U.S. Department of Transportation

Federal Railroad Administration

RESEARCH RESULTS

FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

RR 18-06 | **March 2018**

FULL-SCALE SHELL IMPACT TEST OF A DOT-105 TANK CAR

SUMMARY

On April 27, 2016, FRA conducted a full-scale shell impact test of a DOT105A500W (DOT-105) tank car at the Transportation Technology Center (TTC) in Pueblo, CO. The shell of the car was struck at its mid-length by a 297,000 pound ram car equipped with a 12-inch by 12-inch impactor. Figure 1 shows the tank car in its pre-test position against the impact wall at TTC.

Figure 1. Pre-test photo of DOT-105

The objective of this test was to generate data that could be used to validate results from finite element (FE) simulations of the same test. The data, photos, and videos from this test will be made public to facilitate their use in future model validation activities.

The test tank car was filled to 89.4% of its capacity with water and pressurized to 100 psi, which is typical for this type of car in service. The target test speed, based on pre-test finite element analysis (FEA), was 15 mph. The actual impact occurred at 15.16 mph. This speed corresponds to an impact of approximately 2.25 million foot-pounds of energy.

After an indentation of approximately 38 inches, the tank was punctured at a peak force of approximately 1.4 million pounds. The impact vehicle and the tank itself rebounded from the impact wall after the test, leaving approximately a 30 inch gap between the wall and the back of the tank.

A review of the test measurements indicates that the impactor had slowed to less than 1 mph when puncture occurred, demonstrating that the impact speed of 15.16 mph only slightly exceeded the speed necessary to puncture this car. Figure 2 shows the tank car in its post-test condition.

Figure 2. Post-test photo of DOT-105

Pre-test FEA was performed with two different stress-strain responses, without knowing the exact material properties for this car. Pre-test modeling, which was conducted with a material that slightly exceeded the ductility requirement of TC128B, indicated that a puncture was likely to occur at a speed of 14.5 mph, while FEA with a material that greatly exceeded the ductility requirement of specification TC128B indicated puncture was likely to occur at a speed of approximately 17 mph.

BACKGROUND

FRA wishes to improve the puncture resistance of tank cars to the loss of lading that can occur during derailments. The agency would like to develop standardized test methodologies to quantify the puncture resistance of tank car designs. By gaining an understanding of the current capabilities of numerical simulations (e.g., FEA), FRA would then be able to better understand the current capabilities of numerical simulations to be used to model the dynamic and puncture responses of a tank car under shell impact conditions. The agency has undertaken a series of full-scale impact tests to examine the shell puncture resistance of tank cars. [1] [2] [3] [4]

OBJECTIVES

In this test, the DOT-105 tank car was expected to receive the impact at a speed that was close to the threshold speed for causing a puncture. Because the actual material response of the tank shell was not known before the test, the puncture range was estimated to be 14.5 mph to 17 mph (based on pre-test models).

The target test speed of 15 mph was chosen to be a speed at the lower-end of this range so that puncture was a possible outcome, but not the only possible outcome. Whether the tank was punctured or it failed to puncture, this test was supposed to strike the car at a speed close to the puncture/non-puncture threshold.

The DOT-105 tank car was loaded as if it were carrying its intended commodity, but it contained water instead. The outage and pressures selected for this test are consistent with typical service conditions.

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

Table 1. Summary of Tank Car Parameters

Parameter	Value
Commodity in Test	Water
Tank Capacity	17,360 gallons (nominal)
Outage in Test	10.6%
Shell Thickness	0.775”
Shell Material:	TC128B
Shell Diameter (I.D.)	100.45”
Jacket Thickness	11 gage
Jacket Material	AISI 1010 (assumed)
Thermal Protection	4” foam

METHODS

The moving impact car and the stationary tank car were instrumented during this test. The primary instrumentation on the impact car consisted of accelerometers, which allowed the team to derive velocity and displacement. Speed sensors on the impact car recorded its speed just prior to impact.

