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Low-Cost Coupler Force Calculation from Impact Testing

DOT/FRA/ORD-23/11

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13. ABSTRACT (Maximum 200 words)

Fractures in the stub sills of tank cars pose a significant problem for the rail industry due to the potential for damage to the tank structure and eventual release of the contents. Previous FRA research revealed that high magnitude coupling forces that occur in yard operations have the potential to exceed yield limits of mild steel. FRA, Union Tank Car, and Amsted Rail completed a cooperative test program at Amsted Rail's test facility in Camp Hill, PA, in 2018 to characterize coupling loads for tank cars in yard operations. ENSCO developed and validated a new low-cost method of calculating the longitudinal coupler force using carbody accelerations with 60 Hz filter cutoff frequency. The new method employs a derived linear relationship to calculate the longitudinal coupler force. It is equal to the longitudinal carbody acceleration multiplied by a constant 86.94 kips/g. Further improvement to the new method is possible by adjusting the accelerometer placement on the car and finetuning the filter cutoff frequency. The new method will facilitate and improve future research by providing feasible means to collect large amount of longitudinal coupler force measurements.

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Tank Cars, Rail, Stub Sill Failures, Impact Test, Yard Operation, Car Coupling, Draft Gear, Instrumented Couplers, Longitudinal Force, Low-Cost

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

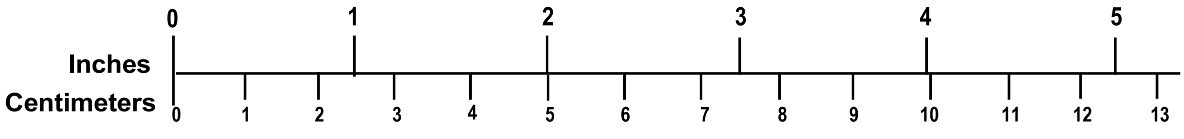
VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE 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

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Executive Summary

Fractures in the stub sills of tank cars pose a significant problem for the rail industry due to the potential for damage to the tank structure and the eventual release of its contents. Previous research studies revealed that high magnitude coupling forces that occur in yard operations have the potential to exceed the yield limits of mild steel and initiate stub sill damage. These high force events in rail yards may be mitigated by limiting the combination of coupling speeds and impacting mass limits.

In 2018, the Federal Railroad Administration (FRA) conducted a series of impact tests for different tank car configurations at various coupling speeds. The objective of this research study was to characterize the load environment on tank cars during yard operations. The focus was to identify important factors such as speed and configurations of striking (i.e., hammer) and impact absorbing (i.e., anvil) cars during impacts to help industry establish yard operation scenarios that cause less damage to tank car stub sills.

FRA contracted ENSCO Inc. (ENSCO) to instrument a tank car and conduct a series of impact tests simulating various coupling conditions at Amsted Rail's test facility in Camp Hill, PA. A research team from ENSCO instrumented a tank car loaned to FRA by Union Tank with multiple transducers and a data collection system that supported the high sampling rates required for impact testing. Researchers collected more than 700 impact tests comprised of different car configurations, end-of-car units, and coupling speeds. The data files contained 40 channels including acceleration, force, speed, and strain data.

ENSCO developed a low-cost method to calculate longitudinal coupler forces using accelerations. The team compared the results produced by this new method with measured data to determine its accuracy. The results of the comparison analysis are presented in this report. The comparison between the calculated and measured longitudinal coupler forces shows good agreement. This new method will simplify and improve future research by providing a feasible means to collect large amounts of longitudinal coupler force measurements.

Researchers found that longitudinal coupler forces calculated from carbody acceleration with 60 Hz filter cutoff frequency showed the best results. The team derived a linear relationship to calculate the longitudinal coupler force that is equal to the longitudinal carbody acceleration multiplied by a constant 86.94 kips/g. The standard deviation of the error is 110 kips. Further improvement to this new method is possible by adjusting the accelerometer placements on the car and finetuning the filter cutoff frequency.

1. Introduction

Researchers analyzed and evaluated a newly-developed, low-cost method to measure longitudinal coupler forces to replace or supplement the current instrumented couplers. The analysis uses measured data from a 2018 cooperative test program conducted at Amsted Rail's test facility in Camp Hill, PA, by ENSCO, Inc. (ENSCO), under the sponsorship of the Federal Railroad Administration (FRA). The team gathered impact data on a test track simulating hump yard operation for train make-up.

1.1 Background

The industry has observed fractures on tank car stub sills for many years. Undetected, 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. As a result of this concern, the industry has implemented special requirements for the construction, inspection, and repair of tank cars.

Research into the underlying cause of stub sill tank car cracking and propagation is ongoing. It is believed that the fractures are initiated by discrete events resulting in high stresses. Previous research studies conducted by FRA (Sundaram, 2016) revealed that high magnitude coupling forces that occur in yard operations have the potential to exceed yield limits of mild steel. Stub sill failures were primarily attributed to high forces generated in yards that initiate the damage followed by crack propagation resulting from high vertical coupler force events occurring in mainline operations. High-force events in yards could be mitigated with better understanding of the contributing factors to these high impact loadings during yard operations.

Examples of stub sill fractures observed by CSX Transportation are shown in Figure 1 and Figure 2. These fractures are catastrophic in nature. The industry has improved weld design so the weld between the head brace and stub sill should fail before the weld between the pad and tank.

