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Comparison of Measured and Simulated Longitudinal Coupler Force on Tank Cars

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14. ABSTRACT
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 the 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. The statistical analysis revealed that the peak longitudinal coupler force is mostly influenced by coupling speed and draft gear type, not configurations of loaded and empty cars. The TEDS software tool was used to run simulations on a subset of these impact tests. The comparison between the measured and simulated longitudinal coupler force showed relatively good results. However, the simulation could be improved. One or two more iterations of fine tuning the model parameters could potentially improve the comparison in the future.

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Tank Cars, Rail, Stub Sill Failures, Impact Test, Yard Operation, Car Coupling, Draft Gear, Instrumented Couplers, Longitudinal Force, Simulation, Modeling

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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

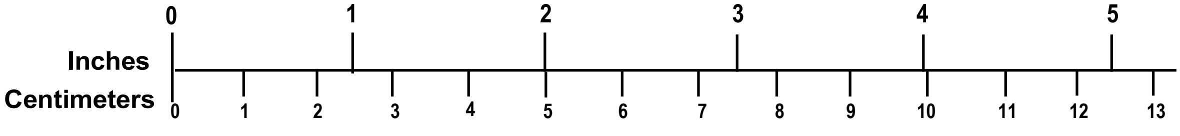
VOLUME (APPROXIMATE)

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.

The research team compared a selected subset of these impact tests to simulations performed using Train Energy and Dynamics Simulator (TEDS) software. The focus of research was to compare the measured longitudinal impact forces to the simulations. This will increase confidence in the simulation tools for future research.

Table 1 shows the summary results of the simulated data as compared to the measured data. The longitudinal coupler force comparison shows relatively good agreement with the measured results. Only in two scenarios were the simulation results considerably higher than measured forces.

Table 1. Summary Comparison Results

Draft Gear	Load	Speed			
		4 mph	6 mph	8 mph	10 mph
901E	Empty	Slighty Low	Slighty Low	Slighty Low	Low
	Half	Slightly Low	Good	Good	Good
	Full	Good	Good	Slightly High	High
901E	Full	Good	Good	Slightly High	High
901G		Slightly High	Good	Good	Good
921B		Good	Slightly High	Slighty High	Slightly High

In conclusion, researchers determined the comparison between the measured and simulated longitudinal coupler force showed relatively good results, although the simulation could be improved. Another iteration of fine tuning the model parameters would improve the comparison for future use.

1. Introduction

The Federal Railroad Administration (FRA) sponsored a research team from ENSCO Inc. (ENSCO) to compare simulations to measured longitudinal coupler forces to better understand the accuracy and differences between the two. The team used measured data from a cooperative test program conducted at Amsted Rail's test facility in Camp Hill, PA. Researchers gathered impact data on a test track simulating hump yard operation for train make-up. Sharma and Associates Inc. (Sharma) performed the simulations using Train Energy and Dynamics Simulator (TEDS) software with the cooperation of ENSCO and FRA.

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 this research was to characterize the load environment on tank cars during yard operations. The focus of this report is to compare the measured longitudinal impact forces to simulations to provide increased confidence in these tools for future research.

1.3 Overall Approach

FRA, Union Tank Car, and Amsted Rail conducted a cooperative tank car test program at Amsted Rail's test facility in Camp Hill, PA, in 2018. The team instrumented a tank car loaned to FRA by Union Tank Car with multiple transducers. Researchers 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, and compared a subset of these impact tests to the simulations. Sharma conducted the simulations using the TEDS software tool with the help of ENSCO and FRA. 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.

