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RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

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YARD IMPACT TEST OF A TANK CAR

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 that can lead to a release of the contents, as shown in Figure 1. Previous research studies revealed that high magnitude coupling forces that occur in yard operations have the potential to exceed yield limits of mild steel and initiate stub sill damage.

In 2018, the Federal Railroad Administration's (FRA) Office of Research, Development and Technology conducted a series of impact tests for different car configurations at various coupling speeds to better understand the load environment of tank cars during yard operations, and to identify hazardous operating scenarios. More than 700 impact tests were conducted. For each impact test, 40 data channels comprised of acceleration, force, speed, and strain data were recorded. This report presents the analysis of impact test data. The analysis considered longitudinal coupler forces as well as transferred energy between cars during yard operations for different draft gear types.

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. However, the impulse at the impact that is used as a measure of transferred energy between cars is largely dependent on configurations of loaded and empty cars as opposed to draft gear type.

Figure 1. Example of a cracked sill

BACKGROUND

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

Research into the underlying cause of stub sill tank car cracking and propagation continues. It is believed that the fractures are initiated by discrete events resulting in high stresses. Previous research studies conducted by FRA revealed that high magnitude coupling forces that occur in yard operations have the potential to exceed yield limits of mild steel [1]. The reasons for stub sill failures were primarily attributed to high forces generated in yards initiating damage followed by crack propagation resulting from high vertical coupler force events occurring in mainline operations. High-force events in yards could be mitigated if there was a better understanding of the contributing factors to these high impact loadings during yard operations.

To better characterize the load environment of the tank car operations in yards, FRA, Union Tank Car Company, and Amsted Rail completed a cooperative test program at Amsted Rail's test facility in Camp Hill, PA, in 2018. A tank car loaned to FRA by Union Tank Car Company was instrumented with multiple transducers and a data collection system that supported high sampling rates required for conducting impact testing. Impact data for different car configurations, end-of-car units, and coupling speeds were collected.

OBJECTIVES

The objective of this research study was to characterize the load environment on tank cars during yard operations. The main focus was to identify important factors such as speed and configurations of striking (hammer) and impact absorbing (anvil) cars during impacts to help the railroad industry establish yard operation scenarios that cause less damage to tank car stub sills.

METHODS

A comprehensive test matrix was established to test various coupling conditions during yard operations. This included:

- 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 four cars with brakes on,
- Multiple coupling speeds - 4, 6, 7, 7.5, 8, 9, and 10 mph.

The instrumented tank car was equipped for the test program with instrumented couplers on both ends of the car, a vertical coupler force measurement system, multiple accelerometers, and multiple rosette strain gages at different locations around stub sills that were identified as the high stress locations. Figure 2 shows the location of the stub sill's instrumentation. In addition, other transducers such as a laser speedometer for measuring the coupling speed, temperature sensor, and humidity sensors were used to collect data. In total, 702 impact tests were conducted during the test program.

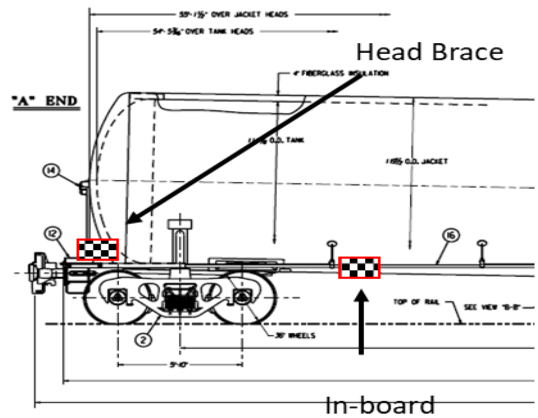

Figure 2. Location of instrumentation of the stub sill

RESULTS

After filtering the data to remove invalid data and noise, a statistical analysis was conducted to study the effect of different parameters on the coupling behavior.

The peak longitudinal impact force measured by the instrumented coupler was assessed. In addition to coupling force, the impulse at the impact between coupling cars was studied. The impulse was calculated by integrating the impact force during the time period of the impact. The impulse, based on Newton's second law, is equal to the change of momentum:

$$J = \int Fdt = \Delta P = mv_2 - mv_1$$

where J is the impulse and ΔP is the change of momentum during impact. The impulse data is used as a measure of energy transferred between cars during impact.

Figure 3 shows impact force data (left) and impulse (right) for different hammer configurations and a given anvil configuration. Tank cars of different weights were used to create different hammer configurations. The results show that the weight of the hammer tank car has a limited effect on the peak impact force. However, the tank car's weight has considerable effect on the impulse. This is in line with Newton's law since the larger mass corresponds to larger momentum and hence higher energy transfer.

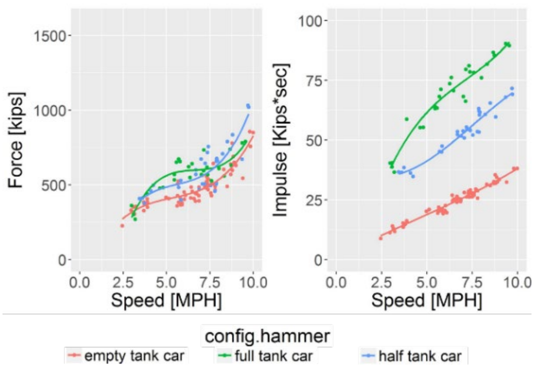

Figure 3. Impact Force Data and Impulse Data Comparison for Different Hammer Configurations.

