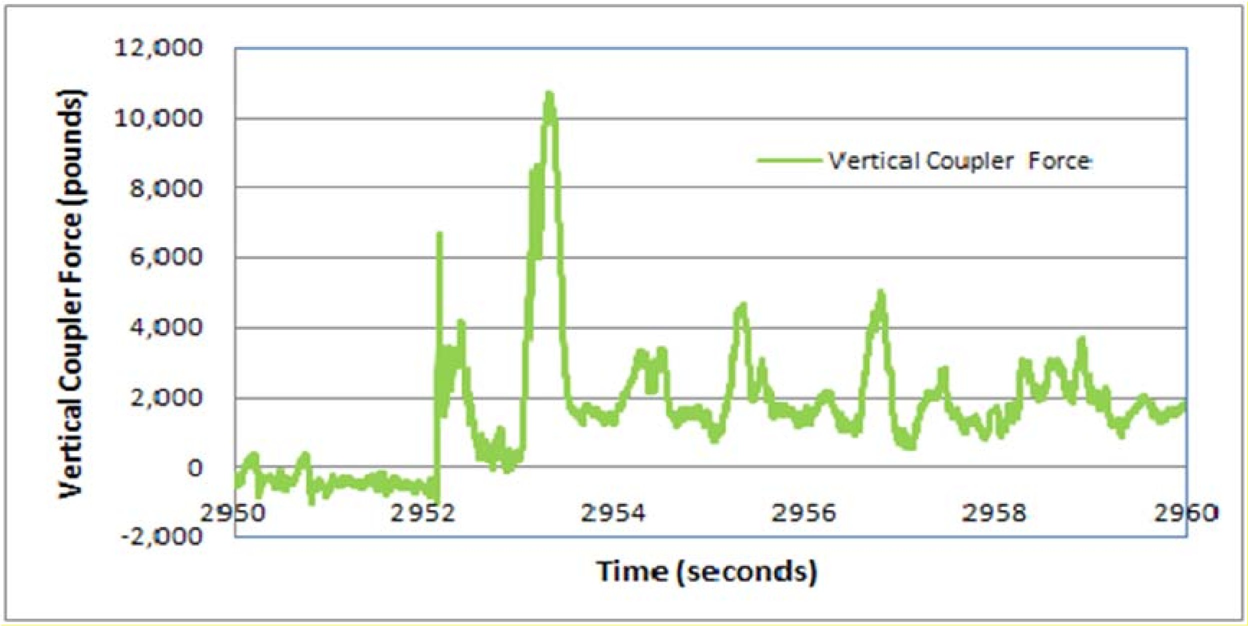

Figure 20. Highest Positive Vertical Coupler Force Observed During Testing

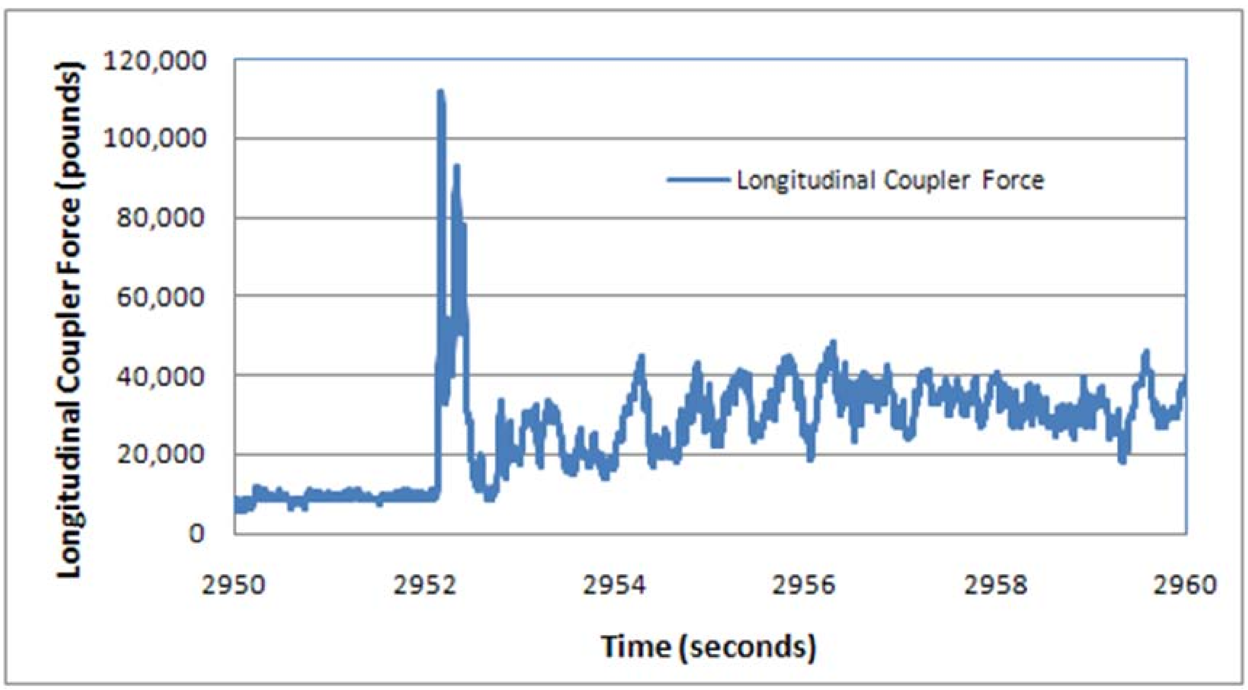

Figure 21. Corresponding Longitudinal Coupler Force for this Event

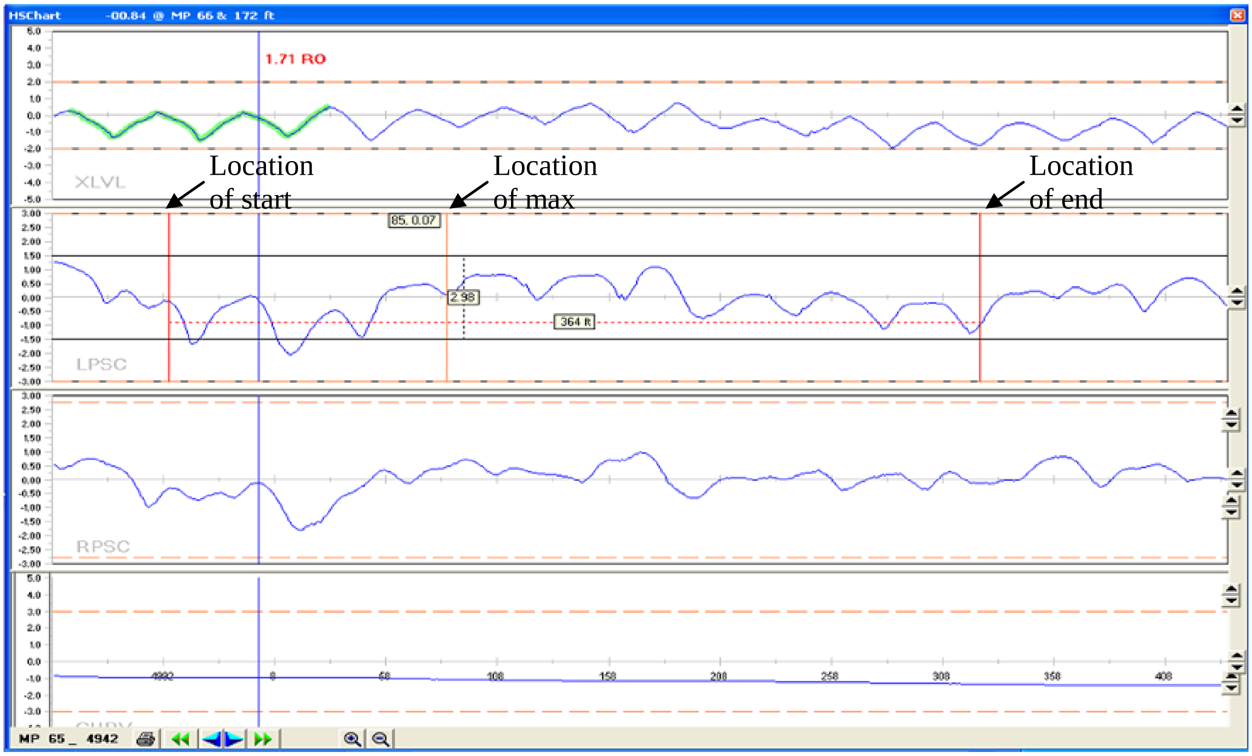

Figure 22. Relevant Track Geometry Data for this Event

3.4.4. Negative Vertical Coupler Force

Negative vertical coupler force locations were chosen based on the highest negative values determined during the entire testing and by using a filter of 25 Hz. Three locations were analyzed in depth using the array of data collected to see which parameters make the most impact on these events. The highest location with a vertical coupler force of -9.8 kips is presented using Figure 23–25. All the locations analyzed depicted the following characteristics:

- Dips or bumps in space curve profile on both rails were observed in the geometry data at these locations.
- An approximate wavelength of 100 ft seemed to be common among the top locations, which is similar to the positive locations.
- No exceptions (and no near exceptions) to 62-feet MCO profile was observed for these locations.
- One case was also at a switch point on the track, which may have been the input to the event.
- Another case had repeated profile deviations that contributed to several negative vertical coupler force spikes.
- These locations conversely resulted in longitudinal coupler forces but not as high as those seen for the positive vertical coupler force events.
- Speed of the train consist was not found to be a contributing factor.

