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**Federal Railroad
Administration**

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13. ABSTRACT

This report documents the procedure and results of the controlled testing conducted during Phase II of a tank car operating environment program involving the Association of American Railroads, the Railway Supply Institute (formerly Railway Progress Institute), the Federal Railroad Administration, and Transport Canada. This investigation is part of an ongoing assessment of what is necessary for a complete system optimization (i.e., to assure safety while minimizing total cost).

The same donated tank car that was used for all of the Phase I testing (with transducers and instrumented couplers mounted) was placed in over-the-road service for a period of 6 months. A wireless Internet connection utilizing two-way text messaging was the primary system used to monitor the summary data from each channel. Relationships between strain gage output and associated forces were established before onsite and over-the-road testing began. By the end of the over-the-road test in January 2005, the transducers, data acquisition system, and its power supply were operating relatively well. Problems remain to be solved, however, before a similar system is installed on a larger number of test cars.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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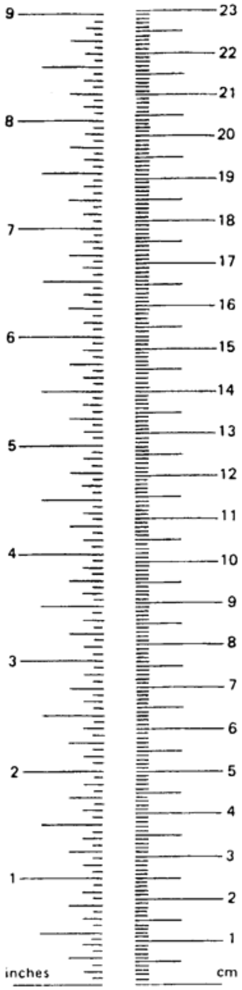
* 1 in = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
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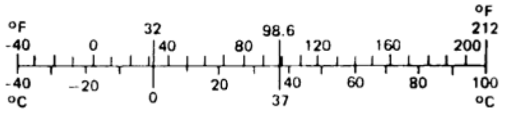

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Executive Summary

The Association of American Railroads (AAR), the Railway Supply Institute (formerly the Railway Progress Institute), the Federal Railroad Administration (FRA), and Transport Canada (TC) are funding a cooperative investigation of the operating environment of tank cars. AAR subsidiary Transportation Technology Center, Inc. (TTCI) is conducting this evaluation at the FRA's Transportation Technology Center (TTC), Pueblo, CO.

Two technical groups are cooperating on this project. One of the groups, known as the Tank Car Operating Environment Task Force (TCOE-TF), is evaluating a possible inverse relationship between the costs associated with the design/construction of tank cars and handling/operation of those cars. The TCOE-TF would like to establish the credibility of a reasonably priced device that would collect reliable data that could be used to investigate the frequency and magnitude of the largest forces encountered by tank cars during over-the-road service. The second group, the Stub Sill Working Group (SSWG), is investigating the use of failure or durability analysis to predict the proper inspection interval for stub sill tank cars. SSWG has a need to verify the full range of forces that tank cars experience in the railroad operating environment.

This investigation is part of an ongoing assessment of what is necessary for a complete system optimization (i.e., to assure safety while minimizing total cost). Since the research needs are so closely related, the two groups have agreed to work together to achieve both objectives.

This status report describes the procedure and results of the initial tasks of the program's Phase II and the placement of 1 donated tank car (with transducers and instrumented couplers mounted) in over-the-road service for a period of 6 months.

By the end of the over-the-road test in January 2005, the transducers, data acquisition system, and its power supply were operating relatively well. Problems remain to be solved, however, before a similar system is installed on a larger number of test cars. The recommended solutions to these problems can be divided into two categories. The first category would use the system in a form very similar to that used in this Phase IIA test. This would be the less costly option. The second category would make some significant changes to the structure of the data acquisition system. Section 4.3 discusses the following list of recommended solutions in more detail:

1. *Distinct Data Acquisition Systems*: In the next phase of this project, two types of data acquisition systems should be recognized and applied to different test cars. The objective of the first design will be only to monitor significant impact events. In order to meet this objective, the data acquisition system will only consist of three accelerometers, plus a data recording and storage system. The second data acquisition design would have a system sufficiently sophisticated enough to measure coupler and bolster forces at all times when car speed is above 5 mph.

2. *Provisions for Electrical Power*: The primary problem faced in the Phase IIA test was the provision of adequate electrical power for proper operation of the data acquisition system. For the second type of data collection system, improvements must be made to assure that reliable power is available.

3. *Reporting of System Health*: A second problem encountered during the Phase IIA test was the lack of consistent reporting on the condition or health of the data acquisition system. This inconsistency resulted from the power problems noted previously, as well as the erratic nature of cell phone coverage. The most straightforward solution would be to use low power satellite phone technology for the primary communication and the Internet modem/cell phone connections as a backup.

4. *Reduction of Data Channels*: To help lower the power requirements of the data acquisition system, it is recommended that the number of channels of data recorded be limited to approximately 12.

5. *Onboard Data Processing*: In addition to the file reduction steps in Recommendation #4, the team recommended that serious consideration be given to the development of a data acquisition system that incorporates significant modifications to the design used in Phase IIA.

The option would always be available to retain any and all time domain files with the realization that file storage will be filled quicker, and it will likely be impractical to transmit such files from the car to a central location in a cost-effective manner using current technology.

1.0 Introduction

AAR, RSI, FRA, and TC are funding a cooperative investigation of the operating environment of tank cars. AAR subsidiary TTCI is conducting this evaluation at the FRA's Transportation Technology Center (TTC), in Pueblo, CO.

Two technical groups are cooperating on this project. TCOE-TF is evaluating a possible inverse relationship between the costs associated with the design/construction of tank cars and handling/operation of those cars. TCOE-TF would like to establish the credibility of a reasonably priced device that would collect reliable data that could be used to investigate the frequency and magnitude of the largest forces encountered by tank cars during over-the-road service. SSWG is investigating the use of failure or durability analysis to predict the proper inspection interval for stub sill tank cars. SSWG has a need to verify the full range of forces that tank cars experience in the railroad operating environment.

This investigation is part of an ongoing assessment of what is necessary for a complete system optimization (i.e., to assure safety while minimizing total cost). Since the research needs are so closely related, the two groups have agreed to work together to achieve both objectives.

In the fall of 1997, TCOE-TF met to discuss issues and outline a plan of attack. At the meeting, topics of discussion included the following: the evolution of freight and tank car design standards, a few unique aspects of stub sill railcar designs, the industry's knowledge to date of the operating environment, some railroad ride quality efforts currently in progress, and the information contained in accident databases.

At the conclusion of this meeting, two technical advisory groups (TAGs) were formed to undertake further research. The first of these, the cost TAG, was asked to assess costs associated with tank car events approaching and exceeding design specifications. The second team, the test plan TAG, was asked to develop a methodology for the measurement and reporting of those events. As a result of the efforts of the second team, a test methodology comprised of three phases was developed. Phase I addressed the development and proof of a methodology to infer peak longitudinal and vertical coupler forces from data collected using a relatively inexpensive set of transducers. Phase I also included the development of the inexpensive transducer and data collection package. Phase I was completed in December 2002. Phase II was designed to provide further validation of such a process by subjecting as many as five cars with the minimal transducer package to the over-the-road service environment. If Phases I and II were successful, Phase III would implement the installation of the inexpensive transducer packages on a large number of tank cars to collect environment data.

This status report describes the procedure and results of the initial tasks of Phase II of the program and the placement of 1 donated tank car (with transducers and instrumented couplers mounted) in over-the-road service for a period of 6 months.

2.0 Objective and Background

2.1 Background–Phase I

As a portion of Phase I of the Tank Car Operating Environment Program, four car-to-car impact sequences have been completed. Brief details of these impact sequences are as follows:

- *Sequence 1*–Empty, instrumented tank car was allowed to roll into a stationary 3-car anvil string at speeds of 2, 4, 6, and 8 mph.
- *Sequence 2*–Loaded, instrumented tank car rolling into stationary 3-car anvil string at speeds of 2, 4, 6, and 8 mph. The hand and air brakes were set on the two stationary cars farthest from the impact.
- *Sequence 3*–Loaded, hopper car rolling into instrumented, stationary tank car at speeds of 2, 4, 6, and 7 mph. Tank car was not coupled to any other cars. The hand and air brakes were set on the stationary tank car.
- *Sequence 4*–Loaded, hopper car rolling into instrumented, stationary tank car at speeds of 2, 4, 6, and 6.5 mph. Tank car was the lead car in a five-car anvil string. The hand and air brakes were set on all of the stationary cars.

Phase I testing also included the controlled application of vertical force pulses to the end of the stub sill with the tank car empty, as well as fully loaded. These vertical force application tests were conducted in an effort to simulate some of the vertical forces that the stub sill may experience during normal in-train operations. The objective of these first tests was to study, through controlled testing, the feasibility of estimating or calculating peak longitudinal and vertical coupler force using only the recorded output from car-mounted accelerometers or strain gages.

The body of data from the initial testing has shown that definite relationships can be established between accelerometer or strain gage output and peak longitudinal and vertical coupler forces. The impact data has also shown, however, that while accelerometer output may be able to predict the forces due to yard impacts with sufficient accuracy, strain gage and instrumented coupler output will most likely be required to produce coupler force data accurate enough to be used for fatigue or DTA. The final task of Phase I was to record accelerometer and strain gage response during a relatively short-term test that would allow the instrumented tank car to be exposed to an operating environment similar to that of standard over-the-road service. Even though data for impact severity analysis and environmental data for fatigue or structural durability analysis will most likely be supplied by different types of transducer systems (accelerometers versus strain gages or instrumented couplers), it was expedient and desirable for this test, as well as for the initial portion of Phase II, that both systems remain on a single car. This simulated over-the-road test was completed at TTC's Facility for Accelerated Service Testing (FAST) high tonnage loop. Completion of this final task of Phase I met the following objectives:

- Confirm that relationships between strain gage or accelerometer output and peak coupler force can also be established for the lower magnitude coupler forces produced by normal train action. The results of the impact tests allowed the study of these relationships for peak compressive forces greater than about 250,000 to 300,000 lb. The TAG wanted to study the validity of such relationships for both tensile and compressive forces with magnitudes from near zero to 250,000 to 300,000 lb.

- Allow the troubleshooting and development, in a relatively controlled test environment, of a data acquisition and storage system that could be operational on the test car for a relatively long period of time (4 to 6 weeks).
- Allow the development of a reliable power generation system (again in a controlled environment) that can provide consistent, long-term power for the onboard data acquisition hardware while being hidden from casual observation.

2.2 Objective–Phase IIA

The tasks of Phase II were designed to build upon the work completed under Phase I by meeting the following objectives:

- Provide for further development of the transducer package, data acquisition system, and data transmittal systems. This development will include the design of an installation for these systems that will make them relatively invisible to the casual observer on the ground.
- Demonstrate that these systems can reliably provide information on the coupler and body bolster force operating environments under long-term standard railroad working conditions. Such conditions may include yard impacts, as well as normal over-the-road operations. This system will be able to record all of the primary environmental forces imposed on a tank car that can produce significant fatigue damage. Phase IIA was not designed to produce a complete stand-alone load spectrum for any of the instrumented locations. The main objective was to finalize a test design that could eventually accomplish that goal.
- The data transducer and acquisition system used in Phase IIA included rugged but relatively inexpensive components that may be used to monitor the existence of severe or exceptional impacts, as well as to report the quantity and severity of those events to a central location within 48 hours.

In keeping with the philosophy of proving the viability of concepts before larger scale tasks are undertaken and in order to meet funding requirements, Phase II was structured into sub-phases A and B. The tasks of Sub-Phase A (Phase IIA) were designed to install the transducer/data acquisition/data transmittal system on one donated stub sill tank car. This car was then allowed to operate in standard service for approximately 6 months. At the end of this test period, the objective was to determine if the body of data collected during the test would allow dynamic vertical and longitudinal coupler forces, as well as bolster forces, to be consistently determined with acceptable accuracy. This objective also included proof that the system could provide such data consistently and reliably. If the objectives of Phase IIA were met, the next tasks of Phase IIA could be to install similar systems on at least three additional donated cars. These cars should be of common, contemporary designs, significantly different from that of the first car tested.

3.0 Test Procedure–Phase IIA

3.1 Test Car

The test car to be used for Phase IIA was the same as that used for all of the Phase I testing. The basic specifications are as follows (Figure 1):

- Manufacturer: American Car and Foundry
- Car No.: VICX 1725 (Certificate of Construction No. 21826)
- Empty Weight: 75,400 lb
- Maximum Weight with Payload of Water: 263,000 lb
- Tank Design: ACF 4-B-7188, 22,500 Gallon Capacity
- Underframe Design: ACF 4-B-7190 Stub Sill
- Coupler Design: 6 ¼ x 8 Type E, Top & Bottom Shelf
- Draft Gear Design: Cardwell Westinghouse Mark 50 All Steel Design (friction wedges plus springs)
- Trucks: Standard Three Piece, Bolster Castings–ASF, AAR-B-2047, 22057-FT, 2-68, #2319 (A-End) and #2345 (B-End)

Figure 1. VICX 1725 Test Car

Modifications completed on the car to conceal the cabling, transducers, data acquisition, and data transmittal systems were as follows:

- All strain gages and accelerometers concealed by jacketing or fabricated sheet metal covers were painted the same color as the test car.
- All openings in the jacket created to allow the mounting of transducers directly on the tank shell were covered with patches.

- Cabling from transducers to acquisition system concealed within metal conduit were painted the same color as the car.
- Data acquisition and transmittal systems contained within metal boxes were designed to blend with the existing structural details.
- A power generation system is located between the side frames of one of the bogies. Section 3.2 describes this system in more detail.

The test car was loaded with water and weighed before testing began. The total weight of the car was measured at 263,350 lb, 130,700 lb on the A-end, and 132,650 lb on the B-end.

Figure 2. VICX 1725 Test Car–Conduit

Figure 3. VICX 1725 Test Car–Storage Box

3.2 Instrumentation

3.2.1 Transducers

During the over-the-road testing, output in g's was recorded from the four individual accelerometers listed below. Microstrain output was also recorded from strain gages mounted on both bolsters and the stub sills as listed below. Refer to the Appendix for accelerometer and strain gage locations.

- Two longitudinal accelerometers at location #6
- Two vertical accelerometers at location #6
- Strain gages at locations: #21-22 (locations #21-22 are typical of both ends of the car)
- Strain gages on both of the bolsters, as shown in Figure A-3 in the Appendix
- Instrumented Miner Dyno Coupler designed to measure longitudinal force at each end of the car

One set of accelerometers installed independently on a common block were 100 g units manufactured by Endevco. The mounting block for these accelerometers was attached to the car structure by welds. The remaining accelerometers were 60 g units contained within a PS-100 self-contained event recorder supplied by Independent Witness (IW) of Salt Lake City, UT. This unit, with the capability to record and store event counts, peak values, and time domain wave forms, was mounted using its own bracket welded to the tank structure.