Figure 1. Stub Sill Fracture Observed in Callahan, FL, December 2009 (Sundaram, 2016)

Figure 2. Stub Sill Fracture Observed in Charleston, WV, January 2010 (Sundaram, 2016)

1.2 Objectives

The overall objective of the tank car research effort was to characterize the load environment on tank cars during yard operations. The focus of this report is to present analysis to validate a newly-developed, low-cost method to measure longitudinal coupler forces.

1.3 Overall Approach

To better characterize the load environment of the tank car operations in yards, FRA, Union Tank Car, and Amsted Rail conducted a cooperative test program at Amsted Rail's test facility in Camp Hill, PA, in 2018. Under this effort, researchers instrumented a tank car loaned to FRA by Union Tank Car with multiple transducers. The team employed a data collection system that supported high sampling rates required for conducting impact testing. The team collected impact data for different car configurations, end-of-car units, and coupling speeds during 702 impact tests. Researchers collected a data file for each impact test with 40 data channels comprised of acceleration, force, speed, and strain data. Figure 3 shows the tank car used for this effort. Figure 4 shows a detailed view of the end of the tank car with the stub sill attachment. A previous report by FRA (Meymand, 2020) documented detailed results of this impact testing.

Figure 3. Instrumented Tank Car

Figure 4. Detail View of the Stub Sill and Head Brace Attached to the Tank of the Instrumented Tank Car

The team analyzed this data to develop a low-cost method to calculate longitudinal coupler forces from measured accelerations. Researchers investigated different combinations of accelerometer placements and filter cutoff frequencies to determine which produced the best results. For each case, the team calculated the peak values for the accelerations and compared them to measured and longitudinal coupler forces.

1.4 Scope

The scope of this report is limited to the validation of the newly-developed, low-cost method to measure longitudinal coupler forces during impacts.

1.5 Organization of the Report

Section 2 discusses the test methodology for obtaining the measured data and details the impact test matrix and different test scenarios considered for the testing program. Section 3 presents comparisons between the longitudinal forces calculated using the new method and the forces measured at the instrumented coupler. Conclusions are discussed in Section 4.

2. Test Methodology

This section describes the instrumented tank car, the different sensors used during the test program, and the test track that was used for conducting the impact tests. This section also details the impact test matrix and different test scenarios considered during the testing program.

2.1 Instrumented Tank Car

The research team instrumented a tank car loaned to FRA by Union Tank Car with multiple transducers and a data collection system that supported high sampling rates required for conducting impact testing. The team equipped the instrumented tank car with instrumented couplers on both ends of the car, a vertical coupler force measurement system, multiple accelerometers, and multiple rosette strain gages at high stress locations around stub sills. Figure 5 shows a schematic of the test tank car's instrumentation.

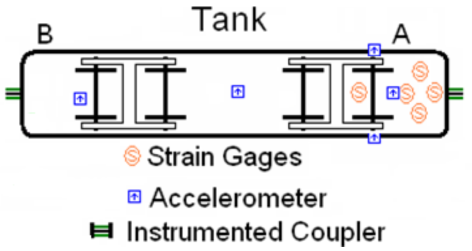

Figure 5. Schematic Diagram of Tank Car's Instrumentation

2.1.1 Longitudinal Coupler Forces

Researchers measured the longitudinal coupler forces on both the A-end and B-end of the tank car. Two instrumented couplers outfitted with strain gauge bridges measured the longitudinal forces. Figure 6 shows an image of an instrumented coupler installed on the A-end of the car.

Figure 6. Instrumented Coupler for Measuring Longitudinal Coupler Forces

2.1.2 Accelerometers

Researchers installed five accelerometers at multiple locations on the tank car. A triaxial accelerometer mounted on top of the carbody (see Figure 7) measured accelerations in longitudinal, lateral, and vertical directions. Two dual axis accelerometers, mounted on the stub sill at each end of the car (see Figure 8), measured accelerations in the longitudinal and vertical directions. Two uniaxial accelerometers mounted to the bearing adapter measured the vertical acceleration on the axles.

Figure 7. Triaxial Accelerometer Mounted on Top of the Carbody

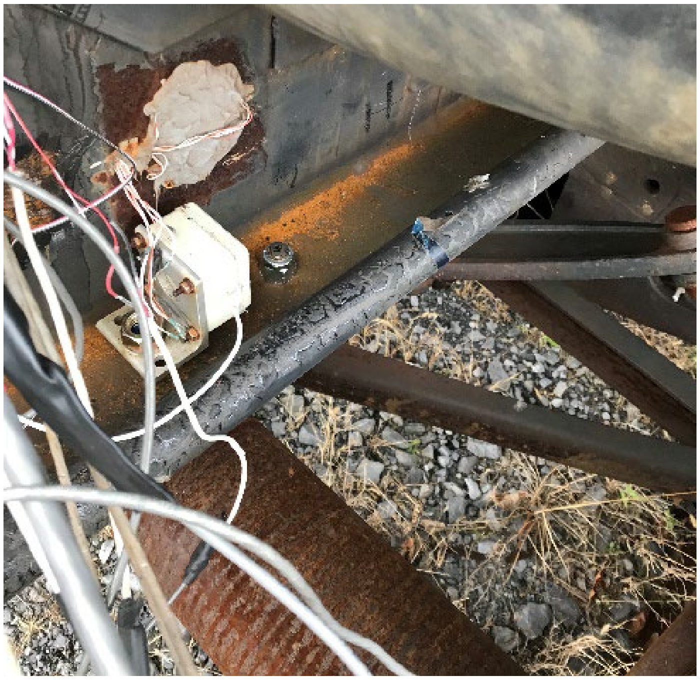

Figure 8. Dual-Axis Accelerometer Mounted on the Stub Sill at Each End of the Car

2.1.3 Other Sensors

In addition to the instrumented coupler, researchers used many additional sensors that are not part of this comparison report. These include one vertical coupler force sensor, five sets of rosette strain gages installed on various locations around the stub sill on the A-end (striking end) of the car, several carbody accelerometers, a laser speedometer for measuring the coupling speed, a temperature sensor, and humidity sensors.

