U.S. Department of Transportation

Federal Railroad Administration

RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 21-24 | **November** 2021

HIGHWAY-RAIL GRADE CROSSING COLLISION TEST OF A FUEL TENDER

SUMMARY

On September 22, 2021, the Federal Railroad Administration (FRA) conducted a full-scale grade crossing impact test of a locomotive fuel tender at the Transportation Technology Center (TTC) in Pueblo, CO. The Volpe National Transportation Systems Center and Transportation Technology Center, Inc. performed the analysis, test planning, reporting, instrumentation setup, data collection, and test execution. The fuel tender was designed and constructed in accordance with the Association of American Railroads (AAR) standard M-1004 [1].

This fuel tender was a double-walled tank (i.e., tank-within-a-tank) designed to carry a cryogenic liquid (i.e., liquefied natural gas), as a locomotive fuel. The tested tender was purpose-built for this test with the structural features of a fuel tender, including all piping and valves found in normal service. The tested tender did not feature all the equipment required of a functional fuel tender (e.g., trucks, heat exchanger). The tender was coupled between two six-axle freight locomotives, as defined in the standard. The protective housing around the external piping and valves was struck by an 80,000-pound dump truck that had been modified to travel on railroad tracks. Figure 1 shows the tank car in its pre-test position at the TTC.

This test used cryogenic liquid nitrogen (LN2) as a stand-in for the cryogenic materials used as a locomotive fuel. The target impact speed was no less than the 40 mph as given in M-1004. The measured impact speed of approximately 43 mph corresponded to an impact kinetic energy of approximately 4.9 million foot-pounds.

The tender resisted the impact without tearing either the inner or the outer tank. The tender and locomotives derailed but remained upright. No leaks were observed in any of the piping following the impact, and the locomotive fuel supply valve functioned as intended during the test. Figure 2 shows the post-impact positions of the dump truck, tender, and locomotives.

BACKGROUND

The AAR developed a new standard M-1004, “Specification for Fuel Tenders.” This standard contains general requirements, functional requirements (e.g., piping, tender-to-locomotive interfaces, etc.), trackworthiness, and crashworthiness requirements. This standard contains both prescriptive design loads and scenario-based requirements to demonstrate the crashworthiness of alternative fuel (i.e., fuel source other than diesel) tenders.

FRA has been involved in the development of this standard through the AAR’s Technical Advisory Group (TAG). One of the considerations within M-1004 is protection for the piping and valves that extend outside of the outer tank (jacket) during a highway-rail grade crossing. M-1004 contains two approaches to evaluate the crashworthiness of the protective housing around the piping and valves. M-1004 defines a dynamic scenario, in which an 80,000-

pound highway truck impacts the side of the tender undergoing evaluation at a speed of 40 mph. As an alternative to this dynamic scenario, a prescriptive load case is also provided. In the prescribed load case, a defined load is quasi-statically applied over a defined area, at a defined location on the protective housing.

OBJECTIVES

The primary purpose of the test was to evaluate the performance of the valves after accident loading conditions as specified by the grade crossing collision scenario given in M-1004. The required results of the tender scenario given in M-1004 state that neither the tender's jacket nor its inner tank may be breached. Additionally, the only release of fuel (in this test, LN2) may occur through normal operation of the pressure relief valves or through piping that is outside of the jacket.

In normal operations, the tender would supply fuel to the locomotives through specific piping and valves. While the valves were situated in a protected location beneath the outer tank, the shock of the impact loading could potentially compromise the valves' ability to reclose. After the grade crossing impact test, the ability of these valves to shut-off fuel supply to the locomotives was also evaluated.

METHODS

Standard M-1004 contains minimum thickness values for the inner tank and outer jacket, as well as prescribes the materials to be used in each. Prior to the test, the inner tank was filled to approximately 47 percent by volume with LN2. The remaining 53 percent volume contained pressurized gaseous nitrogen (GN2). Because LN2 is denser than LNG, the filled tank had the same weight as if it were 85 percent full of LNG. The outage was initially pressurized to 26 psig, consistent with the initial conditions given in M-1004.

The tender was coupled to a six-axle freight locomotive on each end, with the couplers between the vehicles placed into draft. The locomotive-tender-locomotive consist was standing on a purpose-built segment of track. While rollover of the tender is not prohibited by M-1004, such an outcome was both a logistical and safety concern for a full-scale impact test. Two rollover inhibitors were constructed of ties and soil adjacent to the bolsters on the downstream (i.e., non-impact) side of the tender. These rollover inhibitors permitted the tender to roll initially in response to the impact but would restrict the tender from further roll if the tender derailed.

The dump truck was modified to include rail axles and was pushed up to the desired impact by a locomotive. The point of impact was aligned with the center of the protective housing (cabinet) surrounding the piping and valves. Key parameters for the grade crossing impact test are summarized in Table 1.