The strain gages at locations #21A-22A (#21B-22B on B-end of car) were Hitec shear gages wired into a half-bridge circuit so that response is sensitive to vertical shear force in the stub sill but relatively insensitive to axial forces or bending moments. The output from these gages was used to determine vertical coupler force. These gages were mounted on the neutral axis of the sill and located between the front draft lugs and the yoke support plate.

The strain gages at locations #1 and #2 on the bolster were single element gages wired into a half-bridge circuit to measure side bearing forces on one end of the bolster. The gages at bolster locations #3 and #4 were connected in a similar manner to measure side bearing forces on the opposite end of the bolster. Two gages at locations #5 and #6 on the bolster were wired into a half-bridge configuration to measure center bowl load.

Redundant strain gages were mounted at all noted locations. These gages only served as backup transducers in the event that problems occurred with the primary units. Figures 4 through 6 further illustrate strain gage placement.

An onboard global positioning system (GPS) supplied car velocity data. In addition to car position, this system provides vehicle speed data with a resolution of at least .5 mph for speeds over 2 mph.

Figure 4. Placement of Strain Gages, Locations #21A-22A

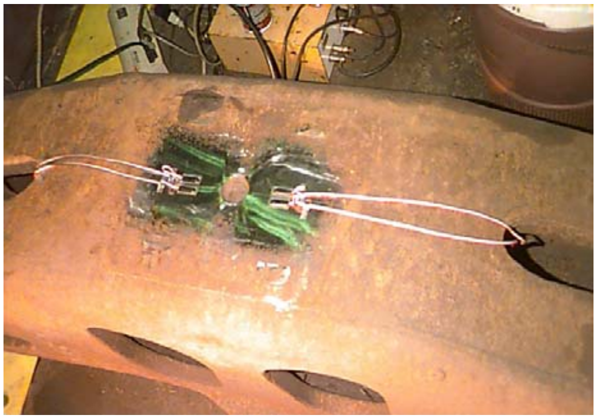

Figure 5. Placement of Strain Gages, Locations #5 and #6 on Bolster

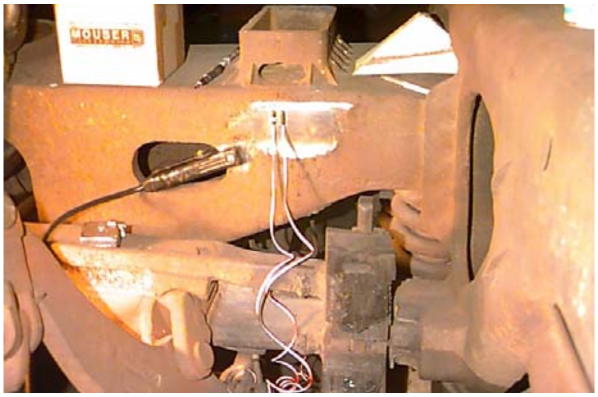

Figure 6. Placement of Strain Gages, Locations #1 and #2 on Bolster

Figure 7. Independent Witness Data Acquisition Unit

3.2.2 Data Acquisition System

A single TTCI unattended data acquisition system (UDAQ) capable of storing at least 32 channels of data was mounted on the test car, contained in the box shown in Figure 3. Table 1 shows the channel listing. The data from the Independent Witness PS-100 unit was sampled at a rate of 1800 Hz and filtered at 180 Hz to prevent aliasing. The sampling and filtering capability is contained within the PS-100 box. All of the remaining data was sampled at a rate of 1024 Hz and filtered at 120 Hz. The strain gage and coupler force data was decimated at 256 Hz to maximize data storage space. Response versus time (time series) data recorded during the duration of the test was stored on the UDAQ system. When possible, the following data were viewed twice daily via a wireless Internet and cell phone connection to monitor system health: battery voltage; charge amperage; GPS location and speed; and maximum, minimum, mean, and standard deviation values for each data channel. The download of this data was to be automatic.

Gel cell batteries charged by an axle driven alternator were used to provide long-term electrical power for the transducers and the UDAQ. The charging system uses urethane rollers contacting the axle to transmit torque through a chain to an automotive alternator. Anytime the car is in motion the alternator would normally supply charging current to 2 gel cell 12 volt, 200 amp-hour storage batteries. This system was tested during initial shakedown runs at TTCI before the car was sent over the road. This system was designed so that it could be partially hidden behind the wheels and side frame when viewed from the side of the car. Figure 8 shows that the alternator is mounted on the bogie set.

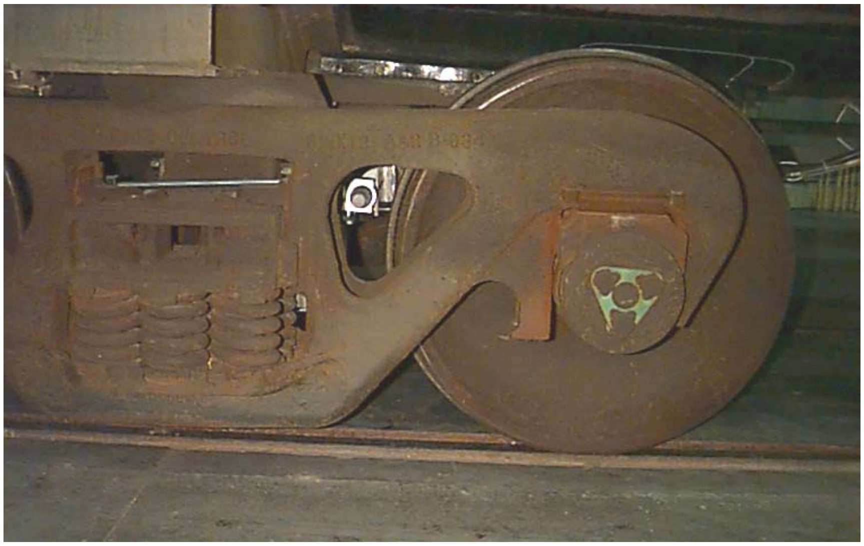

Figure 8. Bogie Group with Axle Generator Installed

3.2.3 Data Download System

The primary system to monitor the summary data from each channel employed a wireless Internet connection utilizing two-way text messaging. Download could be performed anywhere cell phone service or an active connection to the Internet exists. Communication was completed through remote host protocol. An auxiliary monitoring system utilized an onboard satellite telephone connected to the UDAQ computer via a serial cable. The phone utilized a self-tracking, gyro-controlled antenna to maintain consistent contact with the required satellite.

Table 1. Primary Transducer Channels

Channel Number	Transducer
1	Car Velocity
2	Instrumented Coupler A-End
3	Instrumented Coupler B-End
4	Strain Gages at Locations #21A-22A (A-End Vertical Coupler Force)
5	Strain Gages at Locations #21B-22B (B-End Vertical Coupler Force)
6	Strain Gages #1 & #2 (A-End Bolster Side Bearing Load)
7	Strain Gages #3 & #4 (A-End Bolster Side Bearing Load)
8	Strain Gages #5 & #6 (A-End Bolster Center Bowl Load)
9	Strain Gages #1 & #2 (B-End Bolster Side Bearing Load)
10	Strain Gages #3 & #4 (B-End Bolster Side Bearing Load)
11	Strain Gages #5 & #6 (B-End Bolster Center Bowl Load)
12	Vertical, 100 g Accelerometer at Location #6 (6V)
13	Longitudinal, 100 g Accelerometer at Location #6 (6L)
14 thru 23	Spare Instrumented Coupler and Strain Gage Circuits Measuring Vertical Coupler Forces and Bolster Forces
24	Battery Voltage

3.3 Transducer Calibration

Before onsite and over-the-road testing began, the relationships between strain gage output and associated forces were established using the following procedure:

- With instrumented couplers in place on both ends of the car, quasi-static buff and draft loads of up to 250,000 lb were applied while output from gages 21A/22A and 21B/22B were recorded. A calibrated load cell was also installed to confirm the output of the instrumented couplers.
- The output from gages #21A/22A and #21B/22B was used as the primary indicator of vertical coupler force. Output from these gages was recorded during the application of dynamic, as well as static loads to the end of the sill. Initially a hydraulic cylinder was used to apply static vertical loads through a calibrated load cell to the end of the sill. These tests were conducted with the car loaded, and the vertical forces applied were increased slowly from zero to approximately 50,000 lb upward and zero to 20,000 lb downward. Each static loading test was repeated at least three times. In addition to the static forces, dynamic force pulses of increasing amplitude were applied in the upward direction to the end of the sill. Two force pulse sequences were completed. One applied the force from zero to approximately 25,000 lb and the other from zero to 50,000 lb. The half duration of the pulse, t/2, will be approximately 0.5 second (see Figure 8). Each amplitude value was repeated at least three times. Figure 9 shows the configuration for the vertical load application.
- The results of the longitudinal and vertical load tests were used to establish relationships that can be used to calculate vertical coupler forces at both ends of the car using the output from gages 21A/22A and 21B/22B and the instrumented couplers as variables.
- The calibration of the bolster gages, 1 through 6, was accomplished by applying static forces (through calibrated load cells) in the following sequence:
    1. Apply load to center bowl only (at bowl center and at bowl edges independently).
    2. Apply load to one side bearing location only.
    3. Apply load to opposite side bearing location only.
    4. Apply load to each bowl edge and the corresponding side bearing simultaneously.
- Using a hydraulic load frame, the forces were applied slowly from zero to approximately 100,000 lb. These load sequences were repeated at least three times at each location. As with the coupler forces, relationships were established that can be used to calculate center bowl and side bearing forces using the output from gages 1 through 6. Figure 10 shows the bolster loading configuration.

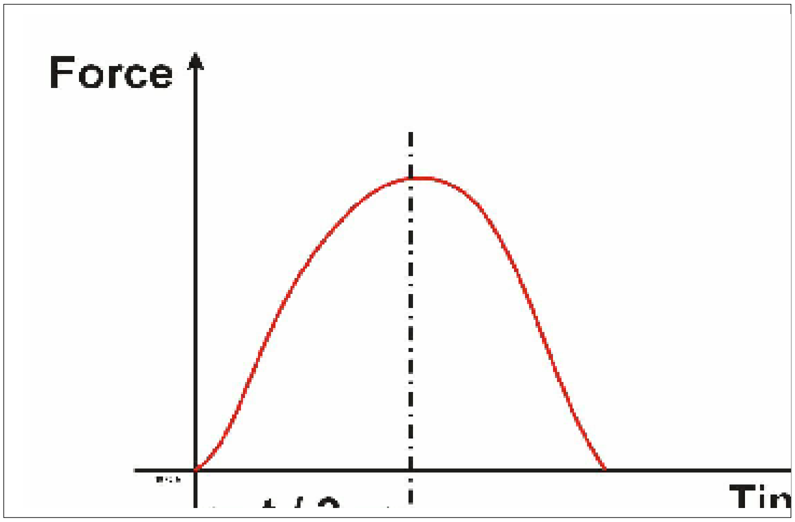

Figure 9. Typical Force versus Time Curve, Vertical Force Calibration

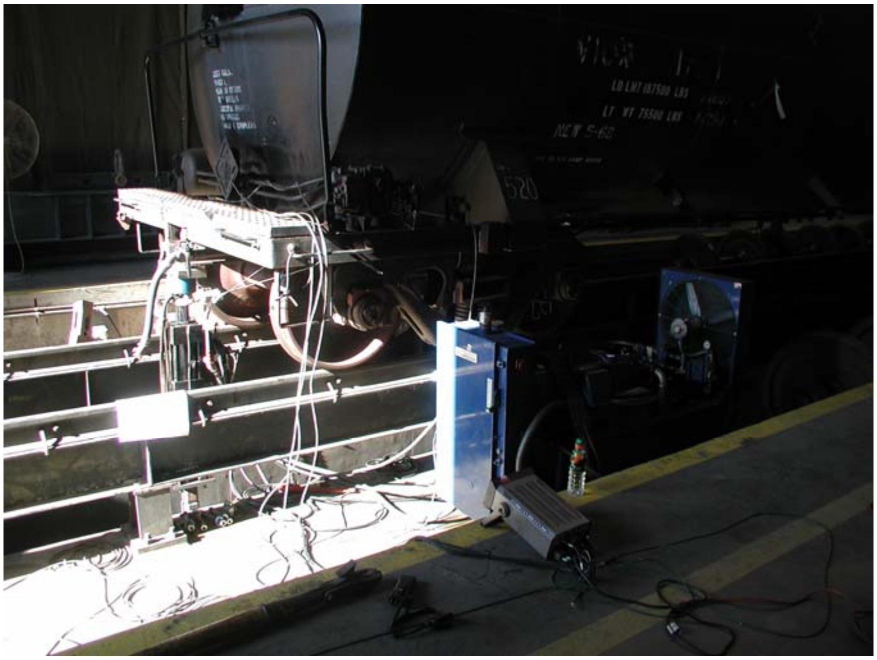

Figure 10. Vertical Force Application

Figure 11. Bolster Load Calibration

3.4 On-Track Trail Test–TTC

After the calibration tasks were completed and the test car/instrumentation package fully assembled, it was placed in a consist and tested on the rails at TTC. This provided an opportunity to demonstrate that all systems on the car were working properly before it departed for the over-the-road tests. The test car was placed in a consist with 3 other cars and operated over the TTC Railroad Test Track and Perturbed Test Track at speeds of up to 50 mph. Results from this test demonstrated that all channels were recording data properly, batteries were being charged as designed, and no apparent problems existed with the axle driven alternator installation. During this trial, test data was recorded and downloaded from all channels. During these trial tests the VICX1725 car was loaded as shown in Section 3.1.