2.1.4 Data Acquisition and Hardware Settings

The team collected data using National Instrument's PCIe6353 Data Acquisition Card. The card supports 32 input analog channels with 16-bit resolution. The collection system recorded 27 channels of data at a rate of 10 kHz. The system used a low-pass, anti-aliasing, fourth order Butterworth filter with a Sallen-Key Topology filter board to filter the input data with a cut-off frequency of 1,000 Hz. A Nuvo-5095GC ruggedized computer collected and stored data through LabView software. The system used +/- 5 V and +/- 12 V power supplies for providing clean power to transducers. Figure 9 shows the junction box that was installed to the side of the tank car. The box contained the computer, acquisition hardware, power supply, analog filter board, and terminal blocks for signal routing and distribution.

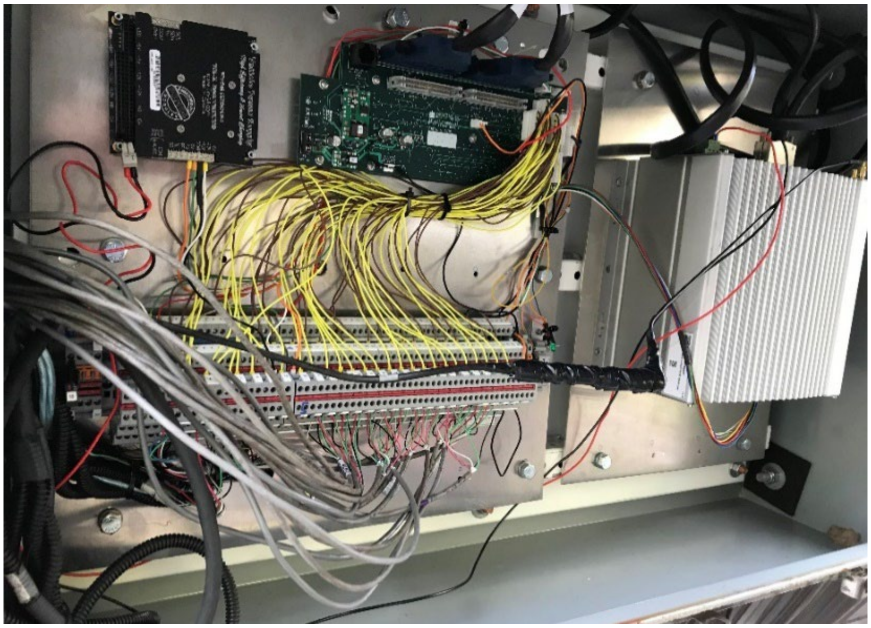

Figure 9. Junction Box with Data Collection System Hardware

Four 115 W, 12 V solar module solar panels and a set of 110 Ah, 12 V AGM batteries powered the system. Figure 10 shows the solar panels and the battery box. The battery box also contained the electronics that controlled battery charging.

Figure 10. Solar Panel and Battery Box on Top of Instrumented Tank Car

2.1.5 Sensor Calibration

The team calibrated all instrumentation prior to testing. Researchers calibrated all portable sensors in a laboratory prior to installation on the vehicle, including accelerometers and longitudinal force bridges on the instrumented couplers. The vertical force bridges on the coupler that converted strains to forces required field calibration.

2.1.6 Tank Car Weights

The research team filled the tank car with water throughout the program to collect information at various tank car weights. The weight of the car with an empty tank was 78.1 kips. The tank car was empty for the initial series of tests. On January 25, 2018, researchers partially filled the tank car with 101 kips of water, resulting in a 179.4 kips tank car. On February 1, 2018, the team loaded the tank car with an additional 84 kips of water, resulting in a fully-loaded tank carload of 263.2 kips. Toward the end of the test program, on May 25, 2018, researchers emptied the water in the tank car to finish the remaining tests. Table 1 shows the schedule for the weight of the tank car during the test program.

Table 1. Tank Car Weights Throughout Test Program

Date		Water Weight [kips]	Total Tank Car Weight [kips]
From	To		
1/9/2018	1/25/2018	0	78.1
1/26/2018	2/1/2018	101.3	179.4
2/2/2018	5/25/2018	185.1	263.2
5/25/2018	6/7/2018	0	78.1

2.2 Impact Testing

The research team conducted the impact test program on Amsted Rail's test track between January 2018 and June 2018. The test program included a series of impact tests for different car configurations, end-of-car units, and coupling speeds that are detailed in the next section. Figure 11 shows the instrumented tank car at Amsted's test track.

To initiate the impact, a bogie coupled to the tank car was attached to a winch that was used to pull the vehicle up a hill. When the car reached the proper position for the intended impact speed, it was released, sending the car toward the stationary test vehicles. This simulated the real-world hump yard operation used for making up trains. In impact testing of this nature, the striking car that is in motion is referred to as the hammer and the stationary cars that are parked down the hill are referred to as the anvil.

