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RESEARCH RESULTS
FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

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FULL-SCALE SHELL IMPACT TEST OF A DOT-117 TANK CAR

SUMMARY

On September 28, 2016, the Federal Railroad Administration (FRA) conducted a full-scale shell impact test of a DOT-117A100W (DOT-117) tank car at the Transportation Technology Center (TTC) in Pueblo, CO. The shell of the car was struck at the mid-length by a 297,000 pound ram car, which was equipped with a 12-inch by 12-inch impactor. Figure 1 shows the tank car in its pre-test position against the TTC impact wall.

Figure 1. Pre-test Photo of DOT-117

TTC test collected data and compared it to data from previous tests conducted with DOT-111 [1] and DOT-112 [2] tank cars, as well as the results from a finite element analysis (FEA) simulation conducted before the test took place.

The test tank car was filled to approximately 95% of its capacity with water, while the remaining 5% outage was at atmospheric pressure. The tank car's jacket has one-half inch thermal protection outside of the 9/16-inch tank shell. The pre-test simulation at 13 mph did not result in puncture of the tank, but a puncture of the simulated tank did occur at 14 mph. Based on these results, the target test speed was 13.5 mph. The actual impact occurred at 13.9 mph and generated approximately 1.9 million foot-pounds of kinetic energy.

The DOT-117 tank car's jacket experienced two vertical tears during the test, but the tank was not punctured. The impact created an approximately 52-inch indentation and a peak force of nearly 900 kips. After the test, the impact vehicle and the tank car itself rebounded from the impact wall, which created a 10 inch to 14 inch gap between the wall and the back of the tank. Figure 2 shows the tank car in its post-test condition.

Figure 2. Post-test Photo of DOT-117

A preliminary comparison between the test measurements and the pre-test FEA indicated excellent agreement between the test data and the predictions. After the test, material coupons were cut from undamaged areas of the tank car and will be subjected to tensile testing. The results of these coupon tests will be used to update the material properties in the FEA model, which will then be re-run at the actual impact speed.

BACKGROUND

FRA's aim with this study is to reduce the possibility of derailed tank cars losing lading by improving the puncture resistance of tank cars. To do so, FRA is:

- Developing standardized test methodologies that can quantify the puncture resistance of tank car designs.
- Performing a series of full-scale impact tests to examine the shell puncture resistance of railroad tank cars.

This series of tests has also examined in the past DOT-105, DOT-111 [1], and DOT-112 [2] tank cars under similar conditions.

OBJECTIVES

In this test, the impact vehicle was intended to hit the DOT-117 tank car at a speed close to the threshold speed for punctures. Pre-test FEA modeling predicted that under these impact conditions, the puncture threshold speed would be between 13 mph and 14 mph. The target speed of 13.5 mph was meant to allow the possibility of a puncture as a possible outcome of this test. The DOT-117 tank car was loaded with water (as if it were carrying its intended commodity). The five percent outage selected for this test was consistent with typical service conditions.

METHODS

Key parameters for the tested car are summarized in Table 1.

Table 1. Summary of Tank Car Parameters

Parameter	Value
Commodity in Test	Water
Tank Capacity	30,100 gallons (nominal)
Outage in Test	5%
Shell Thickness	9/16"
Shell Material	TC128B
Shell Diameter (O.D.)	120"
Jacket Thickness	11 gage
Jacket Material	AISI 1010 (assumed)
Thermal Protection	0.5" ceramic

Sensors were placed on both the moving impact vehicle and the stationary tank car. The primary instrumentation on the impact vehicle consisted of accelerometers, which gathered information on velocity and displacement. Also, the impact car used speed sensors to record its speed just prior to impact.

The tank car was instrumented internally with pressure transducers (in the air and water) and string potentiometers, while its external surface was instrumented with string potentiometers at the ends of the tank and at its support skids to measure the car's overall motion. The instrumentation is summarized in Table 2. The test was recorded by both conventional- and high-speed cameras.

Table 2. Summary of Instrumentation

Type of Instrumentation	Channel Count
Accelerometers	11
Speed Sensors	2
Pressure Transducers	12
String Potentiometers	11
Total Data Channels	**36**

An FEA-based simulation was also performed in conjunction with the test. A schematic of the FEA model is shown in Figure 3. This model used symmetry (half-length) in order to simplify and speed-up the simulations. This model featured explicit modeling of the water and simplified modeling of the air within the tank.

The water was modeled using an equation-of-state (EOS) material model and fully-integrated brick elements, and the air was modeled as an ideal gas using a pneumatic cavity. This pneumatic cavity vented to atmosphere with a prescribed flow rate versus pressure relationship if the air pressure exceeded the start-to-discharge pressure (75 psi). A membrane was defined on the interior of the tank to separate the water phase from the gas phase of the lading. The jacket was modeled using shell elements. The tank was also modeled using shell elements, except in the vicinity of the impact. The impact zone was modeled using solid elements, with elastic-plastic and ductile failure material properties defined. This combination of element type and properties would allow the team to simulate a puncture of the tank, the jacket, or both.