3.5 Extended Over-the-Road Test

During the Phase IIA test the car was scheduled to follow the route detailed below:

Burlington Northern Santa Fe Railroad Section of Route

Pueblo, CO	LaJunta, CO
LaJunta, CO	Amarillo, TX
Amarillo, TX	Lubbock, TX
Lubbock, TX	Sweetwater, TX
Sweetwater, TX	Temple, TX
Temple, TX	Houston, TX
Houston, TX	Lafayette, LA
Lafayette, LA	New Orleans, LA

CN Section of Route

New Orleans, LA	Chicago, IL

NS Section of Route

Chicago, IL	Bellevue, OH
Bellevue, OH	Conway, PA
Conway, PA	Allentown, PA
Allentown, PA	Harrisburg, PA
Harrisburg, PA	Roanoke, VA
Roanoke, VA	Knoxville, TN
Knoxville, TN	Chattanooga, TN
Chattanooga, TN	Birmingham, AL
Birmingham, AL	Meridian, MS
Meridian, MS	New Orleans, LA

The New Orleans to Harrisburg to New Orleans loop would be traveled at least twice. The total distance accumulated for the segment from Pueblo to New Orleans, 2 loops from New Orleans to Harrisburg and back to New Orleans and the return trip from New Orleans to Pueblo, was estimated to be approximately 8,700 miles. The following key points applied to this over-the-road test:

- The car was placed in standard trains and retained all of the original labeling and stenciling. The test car was loaded with water and had water placards installed. The car was weighed on the TTC scales before testing began. The measured weight of the car was 263,350 lb as shown in Section 3.1.
- Data recording began when the car left Pueblo en route to Houston.
- Basic system health and GPS were monitored daily via a wireless Internet connection when connections were adequate. The following data was reported and inspected during these checks: battery voltage; charge amperage; GPS location and speed; and maximum, minimum, mean, and standard deviation values for each data channel.
- Strain and coupler force data were recorded continuously while the car was traveling above 5 mph (see Section 3.6). This time domain data from the first 2 to 3 days of travel would be downloaded in its entirety using the satellite phone connection. This would be a test of the practicality of such data download procedures. As the test progressed, however, continuing concerns with adequate onboard electrical power and the time required to download a full set of data resulted in an abandonment of this portion of the test. Section 4.2 gives further detail. The complete download of data collected occurred only when TTCI personnel visited the car.
- TTCI engineering and instrumentation personnel planned to travel to the car to download data and inspect the systems at least two times during the test's duration. Eventually problems with the maintenance of adequate onboard power resulted in a requirement that TTCI personnel visit the car more than twice. Section 4.2.1 gives details.

- Mileage would also be accumulated with the car empty if time allowed. As the test progressed and electrical power problems persisted, however, the focus had to be concentrated on the accumulation of sufficient, valid data with the car loaded.

3.6 Data Analysis

Data from the strain gages and instrumented couplers was to be recorded continuously while the car was traveling at a speed of more than 5 mph. At a speed of less than 5 mph, this data was recorded and stored only when vertical coupler force at either end of the car exceeded 10,000 lb, longitudinal coupler force at either end of the car exceeded 25,000 lb, or vertical or longitudinal acceleration exceeded 2.5 g. The Independent Witness unit recorded and stored acceleration versus time data only when vertical or longitudinal acceleration exceeded 2.5 g. Notification of the occurrence of events and the severity (maximum acceleration value in each axis), however, was recorded if longitudinal or vertical acceleration exceeded plus or minus 0.5 g. The Independent Witness unit recorded such data regardless of whether the car was moving or stationary. Activation of the unit at speeds less than 5 mph resulted in data being recorded for a duration of 4 to 5 seconds, beginning 0.5 seconds before the time of the triggering event. If a threshold value remained in place for a long period of time (more than 10 seconds), the system ceased recording. Acceleration and strain data was used to determine the following:

- The full spectrum of the vertical and longitudinal coupler force environment at each end of the car. This data was processed as time-dependent traces and as rainflow cycle-counted, range-mean histograms.
- The full spectrum of the bolster center bowl and side bearing loads. These were also the loads applied to the body bolsters. This data was also processed as time dependent traces and as rainflow-counted, range-mean histograms.
- The level of agreement of the peak acceleration values recorded by the individual 100 g accelerometers with those recorded by the Independent Witness PS100 unit. Such a comparison was made on the basis of the peak values of individual events. The reason for this comparison was to evaluate the Independent Witness transducers against the values produced by the known performance of the Endevco units. Good correlation between the two transducers, especially at larger acceleration levels, would provide some level of confidence that the Independent Witness units could be used as stand-alone transducers on future systems.
- The full spectrum of longitudinal acceleration values above 2.5 g were measured by the TTCI-installed and Independent Witness accelerometers. This included time histories and histogram summaries. Similar data was also available from the vertical accelerometers when longitudinal acceleration is greater than 2.5 g.

4.0 Summary of Results

4.1 Transducer Calibration

4.1.1 Strain Gages to Measure Vertical Coupler Force

The following tables list sensitivities of the strain gages mounted on the stub sills and designed to measure vertical coupler force.

Table 2. Vertical Coupler Force versus Gage Output–Upward Force Positive

Load Direction	A-End Primary Gages Kip/Volt	A-End Backup Gages Kip/Volt	B-End Primary Gages Kip/Volt	B-End Backup Gages Kip/Volt
Upward	12.9	13.2	13.1	13.8
Downward	13.1	13.2	12.7	13.0

Table 3. Longitudinal Coupler Force versus Gage Output–Tension Positive

Load Direction	A-End Primary Gages Kip/Volt	A-End Backup Gages Kip/Volt	B-End Primary Gages Kip/Volt	B-End Backup Gages Kip/Volt
Compression	-563.8	-655.3	-112.7	-116.3
Tension	-426.8	-534.4	-289.9	-160.3

4.1.2 Strain Gages to Measure Bolster Center Bowl and Side Bearing Loads

Tables 4 and 5 list sensitivities of the strain gages mounted on the bolsters, designed to measure center bowl and side bearing force. The sensitivity constants shown in Tables 2 and 3 were used to produce equations that could be used to convert voltage output from strain gages to vertical coupler force. In the same way, the sensitivity constants shown in Tables 4 and 5 were used to produce equations that could be used to convert voltage output from strain gages to bolster center bowl and side bearing force. All output voltage versus force relationships were essentially linear.

Table 4. Vertical Force on Bolster versus Strain Gage Output–Casting #2319, A-End

Load Type	Bottom of Bolster Primary Gages Kip/Volt	Bottom of Bolster Backup Gages Kip/Volt	Side Bearing #1/2 Primary Kip/Volt	Side Bearing #1/2 Backup Kip/Volt	Side Bearing #3/4 Primary Kip/Volt	Side Bearing #3/4 Backup Kip/Volt
Center Bowl	45.0	45.2	185.2	210.5	231.4	250.1
Side Bearing Above Location 1/2	21.9	22.9	133.1	137.3	651.6	717.4
Side Bearing Above Location 3/4	574.7	680.7	138.2	139.2	25.0	24.9

Table 5. Vertical Force on Bolster versus Strain Gage Output–Casting #2354, B-End

Load Type	Bottom of Bolster Primary Gages Kip/Volt	Bottom of Bolster Backup Gages Kip/Volt	Side Bearing #1/2 Primary Kip/Volt	Side Bearing #1/2 Backup Kip/Volt	Side Bearing #3/4 Primary Kip/Volt	Side Bearing #3/4 Backup Kip/Volt
Center Bowl	43.3	43.8	186.5	205.5	217.1	194.6
Side Bearing Above Location 1/2	21.1	23.2	151.3	149.4	949.7	738.9
Side Bearing Above Location 3/4	558.6	665.3	137.6	136.4	22.8	24.0

4.2 Extended Over-the-Road Test

4.2.1 Trip Summary

The over-the-road testing portion of this program began July 10, 2004. Except for a segment of time between September 28 and November 17, 2004, the car was on railroads between Pueblo and the eastern United States until January 26, 2005. The car accumulated approximately 15,000 miles during the 6-month duration of the test. Because of data acquisition problems that are detailed below, approximately 220 hours of data was accumulated, covering about 6,800 miles of travel. The accumulated file size for all of the data collected was approximately 40 gigabytes (GB). The following gives a brief chronological summary of the 6 months of testing.

- Car traveled to New Orleans, LA, via Amarillo, Lubbock, and Houston, TX. All systems operated properly through July 13, 2004, when the car arrived in Lubbock. Two attempts were made to download files (about 2.0 GB) recorded on July 10-11, 2004, via satellite phone. The process to list the files before the transmission consumed over 2 hours, which exceeded the preset time limit for the phone to be activated. After July 13, 2004, as the car traveled on to New Orleans, LA, daily contact was lost, and no further attempts were made to download full-time domain data files.
- Team from TTCI traveled to New Orleans, LA, on July 22, 2004, to determine why contact with the car was lost. The team found that the battery voltage was too low. Diagnosis was that much of the time train speed was too low for the alternator to adequately charge the batteries. A different alternator was installed that would provide adequate charging amperage at lower travel speeds. All other systems appeared as they should.
- Between July 27 and August 20, 2004, the car traveled to Chicago, IL, and on to Harrisburg, PA. No further attempts were made to download large time domain files via satellite phone due to concerns of adequate battery voltage. All systems appeared to operate properly until about August 10, 2004. After that date contact was lost. A team from TTCI again visited the car in Harrisburg. The team discovered that one of the drive chains used to power the alternator had been damaged and broken. The chain was replaced. All other components of the data acquisition system appeared in good condition.

- Between August 21 and August 28, 2004, the car remained essentially stationary in Harrisburg. It finally left Harrisburg on August 29, 2004, and arrived in New Orleans on September 6, 2004. Contact was lost before the car left Harrisburg. The team speculated that the battery voltage dropped below the adequate operational level while the car was stationary, and the alternator was never able to bring the voltage back to the proper value. After the car arrived in New Orleans, the decision was made to bring it back to Pueblo, CO, for modifications to the charging system circuits. Between September 13 and September 28, 2004, the car traveled back to Pueblo.
- Between September 28 and November 17, 2004, the car remained in Pueblo for charging circuit modifications and installing an enhanced Independent Witness system that would allow acceleration events and car location to be constantly monitored on the Independent Witness Web site.
- Between November 17 and December 6, 2004, the car traveled from Pueblo to Chicago to Roanoke, VA, and then to New Orleans. Even though contact was sporadic due to cell phone service, all systems appeared to be operating properly; the team decided to send the car for one more loop to Chicago, Roanoke, and back to New Orleans.
- Between December 7, 2004, and January 6, 2005, the car traveled from New Orleans to Chicago to Roanoke and back to New Orleans. After the car arrived in Chicago on December 12, 2004, daily contact was lost and not regained.
- When the car arrived in New Orleans, a TTCI technician traveled to meet it, downloaded data from the data acquisition system, and determined the reason for loss of contact. Instrumentation technicians discovered that one of the axle-to-alternator drive chains had again broken, allowing the battery charge to decrease to a level under that which the acquisition system could not operate.
- Between January 13 and January 26, 2005, the car traveled from New Orleans to Chicago and back to Pueblo. Contact was maintained through this section of the test, and all systems appeared to operate properly.

4.2.2 Data Summary

Approximately 62 percent (covering 27 days) of the 220 hours of data collected during the Phase IIA test has been analyzed in detail. This data analysis includes the following trip segments:

- July 12 to July 15, 2004–Pueblo, CO, to Lubbock, TX
- July 27 to August 2, 2004–New Orleans, LA, to Chicago, IL, to Harrisburg, PA
- November 16 to December 7, 2004–Pueblo, CO, to Chicago, IL, to Roanoke, VA

In addition to the 5,000 files inspected and analyzed in detail, basic statistics, such as maximum, minimum, and mean values, were tabulated for ten 98-second data files recorded during the last days of the test (January 19-26, 2005). These statistics were compared to those of 10 files previously analyzed in detail and found to be very similar in value and character. The close agreement of the statistics for the two groups of files provided confidence that the quality of data contained in the files not yet analyzed in detail was equivalent to the data in the files recorded between July 10 and December 7, 2004. Since the primary objective of this test was to demonstrate that quality environmental data could be recorded and stored over a relatively long period of time, it did not seem an efficient use of the remaining project resources to analyze 100 percent of the data in detail at this time. Figures A-10 through A-27 in the Appendix illustrate the type of summary analysis completed and the range-mean histograms created for the data recorded through December 7, 2004. Similar histograms files could be created for the remainder of data recorded from December 8, 2004, through January26, 2005, if it is eventually thought to be worthwhile.

All channels except one of the B-end bolster side bearing circuits (Channel 10) recorded data without significant problem. This channel began to record values that were unrealistically low, indicating that the bond between one of the gages and the steel surface could have been partially lost. Data from the backup circuit was used to supplement that from Channel 10. Data was processed and summarized to produce the following for each day and for the total body of data accumulated:

- Absolute maximum and minimum values for each channel as applicable.
- Maximum ranges from rainflow cycle-counted, range-mean histograms.
- Number of ranges above certain thresholds also derived from the rainflow cycle-counted, range-mean histograms.
- Comparison of accelerometer response between TTCI-installed units and the Independent Witness units.

Tables A-1 through A-4 in the Appendix show the absolute maximum and minimum values, as well as the maximum ranges, recorded for each channel for the data analyzed in detail. Tables A-5 through A-8 show a summary of the longitudinal coupler, vertical coupler, bolster center bowl, and bolster side bearing load ranges above arbitrarily chosen levels recorded for all of the data analyzed in detail (July 10 through December 5, 2004). This kind of summary indicates the relative severity of the route, as well as a comparison of the severity of the forces at each end of the car. Several observations of interest include the following:

- Both longitudinal and vertical coupler forces at the B-end of the car were somewhat higher than those at the A-end. This was especially significant for the vertical forces. This trend is indicated by the peak values, as well as the number of load range cycles above specific levels. The test car received an extensive post-test inspection when it returned to TTC in January 2005. This inspection revealed 2 pieces of evidence that strongly indicate that the differences in recorded vertical coupler forces between the A- and B-ends were accurate: (1) with each coupler shank resting on the bottom of the stub sill, opening the distance between the top of the shank and the top striker was 1 3/8 inch on the A-end but only 1 1/16 inch on the B-end; (2) there was evidence on the B-end coupler shank that it had contacted the top striker on the stub sill several times with considerable force. No clear evidence of such heavy contact on the A-end existed.
- The vertical center bowl load spectrums on each bolster appear to be comparable. For each bolster, the maximum dynamic vertical force is approximately 2.2 to 2.6 times the static load.
- The vertical load spectrum on the bolster side bearings appears to be relatively similar for all locations except that represented by the data of Channel 7. As Table A-8 shows, the load ranges above 20,000 lb and 40,000 lb on the Channel 7 side bearing were 3 to 5 times higher than for any other side bearing. The side bearing clearance gaps at all 4 locations were relatively consistent at 1/4 to 5/16 inch. Therefore side bearing settings do not appear to have contributed to this difference in load spectrum. It is also possible,

however, that on a used car the variation in spring or damping rates at this corner of the car could have contributed to the differences.

- As Table A-9 shows, some significant differences exist between the Independent Witness peak accelerometer readings and those of the Endevco units installed by TTCI. This is especially true at the lower acceleration levels. When viewing this data, however, several factors must be considered. The Endevco accelerometers had the capability to measure 100 g's full scale. Therefore, the resolution of these units at 2 to 3 g's or 2 to 3 percent of full scale is not that good. The Independent Witness accelerometers were of 60 g full-scale capability, providing somewhat better resolution at low acceleration levels.