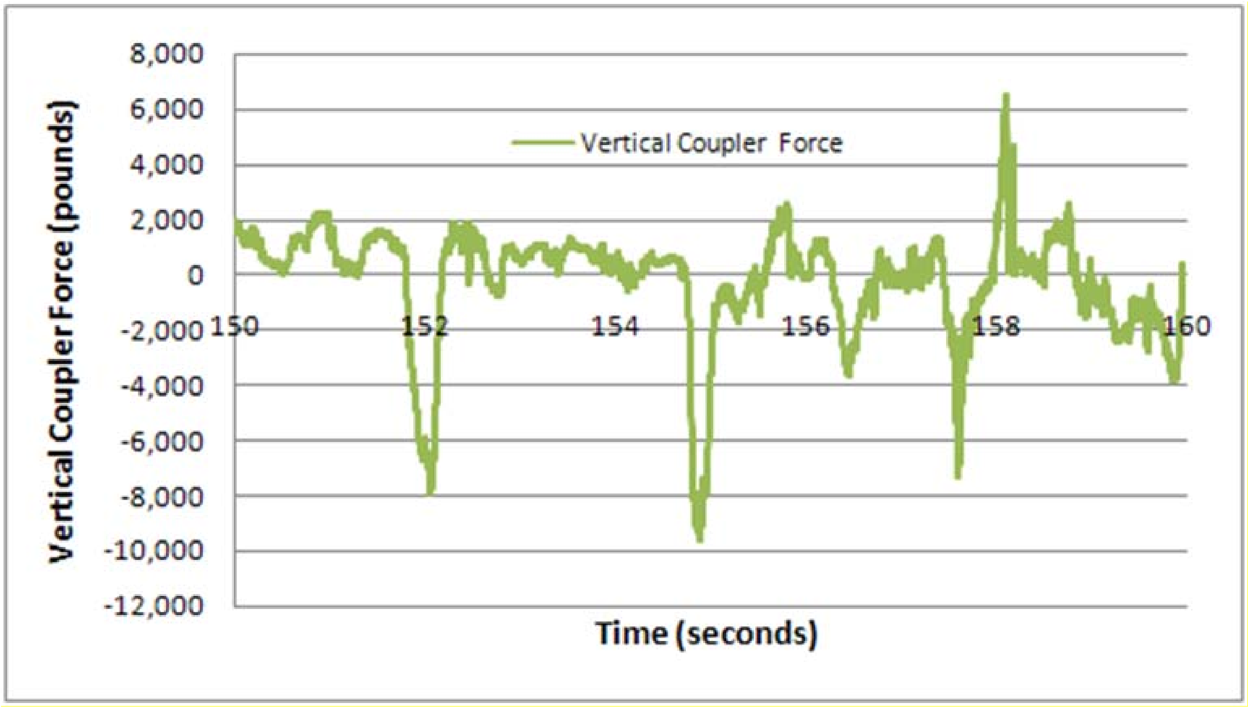

Figure 23. Highest Negative Vertical Coupler Force Observed During Testing

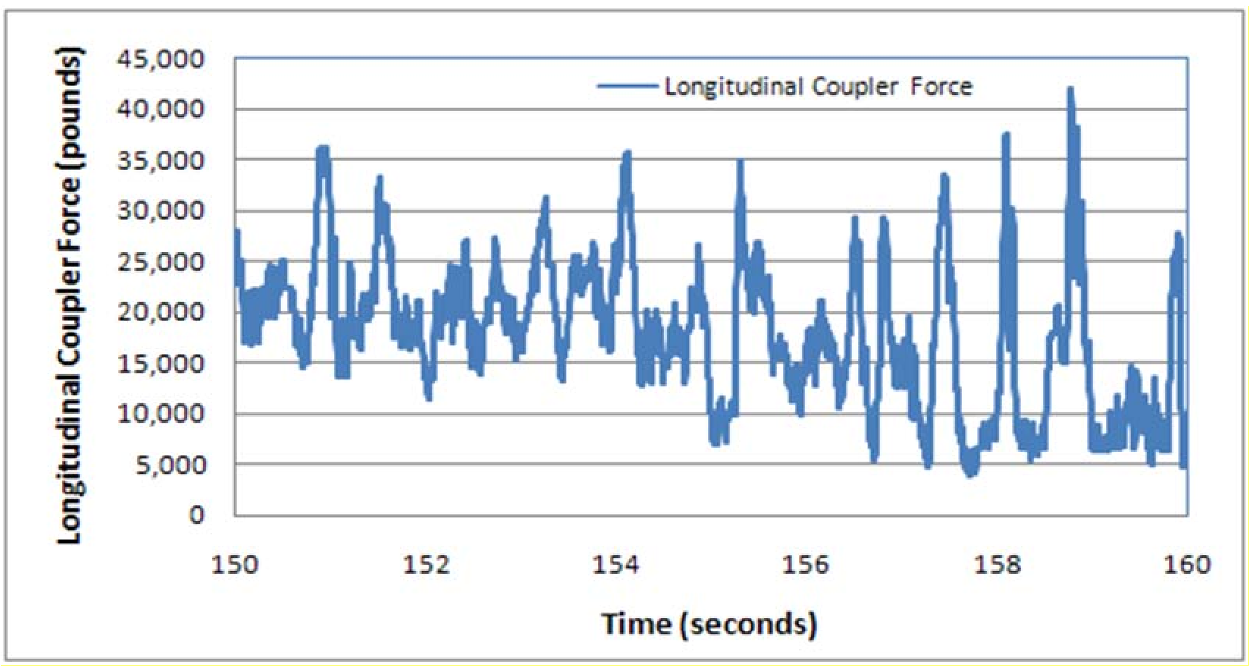

Figure 24. Corresponding Longitudinal Coupler Force for this Event

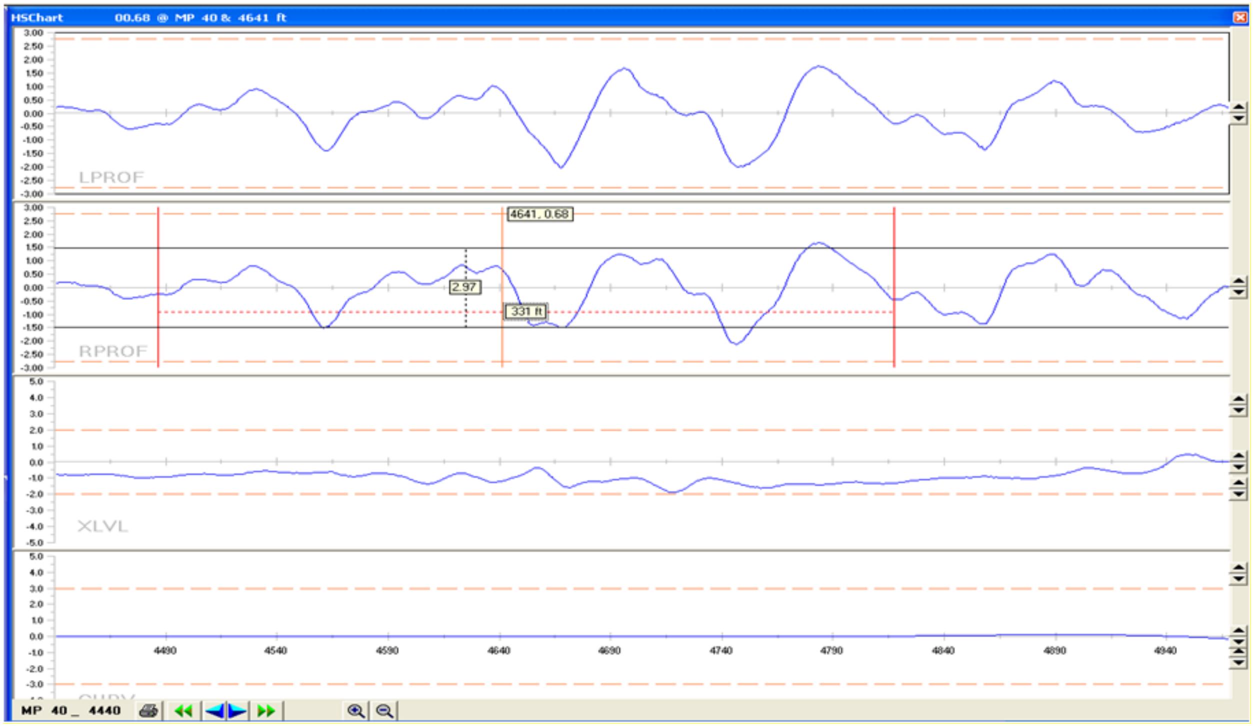

Figure 25. Relevant Track Geometry Data for this Event

3.4.5. Vertical Axle Accelerations

High vertical axle acceleration locations were chosen based on the highest values determined during the entire testing and by using a filter of 10 Hz. Three locations were analyzed in depth using the array of data collected to see which parameters make the most impact on these events. The highest location with a vertical coupler force of -9.7 g is presented using Figure 26–29. All the locations analyzed depicted the following characteristics:

- Speeds that these events were observed at range from 35 to 42 mph for the consist.
- These high vertical acceleration events are mostly caused by switches on the track.
- The automatic location detector (know as ALD) signal showed one or more switches for each event analyzed for this case.
- High acceleration events were accompanied by observation of high bolster forces.
- One case also had moderate spike on vertical coupler force caused by dip in space curve profile (as described previously).

