U.S. Department of Transportation

Federal Railroad Administration

RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 19-03 | **February** 2019

FULL-SCALE SHELL IMPACT TEST OF A DOT-111 TANK CAR

SUMMARY

On October 30, 2018, the Federal Railroad Administration (FRA) conducted a full-scale shell impact test of a DOT-111A100W (DOT-111) tank car meeting voluntary industry standard CPC-1232 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-111 Tank Car

The tank car was filled with water to 95 percent of its capacity. The car was sealed, but not pressurized, which is the typical operating condition for this type of tank car. Based on pre-test finite element analysis (FEA), the target test speed of 13.5 +/- 0.5 mph was chosen so that puncture was a likely outcome. The actual impact occurred at 13.9 mph. This speed corresponds to an impact energy of approximately 1.9 million foot-pounds.

The tank was punctured after an indentation of ~57 inches, at a peak force of ~900,000 pounds. Review of the test measurements showed that the impactor slowed to approximately 0.5 mph when puncture occurred, confirming the model prediction that an impact speed of 13.9 mph only slightly exceeds the speed necessary to puncture this tank car. Figure 2 shows the punctured tank car shell. The puncture initiated under a corner of the impactor and ran vertically along a circumferential weld seam.

Figure 2. Post-test Photo of the Punctured Shell

BACKGROUND

FRA has focused on evaluating the puncture resistance of tank cars in order to examine strategies to lower the potential for loss of lading of tank cars involved in derailments. FRA wants to develop standardized test and simulation methodologies for quantifying the puncture resistance of tank car designs. FRA has undertaken a series of full-scale impact tests to examine the shell puncture resistance of railroad tank cars. This series tested DOT-105 [1] [2], DOT-111 [3], DOT-112 [4], and DOT-117 [5] tank cars under similar shell impact conditions.

A companion FEA was performed alongside each test. The test results were used to validate the pre-test model, as well as for improving future finite element (FE) models.

OBJECTIVES

This test was intended to impact the DOT-111 tank car at a speed that was close to the threshold speed necessary to cause puncture. A target test speed between 13 and 14 mph was chosen so that puncture was a likely outcome.

METHODS

The non-jacketed DOT-111 tank car was loaded with water in a similar manner to its intended service conditions. The outage (5 percent) and pressure (atmospheric) selected for this test are consistent with typical service conditions. 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	31,800 gallons (nominal)
Outage in Test	5%
Shell Thickness	0.5"
Shell Material:	TC128B
Shell Diameter (I.D.)	~122.5"

Both the moving ram car and the stationary tank car were instrumented during this test. The primary instrumentation on the ram car consisted of accelerometers, from which velocity and displacement were derived. Speed sensors on the ram car recorded its speed just prior to impact. The tank car was instrumented internally with pressure transducers (in the air and water) and string potentiometers. Externally, the tank car was instrumented with string potentiometers at the ends of the tank and at its support skids to measure the car's overall motion. The test was recorded by both conventional- and high-speed cameras. The instrumentation is summarized in Table 2.

Table 2. Summary of Instrumentation

Type of Instrumentation	Channel Count
Accelerometers	11
Speed Sensors	2
Pressure Transducers	13
String Potentiometers	10
Total Data Channels	**36**
Digital Video	2 high-speed, 3 conventional-speed

FEA was performed in conjunction with the test. A schematic of the FE model is shown in Figure 3. This model used symmetry (half-length) to simplify and speed-up the simulations. This model featured detailed modeling of the water and simplified modeling of the air within the tank. The water was modeled using a Lagrangian mesh with an equation-of-state (EOS) material behavior and the air was modeled as an ideal gas using a pneumatic cavity. The tank was modeled using shell elements, except in the impact zone. 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 puncture of the tank car to be modeled while minimizing the model's run-time.

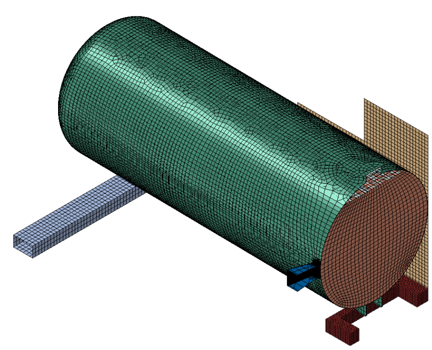

Figure 3. Half-symmetric DOT-111 FE Model

Since the exact material properties for the TC128B steel shell were not known before the test, pre-test simulations were performed using estimated TC128B behaviors. These estimates were based on TC128B materials from previous FRA-sponsored tests and data from post-accident tank car testing performed by the National Transportation Safety Board (NTSB) and Transportation Safety Board of Canada for similar cars to the tested car. The pre-test models using varied TC128 material behaviors resulted in an estimated puncture speed range of 12 to 14 mph for the expected test conditions. Thus, a target test speed of 13.5 +/- 0.5 mph was expected to result in puncture of the tank car without imparting excess energy.

RESULTS

The impact occurred at 13.9 mph and resulted in puncture of the tank. 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 taken from the average of the five longitudinal accelerometers on the ram car. A CFC-60 filter was used on these results. From this graph, it is apparent the impactor's energy nearly dissipated at the time of puncture and that the impactor rebounded from the tank after puncture.

