Research Results

Locomotive Fuel Tank Safety

SUMMARY

In a continuing effort to improve rail safety, reduce the number of injuries and fatalities to rail workers, and reduce the impact of train accidents on the environment, the Federal Railroad Administration (FRA), the Association of American Railroads, and the locomotive builders have worked cooperatively to review the performance and design of locomotive fuel tanks. The FRA undertook this project to further advance understanding of the performance of locomotive fuel tanks and to identify opportunities for further improvement to enhance their crashworthiness. A finite element model of a "generic" fuel tank was the basis for the analysis of three static crash scenarios and one dynamic loading case. Results of these analyses illustrate the power of this approach in determining the contribution of alternative design changes to fuel tank crashworthiness. The results also suggest several practical and cost-effective design improvements.
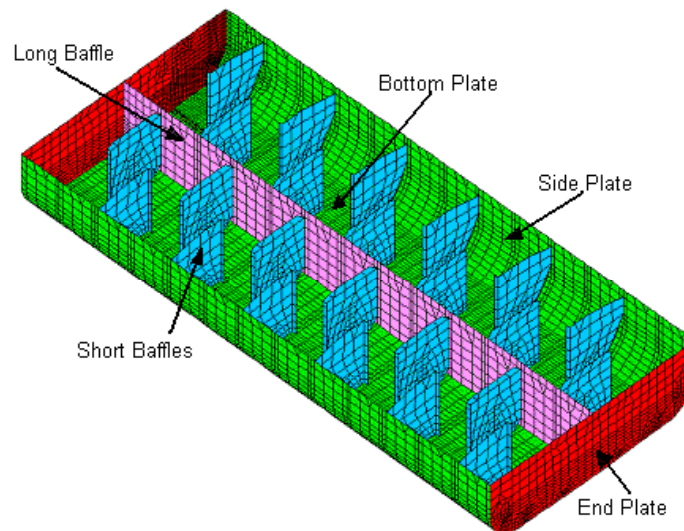
Figure 1. Generic locomotive fuel tank model, with top plate removed

BACKGROUND

Locomotive fuel tank structural integrity plays a vital role in crew safety in the event of a train accident as leaking diesel fuel poses a fire hazard. Aspects of the fuel tank that determine its structural integrity include wall or plate thickness, material type and strength, corner joint weld size, and baffle support strength.   To assure the crashworthiness of locomotive fuel tanks, the FRA, the Association of American Railroads (AAR), the locomotive builders, and the railroads have worked cooperatively to review the performance and design parameters for locomotive fuel tanks. The AAR's Recommended Practice RP-506, issued in 1995, addresses three accident scenarios by prescribing minimum combinations of wall thickness and material strength. All locomotives built since 1995 are expected to conform to this standard.

To advance the understanding of the performance of locomotive fuel tanks and to identify potential areas for further enhancing their crashworthiness, the FRA undertook an analysis of the load scenarios that Recommended Practice RP-506 addresses. Since puncture of the tank by sharp objects such as rails or other accident debris is also a possibility, this analysis also considered dynamic puncture situations that reflect "real" accident scenarios.

Modeling of Locomotive Fuel Tank

A finite element model of a "generic" fuel tank, illustrated in Figure 1, was the basis of this analysis. The model is based on design dimensions and material and/or assembly specifications provided by a large US locomotive manufacturer. This type of fuel tank was selected because many current freight locomotives use it. As such, the model represents the behavior of a large family of tanks in service today.

Each fuel tank component exhibits non-linear material behavior. To properly represent the yielding, ductility and overall limit strengths for the steel types used in the tank, the material stress and strain are represented by an elasto-plastic tri-linear relationship.

The "von Mises" equivalent stress was used as a crosscheck on material strength in local situations. Progressive displacement loading was used to simulate loading conditions. The study analyzed four scenarios, corresponding to the three situations addressed by RP-506 and a penetration case. The first three cases are simplified static loadings applied to either the tank bottom or the tank side. The fourth case is a dynamic loading example.

Minor Derailment Load

In the Minor Derailment Scenario, the locomotive derails but is still parallel to and near the rails. The fuel tank end near the derailed bogie is impacting and supported by a rail surface, with a vertical force resultant equal to half the locomotive body weight x 2g impact therefore equal to the locomotive body weight of 298,000 lb. Assuming a slight angle-down condition of the tank relative to the rail, the force is applied at one of the end plates by the railhead that is perpendicular to the end plate.

Progressive vertical displacement of 0.5 in was imposed on the rail. The model predicted that the end plate would fracture before the load level of 298,000 lb was reached. Figure 2 shows the von Mises stress contour of the fuel tank under this scenario.

