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Maximizing Safety and Weight

A White Paper on 263K+ Tank Cars

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On September 9, 1970, in effort to reduce the risk associated with large-capacity tank cars transporting a hazardous material, the Federal government published a final rule that set the maximum gross rail load (GRL) and capacity for all tank cars constructed on or after November 15, 1971.[1] The final rule prohibited the construction of any tank car after that date exceeding 263,000-pounds GRL or with a capacity greater than 34,500 gallons. The preamble to the final rule focused on four essential safety areas that demanded the need for weight and capacity limitations:

- Probability of a tank puncture associated with the linear increase of kinetic energy and mass;
- The increased human health and environmental risk associated with the potential release of greater quantities of the material;
- Weight-related stress failures in track and equipment; and
- The design of the underframe.

During the next two decades, the growing demand for product and improvements in component material and track related structures compelled the railroad industry to develop new GRL standards. On November 21, 1994, the Association of American Railroads issued Circular Letter c- 8287, *Implementation of AAR Standard S-259 for Freight Cars with 286,000 lb., Gross Rail Loads*. The circular became effective on January 1, 1995. The S-259 standard outlined the requirements for car components and design load factors. Under the standard, the design of the car body must be based on a GRL of 286,000-pounds . Further, standard weight related design loads for 100-ton cars used for fatigue-design criteria must be multiplied by 1.09, with the exception of longitudinal fatigue-design loads. The standard also established minimum equipment requirements for brakes, bearings, axles, wheels, draft systems, springs, and trucks. While most tank cars built in the 1990s comply with the AAR S-259 standard, the majority of the tank cars do not have markings (stenciling) to indicate it. Such tank cars are marked and certified to a GRL of 263,000-pounds.

Recent demands for an increase in GRL have prompted several tank car owners and shippers to ask for an exemption or permit from Federal law. Larger tank cars benefit owners and shippers through fleet reduction and asset utilization and carriers through reduced handling. As of today, the United States issued two GRL exemptions (both for 270,000-pounds GRL), and has one exemption pending for approval for 286,000-pounds GRL. Canada has issued two permits for a 286,000-pounds GRL and one permit for a series of tank cars at a GRL of 270,000-pounds GRL. Transport Canada is also considering two permits for molten sulfur service. As a note, in the United States tank cars marked to an AAR

[1] 35 FR 14216

specification are not subject to the GRL limitations in 49 CFR 179.13 and such tank cars may operate above 263,000-pounds GRL. For example, shippers of molten sulfur are operating tank cars built to the AAR S-259 standard and having a 286,000-pounds GRL.

The growing interest in increased GRL and the demands for safety have prompted the government to review the historical makings of the Federal rule and to place it in perspective with current technology, materials, and the operating environment. Based on this review and the need to ensure for the optimal mix of safety and weight, it is the opinion of the FRA and Transport Canada that applications for an exemption or permit consider the following safety-related items for both new construction and for existing equipment:

1. Puncture resistance

For any given speed, tank cars exceeding 263,000-pounds GRL have greater kinetic energy than their 263,000-pounds GRL counterparts. This additional energy increases the puncture vulnerability of the tank structure upon impact with another object (broken rail, couplers, and other tank cars and car components). The preamble to the 1971 rule stated that inadequate consideration had been given in current design practice to the selection of material thickness to compensate for the greater kinetic energy levels encountered as tank car weight increases. As train operating speeds increase, this kinetic energy increases exponentially. Based on the above considerations, applicants for an exemption or permit must demonstrate, by a quantifiable engineering analysis, using an industry accepted procedure, that a tank car built above a 263,000-pounds GRL has increased head and shell resistance to puncture relative to a baseline tank car built to 263,000-pounds GRL.[2] Applicants must achieve this by improving the puncture resistance of the baseline tank car such as increasing the head and shell thickness, by using different materials of construction, or by modifying design features.

2. Controlling longitudinal loading

Aside from accidents and incidents that occur from time to time and which damage railroad equipment, there are other types of events that result in high dynamic or quasi-static loads applied through the coupler at the time of coupling, during switching, and during train operation.

Numerous examples of these severe impact events or high-train load events have been identified in correspondence to the AAR or have appeared in Tank Car Committee dockets during the recent years. Most of these events could be categorized as extreme in that sill separation, tank failure, or severe distortion of the tank occurred making the event nearly impossible to miss or hide.