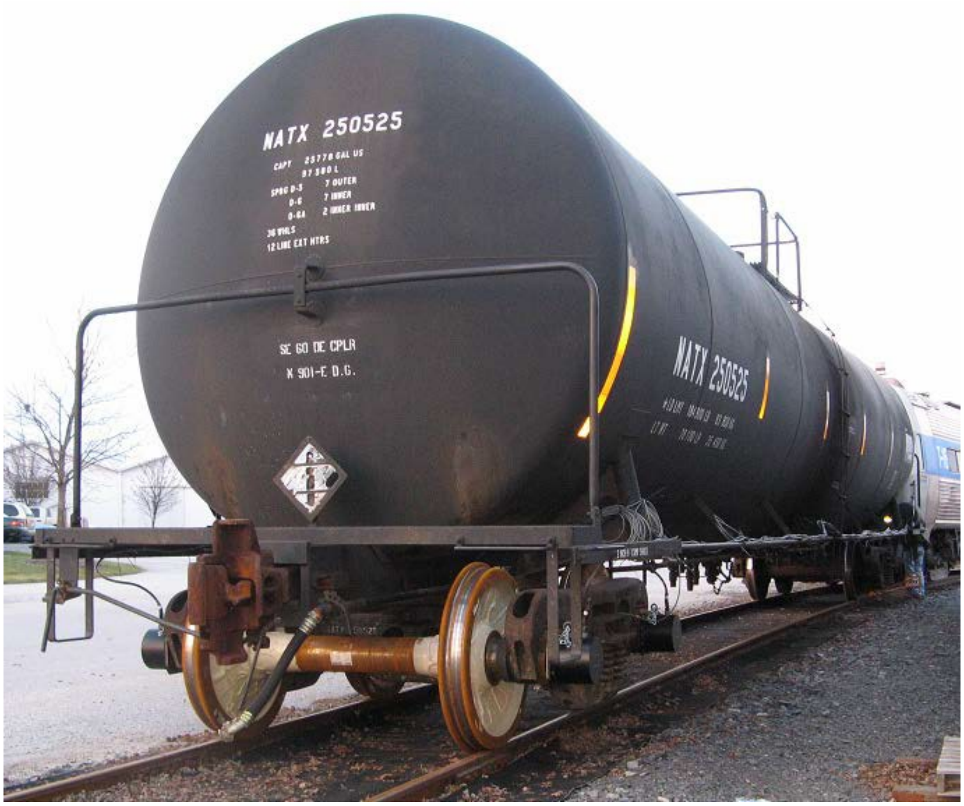

Figure 3. Instrumented Tank Car

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

1.4 Scope

The scope of this report was limited to comparing a subset of the impact test data with the simulation results for different coupling conditions during yard operation. This report serves as a base for improving future research using impact data and simulations.

1.5 Organization of the Report

The test methodology is discussed in Section 2, including a review of the instrumented tank car, 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 for the testing program. Section 3 presents the simulations and the resulting data. The comparisons between the measured and simulated data are shown in Section 4. Conclusions are discussed in Section 5.

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.

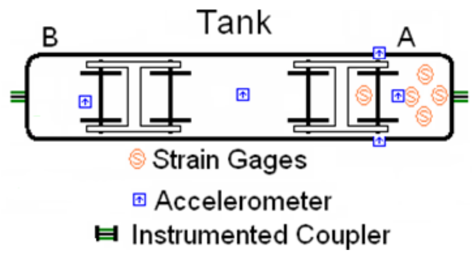

Figure 5. Schematic Diagram of Tank Car's Instrumentation

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 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.

2.1.3 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 supply for providing clean power to transducers. Figure 7 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.

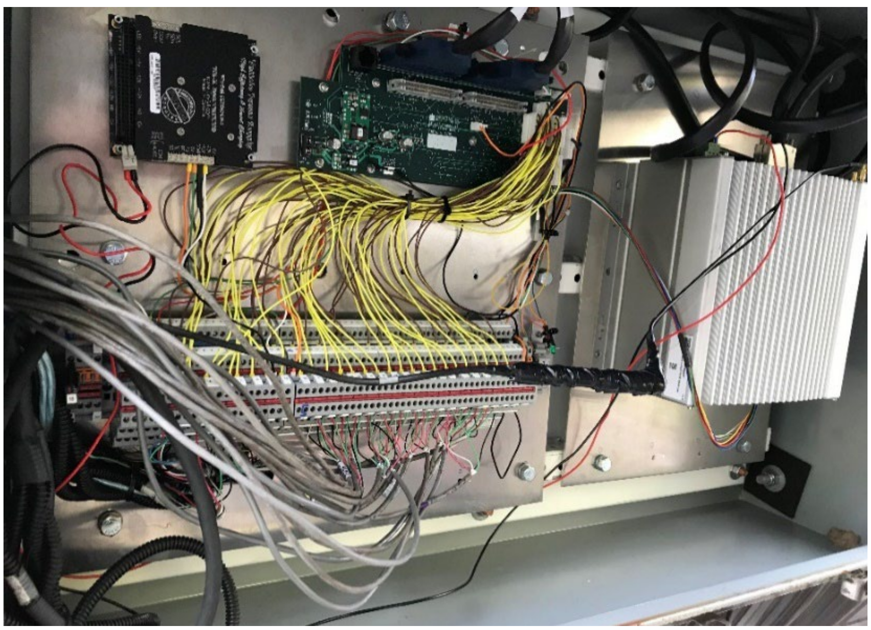

Figure 7. Junction Box with Data Collection System Hardware

Four 115 W, 12 V solar module solar panels and a set of 110 Ah, 12 V AGM batteries powered the system. Figure 8 shows the solar panels and the battery box. The battery box also contained the electronics that controlled battery charging.

Figure 8. Solar Panel and Battery Box on Top of Instrumented Tank Car

2.1.4 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.

2.1.5 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, ENSCO emptied the water in the tank car to finish the remaining tests. Table 2 shows the schedule for the weight of the tank car during the test program.