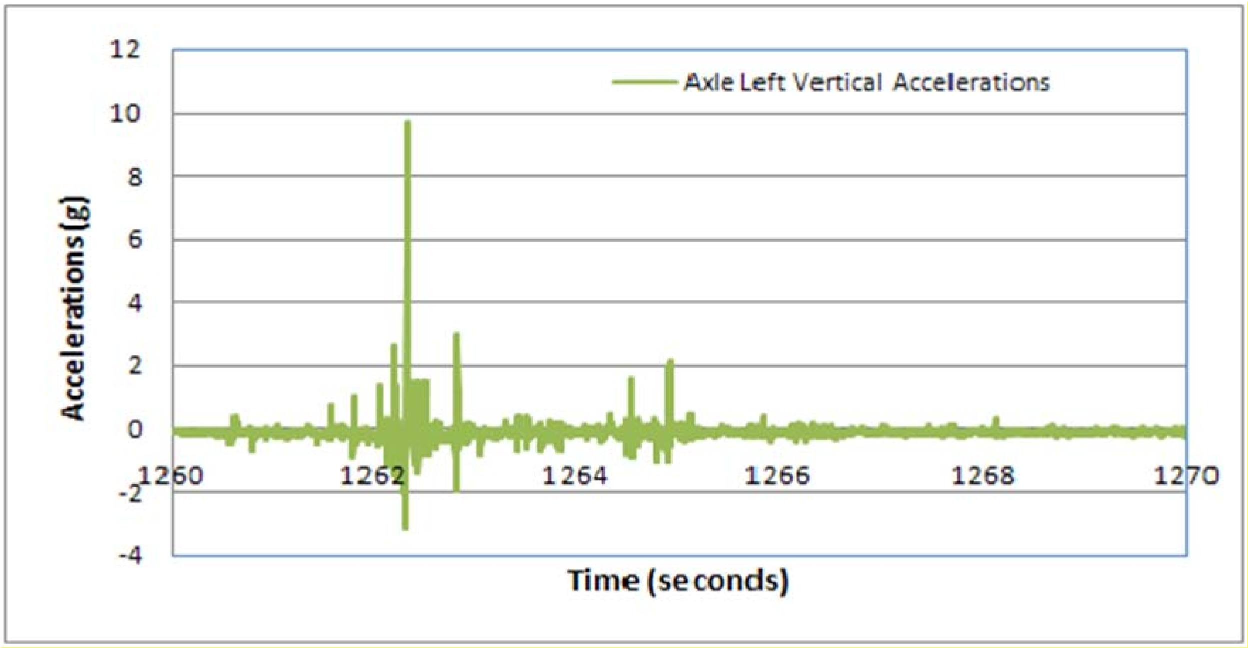

Figure 26. Highest Axle Left Vertical Accelerations during the Testing

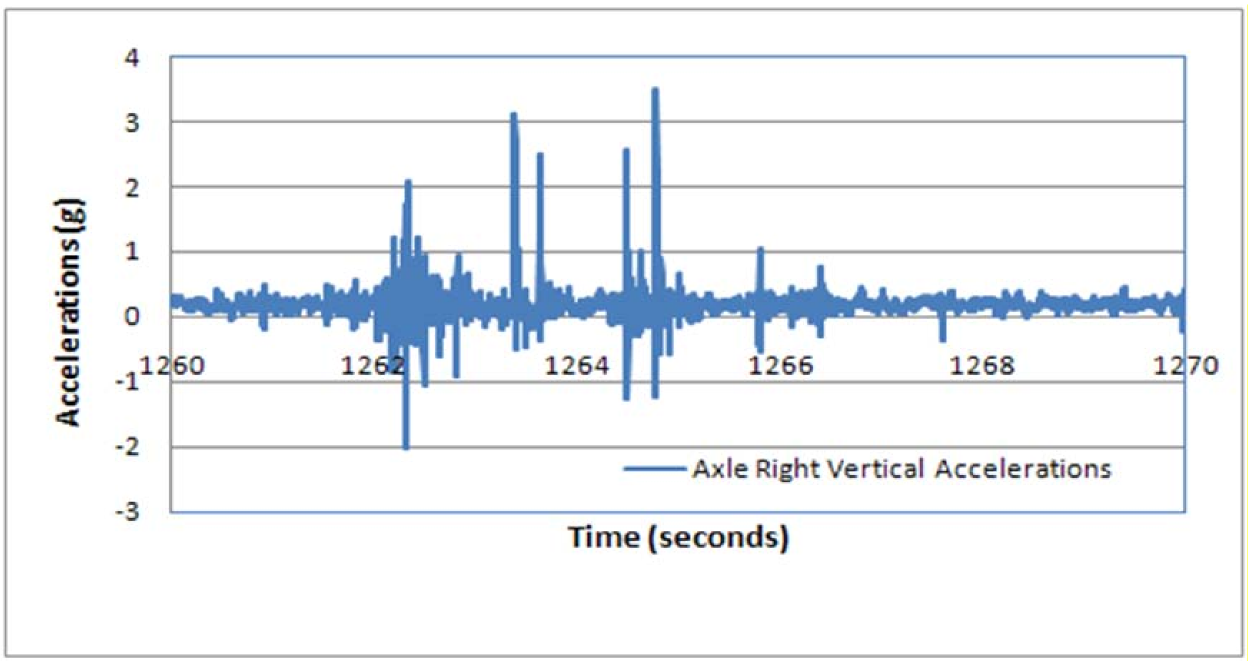

Figure 27. Right Side Axle Vertical Accelerations for this Event

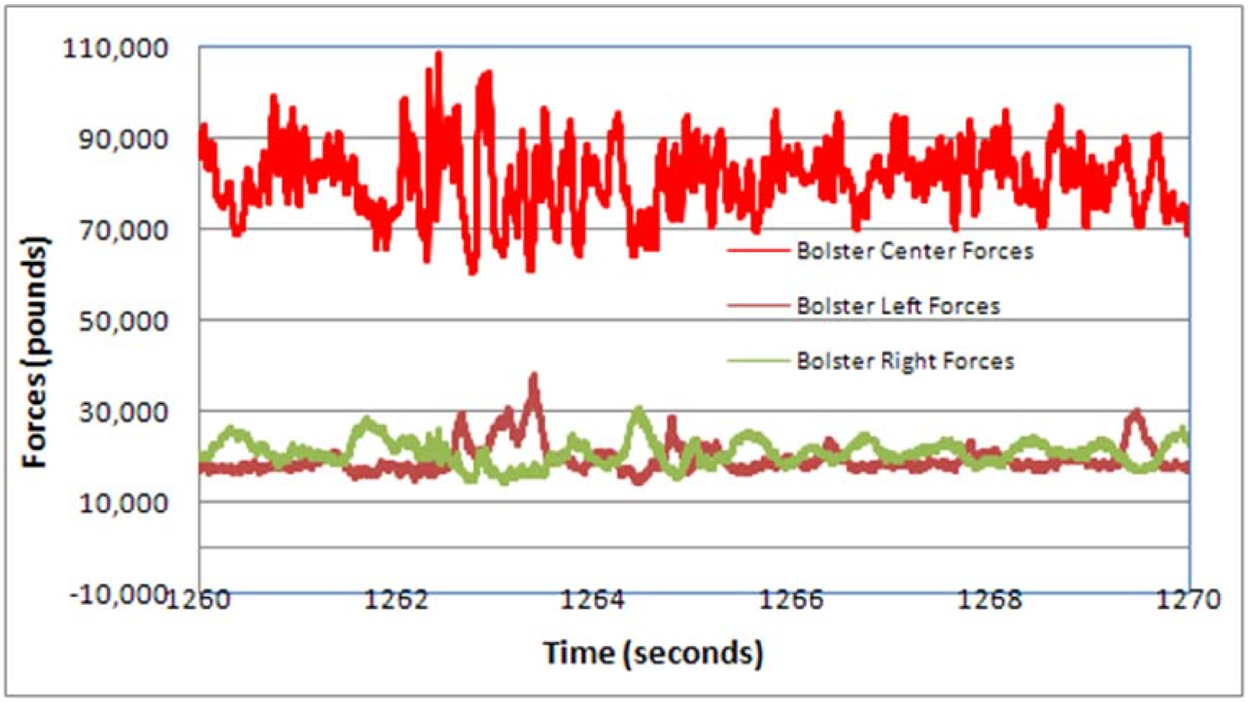

Figure 28. Corresponding Bolster Forces for this Event

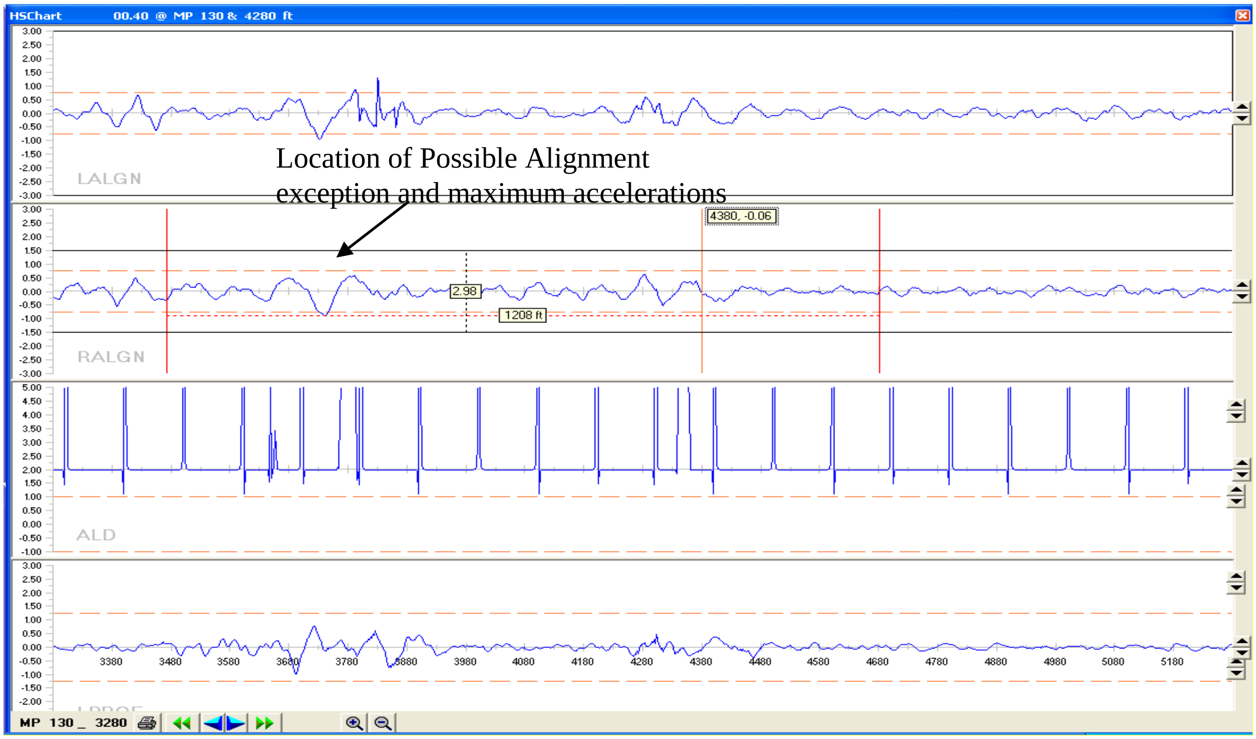

Figure 29. Relevant Track Geometry Data for this Event

3.4.6. Geometry Defects

The effect of geometry defects on the tank car parameters was studied in a limited fashion using a few of the exceptions flagged by DOTX-218.

3.4.6.1. 62-Feet Profile Deviation

Geometry deviations, which were classified as two class drop locations, were chosen for this analysis. One 62-feet profile deviation was chosen for this report as illustrated below in Figure 30. The corresponding tank car force data is shown in Figure 31 and 32. The analyzed locations depicted the following characteristics:

- These locations are very similar in characteristics to the high vertical coupler force locations.
- The big profile deviations seem to result in triggering of several vertical coupler force spikes and corresponding longitudinal coupler force locations.