As Figure 2 illustrates, the stress distribution is highly concentrated. Thus, thickening the distant baffles would not improve the structural integrity. Thickening of the bottom plate offered limited improvement in load capacity. When the corner weld was increased, performance increased significantly, but the tank still failed under the load, with the facture occurring at a larger deformation. When both a thickened bottom plate and a large weld section were modeled, the fuel tank reached a load capacity of 291,000 lb, still below the desired level of 298,000 lb.
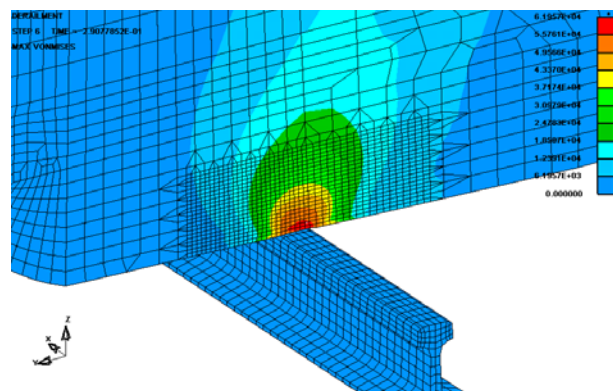

Figure 2. Von Mises stress contour of fuel tank under minor derailment loading after fractures

Jackknife Derailment Load

Under the jackknife derailment scenario, the derailed locomotive remains upright but perpendicular to and astride the tracks, and the fuel tank bottom completely supports the locomotive. The fuel tank is

supported by a rail with a vertical force equal to half the total locomotive weight x 2g impact or 415,000 lb.
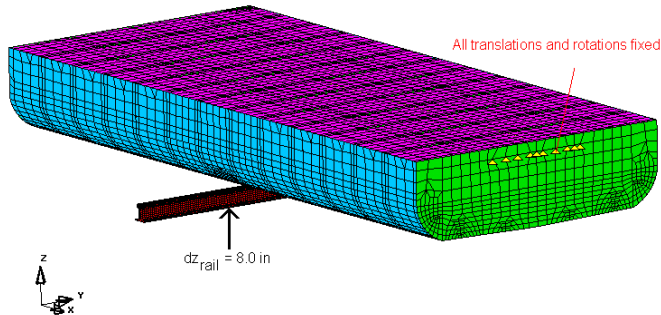
Figure 3 illustrates this scenario.

Figure 3. Jackknife derailment scenario

The analysis showed that the force reached a maximum of 400,000 lb after the fuel tank deflected 6.5 in, with the flattening of the force-deflection curve indicating that the fuel tank exceeded its loading capacity. Additional rail displacement did not further increase the reaction load, and ultimately would crush and fail the fuel tank. While the maximum stress remained below 70,000 psi, the large deformations of the baffles and bottom plate show that the tank could not support the 415,000 lb load in this scenario.

When the bottom plate thickness increased from 0.5 in to 0.625 in, the loading capacity of the fuel tank increased by 25 percent. Altering the bottom plate to 44W low allow steel only decreased the maximum load capacity by 10 percent while still enabling the tank to exceed the required load. Using the weaker steel and a thickened bottom plate, the tank exceeded the target derailment load of 415,000 lb. A 33 percent increase in the thickness of the short baffles resulted in a 5 percent increase in the load capacity of the fuel tank.

Side Bumper Loading

This scenario involved a heavy highway vehicle weighing 80,000 lb impacting the side of the locomotive fuel tank. This case represents the possibility of a truck striking a locomotive while it is stopped or transiting a grade crossing. Since the truck might not be perpendicular to the locomotive, the impact area is assumed to be 6 in high x 49 in wide load patch, which is half of the truck's 8-ft width. The horizontal static load to be applied is 200,000 lb distributed over the impact area. Figure 4 illustrates this scenario.
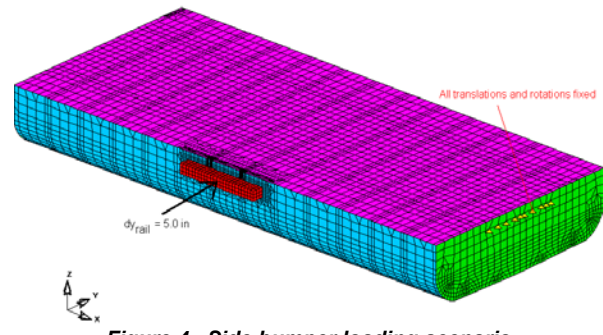

Figure 4. Side bumper loading scenario

The required load level was reached when the bumper displaced about 2.5 in into the fuel tank. The fuel tank exhibited large deformations that included buckling of internal baffles, and the stress was distributed across a large area. When less expensive 44W low-alloy steel and standard mild steel were used for the side plate, load capacity dropped 10 percent. Reduction of the side plate thickness by 10 percent increased the lateral deflection but the tank still reached the desired load of 200,000 lb.