Table 2. 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 9 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 9. 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 3 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 3. 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			■				■		
19		Full	Full	Yes	■						■		
20		Full	Full	Yes		■					■		
21		Full	Full	Yes			■				■		
22		Full	Full	Yes				■			■		
23		Full	Full	Yes					■		■		
24		Full	Full	Yes						■	■		
25	Layout 2	Empty	Full	Yes	■						■		
26		Empty	Full	Yes		■					■		
27		Empty	Full	Yes			■				■		
28		Empty	Full	Yes				■			■		
29		Empty	Full	Yes					■		■		
30		Empty	Full	Yes						■	■		
31		Partially Full	Full	Yes	■						■		
32		Partially Full	Full	Yes		■					■		
33		Partially Full	Full	Yes			■				■		
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37		Full	Full	Yes	■						■		
38		Full	Full	Yes		■					■		
39		Full	Full	Yes			■				■		
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41		Full	Full	Yes					■		■		
42		Full	Full	Yes						■	■		
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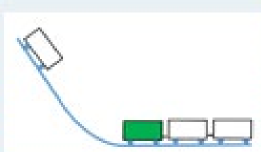
47		Full	Full	Yes					■			■	
48		Full	Full	Yes						■		■	
49		Full	Full	Yes	■								■
50		Full	Full	Yes		■							■
51		Full	Full	Yes			■						■
52		Full	Full	Yes				■					■
53		Full	Full	Yes					■				■
54		Full	Full	Yes						■			■
	The instrumented tank car will be turned (orientation changed)												
55	Layout 3	Full	Full	Yes	■						■		
56		Full	Full	Yes		■					■		
57		Full	Full	Yes			■				■		
58		Full	Full	Yes				■			■		
59		Full	Full	Yes					■		■		
60		Full	Full	Yes						■	■		
61		Full	Full	Yes	■							■	
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65		Full	Full	Yes					■			■	
66		Full	Full	Yes						■		■	
67		Full	Full	Yes	■								■
68		Full	Full	Yes		■							■
69		Full	Full	Yes			■						■
70		Full	Full	Yes				■					■
71		Full	Full	Yes					■				■
72		Full	Full	Yes						■			■
73	Layout 4	Full	Full	Yes	■						■		
74		Full	Full	Yes		■					■		
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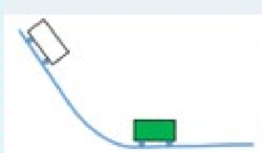
80		Full	Full	Yes		■						■	
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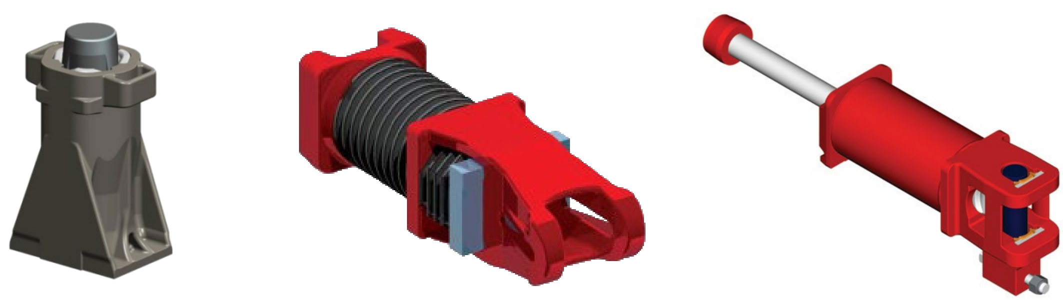
83		Full	Full	Yes					■			■	
84		Full	Full	Yes						■		■	
85		Full	Full	Yes	■								■
86		Full	Full	Yes		■							■
87		Full	Full	Yes			■						■
88		Full	Full	Yes				■					■
89		Full	Full	Yes					■				■
90		Full	Full	Yes						■			■
91		Full	Empty	Yes	■						■		
92		Full	Empty	Yes		■					■		
93		Full	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 10 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.



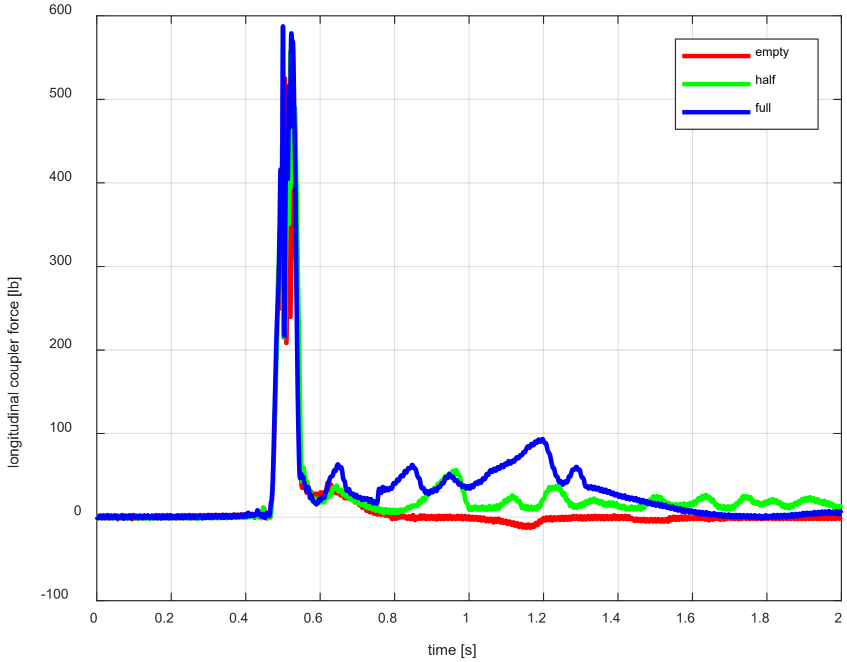
Steel Friction Gear **Elastomer Friction Gear** **Hydraulic Cushioning Unit**