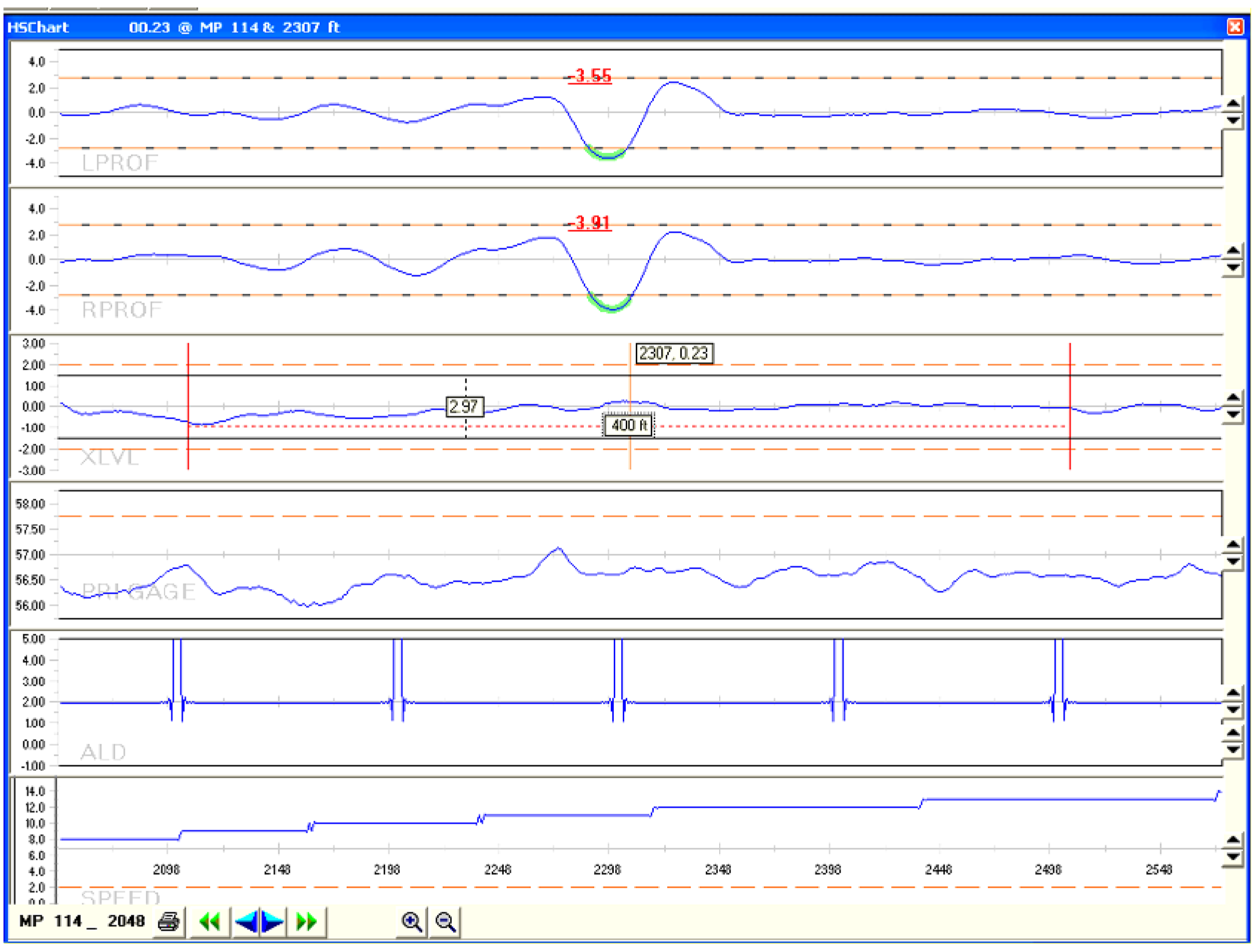

Figure 30. Two Class Drop in 62-feet Profile Chosen for Analysis

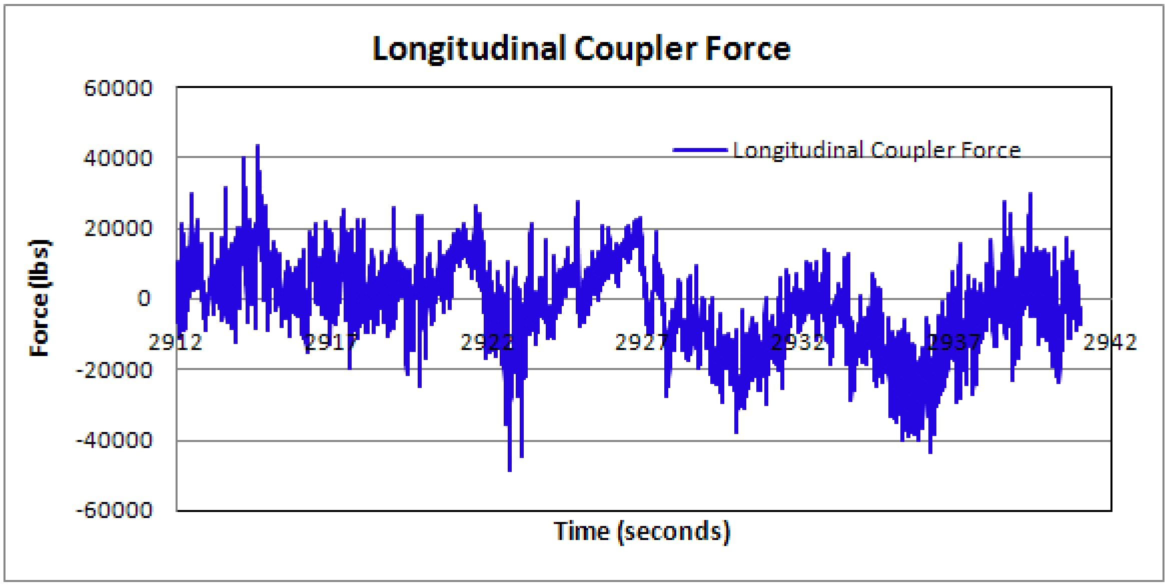

Figure 31. Corresponding Longitudinal Forces showing Large Variations

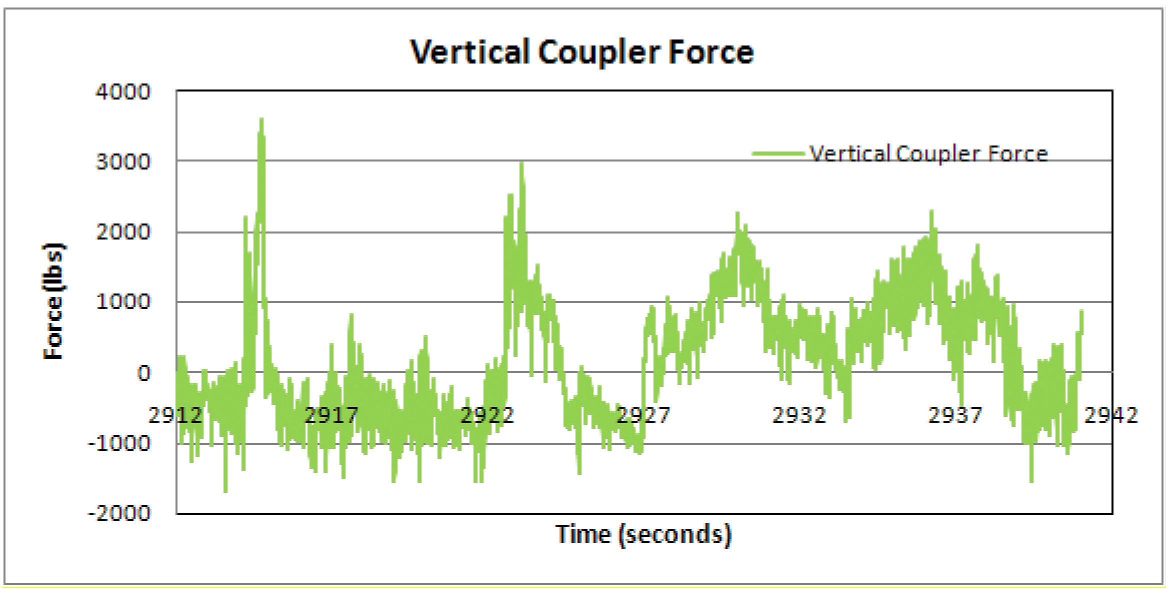

Figure 32. Corresponding Vertical Coupler Forces showing Large Variations

4. Observations

The following observations were made based on the test data and analysis provided in the report.

4.1. Accelerations

1. The axle acceleration provides the input to the carbody and the data does not show extremely high acceleration input from the axle as measured by this test. High acceleration events were accompanied by observation of high bolster forces. These high vertical acceleration events are mostly caused by switches on the track.

2. Maximum carbody accelerations in the negative direction reached about -1g, which represents downward motion of the carbody on to the bolster. These accelerations represent high vertical forces to the stub sill.

4.2. Forces

1. The highest vertical coupler forces were attributed to track geometry deviations; specifically a dip or bump on both rails. The speeds these events occurred at were between 24 and 43 mph. Although track geometry seems to be the cause of these high vertical coupler forces, TSS exceptions for the respective classes were not flagged at these locations. An approximate wavelength of 100 ft seemed to be common among the top locations.

2. The highest longitudinal coupler forces can be attributed to braking/acceleration of the consist resulting in a jerk in the longitudinal direction. These events generally occurred at low speeds (below 35 mph). Track geometry parameters were not found to be a contributing factor for the occurrence of high longitudinal coupler forces. Generally, high longitudinal force locations exhibited large vertical coupler forces too.

3. The vertical and longitudinal coupler forces as reported by this test are lower than what TTCI has reported in their revenue service testing conducted on their tank car. It is attributed to the lighter and shorter consist used for this test rather than the usual freight consists the TTCI car ran in.

4. Bolster forces were not extensively analyzed but it seems that typically axle acceleration events gave rise to changes in the bolster forces.

5. The analysis of the instrumented wheelset forces show that not many locations exist where exceptions took place. There were four V/TI exceptions for the truck side L/V ratio threshold as per the V/TI standards (in place for track class 6 and above).

5. Conclusions and Recommendations

The original goals of this evaluation were to gather data from which the load environment and contributing factors associated with the tank car operation on a hazmat route could be determined. The instrumentation on the tank car, in addition to DOTX-218's geometry system, included two IWS axles, a brake pressure sensor, eight strain bridges, four vertical load adapters, five accelerometers and one instrumented coupler. Thus, the systems simultaneously collected information about the features of the track, the speed and location, the motion of the train, the dynamics of the tank car, and the forces and strains on the tank car's structural parts.

The following key conclusions are drawn from testing and analysis:

- The axle acceleration provides the input to the carbody, but the data does not show extremely high acceleration input from the axle as measured by this test. High acceleration events were accompanied by observation of high bolster forces. These high vertical acceleration events are mostly caused by switches on the track.

- Maximum carbody accelerations in the negative direction reached about -1g, which represents downward motion of the carbody on to the bolster. These accelerations represent high vertical forces to the stub sill.

- The highest vertical coupler forces were attributed to track geometry deviations specifically, a dip or bump on both rails. The speeds in which these events occurred were between 24 and 43 mph. Although track geometry seems to be cause of these high vertical coupler forces, TSS exceptions for the respective classes were not flagged at these locations. An approximate wavelength of 100 ft seemed to be common among the top locations.

- The highest longitudinal coupler forces can be attributed to braking/acceleration of the consist resulting in a jerk in the longitudinal direction. These events generally occurred at low speeds (below 35 mph). Track geometry parameters were not found to be a contributing factor for the occurrence of high longitudinal coupler forces. Generally, high longitudinal force locations exhibited large vertical coupler forces too.

- Bolster forces were not extensively analyzed but it seems that typically axle acceleration events gave rise to changes in the bolster forces.

- The analysis of the instrumented wheelset forces showed us that there were not many locations where exceptions took place. Four V/TI exceptions existed for the truck side L/V ratio threshold as per the V/TI standards (in place for track class 6 and above).

- Track geometry appears to be a strong contributing factor to the load environment of the tank car especially the vertical and the longitudinal coupler forces.

The following key recommendations are inferred from testing and analysis:

- An autonomous test should be designed and run for the second phase of this test program.

- This would allow measurement of revenue consist forces and the actual environment in which the tank car operates. Data from this test can then be analyzed in a statistical manner as well as using correlations to associate these big events with either track geometry and/or train handling.

- Track geometry is a strong contributing factor to the load environment of the car and hence the fractures of the stub sill. The test zone selected for the autonomous measurement should be measured for track geometry either immediately before or immediately after the test.

- The autonomous testing to be conducted in Phase 2 should be conducted on track that has lower than average track geometry to study the relationship of the high forces and track geometry.

APPENDIX A RECORD OF TEST PLAN

Test Plan for the Instrumented Tank Car

Test Plan for the Instrumented Tank Car

1 Background

Fractures have been observed on stub sill tank cars for many years. If undetected and unattended, then these fractures can develop into a variety of tank car failures. Although tank car ruptures are relatively rare, the potential for a catastrophic hazmat release has made this a critical issue within the industry. As a result of this concern, special requirements for the construction, inspection, and repair of tank cars have been implemented.

Research into the underlying cause of stub sill tank car cracking and propagation continues. It is believed by some that the fractures are initiated by discrete events resulting in high stresses. Multiple tests and models have focused on extreme loading events and their contribution to the development of the fatigue cracks. Furthermore, the cracks are believed to be propagated by the stresses of regular over-the-road service. Under direction of the Tank Car Operating Environment Task Force (TCOE-TF) and the Stub Sill Working Group (SSWG), a test program was initiated to develop a methodology for both the measurement and reporting of events approaching and exceeding stub sill tank car design specifications; the TCOE-TF and the SSWG represent cooperative efforts between AAR, the Railway Supply Institute (RSI), FRA and TC.

Phase I of this test program addressed the development and proof of a method to record vertical and longitudinal coupler forces while employing relatively low-cost transducers and instrumentation. Phase II of the test program was established to validate the approach developed in Phase I by instrumenting several tank cars with a minimal set of sensors and instrumentation and conduct over-the-road tests. TTCI has conducted the initial stages of Phase II on a single instrumented vehicle. FRA would like to continue the research started within this program with a second instrumented tank car.

The objective is to better understand the operational environment and forces exerted on tank cars in over-the-road service using methods based on results from the initial efforts conducted during Phase II of the TCOE-TF/SSWG research program. The results of this test effort will either (1) confirm the industry's current understanding of fracture initiation and propagation or (2) reveal additional factors that are critical to the understanding of the phenomena.

2 Technical Approach

ENSCO will install many different sensors on the tank car including accelerometers, strain gages, vertical load adapters, instrumented coupler, instrumented wheelsets, and a pressure transducer. With the tank car coupled adjacent to FRA's T-18 track inspection vehicle, cables will run from the sensors to the equipment located on T-18. The data acquisition equipment will be synchronized to the track geometry system onboard T-18, which will be used to simultaneously measure the track geometry. The tank car will be dynamically tested in a special test over normal freight track.

3 Instrumentation

ENSCO plans to install instrumentation on the tank car to better understand the environment that it experiences. These sensors include accelerometers, strain gages, vertical load adapters, instrumented coupler, instrumented wheelsets, and a pressure transducer. These sensors will be cabled to the signal conditioning equipment and computers onboard T-18.

Strain gages will be attached in several locations to obtain the forces in several components. The first measures the vertical coupler force. A pair of shear gages is mounted on each side of the coupler channel as shown in Figure 1. These gages are wired to form a full bridge. A second set of gages are mounted next to the original set as a spare. These are cabled to a signal conditioning unit onboard T-18.

Figure 1. Shear Gages Measuring Vertical Coupler Force

A second set of strain gages are mounted on the truck bolster underneath the side bearing as shown in Figure 2. One gage is mounted on each side to form a half bridge. Bridge completion resistors are used to complete the bridge. A spare set of gages are mounted adjacent to the main gages. An identical set of gages are mounted on the truck bolster on the other side of the vehicle. These gages are used to measure the side bearing loads.

Figure 2. Strain Gages Measuring Bolster Side Bearing Loads

A third set of strain gages are mounted on each side of the bottom center of the bolster as shown in Figure 3. One gage is mounted on each side to form a half bridge. Bridge completion resistors are used to complete the bridge. A spare set of gages are mounted adjacent to the main gages. These gages are used to measure the bolster center bowl load.

Figure 3. Strain Gages Measuring Bolster Center Bowl Load

Several accelerometers are installed at several locations on the tank car. The first is a triaxial accelerometer mounted on top of the carbody as shown in Figure 4. A second accelerometer will be mounted on top of the carbody near the plate shown in Figure 4 (several feet from the first accelerometer). This will be used to correlate with previous data collect by the car owner. A third and fourth accelerometer will be mounted on the stub sill at each end of the car as shown in Figure 5. These will measure the vertical accelerations. A fifth and sixth accelerometer will be mounted on the bearing adapter on both sides of the first axle as shown in Figure 6. These will measure the vertical axle accelerations.