Table 1. Summary of Parameters in Tender Impact Test

Parameter	Condition in Test
Commodity in Tank	LN2
Nominal Tank Capacity (water, gallons)	29,000
Outage Volume in Test	53% (target)
Outage Pressure (psig)	~26
Jacket Thickness (inches)	3/4
Jacket Material (carbon steel)	TC128 (normalized)
Inner Shell Thickness (inches)	5/8
Inner Shell Material (stainless steel)	T304
Insulation Between Tanks	Multi-layer Insulation and Vacuum

The moving dump truck and the stationary locomotive-tender-locomotive consist were both instrumented for this test. The dump truck was equipped with accelerometers on its frame, engine, transmission, and structures adjacent to the railroad axle attachments. Speed sensors on the dump truck recorded its speed just prior to impact. The tender was instrumented with pressure transducers and temperature sensors in its piping. Externally, string potentiometers were installed between the tender's heads and ground, and between each end of the tender and the adjacent locomotive. String potentiometers were also installed within the instrumentation cabinet adjacent to the point of impact. The test was recorded using conventional-speed and high-speed cameras on the ground and drone-mounted conventional-speed and infrared cameras in the air. Drone photography was used to perform pre- and post-impact reconstruction into a three-dimensional model of the test setup.

Researchers performed a finite element analysis (FEA) in conjunction with the test. A schematic of the finite element (FE) model is shown in Figure 3. In addition to a deformable model of the fuel tender, the FE model also included a deformable dump truck (i.e., based on a publicly available tractor model) and two deformable locomotives (i.e., based on a model provided by AAR as per M-1004). The model also required development of a deformable representation of the three-piece freight trucks under the tender and a deformable track structure beneath the test consist.

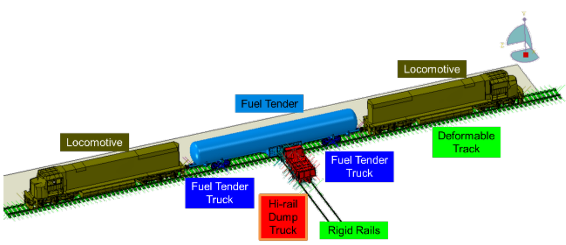

Figure 3. Grade Crossing Impact Scenario FE Model

RESULTS

The impact occurred at approximately 43 mph. The track structure supporting the tender and locomotives experienced both tie shift and rail rollover, resulting in derailment of both tender trucks and the B-end trucks of each locomotive. The tender engaged with the rollover inhibitors on both ends and remained upright. The dump truck cab was destroyed, reducing in length from 10.5 feet pre-test to approximately 2 feet post-test. The welds attaching the dump bed's hinges to the truck frame failed, allowing the dump bed to displace forward approximately 20 and 11 inches relative to its original hinge points (i.e., right and left, respectively). Figure 4 shows the post-impact dump truck and cabinet. Note that the cabinet door opened as a result of the impact, however, no piping damage occurred as a result of this behavior.

Figure 4. Post-impact Dump Truck and Cabinet

During the test, the hose supplying compressed air to the locomotive fuel supply valve was severed. This caused the fuel supply valve to automatically actuate from its open to closed positions. The valve successfully closed completely on its own, demonstrating the ability to shut-off fuel supply to the locomotives even after a grade-crossing impact to the tender. Post-impact examination of both the mechanical gauges and the test instrumentation confirmed that the tank was still holding pressure following the impact. Before the test, the internal pressure was 26 psig. The internal pressure dropped to 22 psig during the test, likely because cold liquid nitrogen splashed into the vapor space and caused it to condense. The inner tank maintained its integrity and no leaks of LN2 were found in any piping. The outer tank maintained its vacuum after the impact.

Following documentation of the post-impact positions of the test vehicles, the tender and dump truck were separated. The dump truck was pulled back from the cabinet. The post-impact cabinet is shown in Figure 5. Note the visible outline of the dump truck on the outer surface of the cabinet doors. Only minor areas of permanent deformation were observed on the cabinet and its doors.

Figure 5. Post-impact Cabinet Following Separation from Dump Truck

CONCLUSIONS

FRA conducted a grade-crossing impact test of a cryogenic fuel tender test article partially filled with LN2 on September 22, 2021. The test was run according to the scenario contained in AAR M-1004. The 43-mph impact destroyed the highway vehicle. The tender derailed but remained upright, maintained its vacuum, and did not leak LN2. The locomotive fuel supply valve functioned as intended during the impact.

FUTURE ACTION

The research team will review and compare the test data, photos, and videos with the behaviors from the FEA model for validation. An update to the pre-test FE model will occur to reflect the actual impact conditions (e.g., temperature, pressure, speed). Additional modeling updates to the track structure, suspension, and coupler behaviors may be made based on test outcomes.

REFERENCES

[1] Association of American Railroads, "AAR Standard M-1004 Specifications for Fuel Tenders," AAR, Washington, DC, 2020.

ACKNOWLEDGEMENTS

FRA would like to thank Volpe and TTCI for their assistance.

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KEYWORDS

Fuel tender, alternative fuels, impact testing, finite element analysis, FEA, hazardous materials

CONTRACT NUMBER

DTFR53-11-D-00008L