Figure 10. Draft Gears Used During Impact Test Program

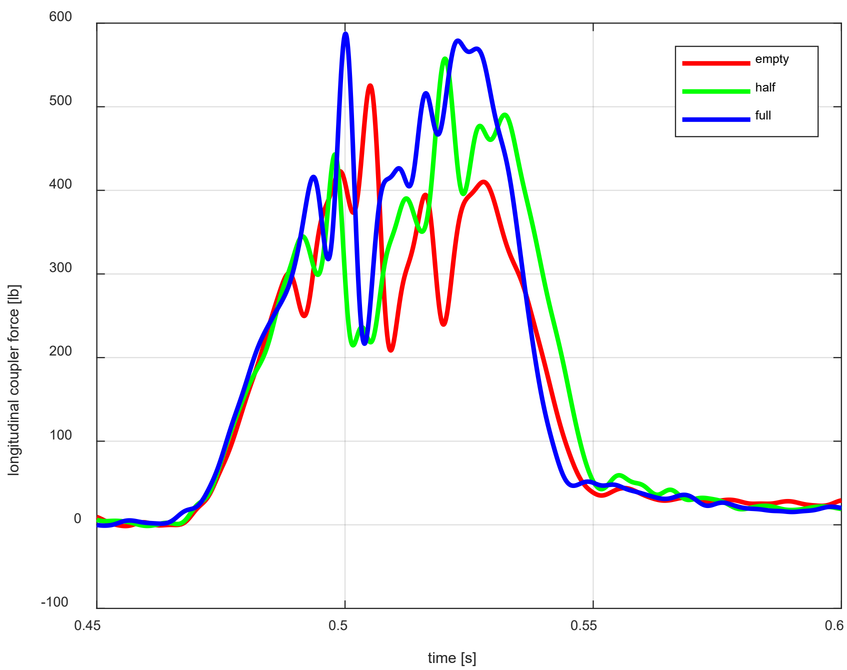
2.4 Measured Longitudinal Coupler Force Results

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

Figure 12 shows impact force data for the tank car in different load conditions. The results show that the weight of the hammer tank car has limited effect on the peak impact force.

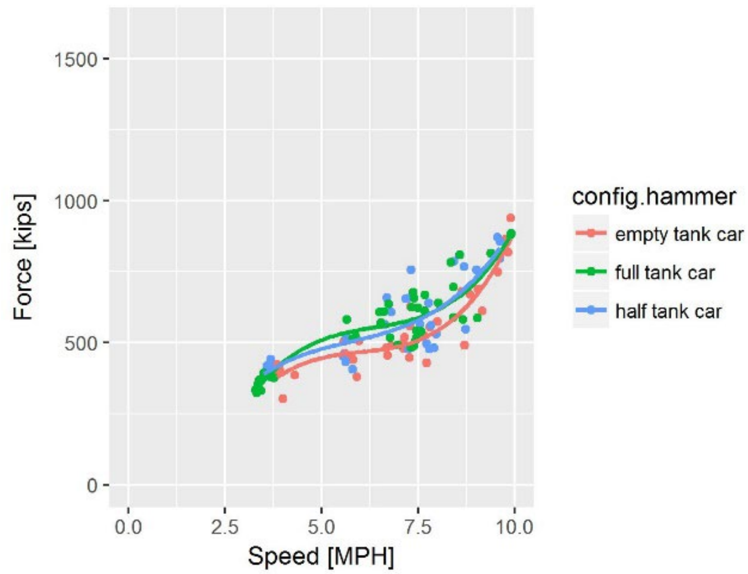


Figure 12. Impact Force Comparison for Different Tank Car Loadings

Figure 13 shows impact force data for a given hammer and anvil configuration using different end-of-car units. The anvil car was a full tank car with the brake applied. The results show that the various end-of-car units performed differently with respect to impact force for different speed ranges. The hydraulic cushioning unit dampened more impact force than both steel friction and elastomer draft gears for all speed ranges. The elastomer draft gear dampened more impact force than the steel friction draft gears performed at low coupling speeds. The peak force started to increase rapidly in steel friction draft gears for coupling speeds of approximately 6.5 mph.