Figure 4. Triaxial Accelerometer Mounted on Top of Carbody

Figure 5. Vertical Accelerometer Mounted on the Stub Sill and Each End of the Car

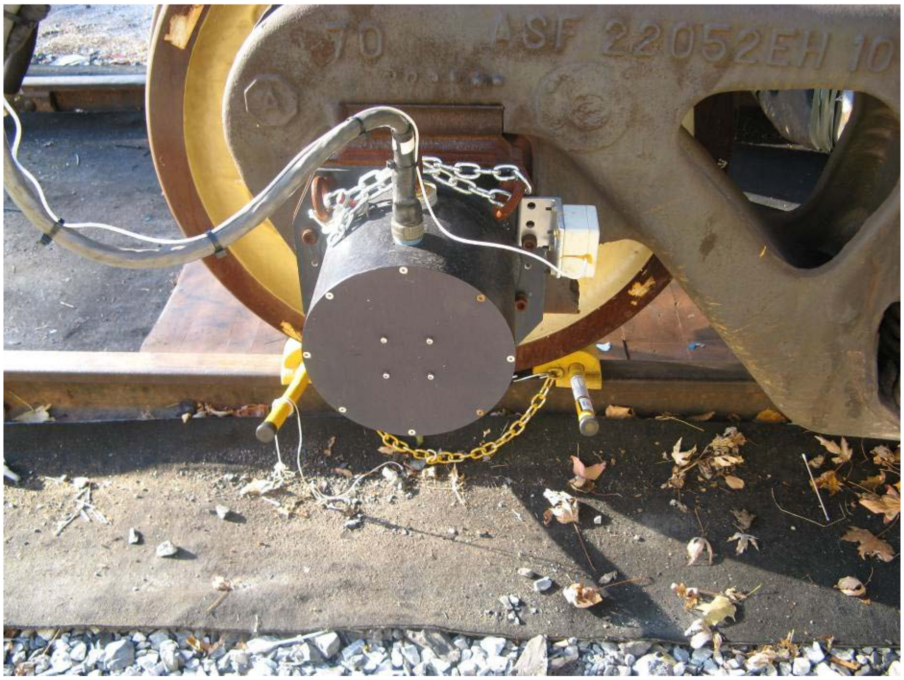

Figure 6. Vertical Accelerometer Mounted on the Axle on Both Sides of the Car

Vertical load adapters are modified bearing adapters used to measure the vertical wheel forces. The vertical load adapters are made using strain gages. After calibrated, they are used like any other load cells. Figure 7 shows a vertical load adapter mounted on the tank car. Four of these are mounted on the B-End of the tank car, opposite most of the instrumentation.

Figure 7. Vertical Load Adapter

One important piece of information needed is when the brakes have been applied. This measurement is achieved by using a pressure transducer to measure the brake cylinder pressure. Only one pressure transducer is needed for the entire vehicle. Figure 8 shows the installation of the brake pressure transducer.

Figure 8. Brake Pressure Transducer

One of the best tools to measure the vehicle dynamics is to use instrumented wheelsets. Each wheel and axle of one truck is instrumented with strain gages in several configurations. Once calibrated, these are used to measure the vertical, lateral, and longitudinal forces at the wheel/rail interface. They are also used to measure the contact position on the wheel. Figure 9 shows the instrumented wheelsets mounted on the A-end of the tank car. The instrumented wheelsets have their own signal conditioning units and computers. They are fully synchronized with T-18's track geometry system. One of the requirements of instrumented wheelsets is that the brakes on those wheels/axles need to be removed or disabled. This is to ensure accurate measurements and to prevent damage to the wheelsets. This will require at least four vehicles in the train consist to ensure that there is at least 85 percent braking.

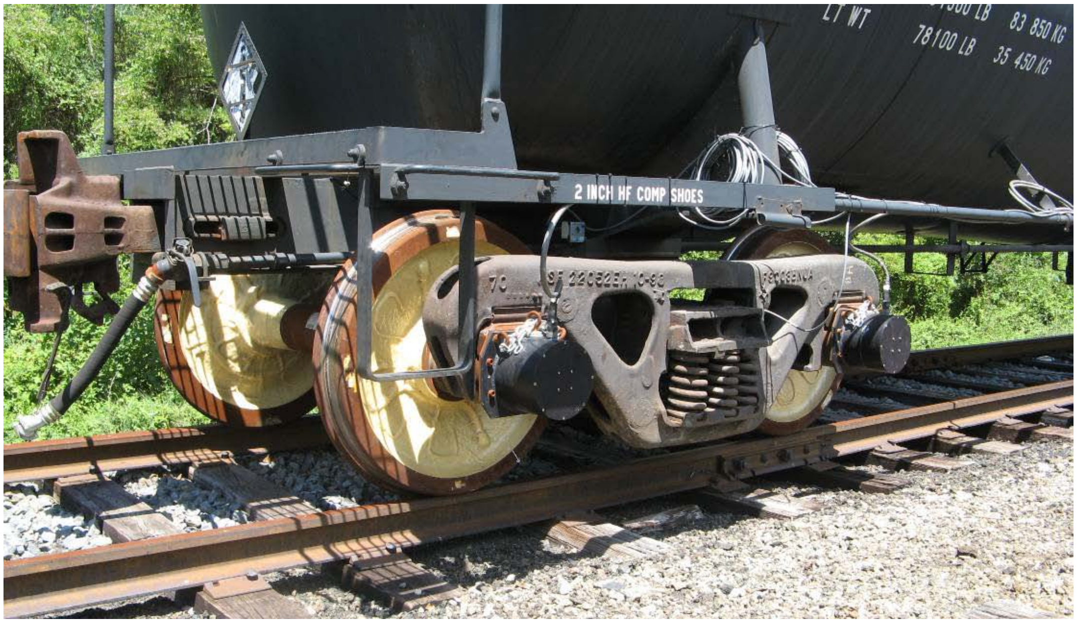

Figure 9. Instrumented Wheelsets

The last sensor is an instrumented coupler as shown in Figure 10. The instrumented coupler uses strain gages to measure the longitudinal coupler force. Because only one instrumented coupler was available, it will be mounted between the tank car and the rest of the consist (opposite T-18).

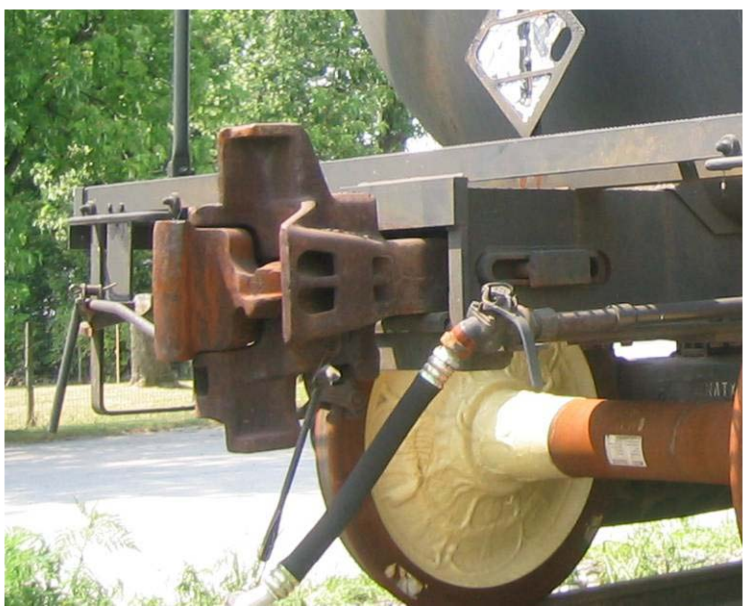

Figure 9. Instrumented Wheelsets

The T-18 track geometry inspection vehicle will serve two primary functions. It will provide a location for the signal conditioning equipment, computers, and personnel for the dynamic testing. T-18 will also collect the track geometry measurements as well as all associated data such as GPS location. The track geometry system will provide synchronization signals to the tank car system and the instrumented wheelset system.

4 Installation

ENSCO will perform the installation at its facility in Biglerville, PA. Strain gages will be installed using weldable gages to ensure a good bond during the cold weather. A crane or boom truck will be used to lift the tank car to install the instrumented wheelsets, vertical load adapters, and instrumented coupler. The accelerometers will be bolted at the appropriate locations. The cabling will run the length of the tank to T-18 while avoiding the walkways where possible. Appropriate service loops will be used between the truck and carbody and between the tank car and T-18.

5 Calibration

All of the sensors will need to be calibrated before dynamic testing. The accelerometers and pressure transducer have been calibrated by the manufacturer. The instrumented wheelsets, vertical load adapters, and instrumented coupler have been calibrated in the lab. The strain gages mounted to the tank car will need to be calibrated in the field. By using a crane or boom truck, the bolster side bearing loads and the bolster center bowl load will be calibrated by lifting the carbody. Then the load will be applied one at a time through each side bearing and the center bowl. The vertical coupler force will be calibrated by lifting the coupler.

6 Train Consist

The special train will consist of at least four vehicles. This is required because the brakes on one truck of the tank car were removed for the instrumented wheelsets. This is required to ensure that there is at least 85 percent braking on the train. The fourth vehicle can be a freight vehicle or another locomotive, depending on availability. Figure 10 shows the train consisting of a locomotive, a vehicle of any type, the tank car (NATX 250525), and T-18 (DOTX 218).

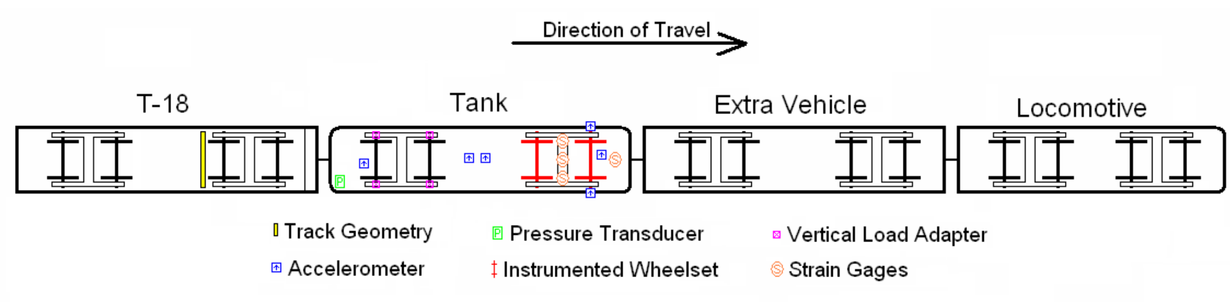

Figure 10: Train Consist

7 Dynamic Testing

To completely check out the system, a short shakedown test will be performed. Because the installation will occur in Biglerville, PA, which is located in approximately the middle of the Gettysburg and Northern Railroad, the shakedown test will start in Biglerville. The train will travel in either direction to Mount Holly Springs or Gettysburg and back to Biglerville. This railroad has a maximum speed limit of 10 mph. After completion of this trip, the data will be analyzed and any corrections to the system will be made.

The over-the-road dynamic test will be performed over an approximately 500-mile roundtrip. The track geometry system cannot measure during a snow storm or after a heavy snow. The test route will be longer than necessary to accommodate the need to extend it if there is snow. If all the data is good, the trip will be cut short to the normal length. The test route will start from Biglerville, PA. The train will travel south to Gettysburg, PA, on the Gettysburg and Northern railroad. Then the train will travel east to Baltimore, MD on the CSX railroad. The train will continue south on CSX to Hamlet, NC. Assuming that the data is good to this point, the train will return on the same route. If necessary, the train will continue south on CSX to Savannah, GA, before returning back on the same route. The test will end back at Biglerville, PA. Table 1 shows the full schedule if the extra data is needed. Table 2 show the reduced schedule if all of the data is good. The actual dates may change due to scheduling requirements.