Another interesting observation made from inspection of the force range data was that some sections of the route produced relatively high forces more often than others:

- Longitudinal and vertical coupler forces occurred more often on an event per hour basis during the July 28-30, 2004, timeframe when the car was traveling from New Orleans to Chicago.
- Relatively high bolster forces occurred more often by a significant amount on November 18, 2004, when the car was traveling from Pueblo to Chicago. This is an indication of relatively consistent significant pitch or bounce motion.
- Relatively high side bearing forces occurred more often on July 10, 2004, when the car was traveling from Pueblo to Lubbock. This is an indication of relatively consistent significant roll motion.

Figures A-4 through A-7 in the Appendix show some time versus force data for typical high load events. Figures A-10 through A-30 show rainflow cycle-counted, range-mean histograms for 3 days for which the data has been analyzed in detail.

Some effort was made to investigate the level of correlation between longitudinal and vertical coupler forces at any particular step in time. The team determined that even though occasions exist when a noticeable relationship exists between longitudinal and vertical coupler force levels, any correlation is not consistent or exact enough to be used as a tool in the computation of stress levels within the structure. Figures A-8 and A-9 show an example of this. Figure A-8 shows that during this 2,000 seconds of data, the longitudinal and vertical forces follow similar trends, but a cross plot of the same data shows considerable scatter when the values from 1 channel are plotted against those of the other.

4.3 Conclusions and Recommendations

By the end of the over-the-road test in January 2005, the transducers, data acquisition system, and its power supply were operating relatively well. The signal was lost from the B-end instrumented coupler at some point when the car was traveling back to Pueblo in January 2005. It appears, however, that a person must have disconnected a coupler for the primary data cable, resulting in loss of signal. This coupler was located between the knuckle and the end of the stub sill. Problems remain to be solved, however, before a similar system is installed on a larger number of test cars. The recommended solutions to these problems can be divided into two categories. The first category would use the system in a form very similar to that used in this Phase IIA test. This would be the less costly option. The second category would make some significant changes to the structure of the data acquisition system. The following lists these problems and possible solutions in the recommendations below:

1. *Distinct Data Acquisition Systems*: In the next phase of this project, two types of data acquisition systems should be recognized and applied to different test cars. The objective of the first design will be only to monitor significant impact events. In order to meet this objective, the data acquisition system will only consist of three accelerometers, plus a data recording and storage system. The least complicated option for such a system would be powered by small long-lasting batteries and would require a periodic manual data download. A more costly option would transmit location and event data via a low power satellite phone connection to a central location that would process the data so that it could be displayed on an Internet Web site. This system would require larger batteries that could be adequately charged with a small solar cell. Both systems would record data only when acceleration levels exceeded relatively high predetermined levels. The technology for both systems is currently available from Independent Witness Incorporated in Salt Lake City, UT. The second type of car would have a data acquisition system sufficiently sophisticated to measure coupler and bolster forces at all times when car speed is above 5 mph. The data supplied by this type of option would be used for fatigue or crack growth analysis. The following addresses the second type of system.

2. *Provisions for Electrical Power*: The primary problem faced in the Phase IIA test was the provision of adequate electrical power for proper operation of the data acquisition system. For the second type of data collection system, improvements must be made to assure that reliable power is available. Even though most components of the electrical system were working adequately at the end of the Phase IIA test, the problem of alternator drive chain breakage has not been totally solved. The solution to this problem could take two forms. The most straightforward and least expensive solution could be to drive the alternator with a cogged belt instead of a chain. This would eliminate the problems associated with misalignment and lack of lubrication. A guard should also be provided to protect the belt from flying debris. The following gives a more comprehensive proposal to lessen the problems associated with providing electrical power.

3. *Reporting of System Health*: A second problem encountered during the Phase IIA test was the lack of consistent reporting on the condition or health of the data acquisition system. This inconsistency was due to the power problems noted previously, as well as the erratic nature of cell phone coverage. The most straightforward solution would be to use low power satellite phone technology for the primary communication and the Internet modem/cell phone connections as a backup.

4. *Reduction of Data Channels*: To help lower the power requirements of the data acquisition system, it is recommended that the number of channels of data recorded be limited to approximately 12: coupler forces at each end, center bowl and side bearing forces for each bolster, car speed, and battery voltage. Backup transducers could be installed; but if a primary unit fails the secondary unit would have to be brought online

manually. With this reduction of channels, however, it is still anticipated that a battery charging system other than solar cells would be required. The team recommended that the sample rate for all channels be reduced to a maximum of 256 samples per second. With the reduction of channels and the sample rate, the current UDAQ system could store up to 7 to 8 months of data before a download would be required.

5. *Onboard Data Processing*: In addition to the file reduction steps in Recommendation #4, the team recommended that serious consideration be given to the development of a data acquisition system that incorporates significant modifications to the design used in Phase IIA. This system could be developed with the assistance of Independent Witness Incorporated using some of their storage and reporting technology. Some of the features would be as follows:

    - Lower power requirements than the UDAQ system, using smaller batteries and possibly one small solar cell for recharging the batteries.
    - Up to 12 channels recording data at 256 samples per second.
    - Newly developed software that would internally monitor all channels for health by basic statistical analysis. If a channel is deemed healthy, the software would convert the time domain files to cycle counted histograms using one or two of several available methods. An option would then be available to overwrite the time domain files, saving file storage space and power consumption. The statistical data files and histograms files, significantly smaller than time domain files, could be transmitted to a central site via low power satellite phone communications.
    - The option could be available to access channel statistics and histogram data via an Internet site maintained by Independent Witness.

The option would always be available to retain any and all time domain files with the realization that file storage will be filled quicker, and it will likely be impractical to transmit such files from the car to a central location in a cost-effective manner using current technology.

Appendix.

Accelerometer and Strain Gage Locations

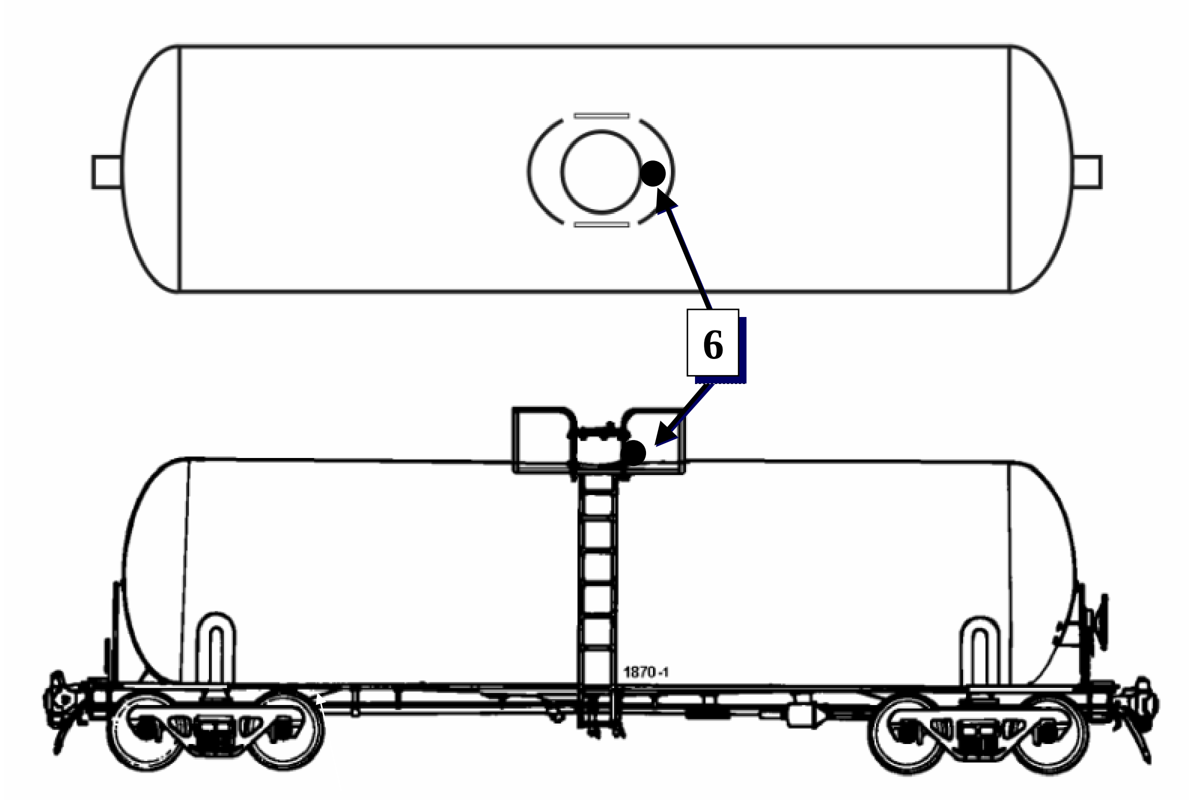

Figure A-1. Accelerometer Locations

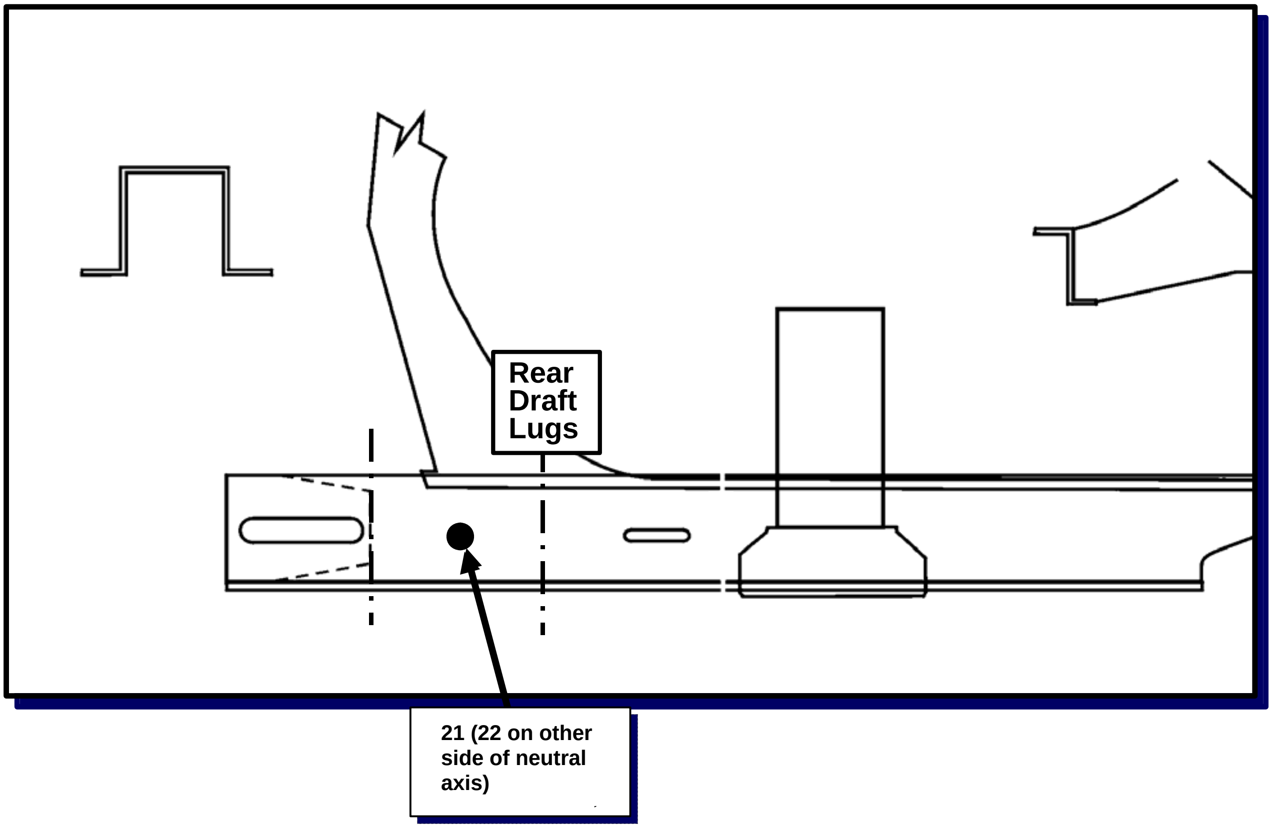

Figure A-2. Strain Gage Locations Measuring Vertical Force–Stub Sill

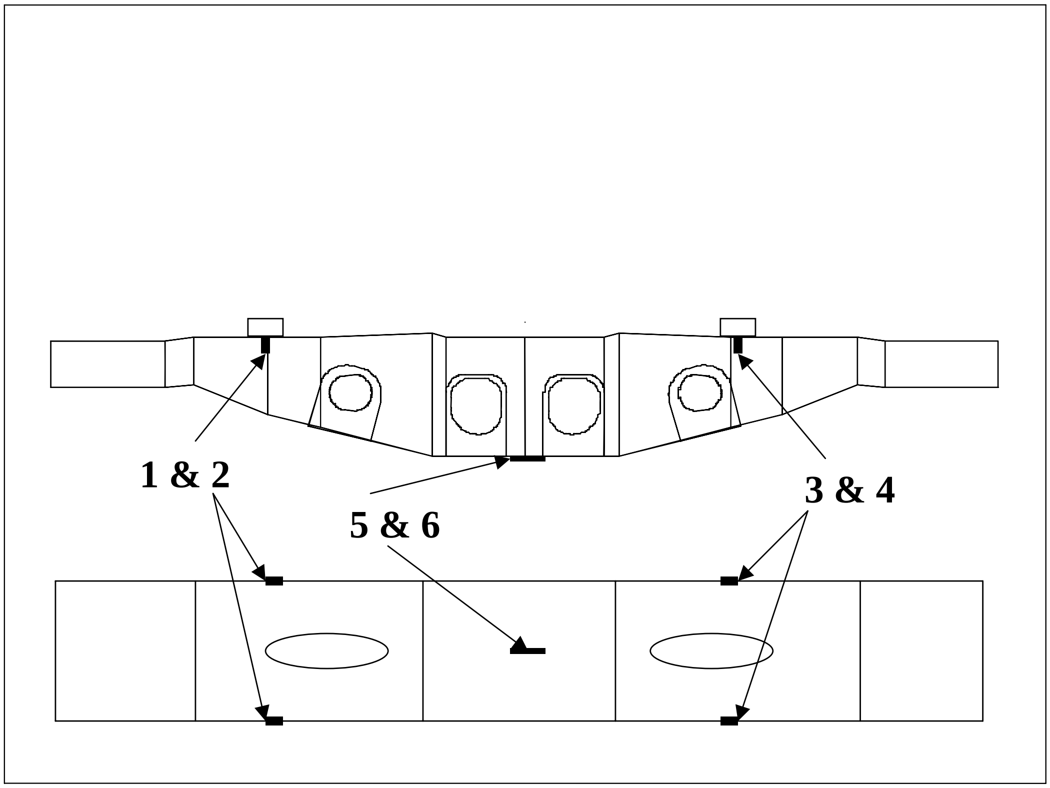

Figure A-3. Strain Gage Locations–Bolsters

SUMMARY OF DATA

Table A-1. Maximum/Minimum Peak Values and Ranges–Longitudinal Coupler Forces

Date	Location	A-End Maximum (lb)	A-End Minimum (lb)	A-End Maximum Range (lb)	B-End Maximum (lb)	B-End Minimum (lb)	B-End Maximum Range (lb)
July 30	New Orleans to Chicago	413,200		563,740			
November 18	Pueblo to Chicago		-128,440			-277,070	
July 31	New Orleans to Chicago				682,150		931,690