Figure 11. Instrumented Tank Car at the Amsted Test Track

2.3 Test Matrix and Data Collected

Researchers established a comprehensive test matrix to test various coupling conditions and car configurations during yard operations. The test matrix included the following conditions:

- Different tank car weights: empty, partially loaded, and fully loaded with water
- Different end-of-car units: steel friction draft gear, elastomer draft gear, and hydraulic cushioning units
- Different anvil configurations: one car with brakes on, one car with brakes off, and 4 cars with brakes on
- Multiple coupling speeds: Target speeds of 4, 6, 7, 7.5, 8, 9 and 10 mph

Table 2 shows the detailed test matrix that was used for the impact test program. During the impact test program, the group conducted more than 700 impact tests. For each impact test, researchers recorded approximately 40 data channels comprised of acceleration, force, speed, and strain data. The green car shown in the schematics within the table indicates the instrumented tank car. The Amsted test track was not capable of conducting impact tests with more than one hammer car.

Table 2. Test Matrix for Impact Test Program

#	Layout	Loaded/Empty		Anvile Car's	Speed						Draft Gear		
	(Green car is the instrumented car)	Hammer	Anvil	Hand brake	4	6	7	7.5	8	10	901E	901G	921B/D
1	Layout 1 	Empty	Full	No	🟥						🟥		
2		Empty	Full	No			🟥				🟥		
3		Empty	Full	Yes	🟥						🟥		
4		Empty	Full	Yes		🟥					🟥		
5		Empty	Full	Yes			🟥				🟥		
6		Empty	Full	Yes				🟥			🟥		
7		Empty	Full	Yes					🟥		🟥		
8		Empty	Full	Yes						🟥	🟥		
9		Partially Full	Full	No	🟥						🟥		
10		Partially Full	Full	No			🟥				🟥		
11		Partially Full	Full	Yes	🟥						🟥		
12		Partially Full	Full	Yes		🟥					🟥		
13		Partially Full	Full	Yes			🟥				🟥		
14		Partially Full	Full	Yes				🟥			🟥		
15		Partially Full	Full	Yes					🟥		🟥		
16		Partially Full	Full	Yes						🟥	🟥		
17		Full	Full	No	🟥						🟥		
18		Full	Full	No			🟥				🟥		
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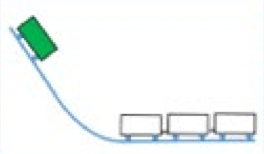
25	Layout 2 	Empty	Full	Yes	🟥						🟥		
26		Empty	Full	Yes		🟥					🟥		
27		Empty	Full	Yes			🟥				🟥		
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29		Empty	Full	Yes					🟥		🟥		
30		Empty	Full	Yes						🟥	🟥		
31		Partially Full	Full	Yes	🟥						🟥		
32		Partially Full	Full	Yes		🟥					🟥		
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35		Partially Full	Full	Yes					🟥		🟥		
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39		Full	Full	Yes			🟥				🟥		
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42		Full	Full	Yes						🟥	🟥		
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44		Full	Full	Yes		🟥						🟥	
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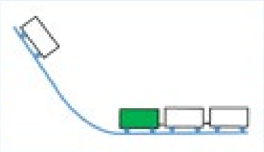
	The instrumented tank car will be turned (orientation changed)												
55	Layout 3 	Full	Full	Yes	🟥						🟥		
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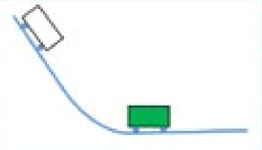
73	Layout 4 	Full	Full	Yes	🟥						🟥		
74		Full	Full	Yes		🟥					🟥		
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76		Full	Full	Yes				🟥			🟥		
77		Full	Full	Yes					🟥		🟥		
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85		Full	Full	Yes	🟥								🟥
86		Full	Full	Yes		🟥							🟥
87		Full	Full	Yes			🟥						🟥
88		Full	Full	Yes				🟥					🟥
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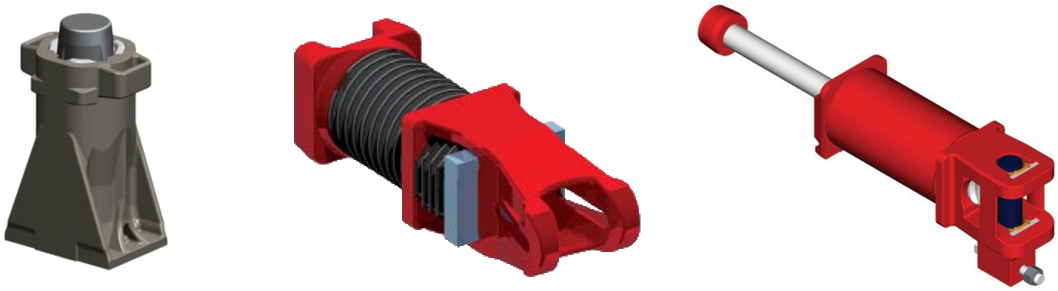
92		Full	Empty	Yes		🟥					🟥		
93		Full	Empty	Yes			🟥				🟥		
94		Full	Empty	Yes				🟥			🟥		
95		Full	Empty	Yes					🟥		🟥		
96		Full	Empty	Yes						🟥	🟥		

During the test program, the team tested different end-of-car units. These shock-absorbing devices, also referred to as draft gear, increase the free movement of adjoining coupler cars under stress as the train is started or stopped. Draft gears cushion the impact of coupling cars during hump yard operations during the make-up of trains, as well as absorb energy associated with in-train forces due to slack motion during train movements. Draft gears absorb energy in both pulling and pushing directions.