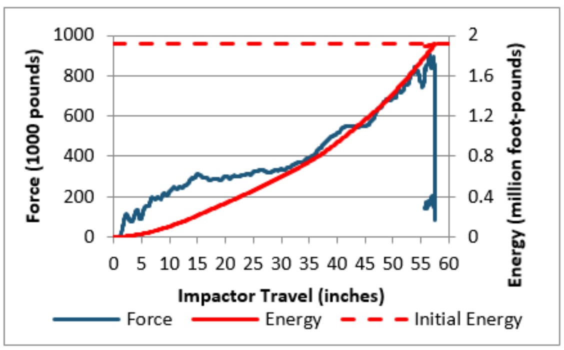

Figure 4. Test Force- and Energy-displacement Results at 13.9 mph

The force-displacement results from the test and from the pre-test FE model, run at 14 mph, are compared to one another in Figure 5. The model was run with two different estimated tank shell materials: (1) lower represents a lower-bound estimate for strength and ductility, and (2) upper represents an upper-bound estimate on strength and ductility. The two pre-test FE models' results both predicted puncture at 14 mph, which is consistent with the test result. Each pre-test FE model exhibits qualitative agreement with the test measurements, but the FE results estimated a stiffer response after roughly 30 inches of indentation.

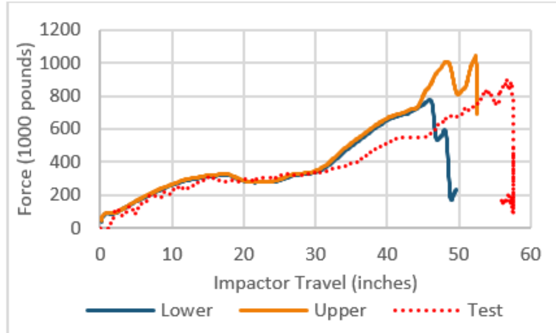

Figure 5. Pre-test FEA (14 mph) and Test (13.9 mph) Force-displacement Results

The average air pressures in the pre-test FE models are compared to the average air pressure measured during the test in Figure 6. Overall, the models exhibited a qualitatively similar response to the test measurements, but the air pressure increased more gradually in the test than in the models subsequent to 0.1 seconds.

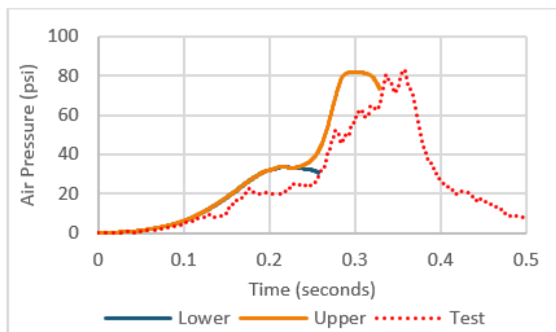

Figure 6. FEA and Test Average Air Pressure Results

Review of high-speed video from above the tank car's manway revealed that water was forced out of the car through the manway lid, nozzle cover, and pressure relief valve (PRV). While the pre-test FE models included the PRV, these models did not allow fluid leakage through the manway or nozzle closures. The effects of this leakage will be investigated using the post-test FE models.

CONCLUSIONS

A puncture test of a DOT-111 tank car was conducted on October 30, 2018. The impact occurred at 13.9 mph with a 297,000-pound ram car equipped with a 12-inch by 12-inch impactor. The impact resulted in puncture of the tank car after the impactor slowed to approximately 0.5 mph, indicating the impact speed only slightly exceeded the impact speed necessary to cause puncture of this car under the test conditions.

FUTURE ACTION

Material samples will be cut from the tank car and characterized by tensile testing. A post-test FEA will be conducted to capture the actual impact conditions including the water leakage, measured material properties of the tank car shell, and test speed. The test data, photos, and videos will be reviewed and further compared with the behaviors from the FEA model in a model validation effort. The test results will also be compared with the corresponding measurements from the previously-conducted tank car impact tests to understand the similarities and differences in the structural responses of different tank cars under substantially-similar impact conditions.

REFERENCES

[1] FRA. (2018, February). *Full-Scale Shell Impact Test of a DOT-117 Tank Car*. RR 18-03. U.S. Department of Transportation.

[2] Kirkpatrick, S. (2012, September). *Detailed Puncture Analyses of Various Tank Car Designs: Final Report - Revision 1*. U.S. Department of Transportation.

[3] Kirkpatrick, S., Rakoczy, P., and MacNeill, R. A. (2015, October). *Side Impact Test and Analyses of a DOT-111 Tank Car*. Technical Results, DOT/FRA/ORD-15/30. U.S. Department of Transportation.

[4] Rakoczy, P., and Carolan, M. (2016, December). *Side Impact Test and Analysis of a DOT-112 Tank Car*.Technical Results, DOT/FRA/ORD-16/38. U.S. Department of Transportation.

[5] FRA. (2018, March). *Full-Scale Shell Impact of a DOT-105 Tank Car*. RR 18-06. Retrieved from U.S. Department of Transportation.

ACKNOWLEDGEMENTS

FEA, 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.

CONTACT

Francisco González, III
Hazardous Materials Program Manager
Federal Railroad Administration
Office of Research, Development and Technology
1200 New Jersey Avenue, SE
Washington, DC 20590
(202) 493-6076
francisco.gonzalez@dot.gov

KEYWORDS

Tank cars, impact testing, puncture resistance, hazardous materials, hazmat, finite element analysis, model validation