U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

RR 14-30 | **August** 2014

FULL-SCALE SHELL IMPACT TEST OF A DOT-112 TANK CAR

SUMMARY

On February 26, 2014, FRA conducted a full-scale side impact test of a DOT112J340W specification tank car (DOT112) at the Transportation Technology Center, Inc. (TTCI) 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. The intent of this test was to demonstrate that the car could successfully resist a moderately high-energy impact without puncturing the tank shell. Figure 1 shows the tank car in its pre-test position against the impact wall at TTCI.

Figure 1. Pre-test Photo of DOT112

The objectives of this test were to compare the structural performance of the DOT112 car to that of a general purpose (DOT111) tank car and provide data to validate existing models. In December of 2013, FRA had conducted a companion test on a DOT111 specification tank car under similar impact conditions. The full-scale test on the DOT112 car examines the potential improvement in shell puncture resistance offered by a tank car with an increased shell thickness.

The tank car tank was filled to approximately 96 percent of its shell-full capacity with water. While the DOT112 tank car is capable of pressurization, this test was conducted without pressurizing the car. Based on pre-test finite element analysis (FEA), the target test speed was 15 mph. The actual impact occurred at 14.7 mph. This speed corresponds to an impact energy of approximately 2.1 million foot-pounds of energy. The tank experienced a maximum indentation of approximately 52 inches and a peak force of approximately 1.1 million pounds. The tank did not puncture, causing the impact vehicle to rebound. Figure 2 shows the tank car in its post-test condition.

Figure 2. Post-test Photo of DOT112

BACKGROUND

FRA has focused on improving the puncture resistance of tank cars in order to lower the potential for loss of lading of tank cars involved in derailments. FRA seeks to develop standardized test methodologies for quantifying the puncture resistance of tank car designs. FRA is performing a series of full-scale impact tests to examine the shell puncture resistance of tank cars.

OBJECTIVES

The objective of this test was to impact the DOT112 tank car at a speed that would demonstrate its ability to resist puncture during a moderately high-energy side impact. The goal was to impact the tank at a speed just below the puncture threshold, resulting in a non-puncture test. The DOT112 was not loaded as if it were carrying its intended commodity, but rather was loaded as if it were in service as a general purpose tank car. Previously, FRA tested a DOT111 tank car at a slightly lower impact speed on December 18, 2013, resulting in the puncture of that tank car.

METHODS

The test was performed using a DOT112 specification tank car. Key parameters for this car are summarized in Table 1. 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, intended to capture the deceleration of the car as it struck the tank car. Speed sensors on the ram car recorded its speed just prior to impact.

Table 1. Summary of Tank Car Parameters

Parameter	Value
Commodity in Test	Water
Tank Capacity	33,800 gallons (nominal)
Outage in Test	4%
Shell Thickness	0.618”
Head Thickness	11/16”
Shell Material:	TC128B, Normalized
Shell Diameter (I.D.)	117 7/8”
Jacket Thickness	11 gage
Jacket Material	A1011
Thermal Protection	½”

The tank car was instrumented internally with pressure transducers and string potentiometers. The pressure transducers were intended to capture the wave behavior of the water within the tank (sloshing) and the pressure in the outage. The string potentiometers were installed in the area of impact to measure both the dent depth and the vertical displacement of the tank during its impact. Externally, the tank car was instrumented with string potentiometers at the ends of the tank and at its support skids to measure the overall motions of the tank car. An additional pressure transducer was installed at the pressure relief valve to determine whether pressure within the tank car caused the valve to release during the test. 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	10
String Potentiometers	10
Total Data Channels	**33**
Digital Video	4 conventional-speed 3 high-speed

A finite element (FE) analysis was performed in conjunction with the test. A schematic of the FE model is shown in Figure 3. This model used symmetry (half-length) in order to simplify and speed-up the simulations. This model featured an explicit modeling of the water and air within the tank. The water was modeled using an equation-of-state (EOS) approach and Lagrangian elements, while the air was modeled as an ideal gas using a technique known as smoothed particle hydrodynamics (SPH). The jacket was modeled using shell elements. The tank was 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 types and properties could allow puncture to be modeled, if puncture had occurred. Following the test, the FE model was re-run at the actual impact speed.