Figure 12 illustrates the three types of draft gears used during the test program. 901E steel friction draft gear (left) contains steel wedges that are geometrically arranged to absorb the coupler force using the stick-slip phenomena. The steel friction gear provides a maximum travel of 3 inches. 901G elastomer friction gear (middle) consists of elastomer pads that absorb energy via hysteresis. The elastomer friction gears also provide a maximum travel of 3 inches. Hydraulic cushioning units (right) absorb energy by pushing hydraulic fluid through specially designed valves based on viscous friction. The hydraulic units provide travel of more than 10 inches.



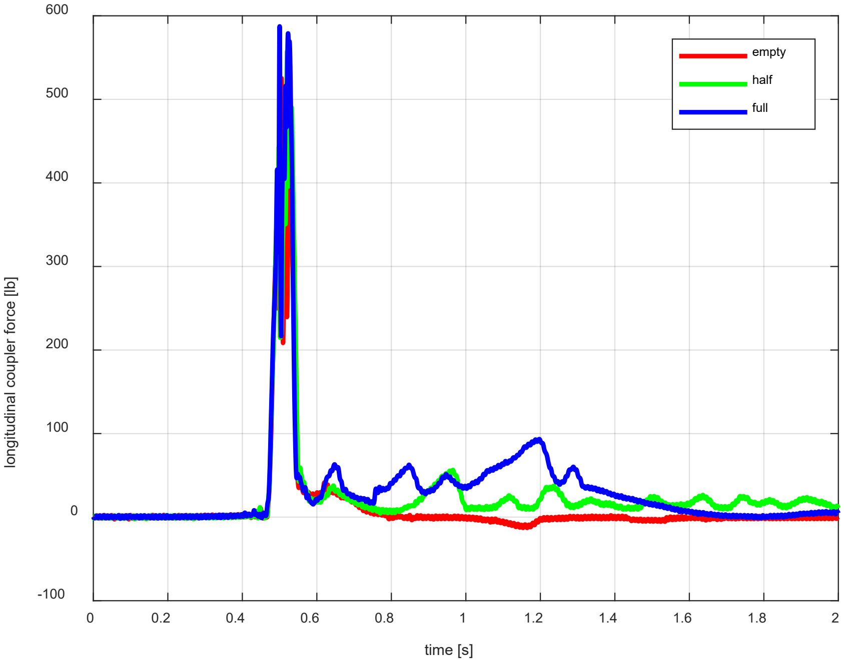
Steel Friction Gear **Elastomer Friction Gear** **Hydraulic Cushioning Unit**

Figure 12. Draft Gears Used During Impact Test Program

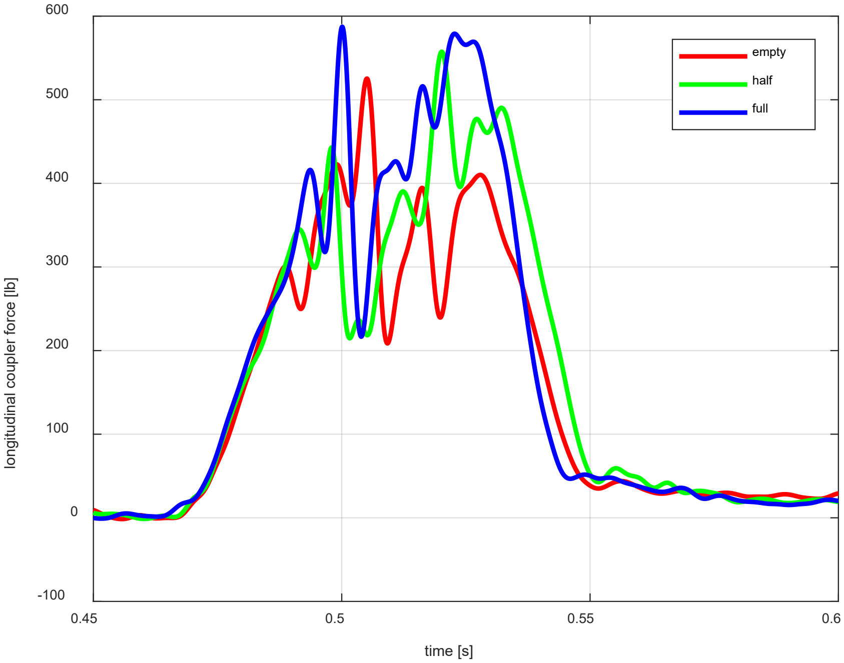
2.4 Measured Longitudinal Coupler Force Results

After filtering the data to remove invalid measurements and noise, researchers conducted a statistical analysis to study the effect of different parameters on the coupling behavior. The team assessed the peak longitudinal impact force measured by the instrumented couplers.

Figure 13 shows the coupling forces during impact for three impacting cars with different weights. The other coupling conditions (anvil configuration, draft gear type, and coupling speed) were the same for the three impact tests. The coupling speed for all three tests was approximately 7 mph.



Overall Time Range



Impact Time Period

Figure 13. Comparison of Coupling Force During Impact Empty, Half-Full and Full Tank Cars

3. Validation of Longitudinal Forces Calculated from Measured Accelerations

The research team worked to validate a new low-cost method to calculate longitudinal coupler forces from measured accelerations. The team compared the calculated longitudinal forces to those directly measured by the instrumented coupler.