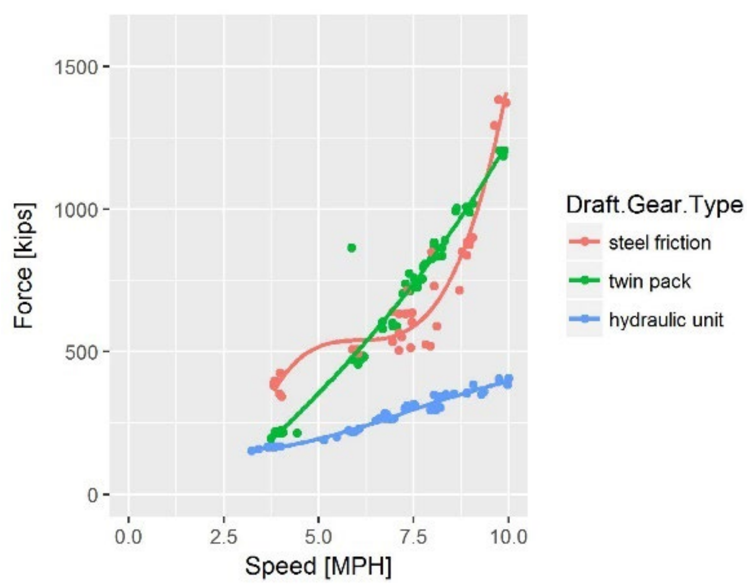


Figure 13. Impact Force Data Comparison for Different End-of-Car Units

3. Simulation Analysis and Results

Modeling and simulation software is used to predict longitudinal forces. It is faster and much more feasible than field testing. However, modeling results must be confirmed with measurements to ensure their accuracy. The team used TEDS software to perform all the simulation in cooperation with ENSCO and FRA.

The impact testing included over 700 tests. The first step was to reduce the number of necessary simulations while keeping a variety of the most import variables. The team accomplished this by reducing the number of speeds, types of configurations, number of cars, and whether the handbrakes were applied. This reduced the comparison analysis to two scenarios. The first used the 901E draft gear with the tank car in three load conditions. The second used the three different draft gears with the tank car fully loaded. Note that the tank car with its instrumented couplers always used 901E draft gear. Table 4 shows the reduced matrix that was used for the simulations. The 921B and 921D draft gear were run as separate simulations. Over the course of the effort, researchers refined the modeling parameters to achieve better results.

Table 4. Test Matrix Used for Simulations

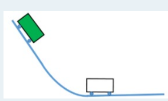
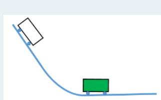
	Layout	Loaded/Empty		Anvile Car's	Speed						Draft Gear		
#	(Green car is the instrumented car)	Hammer	Anvil	Hand brake	4	6	7	7.5	8	10	901E	901G	921B/D
3	Layout 1 	Empty	Full	Yes									
4		Empty	Full	Yes									
7		Empty	Full	Yes									
8		Empty	Full	Yes									
11		Half	Full	Yes									
12		Half	Full	Yes									
15		Half	Full	Yes									
16		Half	Full	Yes									
19		Full	Full	Yes									
20		Full	Full	Yes									
23		Full	Full	Yes									
24		Full	Full	Yes									
The instrumented tank car will be turned (orientation changed)													
73	Layout 4 	Full	Full	Yes								Repeat of above	
74		Full	Full	Yes								Repeat of above	
77		Full	Full	Yes								Repeat of above	
78		Full	Full	Yes								Repeat of above	
79		Full	Full	Yes									
80		Full	Full	Yes									
83		Full	Full	Yes									
84		Full	Full	Yes									
85		Full	Full	Yes									
86		Full	Full	Yes									
89		Full	Full	Yes									
90		Full	Full	Yes									

Figure 14 shows the comparison of the longitudinal coupling force during impact for the 901G draft gear for the fully-loaded tank car. The four traces show the four different speeds from 4 to 10 mph. As predicted, the higher speeds corresponded to higher forces.

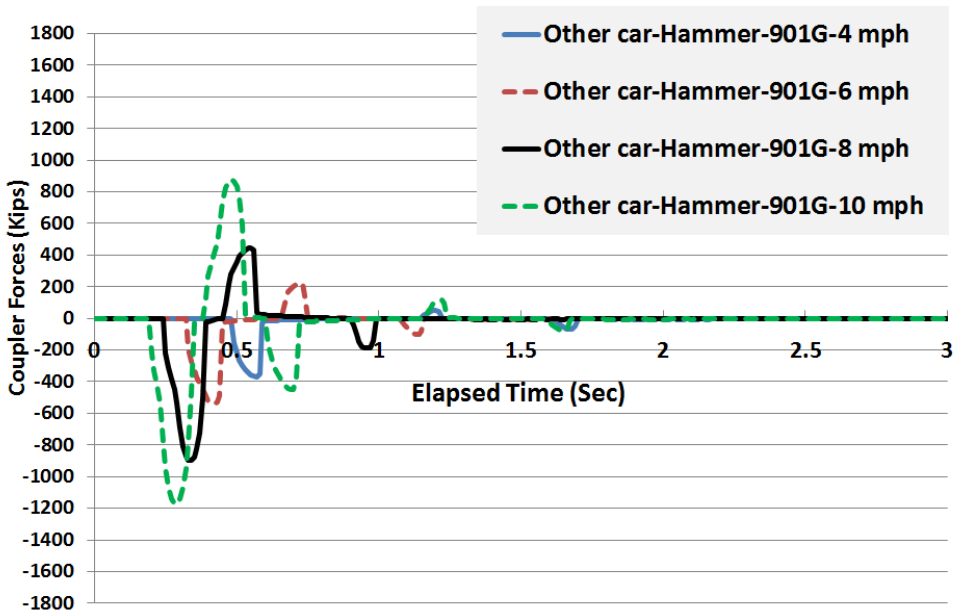


Figure 14. Simulated Longitudinal Coupler Forces for the 901G Draft Gear

The peak values from the time traces were compared to the measured coupling forces. Figure 15 shows a summary of all the simulated longitudinal coupler forces with lines connecting the four speeds for each configuration. As expected, the higher speeds had higher longitudinal forces for all conditions. The full and half-full tank car with the 901E draft gear and the full tank car with the 901G draft gear had much higher longitudinal coupling forces at the higher impact speeds.