Dynamic Penetration Conditions

Actual accidents can involve penetration of the tank end or sidewalls but no dynamic load conditions yet exist in regulations. Two hypothetical cases provided a means to assess penetration resistance. The first case involved a moving rail section traveling in-line and impacting the end plate of the fuel tank. The other involved the same moving rail section impacting the sidewall of the fuel tank at a 45° angle.

The model predicted that the end wall would sustain the impact of the moving rail at speeds up to 50 mph. At 50 mph, the maximum stress level reached 40,000 psi, but the plastic strain did not reach 22 percent so no rupture occurred. When the end wall thickness was reduced by 20 percent, rupture occurred at 40 mph at the point of impact.

With regard to the angled sidewall impact, the tank did not rupture, even with a 50 mph impact. Overall, the maximum stress and reaction forces were lower in the angled sidewall impact than in the end wall penetration scenario. Additional parametric studies, similar to those for the penetration scenarios, found that a sidewall impact at 40 mph would cause the tank to rupture if the sidewall were reduced to 0.3125 in.

Design Improvements

Results of the analyses suggest that the simulation and analysis methods are a useful aid for

understanding tank behavior under severe static and dynamic load conditions.
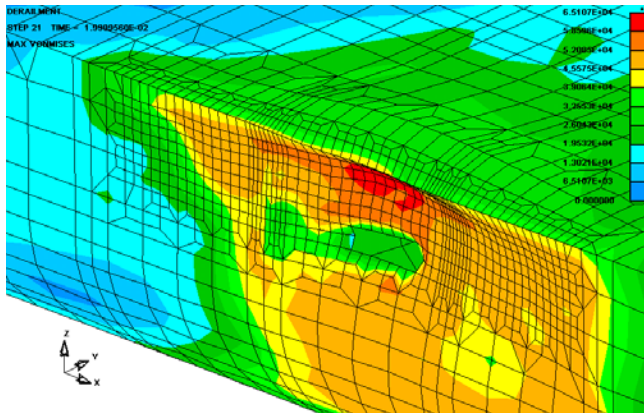
Figure 5. Von Mises stress contour of fuel tank with side wall thickness of 0.3125 in under angled side wall impact

The results described above also suggest the following practical and cost effective design improvements:

- To sustain the minor derailment situation, the *end plate* should be at least 0.75 in thick and made of high-strength steel such as Cor-Ten steel. In addition, corner welds should be added to the bottom plate for reinforcement.
- To sustain the loadings of the jackknife scenario, the *short baffles* could be increased to 0.25 in. Alternatively the *bottom plate* could be made of 0.5 in Cor-Ten steel or a less expensive steel at 0.625-in.
- To sustain the side bumper loading, the *side plate* must be at least 0.45 in if Cor-Ten steel is used. Less expensive lower strength steels can be traded off with plate thickness and internal baffle strength.
- In the case of end wall penetration, failure could occur at a tank corner, due to crumpling, rather than at the point of impact. In this scenario, fuel tank integrity could be preserved up to 50 mph with end plate strength traded against corner weld reinforcement.

The methods used in this study have applicability for a wide range of additional scenarios and tank designs. As such, they provide a means for designers to assess alternative fuel tank characteristics.

CONCLUSIONS

The research work has demonstrated a modern analysis approach to fuel tank design and approval in order to meet the current design standard RP-506. The work has also demonstrated that the design can be optimized for safety and manufacturing costs. The work shows how fuel tank design can be improved. No specific recommendations are offered for changes to the current design requirements at this time-only an approach to analysis.

WANT MORE INFORMATION?

[1] Kokkins, S. & Kwok, P. *Evaluation of Concepts for Locomotive Crew Egress*. (to be published) Washington, DC: Federal Railroad Administration.
[2] Kokkins, S, Kwok, P., Punwani, S.K. & Tsai, N.T. Evaluating Locomotive Fuel Tank Safety and Crashworthiness in *Proceedings of IMECE 2002*, New Orleans, November 2002.

ACKNOWLEDGMENTS

CONTACT

Mr. John Punwani
Federal Railroad Administration
Office of Research and Development
1120 Vermont Avenue - Mail Stop 20
Washington, DC 20590
Tel: 202-493-6369
Fax: 202-493-6333
John.Punwani@fra.dot.gov