Table A-2. Maximum/Minimum Peak Values and Ranges–Vertical Coupler Forces

Date	Location	A-End Maximum (lb)	A-End Minimum (lb)	A-End Maximum Range (lb)	B-End Maximum (lb)	B-End Minimum (lb)	B-End Maximum Range (lb)
November 28	Chicago to Roanoke	55,480		75,970			
November 19	Pueblo to Chicago		-29,530				
July 14	Pueblo to New Orleans				291,600		343,800
November 21	Pueblo to Chicago					-100,780	

Table A-3. Maximum Peak Values and Ranges–A-End Bolster

Date	Location	Center Bowl Maximum (lb)	Center Bowl Maximum Range (lb)	Channel 6 Side Bearing Maximum (lb)	Channel 6 Side Bearing Maximum Range (lb)	Channel 7 Side Bearing Maximum (lb)	Channel 7 Side Bearing Maximum Range (lb)
July 29	New Orleans to Chicago	232,900	195,610				
July 10	Pueblo to New Orleans			105,000	105,000	121,010	121,000

Nominal or average load on bolster approximately 104,000 lb

Table A-4. Maximum Peak Values and Ranges–B-End Bolster

Date	Location	Center Bowl Maximum (lb)	Center Bowl Maximum Range (lb)	Channel 9 Side Bearing Maximum (lb)	Channel 9 Side Bearing Maximum Range (lb)	Channel 10 Side Bearing Maximum (lb)	Channel 10 Side Bearing Maximum Range (lb)
July 29	New Orleans to Chicago	282,950	262,020				
July 10	Pueblo to New Orleans			90,340	90,300		
December 2	Chicago to Roanoke					68,480	68,400

Nominal or average load on bolster approximately 108,000 lb

Table A-5. Load Range Summary–Longitudinal Coupler Force

	Number of Load Range Cycles Above 150,000 lb	Number of Load Range Cycles Above 200,000 lb
A-End Coupler	426	219
B-End Coupler	654	381

Table A-6. Load Range Summary–Vertical Coupler Force

	Number of Load Range Cycles Above 25,000 lb	Number of Load Range Cycles Above 50,000 lb
A-End Coupler	319	18
B-End Coupler	3,323	767

Table A-7. Load Range Summary–Bolster Center Bowl Load

	Number of Load Range Cycles Above 25,000 lb	Number of Load Range Cycles Above 50,000 lb	Number of Load Range Cycles Above 100,000 lb
A-End Coupler	44,340	4,022	75
B-End Coupler	52,945	5,170	154

Table A-8. Load Range Summary–Bolster Side Bearing Loads

	Number of Load Range Cycles Above 20,000 lb	**Number of Load Range Cycles Above 40,000 lb**
A-End Bolster, Channel 6 Side Bearing	137	18
A-End Bolster, Channel 7 Side Bearing	458	136
B-End Bolster, Channel 9 Side Bearing	121	26
A-End Bolster, Channel 6 Side Bearing	196	26

Table A-9. Comparison of Acceleration Values in g's

Date	**Time**	**Location**	**TTCI Accelerometers**				**Independent Witness Accelerometers**			
			Maximum Vertical	**Minimum Vertical**	**Maximum Longitudinal**	**Minimum Longitudinal**	**Maximum Vertical**	**Maximum Vertical**	**Maximum Longitudinal**	**Minimum Longitudinal**
December 4	5:59 p.m.	Roanoke to New Orleans	2.1	-2.4	2.1	-3.5	2.8	-2.5	3.0	-0.5
December 6	9:58 a.m.	Roanoke to New Orleans	2.4	-2.7	2.1	-1.7	1.8	-2.0	2.4	-0.5
December 8	12:36 p.m.	New Orleans to Chicago	6.5	-5.9	2.9	-3.8	10.2	-9.0	4.1	-5.0
December 6	7:20 p.m.	Roanoke to New Orleans	25.3	-20.5	3.9	-9.3	21	-21	4.0	-12.0

TYPICAL TIME DOMAIN DATA

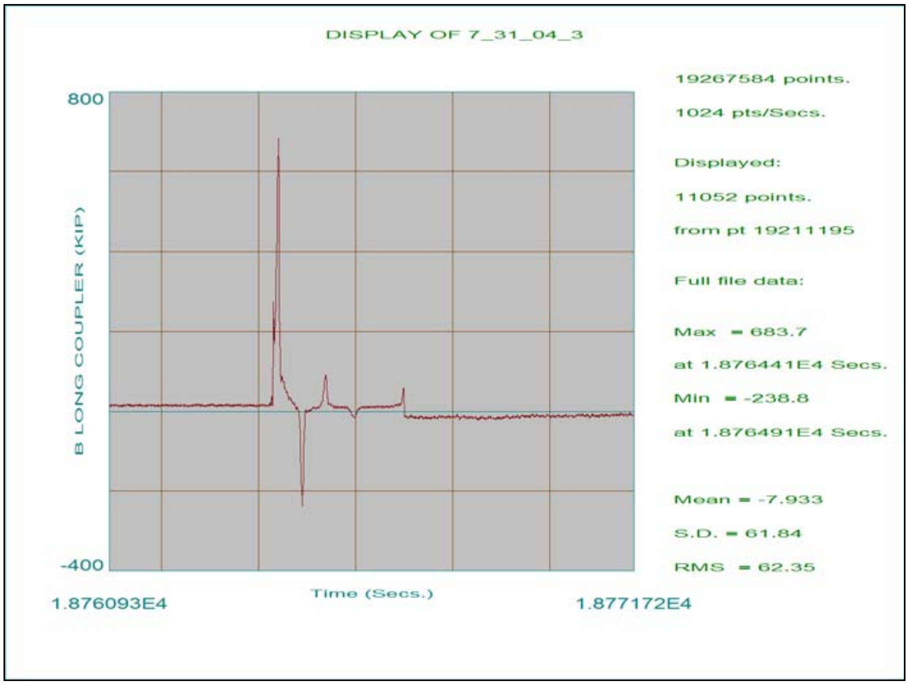

Figure A-4. Longitudinal Coupler Force, B-End, 10.79 Second Duration–July 31, 2004

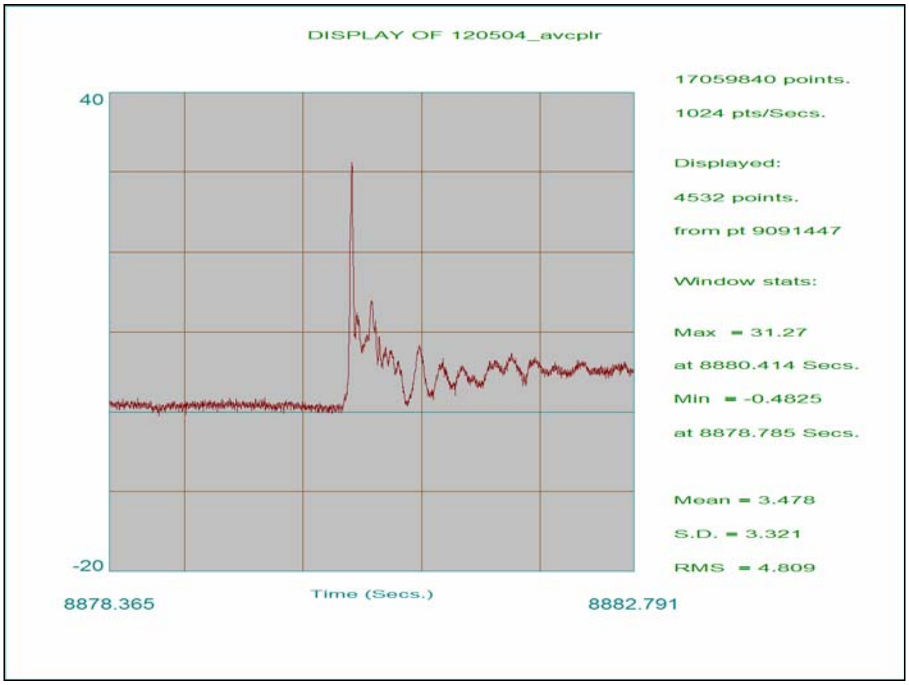

Figure A-5. Vertical Coupler Force, B-End, 4.43 Second Duration–December 5, 2004

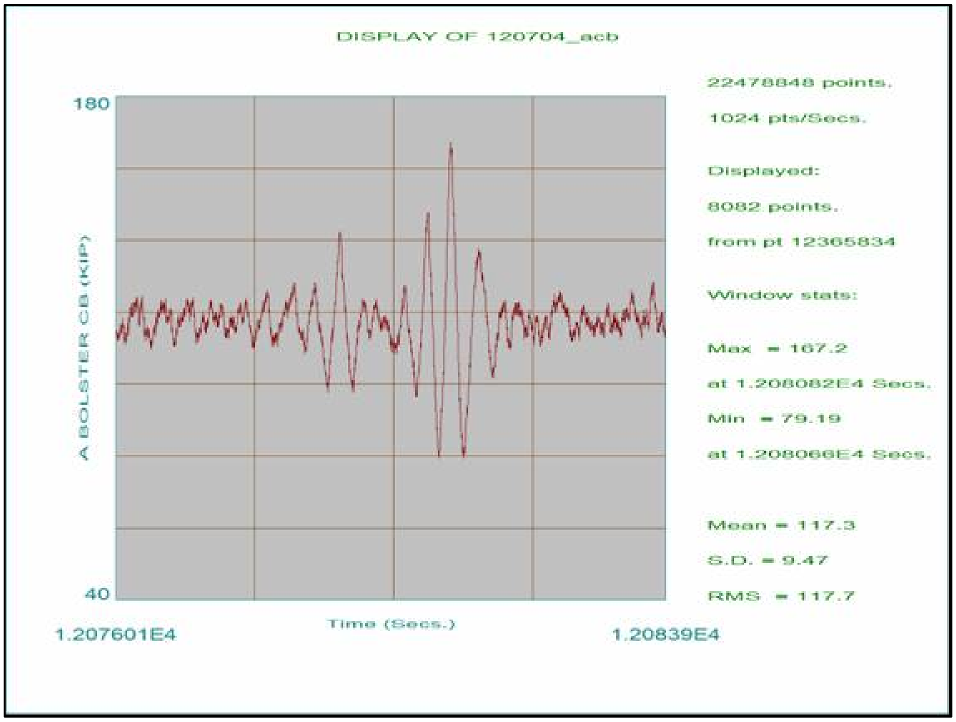

Figure A-6. Dynamic Bolster Center Bowl Load, A-End, 7.9 Second Duration–December 7, 2004

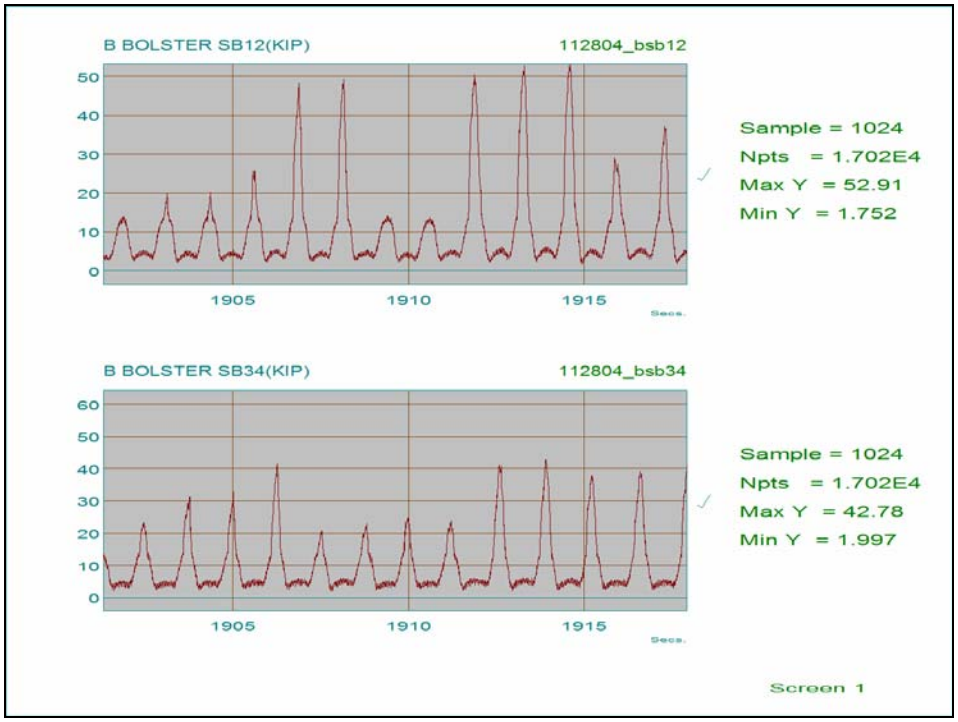

Figure A-7. Dynamic Side Bearing Loads, B-End Bolster, Roll Motion–November 28, 2004