Researchers measured longitudinal accelerations at three different locations near the centerline of the tank car, as shown in Figure 5. The axle accelerometers were not used in this analysis since they only measured vertical accelerations. The team investigated three different filter cutoff frequencies to determine which produced the best results.

For each case, team members applied a given filter cutoff frequency and calculated the peak values for the accelerations. Researchers plotted the peak values against the measured longitudinal coupler forces to determine a relationship between the two.

Figure 14, Figure 15, and Figure 16 show the comparison between the measured longitudinal coupler forces and the carbody longitudinal accelerations filtered with 1,000 Hz, 180 Hz, and 60 Hz cutoff frequency, respectively. All three plots show a similar linear trend. However, the plots for 180 Hz and 1,000 Hz cutoff frequency have large scatter throughout the data range. The plots for 60 Hz cutoff frequency plot shows the best linear fit. Therefore, the team selected the 60 Hz cutoff filter for further development of the algorithm.

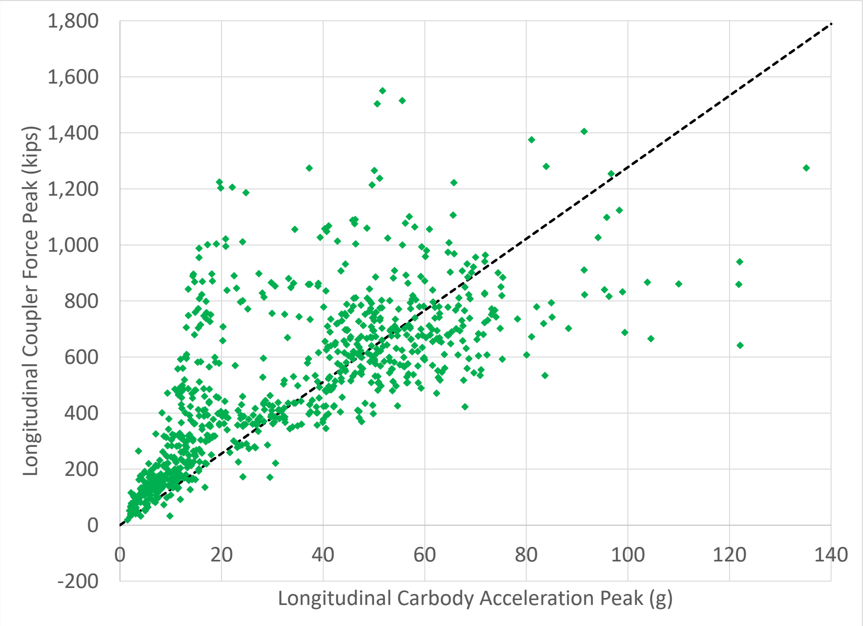


Figure 14. Longitudinal Comparison Using 1,000 Hz Filter and Carbody Accelerations