Table 1. Full Test Schedule Including Extra Testing If Needed

Date	Railroad	Origin	Destination	Distance
5-5-2008	GET	Biglerville, PA	Gettysburg, PA	8
5-6-2008	CSX	Gettysburg, PA	Baltimore, MD	72
5-7-2008	CSX	Baltimore, MD	Richmond, VA	155
5-8-2008	CSX	Richmond, VA	Rocky Mount, NC	105
5-9-2008	CSX	Rocky Mount, NC	Hamlet, NC	154
5-12-2008	CSX	Hamlet, NC	Columbia, SC	108
5-13-2008	CSX	Columbia, SC	Savannah, GA	140
5-14-2008	CSX	Savannah, GA	Columbia, SC	140
5-15-2008	CSX	Columbia, SC	Hamlet, NC	108
5-16-2008	CSX	Hamlet, NC	Rocky Mount, NC	154
5-19-2008	CSX	Rocky Mount, NC	Richmond, VA	105
5-20-2008	CSX	Richmond, VA	Baltimore, MD	155
5-21-2008	CSX	Baltimore, MD	Gettysburg, PA	72
5-22-2008	GET	Gettysburg, PA	Biglerville, PA	8

Table 2. Shortened Test Schedule If Data Is Good

Date	Railroad	Origin	Destination	Distance
5-5-2008	GET	Biglerville, PA	Gettysburg, PA	8
5-6-2008	CSX	Gettysburg, PA	Baltimore, MD	72
5-7-2008	CSX	Baltimore, MD	Richmond, VA	155
5-8-2008	CSX	Richmond, VA	Rocky Mount, NC	105
5-9-2008	CSX	Rocky Mount, NC	Hamlet, NC	154
5-12-2008	CSX	Hamlet, NC	Rocky Mount, NC	154
5-13-2008	CSX	Rocky Mount, NC	Richmond, VA	105
5-14-2008	CSX	Richmond, VA	Baltimore, MD	155

5-15-2008	CSX	Baltimore, MD	Gettysburg, PA	72
5-16-2008	GET	Gettysburg, PA	Biglerville, PA	8

APPENDIX B Listing of Collected Data Files

Filename	Time (min)	Day
20080609CSX01	34.1	6/9/2008
20080609CSX02	22.1	6/9/2008
20080609CSX03	16.2	6/9/2008
20080609CSX04	27.1	6/9/2008
20080609CSX05	32.1	6/9/2008
20080609CSX06	34.7	6/9/2008
20080609CSX07	18.2	6/9/2008
20080609CSX08	63.2	6/9/2008
20080609CSX09	42.2	6/9/2008
20080610CSX01	6	6/10/2008
20080610CSX02	4.8	6/10/2008
20080610CSX03	8.3	6/10/2008
20080610CSX04	24.1	6/10/2008
20080610CSX05	15	6/10/2008
20080610CSX06	25.4	6/10/2008
20080610CSX07	4.7	6/10/2008
20080610CSX08	45.2	6/10/2008
20080610CSX09	59.7	6/10/2008
20080610CSX10	16.9	6/10/2008
20080610CSX11	63.5	6/10/2008
20080610CSX12	39.2	6/10/2008
20080610CSX13	53.4	6/10/2008
20080610CSX15	4.2	6/10/2008
20080610CSX17	4.2	6/10/2008
20080610CSX18	10.8	6/10/2008
20080610CSX19	1.2	6/10/2008
20080611CSX01	2.1	6/11/2008
20080611CSX02	15.4	6/11/2008
20080611CSX03	12.5	6/11/2008
20080611CSX04	29.1	6/11/2008
20080611CSX05	15.4	6/11/2008
20080611CSX06	62.7	6/11/2008
20080611CSX07	3.8	6/11/2008
20080611CSX08	70.5	6/11/2008
20080611CSX09	41.8	6/11/2008
20080611CSX10	27.2	6/11/2008
20080612CSX01	5.7	6/12/2008

Filename	Time (min)	Day
20080612CSX02	38.4	6/12/2008
20080612CSX03	66.9	6/12/2008
20080612CSX04	20.5	6/12/2008
20080612CSX05	107.3	6/12/2008
20080612CSX06	6	6/12/2008
20080612CSX07	1.8	6/12/2008
20080612CSX08	23.8	6/12/2008
20080612CSX09	60.2	6/12/2008
20080613CSX01	36.8	6/13/2008
20080613CSX02	29.7	6/13/2008
20080613CSX03	14.2	6/13/2008
20080613CSX04	1.2	6/13/2008
20080613CSX05	48.1	6/13/2008
20080613CSX06	4.2	6/13/2008
20080613CSX07	33.8	6/13/2008
20080613CSX08	46.8	6/13/2008
20080613CSX09	54.9	6/13/2008
20080613CSX10	4.4	6/13/2008
20080616CSX01	2.9	6/16/2008
20080616CSX02	11.4	6/16/2008
20080616CSX03	20.3	6/16/2008
20080616CSX04	40.6	6/16/2008
20080616CSX05	18	6/16/2008
20080616CSX06	19.7	6/16/2008
20080616CSX07	32.9	6/16/2008
20080616CSX08	5.9	6/16/2008
20080616CSX09	28.6	6/16/2008
20080616CSX10	31.4	6/16/2008
20080616CSX11	5.2	6/16/2008
20080616CSX12	1.1	6/16/2008
20080617CSX01	25.6	6/17/2008
20080617CSX02	17.3	6/17/2008
20080617CSX03	11.9	6/17/2008
20080617CSX04	6.5	6/17/2008
20080617CSX05	2.2	6/17/2008
20080617CSX06	16.5	6/17/2008
20080617CSX07	12.2	6/17/2008
20080617CSX08	4.3	6/17/2008
20080617CSX09	11.7	6/17/2008
20080617CSX10	8.1	6/17/2008

Filename	Time (min)	Day
20080617CSX11	69.3	6/17/2008
20080617CSX12	83.8	6/17/2008
20080617CSX13	63.9	6/17/2008
20080617CSX14	39.5	6/17/2008
20080618CSX01	1.5	6/18/2008
20080618CSX02	1.5	6/18/2008
20080618CSX03	9.4	6/18/2008
20080618CSX04	3.3	6/18/2008
20080618CSX05	3.7	6/18/2008
20080618CSX06	6.2	6/18/2008
20080618CSX08	61.1	6/18/2008
20080618CSX09	40.3	6/18/2008
20080618CSX10	43.5	6/18/2008
20080618CSX11	67.6	6/18/2008

APPENDIX C Listing of Geometry Exceptions during Testing

File RUN ID	MP	FT	Parameter	Value	Length	Curve	Actual	Posted	Track	Latitude	Longitude
2008060303004	**No two class drop exceptions found**										
2008060304004	**No two class drop exceptions found**										
2008060305004	**No two class drop exceptions found**										
2008060306004	**No two class drop exceptions found**										
2008060901004	71	137	Gage Narrow	55.87	2	E	0	2	5	39.83218	-77.23531
	71	1465	Gage Narrow	55.8	4	T	0	2	5	39.8321	-77.2306
	71	1516	L Prof 62	-3.06	6	B	0	2	5	39.8321	-77.23042
	71	1590	Gage Narrow	55.85	2	B	0	2	5	39.83211	-77.23016
	71	4117	Gage Narrow	55.86	2	T	0	2	5	39.83444	-77.22173
	66	2209	Gage Narrow	55.75	7	C	0	2	5	39.85772	-77.1458
	66	2275	Gage Narrow	55.69	7	C	0	2	5	39.85775	-77.14557
	64	2757	Gage Narrow	55.81	3	T	0	2	5	39.86345	-77.10892
2008060902004	56	9146	Twist 31	2.21	9	B	0	2	5	39.80445	-76.9847
2008060903004	**No two class drop exceptions found**										
2008060904004	47	3673	Gage Narrow	55.78	4	B	0	2	5	39.79926	-76.8614
2008061002004	0	1709	Warp 62	2.3	60	B	1	3	5	39.25947	-76.65261
	0	4421	Warp 62	2.53	60	C	1	3	4	39.25522	-76.66036
	6	5822	Gage Wide	57.98	7	E	1	3	2	39.2241	-76.7097
	17	265	Twist 31	1.35	5	B	2	4	2	39.13467	-76.78461
	32	9506	Gage Narrow	55.85	4	E	0	2	5	38.9447	-76.93797
	114	2304	L Prof 62	-3.55	16	T	0	2	5	38.87765	-76.99223
	114	2307	R Prof 62	-3.91	18	T	0	2	5	38.87765	-76.99223
	114	5054	R Prof 62	-3.42	12	T	0	2	5	38.88022	-77.00131
	103	9850	Gage Narrow	55.88	2	T	0	4	2	38.79832	-77.13467
	76	1021	Gage Narrow	55.87	4	C	0	5	2	38.48413	-77.31474
	71	3923	Gage Narrow	55.81	4	C	0	4	2	38.41594	-77.36198
	62	2451	Gage Narrow	55.84	8	C	0	4	2	38.32537	-77.45039
	62	2577	Gage Narrow	55.88	1	C	0	4	2	38.32503	-77.45042
	62	2591	Gage Narrow	55.87	2	C	0	4	2	38.32499	-77.45042
	62	2641	Gage Narrow	55.82	20	C	0	4	2	38.32485	-77.45042
	62	2667	Gage Narrow	55.85	9	C	0	4	2	38.32478	-77.45042
	62	2903	Gage Narrow	55.75	55	C	0	4	2	38.32413	-77.45039
	62	3003	Gage Narrow	55.83	8	E	0	4	2	38.32386	-77.45035
	62	3029	Gage Narrow	55.76	11	E	0	4	2	38.32378	-77.45033
	62	3067	Gage Narrow	55.85	10	E	0	4	2	38.32368	-77.45032
	62	3110	Gage Narrow	55.81	9	E	0	4	2	38.32356	-77.45029
	62	3144	Gage Narrow	55.8	12	E	0	4	2	38.32347	-77.45028
	62	3169	Gage Narrow	55.88	4	E	0	4	2	38.3234	-77.45026

	27	775	Gage Narrow	55.87	1	B	0	4	2	37.92765	-77.45765
	27	1153	Gage Narrow	55.84	18	C	0	4	2	37.92715	-77.4588
	27	1182	Gage Narrow	55.87	4	C	0	4	2	37.92711	-77.45889
	27	1405	Gage Narrow	55.87	1	C	0	4	2	37.92677	-77.45953
	16	1104	Gage Narrow	55.8	9	T	0	4	2	37.774	-77.47667
	4	4278	Gage Narrow	55.82	6	C	0	2	5	37.59678	-77.48653
	4	4376	Gage Narrow	55.8	5	E	0	2	5	37.59654	-77.48637
	3	2779	Gage Narrow	55.87	1	T	0	2	5	37.58762	-77.48037
	3	4700	Gage Narrow	55.87	4	T	0	2	5	37.5829	-77.47738
	3	4867	Gage Narrow	55.87	1	B	0	2	5	37.5825	-77.47709
2008060906004	10	1141	Gage Narrow	55.79	6	T	0	2	5	39.36704	-76.72602
	10	3960	Gage Narrow	55.8	4	T	0	2	5	39.36081	-76.7205
	10	10073	Gage Narrow	55.69	16	E	0	2	5	39.3519	-76.70399
	8	3076	Gage Narrow	55.71	11	T	0	2	5	39.34643	-76.69408
2008061101004	38	356	Gage Narrow	55.87	1	C	0	3	2	37.01917	-77.39307
	38	1228	Gage Narrow	55.87	5	C	0	3	2	37.01677	-77.39307
	38	1391	Gage Narrow	55.88	1	C	0	3	2	37.01633	-77.3931
	38	1400	Gage Narrow	55.86	6	C	0	3	2	37.0163	-77.3931
	38	1412	Gage Narrow	55.87	4	C	0	3	2	37.01627	-77.3931
	38	2248	Gage Narrow	55.87	8	C	0	3	2	37.01398	-77.39337
	81	2227	Gage Narrow	55.82	4	T	0	5	1	36.43055	-77.59432
	81	2365	Gage Narrow	55.84	8	T	0	5	1	36.43029	-77.59467
	81	2580	Gage Narrow	55.68	13	T	0	5	1	36.42989	-77.5952
	83	2041	Gage Narrow	55.86	3	C	0	3	1	36.41931	-77.60525
2008061201004	135	5292	Gage Narrow	55.83	4	T	0	4	1	35.7196	-77.90958
	135	5758	Gage Narrow	55.77	9	T	0	4	1	35.71843	-77.91022
	177	3863	L Runoff	-1.62	31	T	3	5	5	35.40504	-78.52387
	207	3115	Gage Narrow	55.77	10	T	0	4	5	35.07755	-78.86089
	207	3259	Gage Narrow	55.77	8	T	0	4	5	35.07732	-78.86127
	207	3331	Gage Narrow	55.87	2	T	0	4	5	35.0772	-78.86147
	207	3394	Gage Narrow	55.75	11	T	0	4	5	35.07707	-78.86163
	239	4948	Gage Narrow	55.61	15	T	0	5	5	34.69629	-79.17703
	281	2244	Gage Narrow	55.85	2	T	0	2	6	34.71085	-79.27431
	281	2284	Gage Narrow	55.87	3	T	0	2	6	34.7109	-79.27444
	281	2334	Gage Narrow	55.86	1	T	0	2	6	34.71095	-79.27459
	281	2491	Gage Narrow	55.76	8	T	0	2	6	34.71112	-79.27507
	281	2727	Gage Narrow	55.82	3	T	0	2	6	34.71138	-79.27579
	281	2758	Gage Narrow	55.87	1	T	0	2	6	34.71141	-79.27589
	281	3182	Gage Narrow	55.84	3	T	0	2	6	34.71187	-79.27718
	281	3344	Gage Narrow	55.87	1	T	0	2	6	34.71205	-79.27768
	281	3418	Gage Narrow	55.87	1	T	0	2	6	34.71213	-79.27791