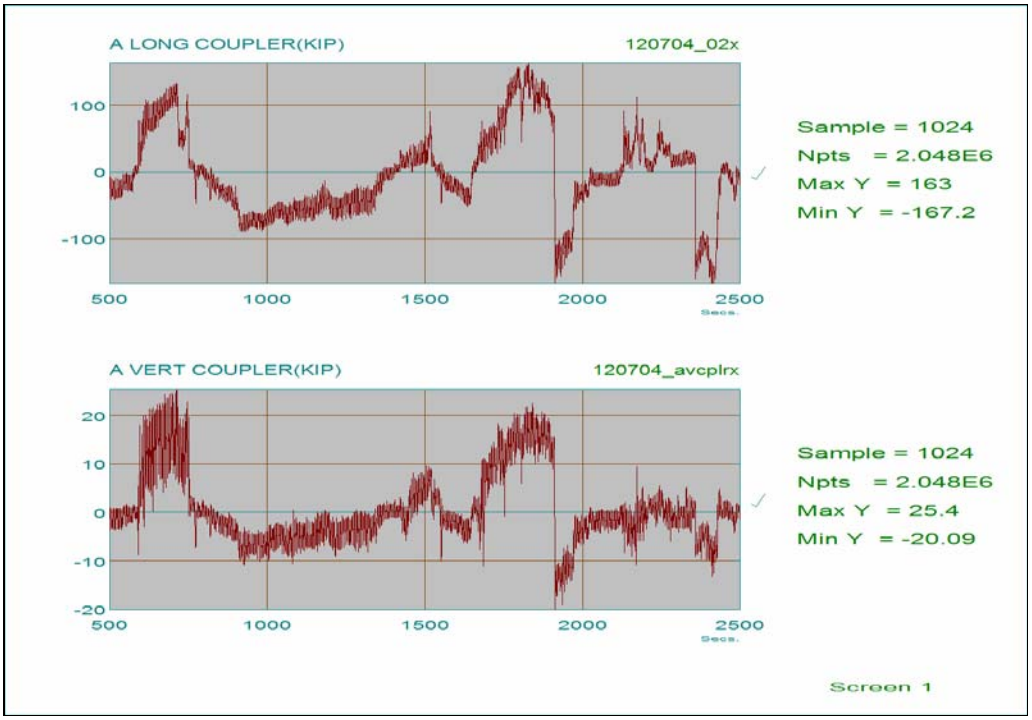

Figure A-8. Longitudinal and Vertical Coupler Force versus Time, A-End–December 7, 2004

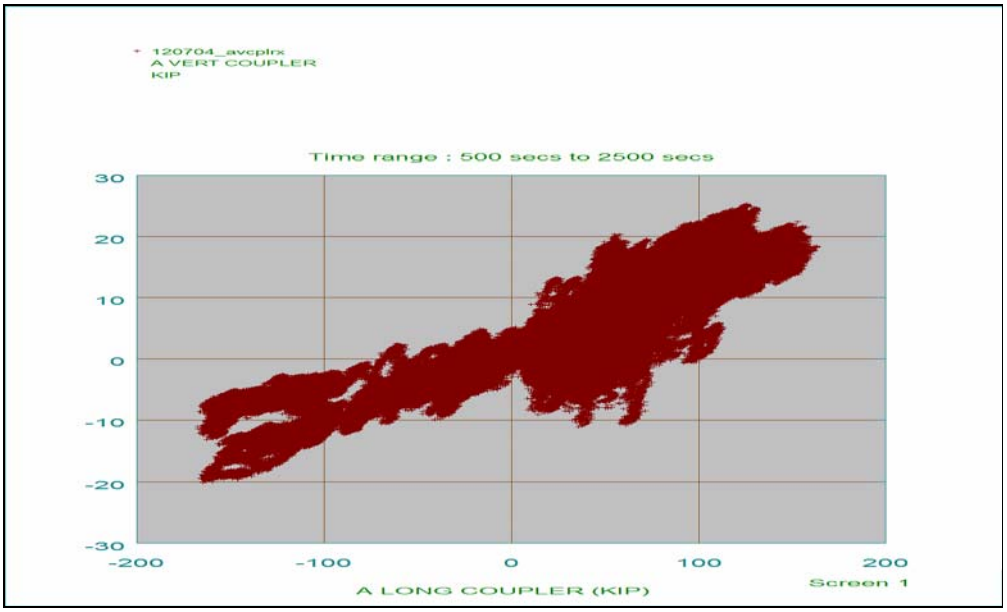

Figure A-9. Longitudinal versus Vertical Coupler Force, A-End–December 7, 2004

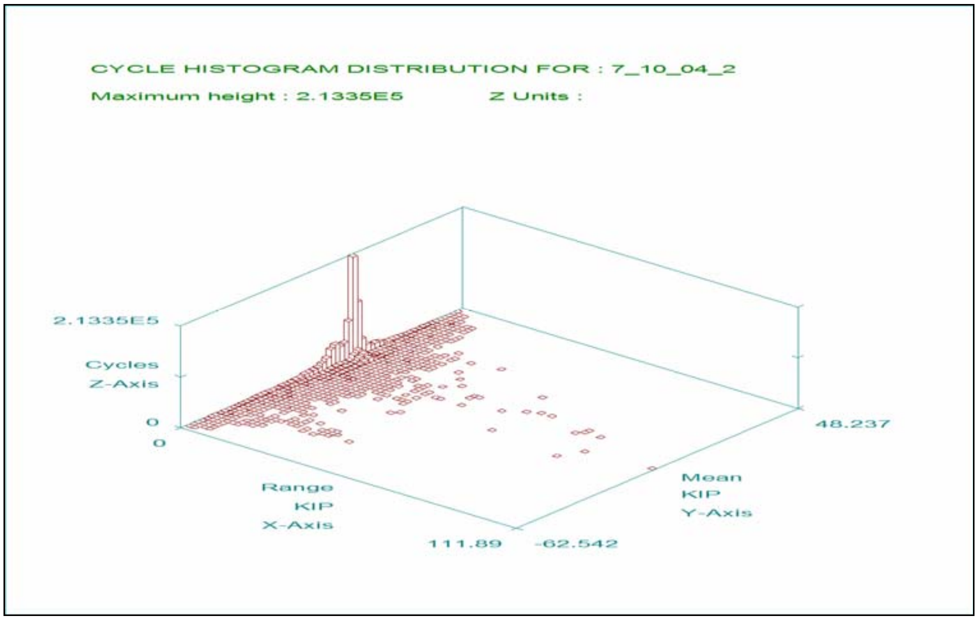

Figure A-10. Range Mean Histogram, A-End Longitudinal Coupler Force–July 10, 2004

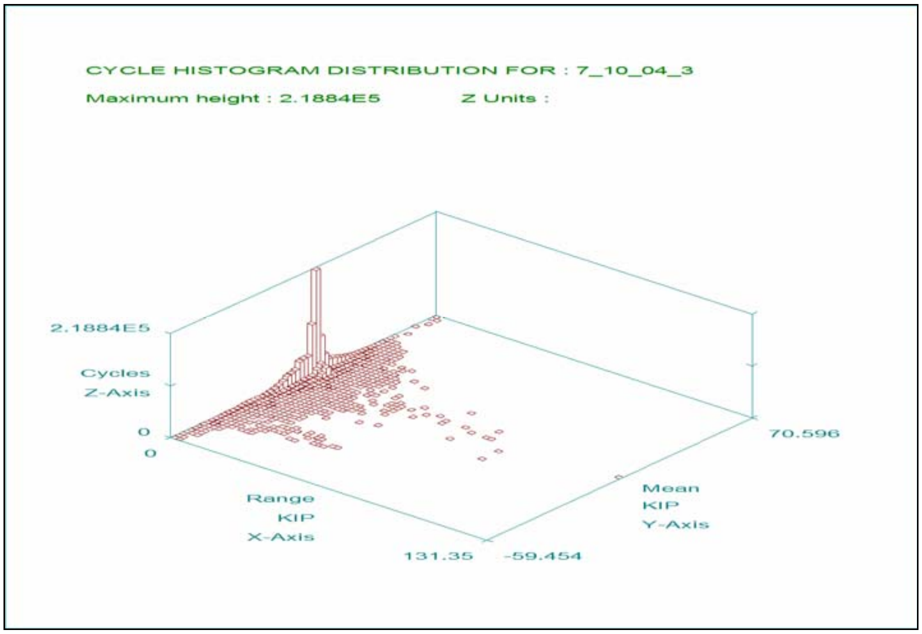

Figure A-11. Range Mean Histogram, B-End Longitudinal Coupler Force–July 10, 2004

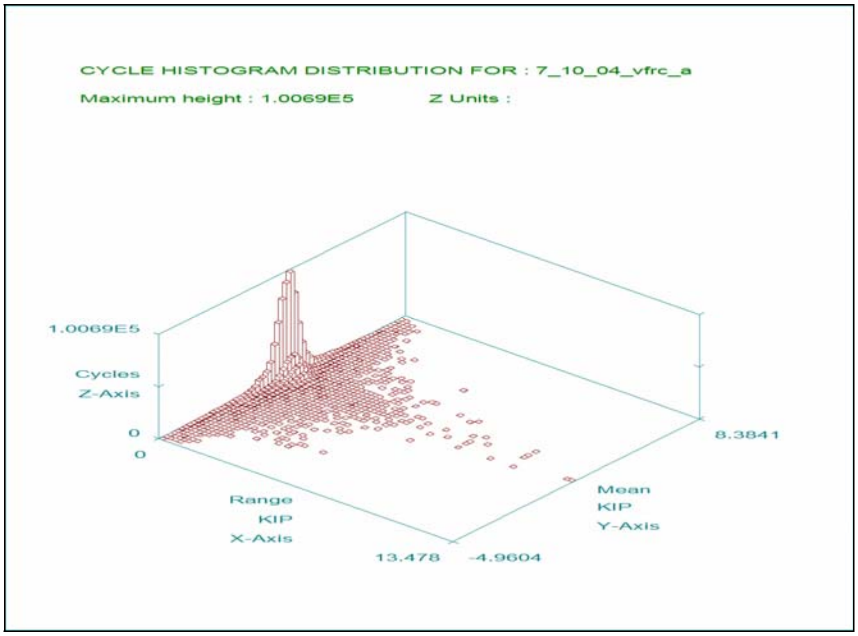

Figure A-12. Range Mean Histogram, A-End Vertical Coupler Force–July 10, 2004

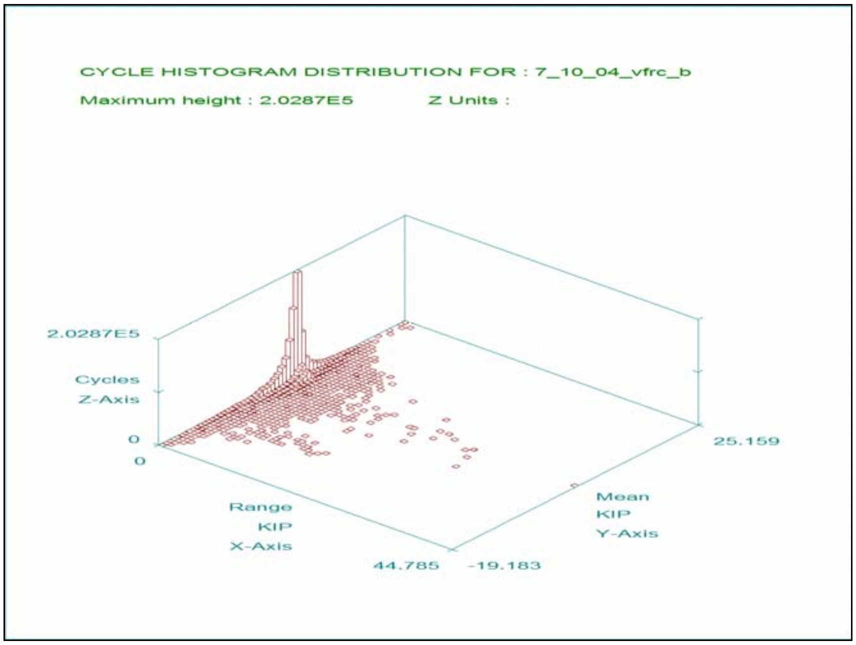

Figure A-13. Range Mean Histogram, B-End Vertical Coupler Force–July 10, 2004

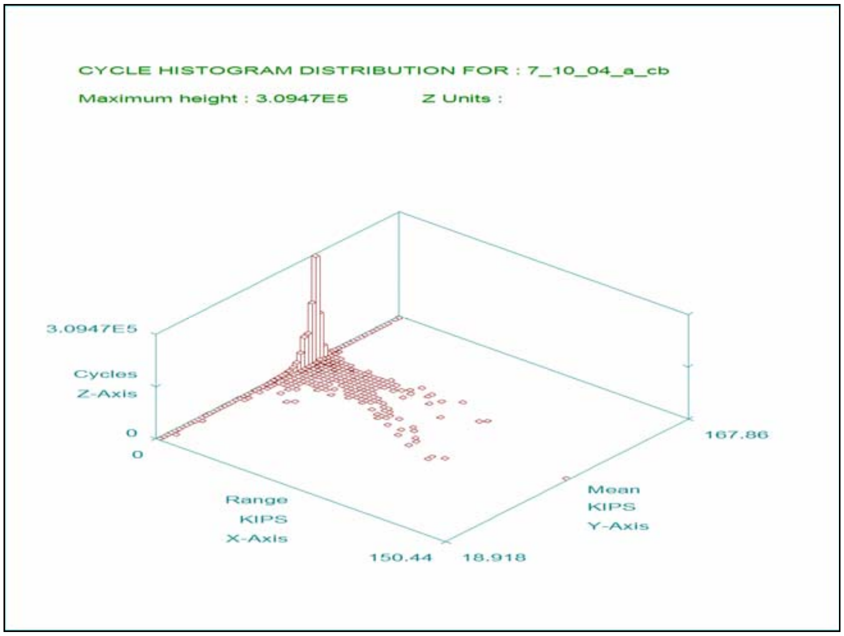

Figure A-14. Range Mean Histogram, A-End Bolster Center Bowl Load–July 10, 2004

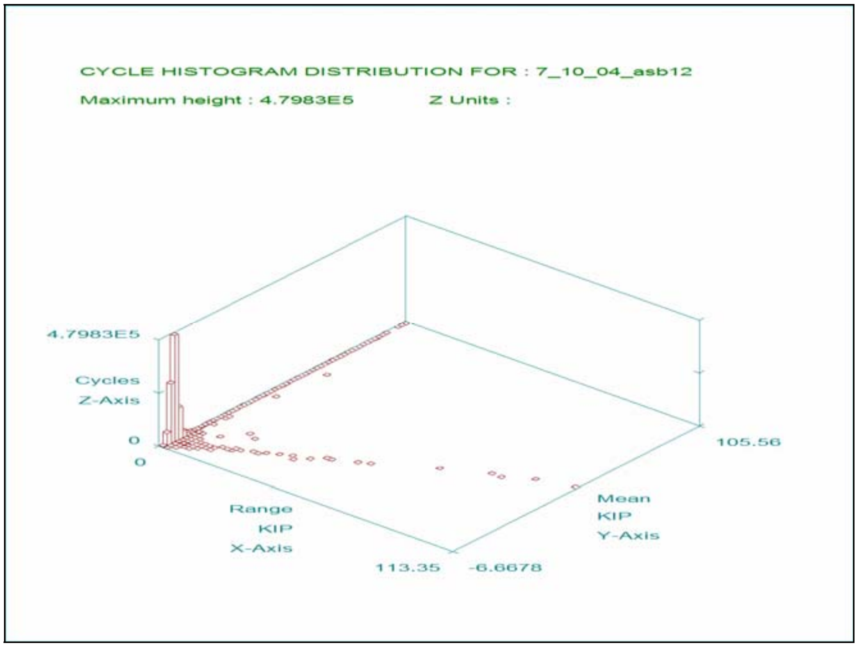

Figure A-15. Range Mean Histogram, A-End Bolster Side Bearing Load, Channel 6 End–July 10, 2004