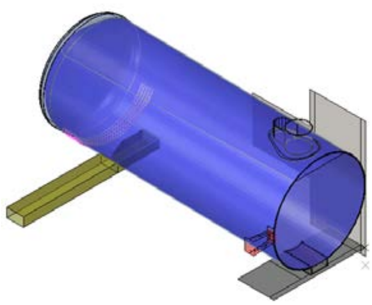

Figure 3. Half-symmetric DOT-117 FEA Model

RESULTS

The impact occurred at 13.9 mph and tore the jacket, but did not puncture the tank. The impactor had a maximum displacement of approximately 52 inches after making contact with the jacket of the tank. The peak force during the impact was nearly 900 kips. The force-displacement and energy-displacement results from the test are shown in Figure 4, as well as the initial kinetic energy of the ram. These results are the average of the five longitudinal accelerometers mounted on the impact cart, with data filtered according to SAE J211/1. [3]

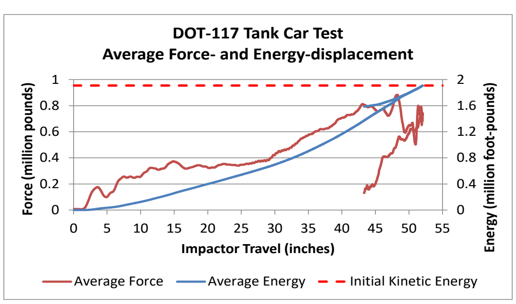

Figure 4. Force- and Energy-displacement Test Results

The force-displacement results from the test and from the pre-test FEA model were run at 13 mph and 14 mph. They are compared to one another in Figure 5. The pre-test model used a material response based on strength and ductility measurements of the plates used to build this car. Generally, there was good agreement between the test and the model over the full range of the test measurements.

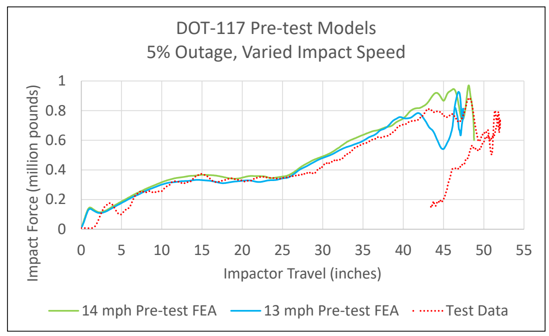

Figure 5. Pre-test FEA and Force-displacement Test Results

The average air pressure in the pre-test FEA models were compared to the air pressure measured during the test in Figure 6. Overall, there was good agreement between the air pressure in the FEA model and the test.

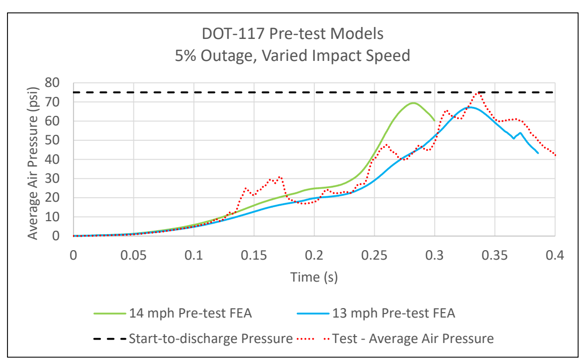

Figure 6. Pre-test FEA and Test Air Pressure Results

CONCLUSIONS

A shell impact test of a DOT-117 tank car was conducted on September 28, 2016. The impact occurred at 13.9 mph. The test outcome and measurements compared very well with pre-test finite element analysis predictions. A maximum indentation of approximately 52 inches occurred, but the tank shell was not punctured.

FUTURE ACTION

Material samples will be cut from the car and subjected to characterization tests. Their actual material properties will be used in a post-test FEA model. The test data, photos, and videos will be reviewed and further compared with the behaviors from the FEA model. The post-test FEA model will be run using actual material properties at the measured test speed.

REFERENCES

[1] S. W. Kirkpatrick, P. Rakoczy, R. MacNeill and A. Anderson, "Side Impact Test and Analyses of a DOT-111 Tank Car," Federal Railroad Administration, Washington, DC, 2015. https://www.fra.dot.gov/eLib/details/L17092#p1_z5_gD_kDOT-111

[2] P. Rakoczy and M. Carolan, "Side Impact Test and Analysis of a DOT-112 Tank Car," Federal Railroad Administration, Washington, DC, 2016. https://www.fra.dot.gov/eLib/details/L18451#p1_z5_gD_kDOT-112

[3] "Instrumentation for Impact Test-Part 1-Electronic Instrumentation J211/1_199503," ASE International, 1995. [Online]. Available: https://www.sae.org/standards/content/j211/1_199503/. [Accessed 2016].

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KEYWORDS

DOT-117, tank cars, impact testing, puncture resistance, hazardous materials, hazmat, finite element analysis, FEA