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

SUMMARY

On December 18, 2013, FRA conducted a full-scale shell impact test of a DOT111A100W1 specification tank car (DOT111) at the Transportation Technology Center, Inc. (TTCI) in Pueblo, CO. The tank car selected for this test was a jacketed DOT111 (general purpose) tank car with heating coils and sloping shell rings. The shell of the car was struck at its mid-length by a 297,125 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 TTCI.

Figure 1. Pre-test Photo of DOT111

The objective of this test was to evaluate the structural performance of the DOT111 and provide data to validate existing computer models. The car was filled to approximately 97 percent of its capacity with water and it was not pressurized. The impact occurred at 14.0 mph, corresponding to an impact energy of approximately 1.95 million foot-pounds. This test resulted in puncture of the tank car's jacket and shell. Figure 2 shows the post-test position of the tank car and the ram car.

Figure 2. Post-test Photo of Tank Car and Ram Car

The peak impact force measured during the test was approximately 960 kips. The energy to just cause puncture was calculated to be 1.45 million foot-pounds, or the energy of a 12.1 mph impact with this impact vehicle. The interior of the puncture zone is shown in Figure 3, following removal of a portion of the tank's shell post-test.

Figure 3. Post-test Photo of Interior Shell Impact Zone

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 impact tests that examine the shell puncture resistance of tank cars. This was the first test in this series.

OBJECTIVES

The objective of this test was to impact the DOT111 tank car at a speed that would result in puncture. Key results include the global force-displacement response, the mode of deformation, and the energy necessary to cause puncture.

METHODS

The tank car used in this test was built as a DOT111. This car featured a jacket, heating coils, and sloped shell rings. These features are not common to all DOT111 tank cars. The car was filled with water to 97 percent capacity and the outage in the car was planned to be 3 percent, but post-test analysis indicates it may have been closer to 2 percent. Key parameters for this test are summarized in Table 1.

Table 1. Summary of Tank Car Parameters

Parameter	Value
Commodity in Test	Water
Tank Capacity	~23,500 gallons (nominal)
Outage in Test	2-3%
Shell Thickness	7/16”
Head Thickness	7/16”
Shell Material:	ASTM A515 Grade 70
Shell Diameter (I.D.)	110 ¼” (center) 106” (head)
Jacket Thickness	11 gage
Jacket Material	ASTM A569
Insulation	4”

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 ram car as it struck the tank car. Speed sensors on the ram car recorded its speed just prior to impact. 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	8
String Potentiometers	10
Total Data Channels	**31**
Digital Video	4 conventional-speed 3 high-speed

Finite element (FE) analysis was performed in conjunction with the test. Several FE models were developed during this testing program to study various effects on the impact response, such as the influence of outage or inclusion of heating coils in the impact zone.

The model shown in Figure 4 featured an arbitrary Lagrangian-Eulerian (ALE) representation of the water, and a 2.25 percent outage modeled using a pressure-volume relationship.

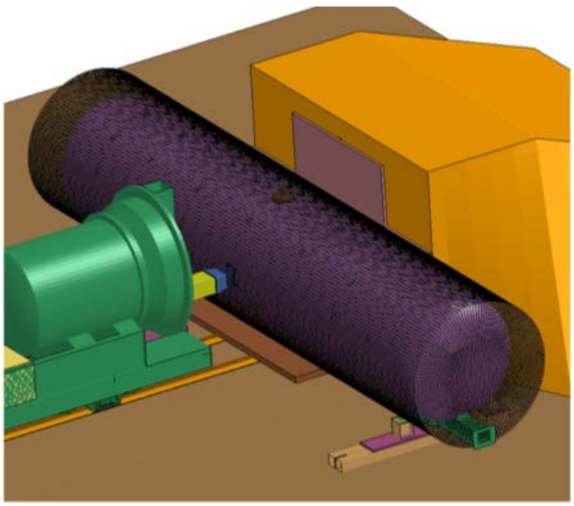

Figure 4. DOT111 ALE Lading Global Response FE Model

FINDINGS

The impact occurred at 14.0 mph and punctured the jacket and tank. The impactor had a displacement of approximately 42 inches when the puncture occurred. The peak force during the impact was approximately 960 kips. The force-displacement and energy-displacement results from the test are shown in Figure 5. 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.