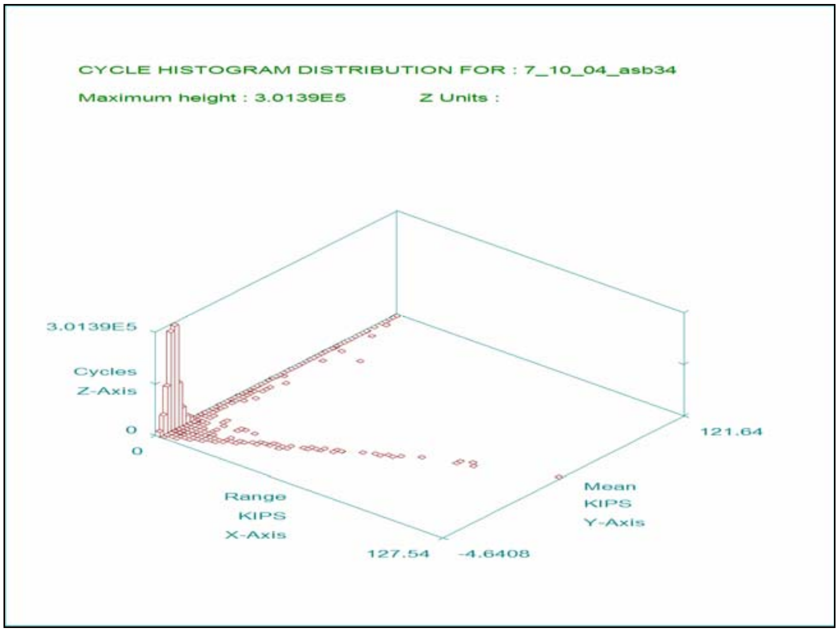

Figure A-16. Range Mean Histogram, A-End Bolster Side Bearing Load, Channel 7 End–July 10, 2004

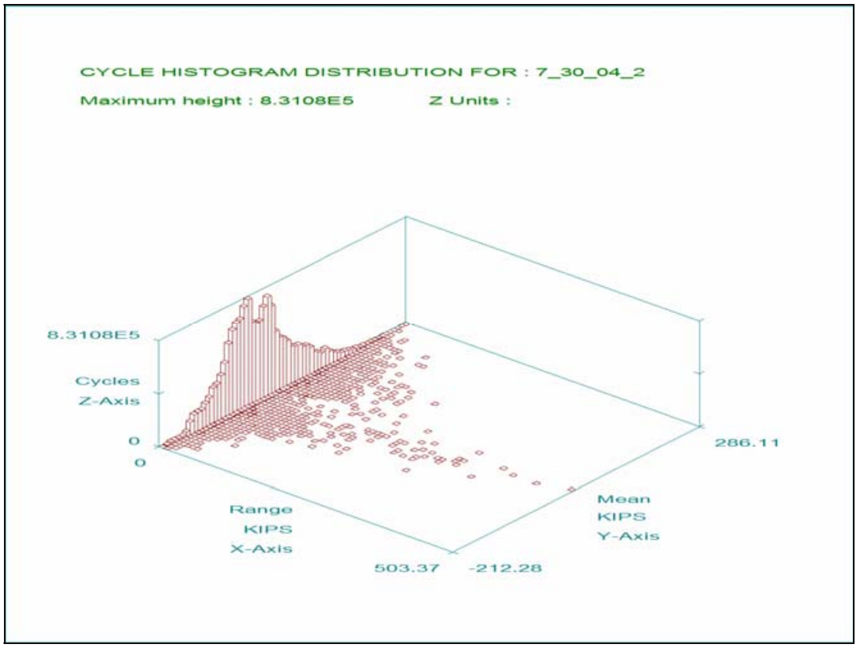

Figure A-17. Range Mean Histogram, A-End Longitudinal Coupler Force–July 30, 2004

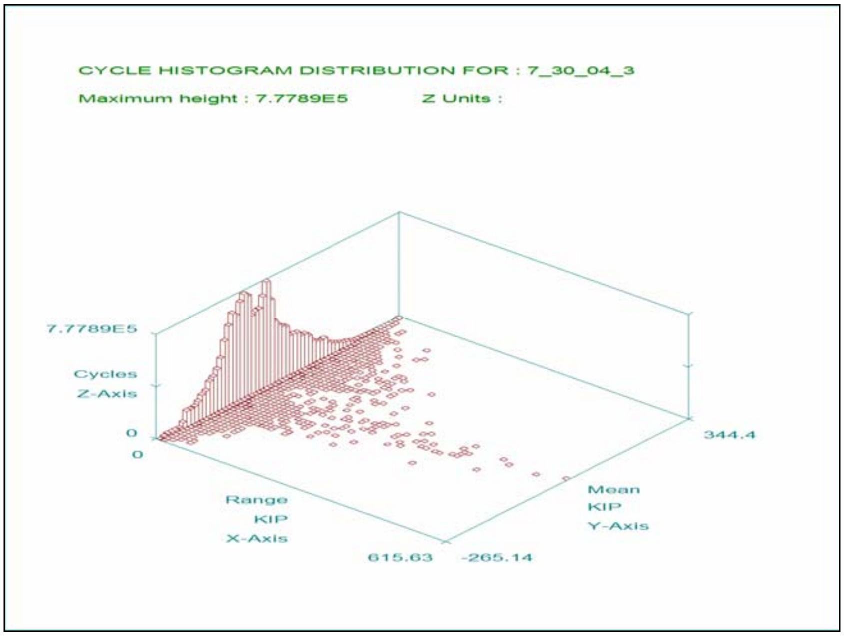

Figure A-18. Range Mean Histogram, B-End Longitudinal Coupler Force–July 30, 2004

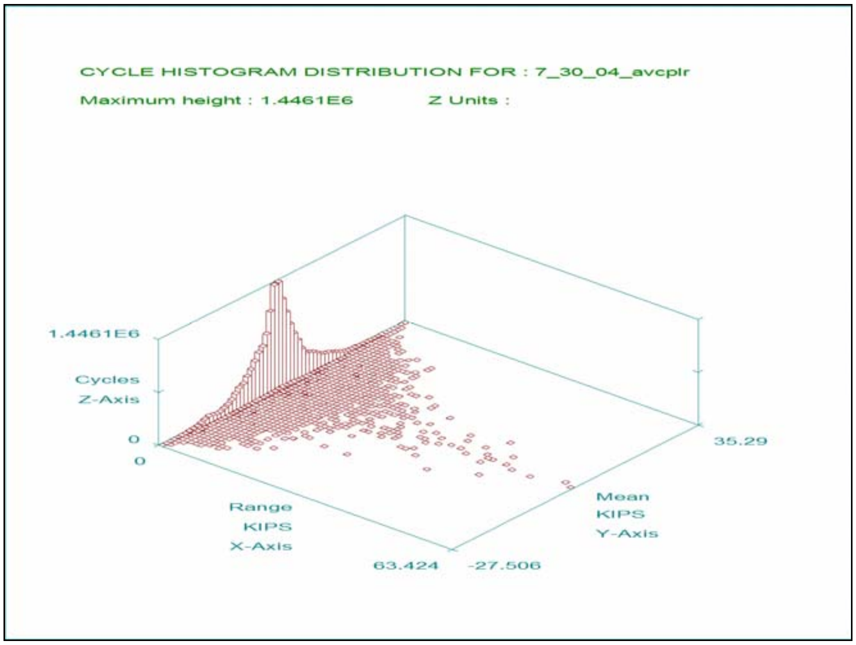

Figure A-19. Range Mean Histogram, A-End Vertical Coupler Force–July 30, 2004

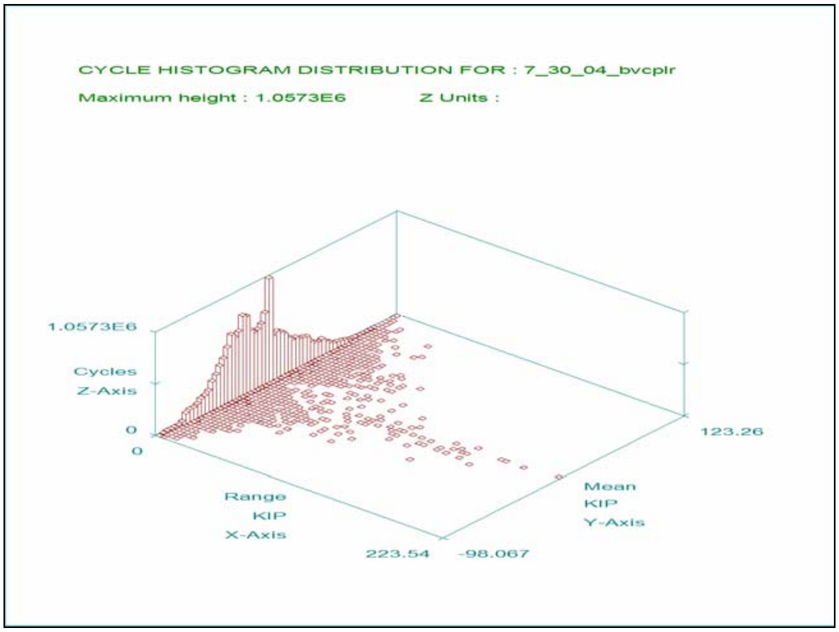

Figure A-20. Range Mean Histogram, B-End Vertical Coupler Force–July 30, 2004

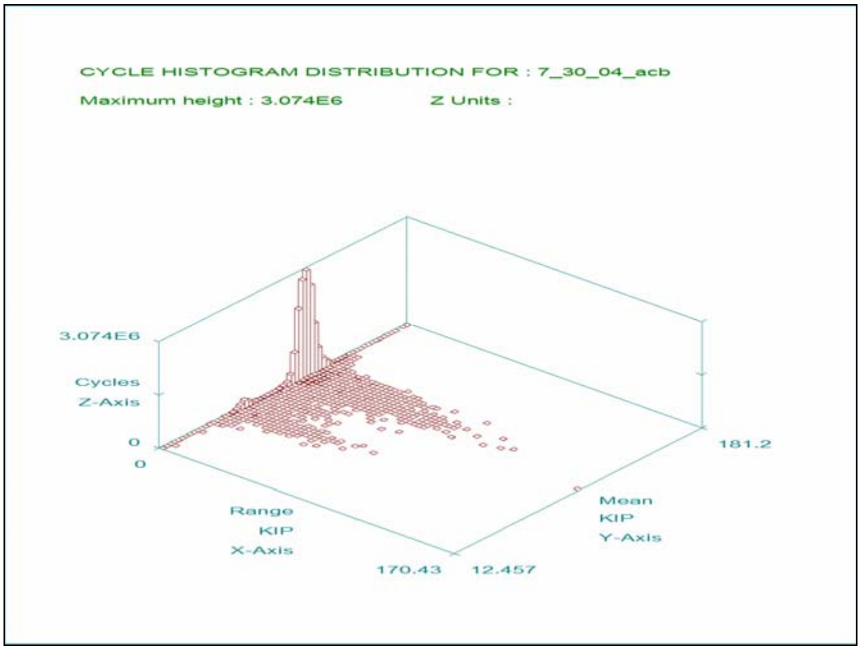

Figure A-21. Range Mean Histogram, A-End Bolster Center Bowl Load–July 30, 2004

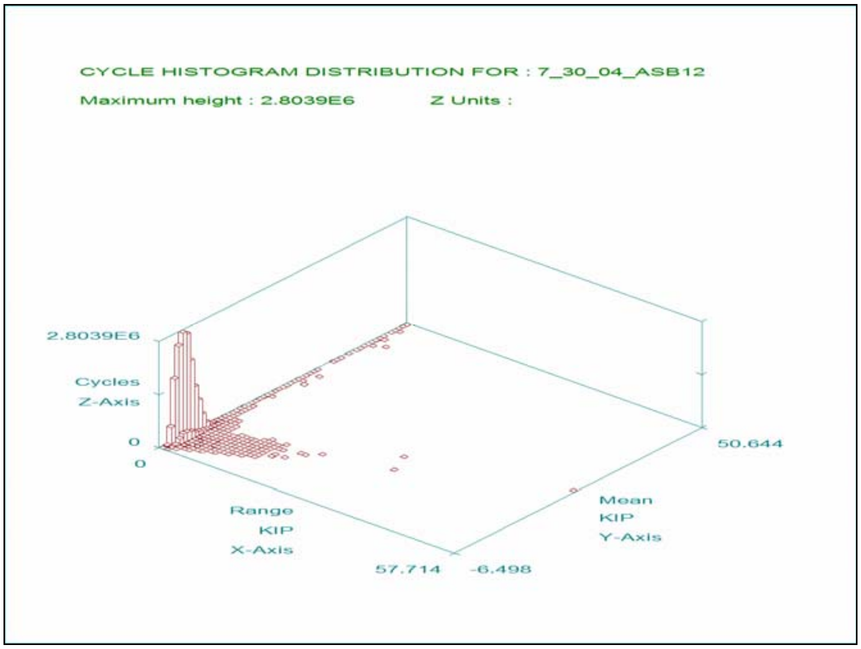

Figure A-22. Range Mean Histogram, A-End Bolster Side Bearing Load, Channel 6 End–July 30, 2004

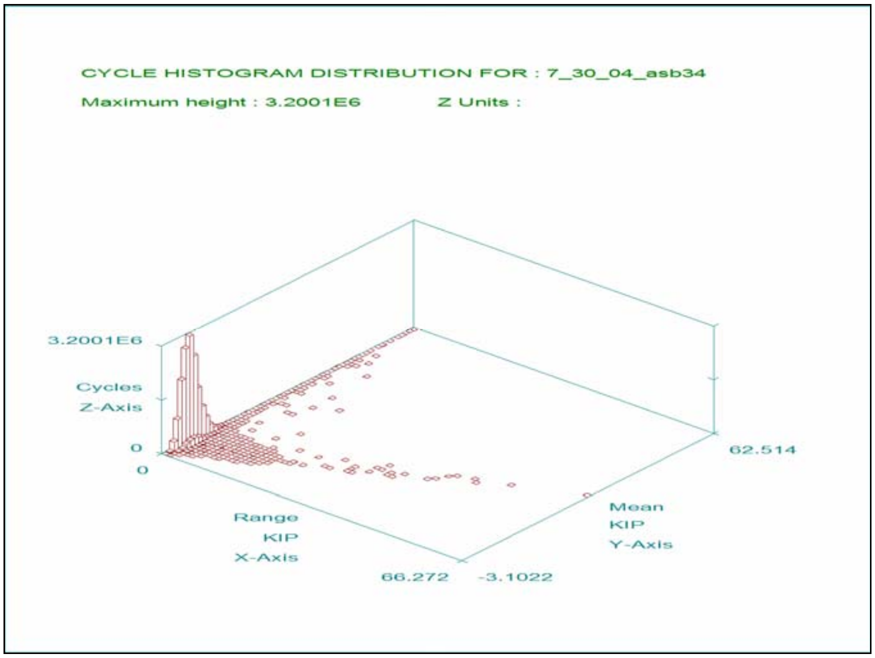

Figure A-23. Range Mean Histogram, A-End Bolster Side Bearing Load, Channel 7 End–July 30, 2004