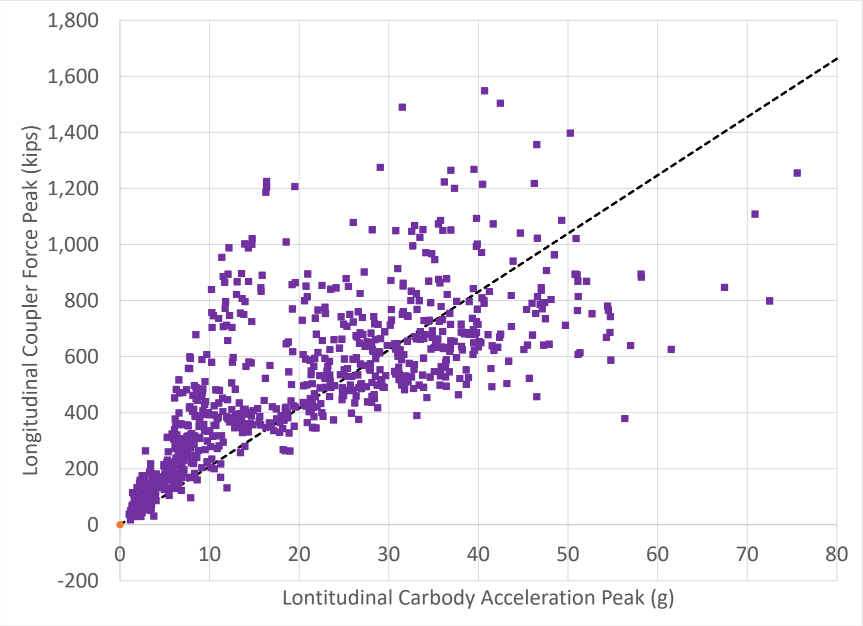


Figure 15. Longitudinal Comparison Using 180 Hz Filter and Carbody Accelerations

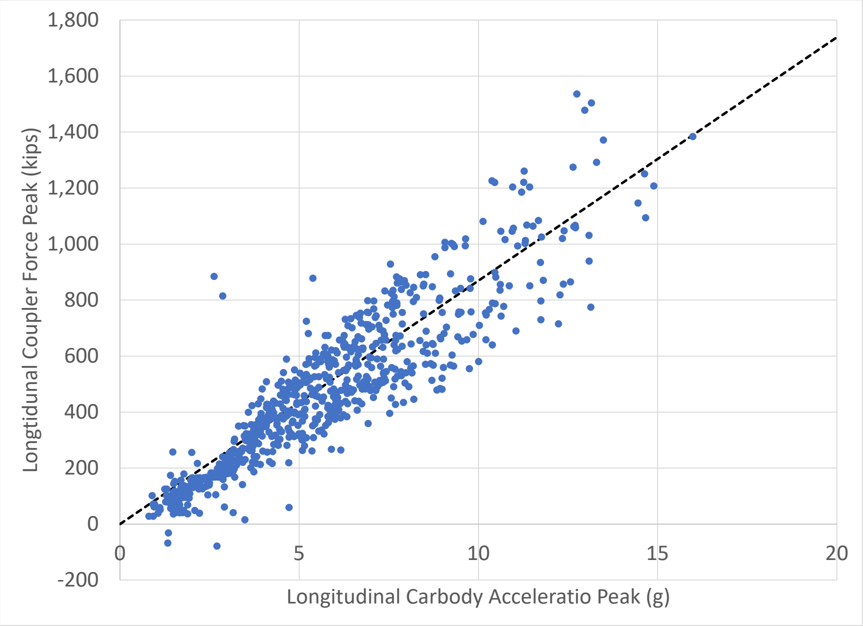


Figure 16. Longitudinal Comparison Using 60 Hz Filter and Carbody Accelerations

In the next step, the team investigated which available accelerometer placement produced the best results. Figure 16, Figure 17, and Figure 18 show the comparison between the measured longitudinal coupler force and the longitudinal accelerations using a 60 Hz cutoff filter on the carbody, Stub Sill A, and Stub Sill B, respectively. The carbody acceleration plot showed the best linear fit. The Stub Sill A acceleration plot showed a large amount of scatter and a poor linear fit, and the Stub Sill B acceleration plot showed large scatter and no discernable trend. Therefore, the team selected the carbody accelerations to develop the final algorithm.

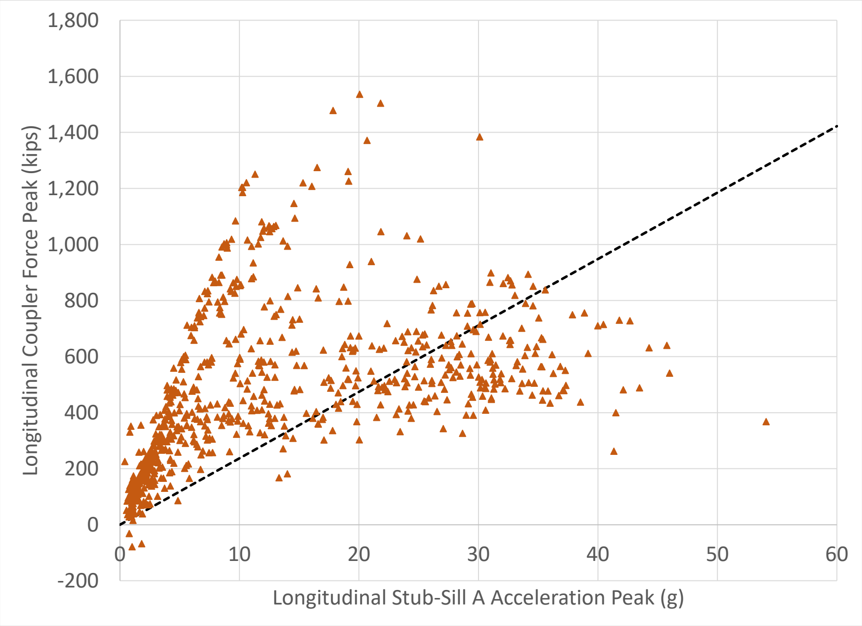


Figure 17. Longitudinal Comparison Using 60 Hz Filter and Stub Sill A Accelerations

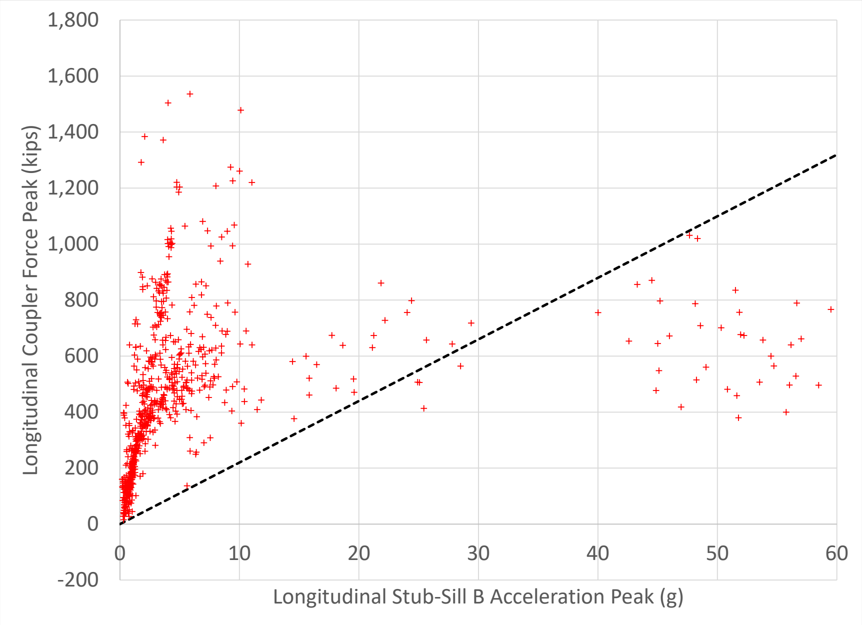


Figure 18. Longitudinal Comparison Using 60 Hz Filter and Stub Sill B Accelerations

Researchers derived a linear relationship to calculate the longitudinal coupler force using a 60 Hz cutoff filter and carbody accelerations. The calculated coupler force is equal to the peak longitudinal carbody acceleration multiplied by a constant 86.94 kips/g. Figure 19 shows the linear relationship between the calculated and measured longitudinal coupler force. The plot illustrates good linear fit. Figure 20 shows the error between the calculated and measured longitudinal coupler forces; the standard deviation of the error is 110 kips and is represented by the red dashed lines.