The force-displacement results from the test and from the post-test ALE FE model are compared to one another in Figure 6. There is generally good agreement between the test and the model over the full range of the test, although the model predicts slightly more displacement at puncture.

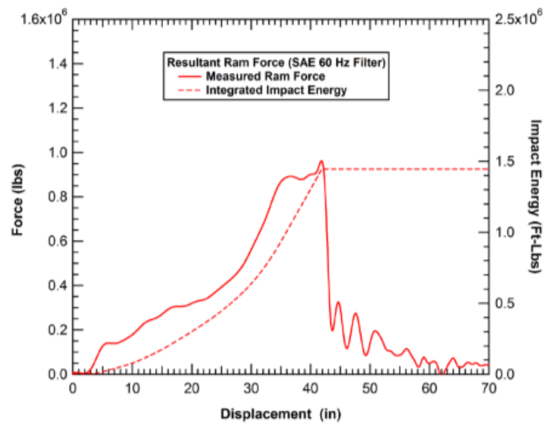

Figure 5. Force- and Energy-displacement Test Results

Water pressure was measured at 8 locations inside the tank during the test. The average pressure at these locations is compared to the pressure in the FE model in Figure 7 (next page). Overall, there is good agreement between the water pressure in the FE model and the test, although the model over-predicts the maximum pressure.

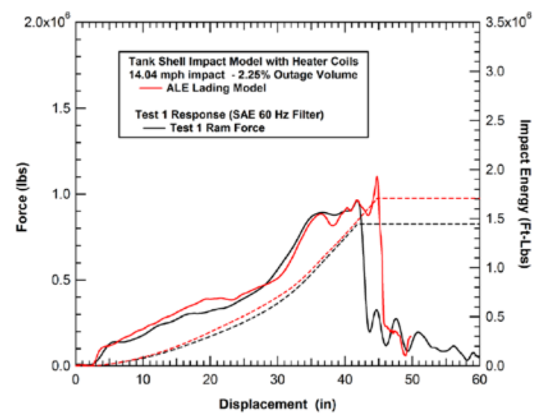

Figure 6. FE and Test Force-displacement and Force-energy Results

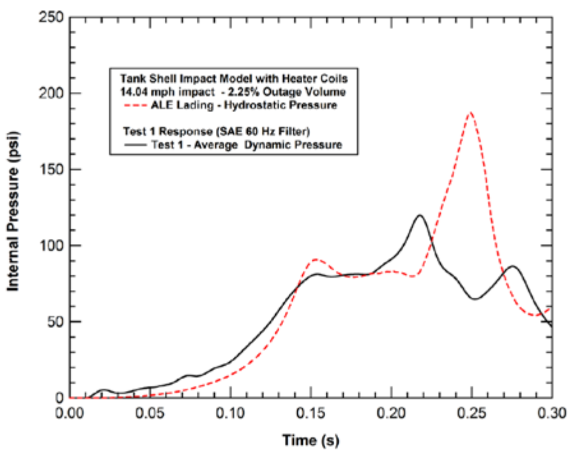

Figure 7. FE and Test Average Water Pressure Results

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

CONCLUSIONS

A puncture test of a jacketed DOT111 was conducted on December 18, 2013. The impact occurred at 14.0 mph, resulting in puncture of the tested car. The energy required to just cause puncture was calculated to be approximately 1.45 million foot-pounds, corresponding to a 12.1 mph impact from the impact vehicle used in this test. It should be noted that because the tank's impact response is non-linear, the minimum impact speed necessary to puncture the car may vary from the 12.1 mph calculated from this 14 mph impact test.

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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