	281	3847	Gage Narrow	55.75	9	T	0	2	6	34.7126	-79.27921
	281	4225	Gage Narrow	55.88	1	T	0	2	6	34.71301	-79.28037
	281	4458	Gage Narrow	55.82	5	T	0	2	6	34.71326	-79.28109
	280	720	Gage Narrow	55.86	4	T	0	2	6	34.71487	-79.28557
	280	2203	Gage Narrow	55.86	2	T	0	2	6	34.71647	-79.29008
	280	2628	Gage Narrow	55.85	6	T	0	2	6	34.71694	-79.29138
	280	2814	Gage Narrow	55.87	2	T	0	2	6	34.71715	-79.29196
	280	3127	Gage Narrow	55.74	5	T	0	2	6	34.71748	-79.29291
	280	3243	Gage Narrow	55.84	2	T	0	2	6	34.7176	-79.29327
	280	3323	Gage Narrow	55.87	2	T	0	2	6	34.71767	-79.2935
	280	3360	Gage Narrow	55.88	1	T	0	2	6	34.7177	-79.29361
	280	3400	Gage Narrow	55.87	2	T	0	2	6	34.71775	-79.29373
	280	3437	Gage Narrow	55.84	4	T	0	2	6	34.71779	-79.29385
	280	3509	Gage Narrow	55.87	2	T	0	2	6	34.71787	-79.29407
	280	3546	Gage Narrow	55.87	3	T	0	2	6	34.71791	-79.29417
	280	4195	Gage Narrow	55.87	1	T	0	2	6	34.71862	-79.29616
	280	4309	Gage Narrow	55.87	2	T	0	2	6	34.71874	-79.29651
	280	4471	Gage Narrow	55.87	3	T	0	2	6	34.71891	-79.297
	280	4508	Gage Narrow	55.82	4	T	0	2	6	34.71895	-79.29712
	280	4546	Gage Narrow	55.83	3	T	0	2	6	34.71899	-79.29723
	280	4587	Gage Narrow	55.83	5	T	0	2	6	34.71904	-79.29736
	280	4625	Gage Narrow	55.81	5	T	0	2	6	34.71909	-79.29747
	279	667	Gage Narrow	55.75	7	T	0	4	5	34.72053	-79.30167
	272	2838	Gage Narrow	55.88	1	T	0	4	5	34.76324	-79.42123
	271	4646	Gage Narrow	55.85	4	T	0	4	5	34.771	-79.44283
	265	534	Gage Narrow	55.79	10	T	0	4	5	34.80172	-79.52817
	263	2046	R Runoff	-2.24	31	T	2	4	5	34.81457	-79.56394
2008061301004	268	1588	Gage Narrow	55.85	3	T	0	4	5	34.78166	-79.4724
	275	1539	Gage Narrow	55.88	1	T	0	4	5	34.74127	-79.35964
	278	5056	Gage Narrow	55.84	5	T	0	4	5	34.72054	-79.30164
	279	746	Gage Narrow	55.85	3	T	0	2	6	34.71909	-79.29746
	279	784	Gage Narrow	55.86	4	T	0	2	6	34.71905	-79.29735
	279	824	Gage Narrow	55.85	3	T	0	2	6	34.71901	-79.29723
	279	864	Gage Narrow	55.81	5	T	0	2	6	34.71896	-79.2971
	279	901	Gage Narrow	55.84	4	T	0	2	6	34.71893	-79.29699
	279	1059	Gage Narrow	55.88	1	T	0	2	6	34.71875	-79.29651
	279	1173	Gage Narrow	55.85	2	T	0	2	6	34.71862	-79.29616
	279	1825	Gage Narrow	55.87	5	T	0	2	6	34.71791	-79.29417
	279	1900	Gage Narrow	55.88	2	T	0	2	6	34.71783	-79.29394
	279	1934	Gage Narrow	55.87	4	T	0	2	6	34.71779	-79.29383
	279	2009	Gage Narrow	55.88	1	T	0	2	6	34.71771	-79.2936

	279	2046	Gage Narrow	55.86	2	T	0	2	6	34.71767	-79.29349
	279	2125	Gage Narrow	55.85	1	T	0	2	6	34.71759	-79.29325
	279	2244	Gage Narrow	55.77	5	T	0	2	6	34.71746	-79.29288
	279	2553	Gage Narrow	55.87	1	T	0	2	6	34.71712	-79.29194
	280	793	Gage Narrow	55.85	4	T	0	2	6	34.71323	-79.28107
	280	1408	Gage Narrow	55.77	7	T	0	2	6	34.71256	-79.27919
	280	2358	Gage Narrow	55.79	5	T	0	2	6	34.71152	-79.27629
	280	2763	Gage Narrow	55.8	7	T	0	2	6	34.71108	-79.27505
	280	2914	Gage Narrow	55.87	1	T	0	2	6	34.71091	-79.27459
	212	6428	Gage Narrow	55.89	2	B	0	3	1	35.04045	-78.89343
	212	6441	Gage Narrow	55.88	2	B	0	3	1	35.04047	-78.89341
	208	2033	Gage Narrow	55.75	10	T	0	3	1	35.07714	-78.86161
	208	2087	Gage Narrow	55.88	2	T	0	3	1	35.07723	-78.86147
	208	2167	Gage Narrow	55.74	9	T	0	4	1	35.07736	-78.86125
	208	2313	Gage Narrow	55.8	11	T	0	4	1	35.0776	-78.86086
	146	699	Gage Narrow	55.86	4	T	0	5	5	35.63267	-78.04066
	133	5384	Gage Narrow	55.85	2	T	0	5	2	35.77162	-77.88098
	133	5450	Gage Narrow	55.86	4	T	0	5	2	35.77178	-77.88089
	133	5888	Gage Narrow	55.84	4	T	0	5	2	35.77288	-77.88028
	126	2164	Gage Narrow	55.85	3	T	0	5	2	35.85652	-77.8343
	122	2649	Gage Narrow	55.83	10	T	0	3	7	35.91197	-77.80791
2008061601004	83	2933	Gage Narrow	55.61	14	T	0	3	5	36.42989	-77.59518
	83	3277	Gage Narrow	55.87	3	T	0	3	5	36.43053	-77.59433
	80	2035	Gage Narrow	55.76	8	C	0	4	2	36.45789	-77.55842
	39	2966	Gage Narrow	55.87	10	C	0	3	2	37.014	-77.39335
	39	3981	Gage Narrow	55.83	5	C	0	3	2	37.01679	-77.39305
	39	4850	Gage Narrow	55.88	1	C	0	3	2	37.01918	-77.39305
2008061701004	**No two class drop exceptions found**										
2008061702004	**No two class drop exceptions found**										
2008061703004	**No two class drop exceptions found**										
2008061703004	0	4328	Gage Narrow	55.86	4	T	0	2	3	37.58125	-77.47521
	15	4637	Gage Narrow	55.85	7	T	0	4	2	37.77404	-77.47663
	60	7471	Gage Narrow	55.83	10	B	0	4	2	38.32347	-77.4503
	60	7503	Gage Narrow	55.86	5	B	0	4	2	38.32356	-77.45033
	60	7586	Gage Narrow	55.87	7	B	0	4	2	38.32379	-77.45036
	60	7757	Gage Narrow	55.79	24	C	0	4	2	38.32425	-77.45042
	60	7983	Gage Narrow	55.85	12	C	0	4	2	38.32487	-77.45044
	60	8185	Gage Narrow	55.86	2	C	0	4	2	38.32543	-77.4504
	98	2419	Gage Narrow	55.88	1	C	0	4	2	38.77099	-77.15977
	98	2595	Gage Narrow	55.85	4	C	0	4	2	38.77138	-77.15942
	9	830	Gage Wide	57.9	5	C	1	3	2	39.22412	-76.70965

	5	8286	Warp 62	2.45	59	B	1	3	1	39.25536	-76.66015
2008061801004	5	4876	Gage Narrow	55.87	3	B	0	2	5	39.33543	-76.6701
	7	2118	Gage Narrow	55.77	13	T	0	2	5	39.34645	-76.69413
	8	430	Gage Narrow	55.72	16	B	0	2	5	39.35194	-76.70404
	8	6529	Gage Narrow	55.82	4	T	0	2	5	39.36081	-76.72051
	8	8677	Gage Narrow	55.86	2	T	0	2	5	39.36572	-76.72444
	8	9351	Gage Narrow	55.74	9	T	0	3	5	39.36707	-76.72607
	0	1473	Twist 31	2.34	10	E	0	2	5	39.80446	-76.98477
	54	2272	Gage Narrow	55.85	9	T	0	2	5	39.80449	-76.9876
	70	3870	Gage Narrow	55.82	5	E	0	2	5	39.8321	-77.23064

APPENDIX D List of IWS Exceptions from Testing

Parameter	% Level	Value	Length	Seconds into File	Sync CT	Sync FT	MP	Feet	Speed	Health	Safety or Maintenance
File name: 2008060910999F01.iex											
Trk L/V L	80.4	0.482	15.6'	2228.827	51	14795	20	8714	15.1	--------	2
Filename: 2008061002004F01.iex											
Trk L/V L	81	0.486	42.6'	1181.787	11	958	6	4534	22.8	--------	2
Trk L/V L	86.2	0.517	52.3'	1184.207	11	1039	6	4615	22.6	--------	2
Trk L/V L	86.7	0.52	55.6'	1185.55	11	1084	6	4660	22.6	--------	2
Trk L/V L	80	0.48	40.5'	1187.453	11	1147	6	4723	22.5	--------	2
Trk L/V L	91.1	0.546	77.4'	1189.867	11	1228	6	4804	22.6	--------	2
Trk L/V L	82.4	0.495	47.5'	1191.617	11	1286	6	4863	22.8	--------	2
Trk L/V L	80.2	0.481	48.3'	1216.777	12	183	6	5759	24.4	--------	2
Trk L/V R	93.6	0.561	188.5'	1219.41	12	278	6	5854	24.3	--------	2
Trk L/V R	83.9	0.503	34.1'	1241.457	12	1063	6	6639	23.7	--------	2
Trk L/V R	83	0.498	21.3'	1244.07	12	1155	6	6731	23.9	--------	2
Trk L/V R	88.5	0.531	49.1'	1245.493	12	1205	6	6781	24	--------	2
Trk L/V R	88.8	0.533	16.6'	1246.903	12	1255	6	6831	24.1	--------	2
Trk L/V R	84.3	0.506	21.0'	1247.597	12	1280	6	6856	24.2	--------	2
Trk L/V R	85.3	0.512	19.3'	1255.98	12	1581	6	7158	24.3	--------	2
Trk L/V L	81.4	0.488	51.1'	1258.62	12	1676	6	7253	24.4	--------	2
Trk L/V R	89.4	0.537	46.6'	1259.007	12	1690	6	7267	24.3	--------	2
Trk L/V R	87.8	0.527	41.6'	1263.453	12	1850	6	7426	24.4	--------	2
Trk L/V R	94.4	0.566	151.9'	1270.593	13	108	6	7684	24.4	--------	2
Trk L/V L	87.6	0.526	490.3'	1271.007	13	122	6	7699	24.3	--------	2
Trk L/V L	82.5	0.495	64.2'	1348.517	14	963	6	10540	23.7	--------	2
Trk L/V L	82.7	0.496	36.0'	1350.873	14	1045	6	10622	23.5	--------	2
Trk L/V L	87.8	0.527	31.1'	1352.91	14	1115	6	10692	23.2	--------	2
Trk L/V L	86.3	0.518	102.6'	1354.77	14	1179	6	10755	23.1	--------	2
Trk L/V L	84.7	0.508	81.9'	1359	14	1323	6	10899	22.9	--------	2
Trk L/V L	82.1	0.493	45.6'	1359.71	14	1346	6	10923	22.8	--------	2
Trk L/V L	95.7	0.574	61.7'	1361.69	14	1413	6	10989	22.9	--------	2
Trk L/V L	87.2	0.523	48.9'	1363.557	14	1477	6	11053	22.9	--------	2
Trk L/V L	99	0.594	146.2'	1367.243	14	1602	6	11178	23.1	--------	2
Trk L/V R	81.7	0.49	109.1'	1370.253	14	1705	6	11282	23.3	--------	2
Trk L/V L	96.7	0.58	117.2'	1374.49	14	1853	6	11429	23.7	--------	2
Trk L/V L	96.7	0.58	145.8'	1379.643	15	35	6	11611	24.1	--------	2
Trk L/V L	81.7	0.49	36.3'	1382.113	15	123	6	11699	24.4	--------	2
Trk L/V R	81.2	0.487	356.9'	1382.163	15	125	6	11701	24.4	--------	2
Trk L/V R	86.1	0.517	108.8'	1386.19	15	271	10	46	24.7	--------	2