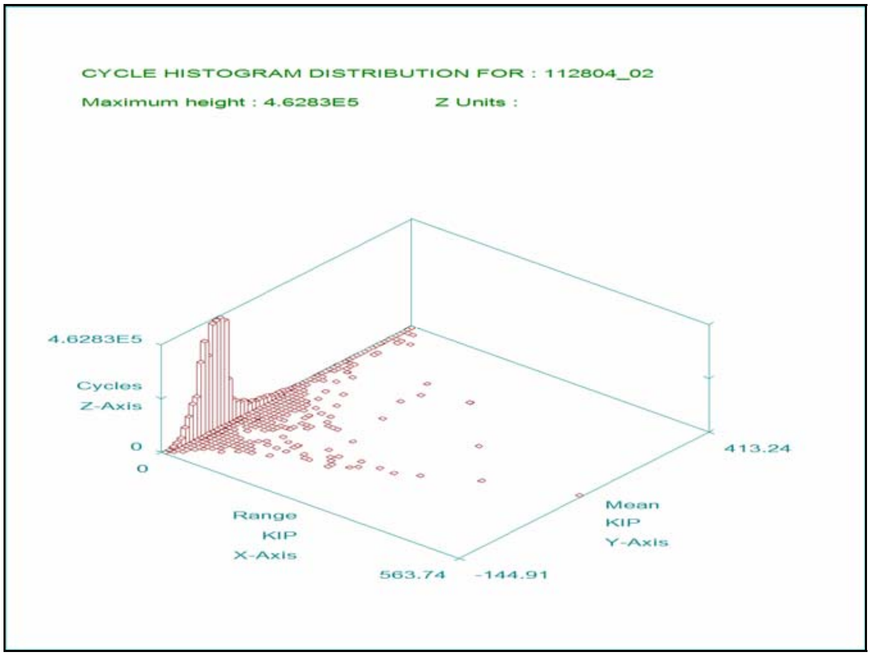

Figure A-24. Range Mean Histogram, A-End Longitudinal Coupler Force–November 28, 2004

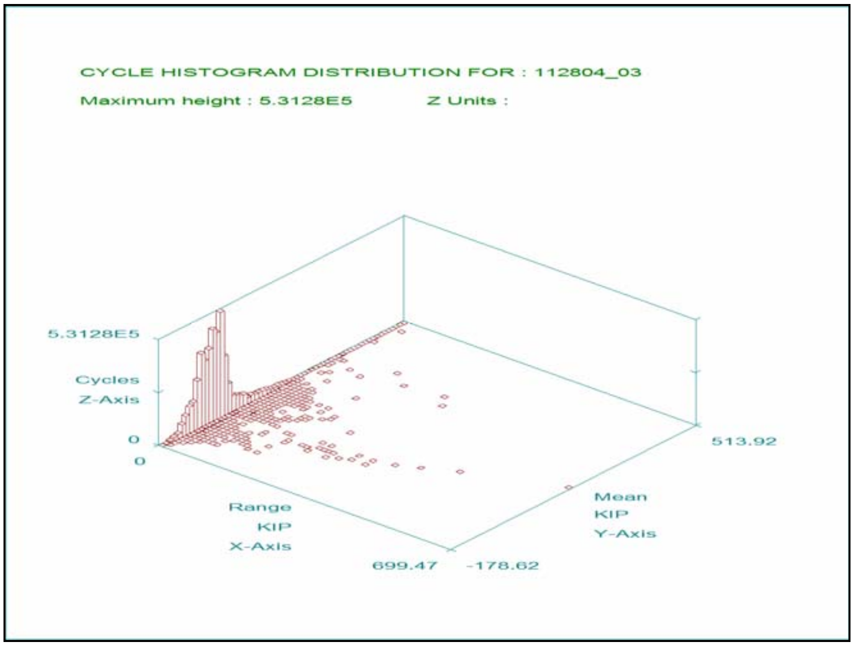

Figure A-25. Range Mean Histogram, B-End Longitudinal Coupler Force–November 28, 2004

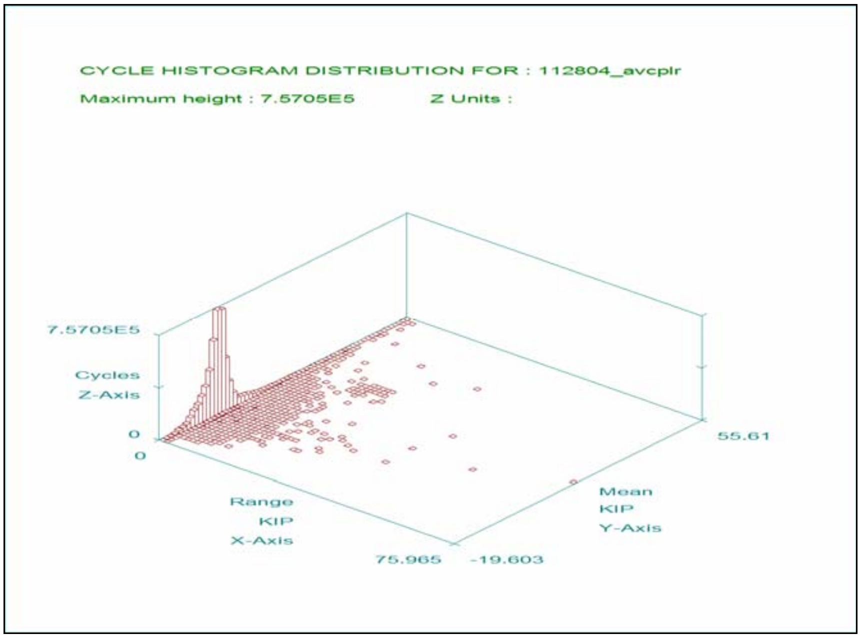

Figure A-26. Range Mean Histogram, A-End Vertical Coupler Force–November 28, 2004

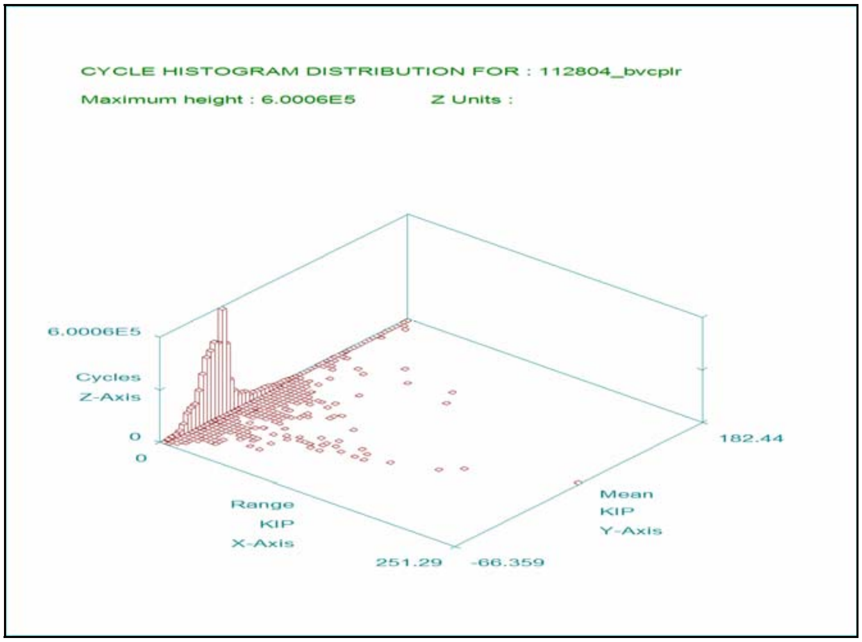

Figure A-27. Range Mean Histogram, B-End Vertical Coupler Force–November 28, 2004

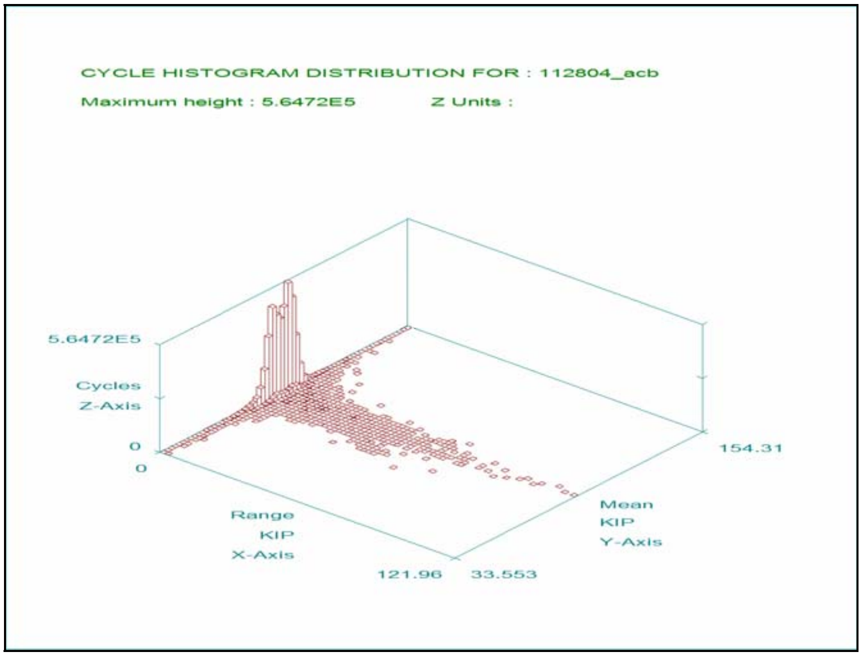

Figure A-28. Range Mean Histogram, A-End Bolster Center Bowl Load–November 28, 2004

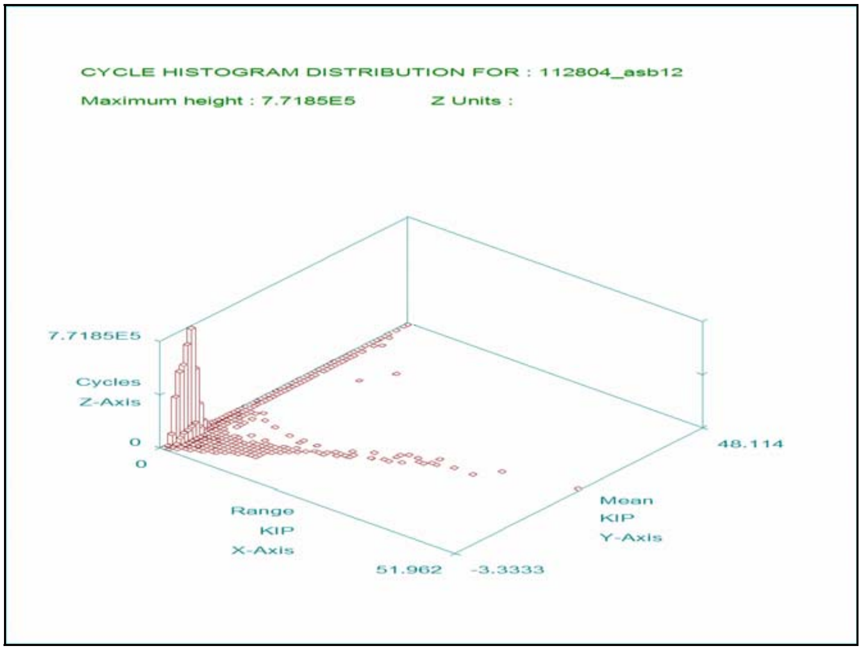

Figure A-29. Range Mean Histogram, A-End Bolster Side Bearing Load, Channel 6 End–November 28, 2004

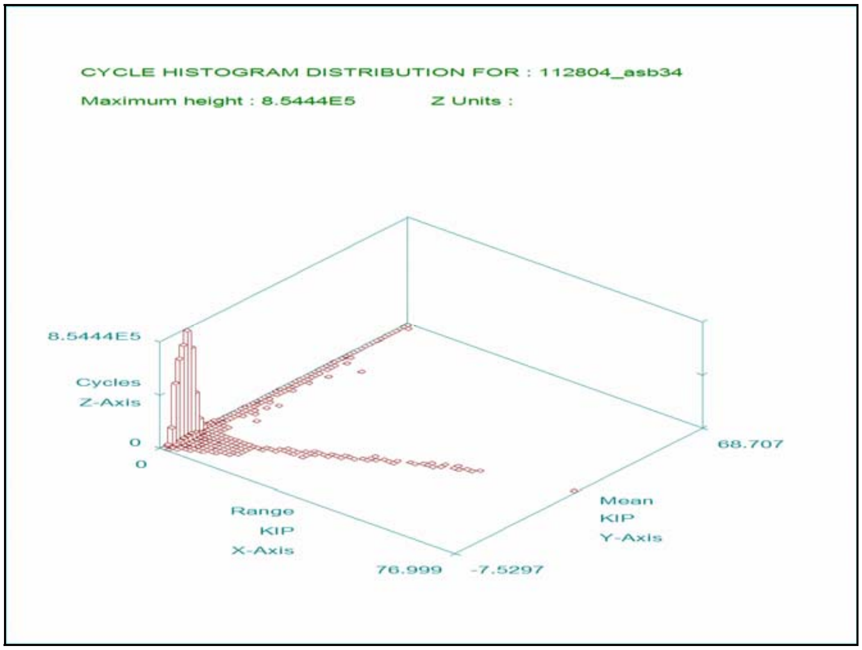

Figure A-30. Range Mean Histogram, A-End Bolster Side Bearing Load, Channel 7 End–November 28, 2004

Acronyms

AAR	Association of American Railroads
DTA	damage tolerance analysis
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
GB	gigabytes
GPS	global positioning system
lb	pound/pounds
RSI	Railway Supply Institute
SSWG	Stub Sill Working Group
TAG	technical advisory group
TC	Transport Canada
TCOE-TF	Tank Car Operating Environment Task Force
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
UDAQ	unattended data acquisition system