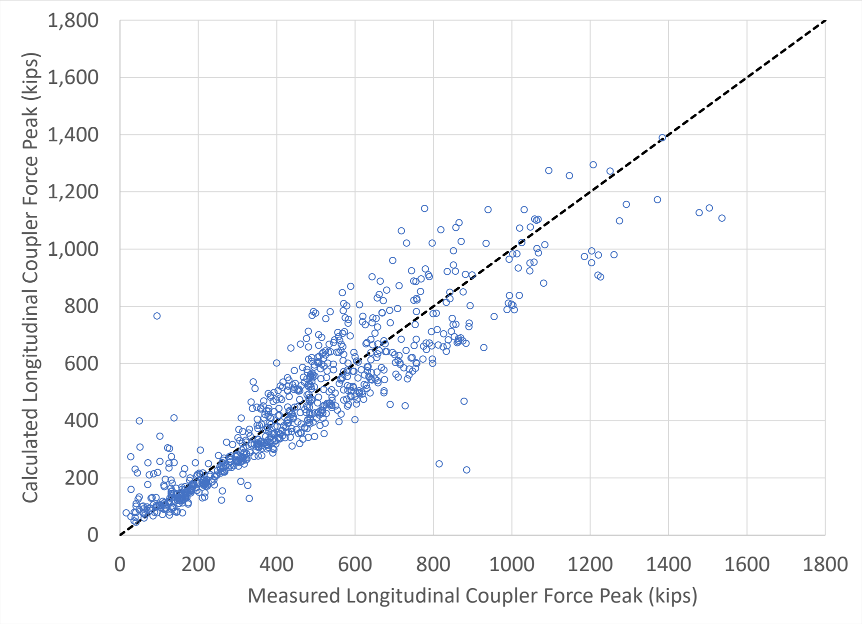


Figure 19. Calculated Coupler Force Comparison Using 60 Hz Filter and Carbody Accelerations

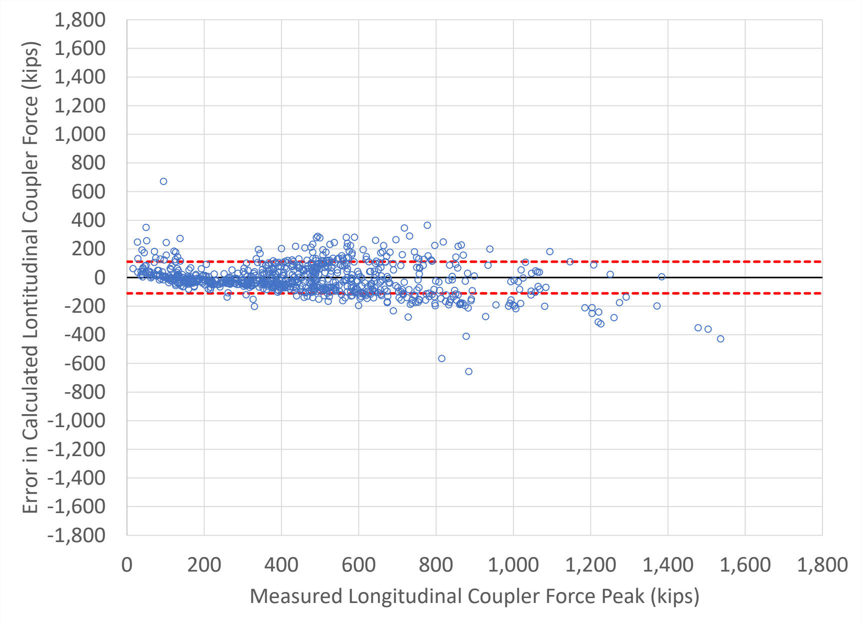


Figure 20. Error in Calculated Coupler Force Comparison Using 60 Hz Filter and Carbody Accelerations

4. Conclusion

The comparison between the calculated and measured longitudinal coupler forces validated the new accelerometer-based method. Longitudinal coupler forces calculated from the carbody acceleration with a 60 Hz filter cutoff frequency showed the best results. The team derived a linear relationship to calculate the longitudinal coupler force equal to the longitudinal carbody acceleration multiplied by a constant 86.94 kips/g. The standard deviation of the error is 110 kips. Further improvement to this new method is possible by adjusting the accelerometer placement on the car and finetuning the filter cutoff frequency.

5. References

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Sundaram, N. (2016). *Force Environment Evaluation of Stub Sills on Tank Cars Using Autonomous Over-the-Road Testing of the Instrumented Tank Car* (Report No. DOT/FRA/ORD-16/39). Federal Railroad Administration.

Sundaram, N., Martin, T., Selby, B., & González, F., III. (2009). *Over-the-Road Testing of the Instrumented Tank Car – A Load Environment Study*. (Report No. DOT-FR-09-10). Federal Railroad Administration.

Abbreviations and Acronyms

ACRONYM	DEFINITION
ENSCO	ENSCO, Inc.
FRA	Federal Railroad Administration