Trk L/V L	99.1	0.594	196.5'	1383.92	15	188	6	11765	24.5	--------	2
Filename: 2008061002004F02.iex											
Trk L/V L	85.5	0.513	17.1'	1039.95	68	14617	32	4106	20.9	--------	2
Trk L/V L	81.6	0.49	32.4'	1041.86	68	14676	32	4165	20.8	--------	2
Trk L/V L	81.1	0.486	47.9'	1109.523	68	16818	32	6307	21.4	--------	2
Trk L/V R	93.7	0.562	55.0'	1108.64	68	16790	32	6279	21.3	--------	2
Trk L/V L	81.9	0.492	122.2'	1131.703	68	17547	32	7036	22.8	--------	2
Trk L/V R	84.5	0.507	13.2'	1134.893	68	17653	32	7143	22.5	--------	2
Trk L/V R	82.6	0.496	30.2'	1136.403	68	17703	32	7192	22.1	--------	2
Trk L/V R	83.6	0.502	27.1'	1140.3	68	17827	32	7316	21.4	--------	2
Trk L/V R	80.5	0.483	20.6'	1141.333	68	17860	32	7349	21.4	--------	2
Trk L/V L	97	0.582	45.5'	1152.523	68	18223	32	7713	22.7	--------	2
Trk L/V L	85.3	0.512	48.6'	1154.41	68	18287	32	7776	22.8	--------	2
Trk L/V L	93.3	0.56	159.1'	1157.553	68	18392	32	7881	22.4	--------	2
Trk L/V L	80.6	0.484	45.3'	1160.967	68	18504	32	7993	22.1	--------	2
Trk L/V L	88.7	0.532	135.3'	1165.747	68	18657	32	8146	21.4	--------	2
Trk L/V L	84.1	0.505	22.7'	1169.107	68	18761	32	8251	20.9	--------	2
Trk L/V L	96.4	0.578	22.4'	1171.227	68	18827	32	8316	20.7	--------	2
Trk L/V L	88	0.528	26.7'	1191.073	68	19424	32	8914	20.8	--------	2
Trk L/V R	80.9	0.485	78.2'	1595.82	83	461	119	2333	21.2	--------	2
Trk L/V L	109.8	0.659	12.3'	1596.537	83	461	119	2333	21	--------	1
Trk L/V L	103.7	0.622	5.3'	1597.267	83	461	119	2333	20.9	--------	1
Trk L/V L	110.5	0.663	8.0'	1597.493	83	461	119	2333	20.9	--------	1
Trk L/V L	101.1	0.606	6.5'	1605.043	83	461	119	2333	20	--------	1
Trk L/V R	85.2	0.511	393.1'	1597.017	83	461	119	2333	20.9	--------	2
Trk L/V R	81.3	0.488	208.3'	1617.227	85	319	119	2660	19.9	--------	2
Trk L/V R	84.6	0.507	24.8'	1736.643	85	3750	117	3116	17.5	--------	2
Trk L/V R	80.3	0.482	14.9'	3404.237	102	1007	111	3553	13.6	--------	2
Trk L/V R	80.6	0.484	32.0'	3409.743	102	1123	111	3669	14.7	--------	2
Filename: 2008061002004F03.iex											
Trk L/V R	87	0.522	27.3'	155.913	106	1914	109	3197	17.8	--------	2
Filename: 2008061101004F01.iex											
Trk L/V L	82.7	0.496	16.6'	408.1	8	1553	0	575	35.4	--------	2
Trk L/V L	83.9	0.504	40.1'	411.94	8	1753	0	776	35.3	--------	2
Trk L/V L	84.4	0.506	35.2'	413.477	8	1834	0	856	35.3	--------	2
Trk L/V R	83.9	0.503	23.9'	492	10	1920	0	4942	39.7	--------	2
Trk L/V R	84.2	0.505	23.2'	492.647	10	1958	0	4980	39.8	--------	2
Trk L/V R	83.2	0.499	13.9'	495.223	11	112	0	5134	40.6	--------	2
Trk L/V R	80.1	0.48	17.2'	495.933	11	155	0	5177	40.9	--------	2
Trk L/V R	81.1	0.486	32.8'	496.797	11	207	0	5229	41.2	--------	2
Trk L/V R	80	0.48	39.3'	497.4	11	244	0	5266	41.4	--------	2

Trk L/V R	88.3	0.53	51.3'	498.327	11	301	0	5323	41.6	--------	2
Trk L/V L	84.1	0.504	958.2'	496.273	11	175	0	5198	41	--------	2
Trk L/V R	80.9	0.485	13.9'	498.923	11	338	0	5360	41.8	--------	2
Trk L/V L	81	0.486	44.6'	1058.417	25	753	5	1956	37.7	--------	2
Trk L/V R	92.6	0.556	39.7'	2826.827	71	562	21	9787	10	--------	2
Trk L/V L	80.2	0.481	46.6'	2858.507	71	1096	21	10321	12.8	--------	2
Trk L/V R	89.7	0.538	11.9'	2860.26	71	1129	21	10355	12.9	--------	2
Trk L/V L	83.4	0.5	72.0'	2865.083	71	1222	21	10447	13.1	--------	2
Trk L/V R	86	0.516	70.6'	2865.067	71	1222	21	10447	13.1	--------	2
Filename: 2008061101004F02.iex											
Trk L/V L	80.7	0.484	26.4'	2247.467	120	1263	42	701	25.8	--------	2
Trk L/V L	80.6	0.484	17.2'	3020.023	144	919	51	790	25.9	--------	2
Filename: 2008061101004F03.iex											
Trk L/V R	83.6	0.501	19.2'	617.55	162	364	57	4524	28.2	--------	2
Filename: 2008061207999F01.iex											
Trk L/V L	92.7	0.556	83.8'	10.07	0	427	0	427	15.1	--------	2
Filename: 2008061301004F04.iex											
Trk L/V R	88.9	0.533	92.1'	42.763	85	1563	285	3401	10.3	--------	2
Trk L/V R	83.5	0.501	7.1'	61.86	85	1835	285	3674	8.9	--------	2
Trk L/V R	80.5	0.483	31.5'	68.653	85	1923	285	3761	8.6	--------	2
Trk L/V L	82.1	0.493	51.4'	69.74	85	1937	285	3775	8.5	--------	2
Trk L/V L	81.3	0.488	11.4'	71.157	85	1954	285	3792	8.4	--------	2
Trk L/V R	82.4	0.494	23.3'	71.047	85	1953	285	3791	8.4	--------	2
Filename: 2008061702004F01.iex											
Trk L/V R	81.7	0.49	34.8'	1034.183	20	1573	5	6343	39.8	--------	2
Trk L/V R	81.4	0.488	25.7'	1038.257	20	1815	5	6585	40.8	--------	2
Trk L/V L	81	0.486	45.8'	1838.013	38	1310	1	127	32.2	--------	2
Trk L/V L	80	0.48	8.7'	1848.107	38	1792	1	610	32.5	--------	2
Filename: 2008061703004F05.iex											
Trk L/V L	81.6	0.49	35.9'	676.72	285	122	109	358	24.9	--------	2
Trk L/V L	88.8	0.533	98.0'	679.077	285	209	109	445	24.9	--------	2
Trk L/V L	89.8	0.539	46.9'	680.993	285	279	109	515	24.9	--------	2
Trk L/V L	83.2	0.499	45.0'	716.353	285	1600	109	1837	24.5	--------	2
Trk L/V L	82.9	0.498	62.4'	718.163	285	1665	109	1901	24.1	--------	2
Trk L/V L	81	0.486	27.1'	994.037	290	675	111	1708	20.3	--------	2
Trk L/V L	80.3	0.482	21.0'	997.49	290	779	111	1812	20.4	--------	2
Trk L/V L	84.2	0.505	30.2'	1002.34	290	926	111	1959	20.7	--------	2
Trk L/V R	81.4	0.488	265.3'	1080.12	291	1420	111	4453	22.3	--------	2
Trk L/V L	94.3	0.566	287.5'	1080.693	291	1439	111	4472	22.4	--------	2
Trk L/V R	81.9	0.492	18.0'	2086.597	308	937	118	642	25.9	--------	2
Trk L/V L	80.4	0.482	297.6'	2085.89	308	910	118	615	25.7	--------	2

Filename: 2008061703004F07.iex											
Trk L/V R	84.6	0.508	75.7'	358.343	377	1847	9	385	24.8	--------	2
Trk L/V L	80.1	0.481	221.6'	376.423	378	534	9	1072	27.2	--------	2
Trk L/V L	81.1	0.487	24.4'	461.283	380	51	9	4590	27	--------	2
Trk L/V L	96.9	0.581	128.4'	475.88	380	607	9	5145	24.9	--------	2
Trk L/V L	80.6	0.484	22.6'	498.19	380	1463	8	770	26.7	--------	2
Trk L/V L	90.1	0.541	56.0'	499.17	380	1502	8	809	26.8	--------	2
Trk L/V L	91.4	0.548	58.3'	502.743	380	1643	8	951	26.9	--------	2
Trk L/V L	82.2	0.493	14.0'	503.3	380	1666	8	973	26.9	--------	2
Trk L/V L	80.9	0.485	62.3'	505.05	380	1735	8	1043	27	--------	2
Filename: 2008061801004F01.iex											
Trk L/V R	90.9	0.546	13.7'	582.547	3	1530	0	6279	8	--------	2
Trk L/V R	86.9	0.522	20.7'	1738.593	16	1303	3	4808	13.5	--------	2
Filename: 2008061801004F02.iex											
Trk L/V L	85.4	0.512	30.9'	147.39	27	6669	8	4550	21.4	--------	2
Trk L/V L	82.6	0.495	16.5'	148.443	27	6702	8	4583	21.5	--------	2
Trk L/V L	89.2	0.535	16.8'	150.253	27	6760	8	4641	21.4	--------	2
Trk L/V L	86.6	0.519	29.2'	151.497	27	6799	8	4680	21.5	--------	2
Trk L/V L	82.1	0.493	11.5'	162.963	27	7172	8	5053	22.5	--------	2
Trk L/V L	85.8	0.515	10.9'	1742.42	58	487	19	2393	22.3	--------	2
Trk L/V L	82.2	0.493	23.1'	1822.617	59	1188	19	5093	21.6	--------	2
Trk L/V R	80	0.48	15.8'	1849.237	60	62	19	5967	22.6	--------	2
Filename: 2008061801004F03.iex											
Trk L/V R	80.6	0.484	10.9'	2117.757	105	2833	37	3817	21.6	--------	2