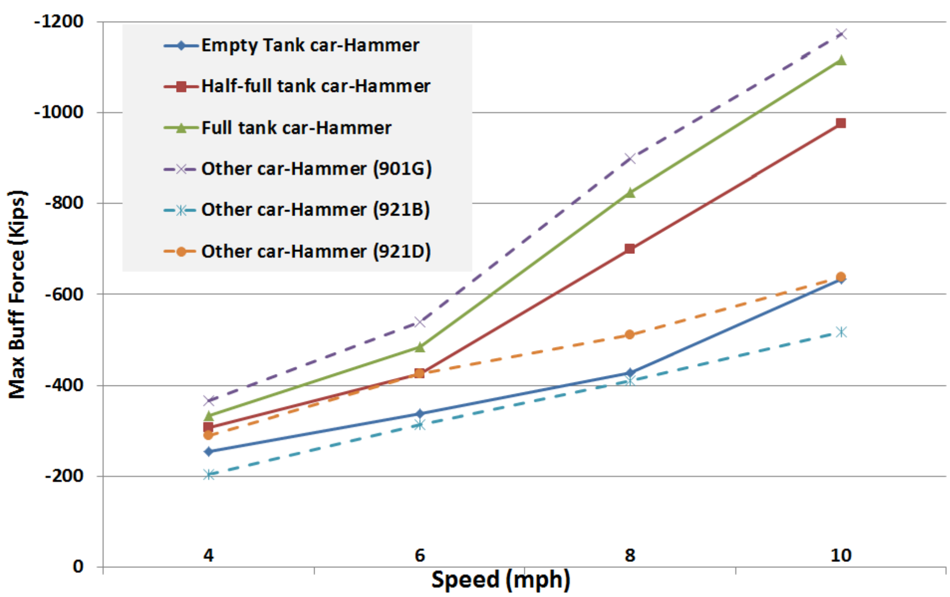


Figure 15. Simulated Longitudinal Coupler Force Summary

4. Comparison Between Measured and Simulation Data

This section presents and summarizes the comparison results between the measured and simulation data. The next three figures show the longitudinal coupler force comparison for the 901E draft gear while varying the tank carload. The tank car is the impacting hammer car. Figure 16 shows the empty tank car. The blue line shows the simulation results at 4, 6, 8, and 10 mph and the red squares show the measured results at the actual impact speed. The black line is the second order polynomial best fit line for the measured points. This figure shows a relatively good fit between the simulations and measured data but with the simulations slightly low.

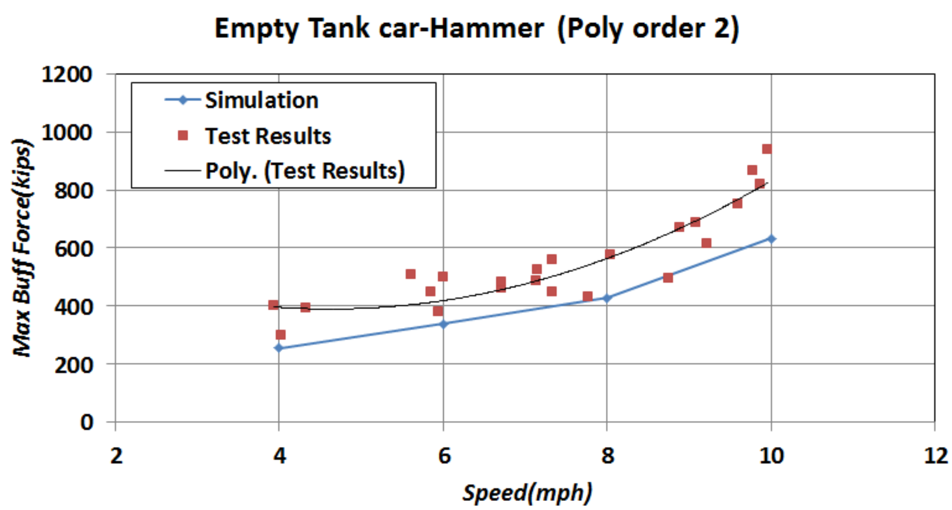


Figure 16. Comparison of Empty Tank Car with 901E Draft Gear

Figure 17 shows the half-full tank car. The blue line shows the simulation results at 4, 6, 8, and 10 mph and the yellow squares show the measured results at the actual impact speed. The black line is the second order polynomial best fit line for the measured points. This figure shows a very good fit between the simulations and measured data but with the simulations slightly low at 4 mph.