Figure 4 shows impact force data (left) and impulse (right) for different anvil configurations and a given hammer configuration. Different consist layouts were used to create different anvil configurations. The results show that the anvil configurations, similar to hammer configurations, have limited effect on the peak impact force, although it has considerable effect on the impulse. This is also in line with Newton's law since different anvil consists cause different car momentum after impact.

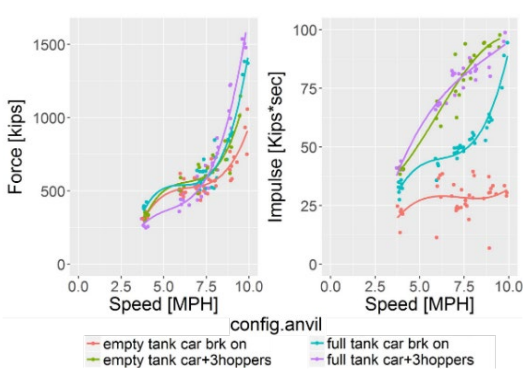

Figure 4. Impact Force Data and Impulse Data Comparison for Different Anvil Configurations.

Figure 5 shows impact force data (left) and impulse (right) for different end-of-car units. The results show that different end-of-car units perform differently in terms of impact force for different speed ranges. Hydraulic cushioning units outperforms steel friction and elastomer draft gears for all speed ranges. Elastomer draft gears perform better for lower coupling speed ranges compared to steel friction draft gears. The peak force starts to increase rapidly in steel friction draft gears for coupling speed of ~6.5 mph. The results also show that the end-of-car unit does not have any considerable effect on the impulse imparted to the anvil cars.

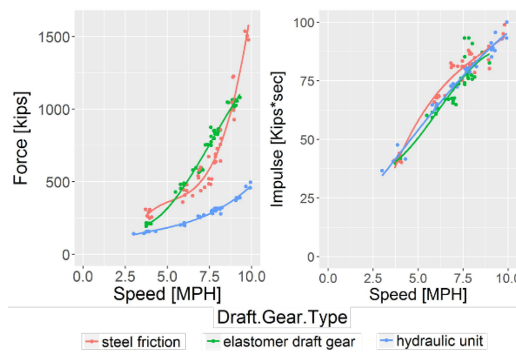

Figure 5. Impact Force Data and Impulse Data Comparison for Different End-of-Car Units.

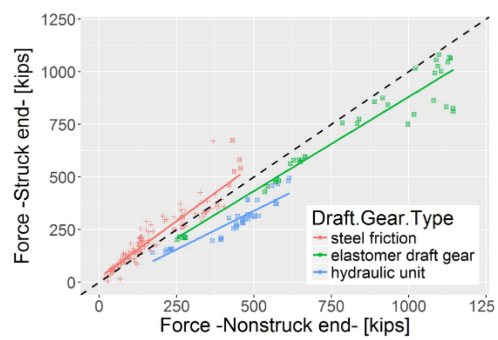

Figure 6. Comparison of Struck and Non-Struck Ends' Impact Force for Different Struck End's Draft Gear Types. The Non-Struck End Draft Gear Was Steel Friction.

The instrumented couplers' readings from both ends of the tank car were compared. Figure 6 compares longitudinal impact force between struck and non-struck ends of the car. The results show that the non-struck end forces are comparable to struck end forces. This shows that the impact force passes through the anvil consist, and all the cars in the anvil consist experience the impact force.

CONCLUSIONS

A comprehensive test program was conducted that focused on tank car impacts. Various coupling conditions were tested to characterize load environment at the impact. The results showed that coupling speed and end-of-car unit type have the most influence on the peak longitudinal impact force, whereas anvil and hammer configurations have a limited effect on the peak impact force. The results also showed that the end-of-car unit type has a limited effect on the transferred energy between impacting cars, whereas hammer and anvil configurations have a considerable effect on the transferred energy.

FUTURE ACTION

The load characterization results from this research will be combined with fatigue characteristics of stub sill material to design the yard operation scenarios. The limits on mass and speed combinations should be designed based on the expected life of tank cars. This report serves as a stepping stone for such analysis with providing the extent of impact loading and energy transferred during yard operations, as well as the effect of different factors on the impact behavior.

REFERENCES

[1] N. Sundaram. (2014) “Force Environment Evaluation of Stub Sills on Tank Cars Using Autonomous Over-the-Road Testing of the Instrumented Tank Car.” Technical Report No. DOT/FRA/ORD-16/39, Washington, DC: U.S. Department of Transportation.

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KEYWORDS

Tank car, stub sill failures, impact test, yard operation, car coupling, draft gear, impact force, transferred energy, anvil configuration, hammer configuration.