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

Table 2. Summary of Instrumentation

Type of Instrumentation	Channel Count
Accelerometers	11
Speed Sensors	2
Pressure Transducers	11
String Potentiometers	10
Total Data Channels	**34**
Digital Video	3 high-speed, 2 conventional-speed

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

The water was modeled using an equation-of-state (EOS) approach and a hydraulic cavity, while the air was modeled as an ideal gas using a pneumatic cavity. The mass of the water was distributed through a membrane representing the interior wall of the tank and the free surface off the water.

The jacket was modeled using shell elements and 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. By including the particular combination of element type (solid elements) and material properties (elastic-plastic and ductile failure) within the FE model, puncture of the tank and jacket could be modeled.

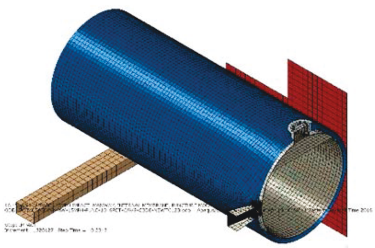

Figure 3. Half-symmetric DOT-105 FE Model

RESULTS

The impact occurred at 15.16 mph and punctured the tank. The impactor had a maximum displacement of approximately 38 inches after making contact with the jacket of the tank. The peak force during the impact was approximately 1.4 million pounds.

The force-displacement and energy-displacement results from the test, as well as the initial kinetic energy of the ram, are shown in Figure 4. These results are from the average of the five longitudinal accelerometers on the impact cart. A CFC60 filter has been used on these results. From this graph, it is clear that the impactor's energy had nearly been completely dissipated at the time of puncture.

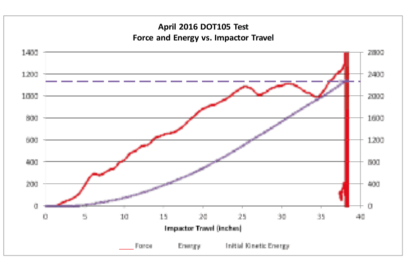

Figure 4. Force- and Energy-displacement Test Results

The force-displacement results from the test and the pre-test FE model at 15 mph are compared to one another in Figure 5. The model used a material with a ductility that slightly exceeded the requirements of TC128. There is generally good agreement between the test and the model, with the model predicting a peak force of approximately 1.4 million pounds and a displacement at puncture of approximately 39 inches.

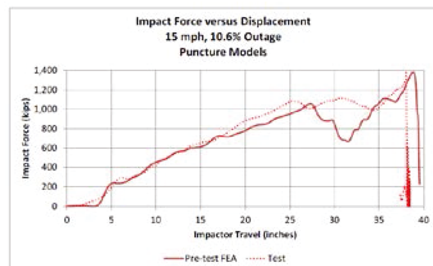

Figure 5. Force-displacement Results, Test and FEA

In Figure 6, the average air pressure in the pre-test FE model is compared to the air pressure measured in the manway during the test. Overall, there is good agreement between the air pressure in the FE model and the test.

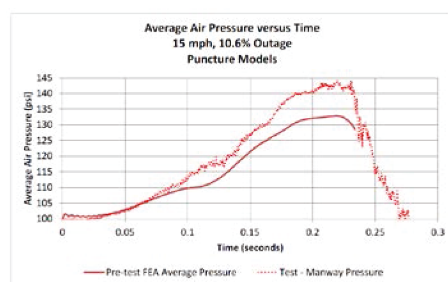

Figure 6. FEA and Test Average Air Pressure Results

CONCLUSIONS

A puncture test of at DOT-105 tank car was conducted on April 27, 2016. The impact occurred at 15.16 mph. Material samples will be cut from the car and subjected to characterization tests. These actual material properties will be used in a post-test FE model.

The post-test FEA model was in good agreement with the test results.

REFERENCES

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[3] Kirkpatrick, S.W. "Detailed Puncture Analyses of Various Tank Car Designs – Final Report – Revision 1." Applied Research Associates, January, 2010. http://www.fra.dot.gov/Elib/Details/L04126

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ACKNOWLEDGEMENTS

Finite element analysis, test planning, and documentation were performed by the Volpe National Transportation Systems Center. Test planning, instrumentation, data collection, test conduct, and documentation were performed by Transportation Technology Center, Inc.

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KEYWORDS
DOT-105, tank cars, impact testing, puncture resistance, hazardous materials, hazmat, finite element analysis, FEA