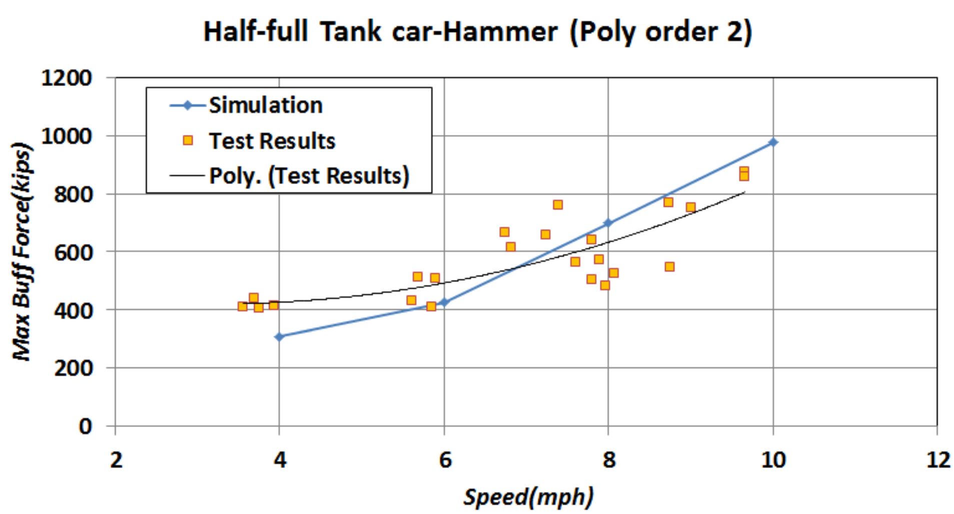


Figure 17. Comparison of Half-full Tank Car with 901E Draft Gear

Figure 18 shows the fully-loaded tank car. The blue line shows the simulation results at 4, 6, 8, and 10 mph and the green squares show the measured results at the actual impact speed. The black line is the second order polynomial best fit line for the measured points. This figure shows a good fit between the simulations and measured data at the lower speeds, but the simulations are slightly high at the higher speeds.

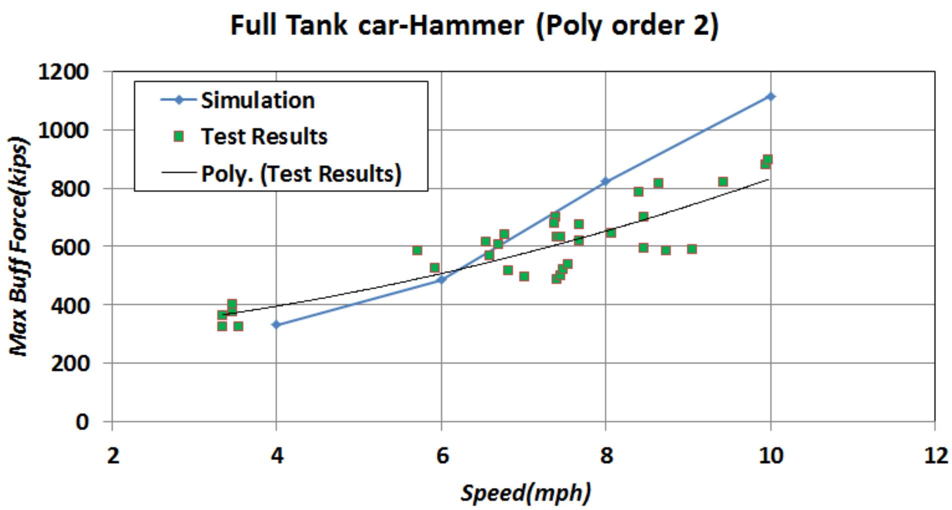


Figure 18. Comparison of Fully-Loaded Tank Car with 901E Draft Gear

The previous figure and the next two figures show the longitudinal coupler force comparison for the fully-loaded tank car with three different draft gears. Figure 18 shows the 901E draft gear. This figure shows a good fit between the simulations and measured data at the lower speeds, but the simulations are slightly high at the higher speeds.

The next two figures show results for the tank car used as the impacted anvil car. Figure 19 shows the results using the 901G draft gear. The blue line shows the simulation results at 4, 6, 8, and 10 mph and the purple squares show the measured results at the actual impact speed. The black line is the second order polynomial best fit line for the measured points. This figure shows a good fit between the simulations and measured data with the simulations only slightly higher at 4 mph.

