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RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

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

SUMMARY

On August 1, 2018, the Federal Railroad Administration (FRA) conducted a full-scale shell impact test of a DOT-105A500W (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 6-inch by 6-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 Tank Car

An objective of conducting this test was to collect data that can be used to verify and/or validate results from finite element analyses (FEA) as part of a framework for comparing the puncture resistance of various tank car designs. The data from this test will be publicly available to facilitate their use in future model validation activities in a full Technical Report (under review).

The tank car was filled to 89.4 percent of its capacity with water. The car was pressurized to ~100 psi, which is a typical in-service pressure for this type of tank car. Based on pre-test FEA, the target test speed was set between 9.5 and 10 mph so that puncture was a likely outcome. The actual impact occurred at 9.7 mph. This speed corresponds to an impact energy of approximately 1 million foot-pounds of energy.

The tank was punctured after an indentation of 27 inches, at a peak force of ~840,000 pounds. Based on review of the test measurements, the impactor slowed to less than 1 mph when puncture occurred, confirming the model prediction that an impact speed of 9.7 mph only slightly exceeds the speed necessary to puncture this tank car. Figure 2 shows the vertical tear in the post-test shell.

Figure 2. Post-test Photo of the Punctured Shell with Jacket Cut Out

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 wants to develop the 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 has 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, and the test results were used to both validate the pre-test model and improve future finite element (FE) models.

OBJECTIVES

This test was intended to impact the DOT-105 tank car at a speed that was close to the threshold speed necessary to cause puncture. Since the actual material response of the tank shell was not known before the test, the material response was estimated using previous shell impact tests with DOT-105 tank cars [1] [2]. A target test speed between 9.5 and 10 mph was chosen so that puncture was a likely outcome.

METHODS

The DOT-105 tank car was loaded using water in a similar manner as if it were carrying its intended commodity. The outage (10.6 percent) and pressure (~100 psi) 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	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)
Insulation	4" foam

Both the moving ram car and the stationary tank car were instrumented during this test. The primary instrumentation on the impact car consisted of accelerometers, from which velocity and displacement were derived. Speed sensors on the impact 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	4 high-speed, 2 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) in order to simplify and speed-up the simulations. This model featured simplified modeling of the water and air within the tank. The water was modeled using a hydraulic cavity approach and 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 of the water. 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 that had elastic-plastic and ductile failure behaviors. This combination of element type and properties would allow puncture of the tank car to be modeled while minimizing the model's run-time.

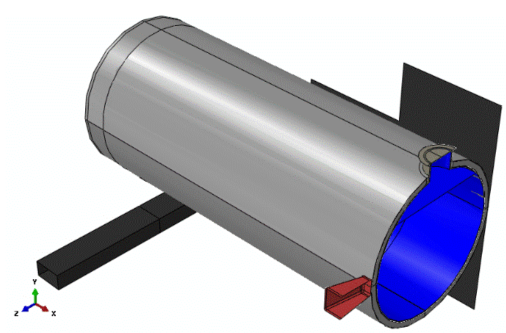

Figure 3. Half-symmetric DOT-105 FE Model

Since the exact material properties for the TC128B steel shell were unknown before the test, pre-test simulations were performed using two different TC128B behaviors based on previously-conducted tank car tests [1] [2]. Pre-test modeling using a material that slightly exceeded the minimum ductility requirement of TC128B indicated puncture was likely to occur at a speed of ~9 mph. The FEA indicated puncture was likely to occur at a speed of ~11 mph if the material greatly exceeded the minimum ductility requirement.

RESULTS

The impact occurred at 9.7 mph and resulted in puncture of the tank. The impactor had a maximum travel of approximately 27 inches after making contact with the jacket of the tank. The peak force during the impact was approximately 993,000 pounds. 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 were taken from the average of the five longitudinal accelerometers mounted on the ram car. A CFC-60 filter was used on these results. From this graph, it is apparent the impactor's energy had nearly been completely dissipated at the time of puncture and that the impactor rebounded from the tank after puncture.

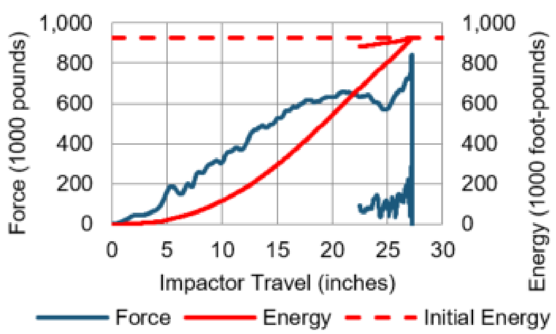

Figure 4. Test Force- and Energy-displacement Results at 9.7 mph

The force-displacement results from the test and from the pre-test FE model, re-run at 9.7 mph, are compared to one another in Figure 5. This model was run with two different tank shell materials: (1) *Mat-A* has a ductility that slightly exceeded the requirements of TC128B and (2) *Mat-B* has a ductility that greatly exceeds the requirements of TC128B. These two material behaviors are derived from samples cut from previously-tested tank cars. The two pre-test FE model results bound the test results, with the test having a displacement at puncture greater than *Mat-A,* but less than the peak displacement of *Mat-B* which did not puncture at 9.7 mph.

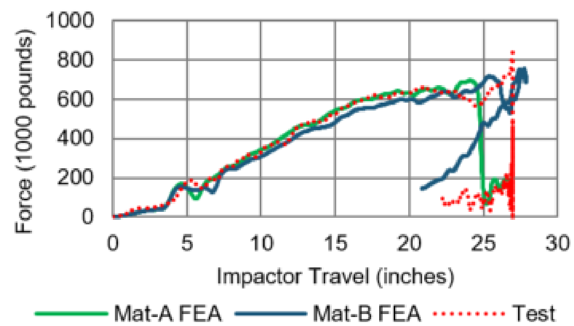

Figure 5. Pre-test FEA and Test Force-displacement Results at 9.7 mph

The average air pressure in the pre-test FE model is compared to the air pressure measured in the manway during the test in Figure 6. Overall, the air pressure measured in the test exhibits a similar response to the responses from the models after settling.

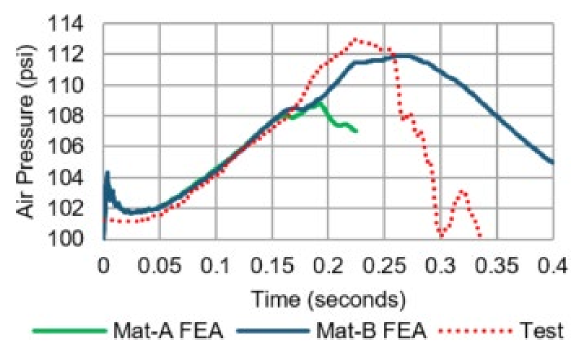

Figure 6. FEA and Test Average Air Pressure Results at 9.7 mph

CONCLUSIONS

A puncture test of a DOT-105 tank car was conducted on August 1, 2018. The impact occurred at 9.7 mph with a 297,000-pound ram car equipped with a 6-inch by 6-inch impactor. The impact resulted in puncture of the tank car after the impactor had slowed to less than 1 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 subjected to characterization tests. These 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 at the measured test speed, and the model results will be compared to the test results in an effort to validate the performance of the model. 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. Finally, the test data will be made available to others seeking to validate their own FE models of tank cars under impact conditions.

REFERENCES

[1] FRA, "Full-Scale Shell Impact Test of a DOT-105 Tank Car," RR 18-06, March 2018. [Online].

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KEYWORDS

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