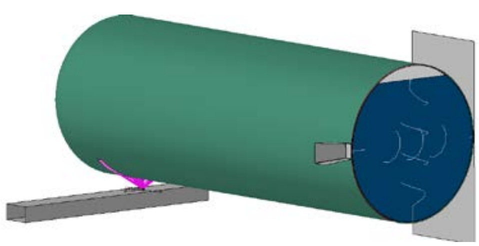

Figure 3. Half-symmetric DOT112 FE Model

FINDINGS

The impact occurred at 14.7 mph and 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 approximately 1.1 million pounds. The force-displacement and energy-displacement results from the test are shown in Figure 4. These results are taken from the average of the five longitudinal accelerometers mounted on the impact cart. Measured accelerations were filtered to Class Frequency Class 60 Hz (CFC60) according to the SAE J211-1 2007 specification.

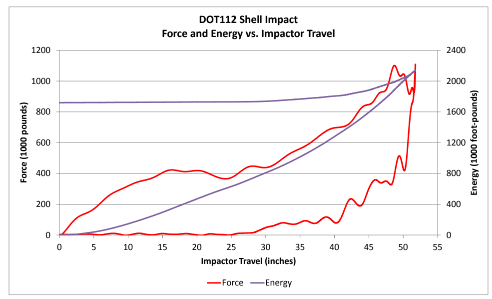

Figure 4. Force- and Energy-displacement Test Results

The force-displacement results from the test and from the FE model are compared to one another in Figure 5. There is generally good agreement between the test and the model over the full range of the test.

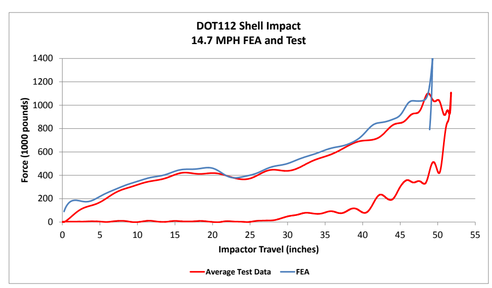

Figure 5. FE and Test Force-displacement Results

The model results in an over prediction of the peak force at the end of the impact event, as the water makes contact with the top of the tank in the model. Figure 6 shows the deformed FE model at the point of maximum displacement of the impactor.

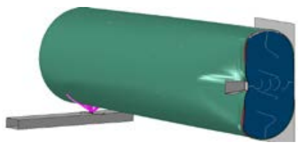

Figure 6. Deformed Shape of FE Model

Water pressure was measured at 9 locations inside the tank during the test. The average pressure at these locations from both the test and the FE model are shown in Figure 7. Overall, there is good agreement between the water pressure in the FE model and the test.

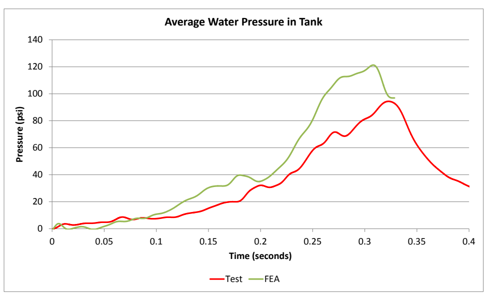

Figure 7. FE and Test Average Water Pressure Results

The detailed test results allow the FE model to be improved and used for predicting behavior in alternative impact scenarios.

CONCLUSIONS

A non-puncture test of at DOT112 was conducted on February 26, 2014. The impact occurred at 14.7 mph. The test results are in good agreement with the post-test FE model. This test successfully demonstrated the ability of the DOT112 to resist puncture under impact conditions that would have resulted in puncture of the DOT111.

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.

CONTACT

Francisco González, III
Hazardous Materials Program Manager
Federal Railroad Administration
Office of Research and Development
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