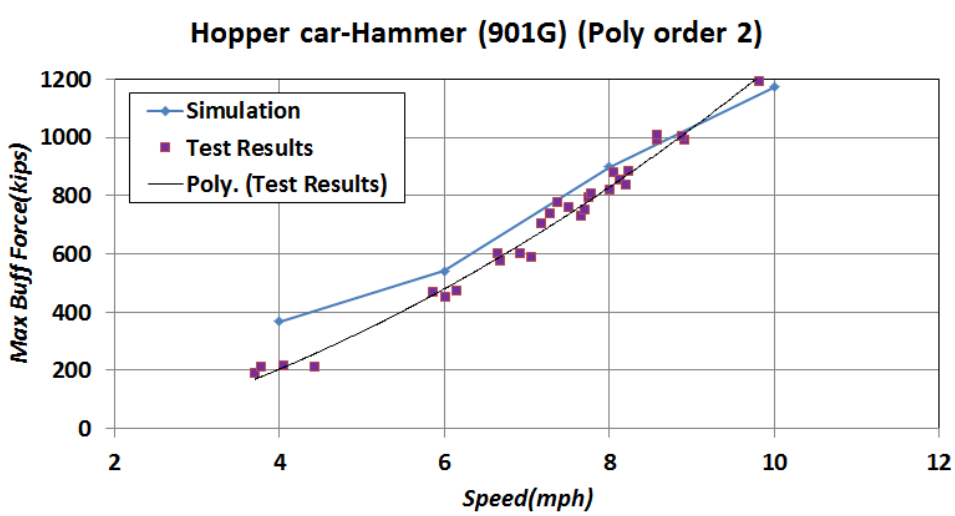


Figure 19. Comparison of Fully-Loaded Tank Car with 901G Draft Gear

Figure 20 shows the results using the 921B draft gear. The blue line shows the simulation results at 4, 6, 8, and 10 mph and the red squares show the measured results at the actual impact speed. The black line is the second order polynomial best fit line for the measured points. This figure shows a good fit between the simulations and measured data with the simulations slightly higher at most speeds.

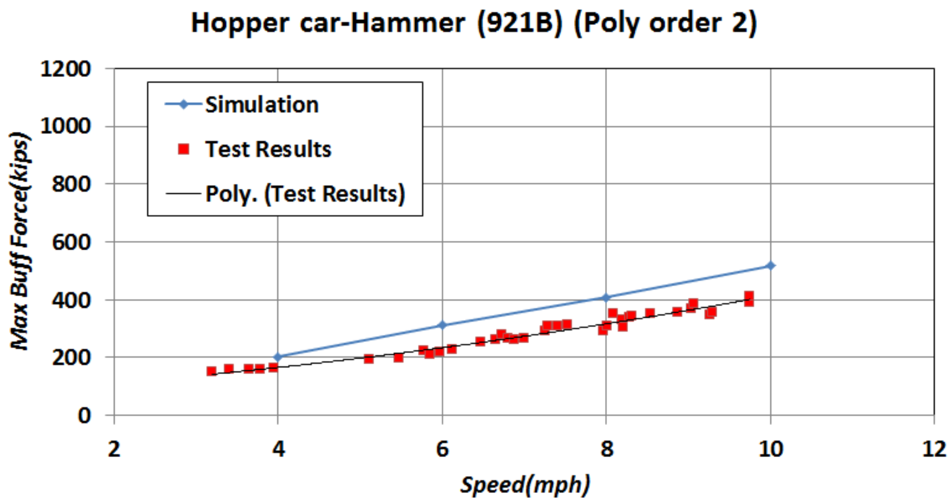


Figure 20. Comparison of Fully-Loaded Tank Car with 921B Draft Gear

5. Conclusion

The comparison between the measured and simulated longitudinal coupler force shows relatively good results. However, the simulation could be improved. One or two more iterations of fine tuning the model parameters could potentially improve the comparison in the future. Table 5 shows the summary results of the simulated data as compared to the measured data, showing almost all differences as either good or only slightly different.

Table 5. Summary Results of Simulation Data Compared to Measurements

Draft Gear	Load	Speed			
		4 mph	6 mph	8 mph	10 mph
901E	Empty	Slighty Low	Slighty Low	Slighty Low	Low
	Half	Slightly Low	Good	Good	Good
	Full	Good	Good	Slightly High	High
901E	Full	Good	Good	Slightly High	High
901G		Slightly High	Good	Good	Good
921B		Good	Slightly High	Slighty High	Slightly High

The following major conclusions were drawn from the data comparison of the longitudinal coupler force:

- The simulations overall show relatively good agreement with the measured results.
- The simulations show good but mixed results over the three tank carload conditions with the 901E draft gear.
  - The empty tank car shows somewhat good agreement, with the simulation slightly low.
  - The half-full tank car shows very good agreement over all speeds.
  - The fully-loaded tank car shows good agreement with the simulation, but slightly high at the higher speeds.
- The simulations show good results for the three draft gears at the fully-loaded tank car condition.
  - The 901E draft gear shows good agreement, with the simulation slightly high at the higher speeds.
  - The 901G draft gear shows good agreement, with the simulation slightly high at 4 mph.
  - The 921B draft gear shows good agreement, with the simulation slightly high at most speeds.

6. References

Meymand, S. (2020). *Impact Test Data Analysis for Load Environment Characterization of Tank Car Stub Sill During Yard Operations* (Report No. DOT/FRA/ORD-20/09). Federal Railroad Administration.

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
Sharma	Sharma & Associates
TEDS	Train Energy and Dynamics Simulator