There is also concern about a similar category of such events of slightly lower magnitude which result in stresses to the structure that exceed the design limits, but are not severe enough to produce obvious defects to the structure. The industry needs to develop means to identify these types of events.

In an effort to regulate and control some of the best known factors that contribute to these high-load events, Transport Canada is introducing new requirements as part of its proposed clear language

[2] The baseline car is one designed to the minimum tank head and shell thickness authorized for the commodity based on the use of ASTM A516 Grade 70 steel.

regulations that would render illegal relative coupling speeds in excess of 7.5 mph during switching. If a rail car couples into a tank car or a tank car couples into another railcar at speeds greater than 7.5 mph, a structural integrity inspection of the tank would be required. A structural integrity inspection would also be called for at lower impact speeds when the ambient temperature is at or below -25 degrees Celsius (-13 degrees Fahrenheit). Transport Canada chose this speed after extensive research performed in Ottawa involving the determination of peak coupler loads generated from impacts of tank cars of varying mass, speed, and number.

Although speed is not the ultimate criteria in determining the severity of a dynamic event, it is the easiest to measure. Ideally the load generated by the impact, or in-train dynamics, should be the parameter that "triggers" an alert.

Rather than using speed as a measure for determining the severity of a dynamic event, FRA is considering research to help develop an "overload detection device" as an integral part of a draft gear. The device would detect dynamic loads near or exceeding the design limits for a tank car. Much like a "telltale" indicator, an overload detection device would provide objective evidence that a condition exists that requires an investigation into the structural integrity of the tank car. In addition to FRA's research, the AAR Operating Environment Task Force, operating under the auspices of the Tank Car Committee is exploring the feasibility of instrumenting and continuously monitoring tank cars for the same purpose using accelerometers and / or strain gauges.

Due to the increased number of 286,000-pounds GRL rail cars in service and longer trains, the magnitude of in-train and yard impact loads is likely to increase. With increasing loads, there are two issues of concern: (1) high-magnitude loads, discussed above, that may result in sudden crack nucleation, rapid crack propagation, or even failure of structurally significant items, such as a high-speed yard impact that results in sill separation; and (2) low-magnitude loads that are associated with crack growth by fatigue. To address these two issues, applicants must select an optimal cushioning system effective in minimizing the detrimental effects of both types of loads.

3. Structural-worthiness

Tank car design involves engineering calculations and tests aimed at demonstrating that the tank car can withstand certain specified static, dynamic, and fatigue producing environmental loads without any adverse effect on the structure. Aside from basic pressure loads (resulting from the pressure of the contents) or weight related loads (such as jacking), there are other specified loads that are independent of the gross weight that must be used with appropriate safety factor to design the tank cars. These loads, essentially applied through the couplers, were mandated more than a decade ago before the advent of the 286,000-pounds GRL car. The question then arises as to whether they should be factored up to take into account the increased gross weight.

For our basic reasoning, we start with a given train length and a certain number of rail cars and a certain routing and speed for the train. Without varying any of the above, we now compare the coupler loads (draft, buff, vertical up and down) generated when running this train with rail cars weighing 263,000-pounds GRL against running this train with rail cars weighing 286,000-pounds GRL. It would appear reasonable to expect the coupler loads to increase with increasing weight.

The question would then be to determine by what factor these coupler loads increase. Without a study to this effect it was deemed conservative to require that the REPOS loads used for fatigue calculations be factored up in a linear way by a factor corresponding to the gross weight increase, that is 286 / 263 or 1.09.

Going a step further and for the reasons mentioned above any request for an increase in GRL requires that the applicant addresses the rationale followed for the static coupler horizontal and vertical design loads they used. The applicant should also address the design impact load selected (e.g. 1,250,000 lbs., or other) taking into consideration the type of draft gear on the car.

To verify structural-worthiness, the applicant must provide test evidence demonstrating that the tank car design has been successfully subjected to the representative structural, static, and impact testing prescribed in M-1001, Chapter XI

4. Track-worthiness

Tank cars, by design, have relatively high torsional rigidity compared to other types of railcars. This high rigidity combined with a higher GRL warrants the use of so-called “advanced” truck designed to carry the increased load while maintaining improved track-worthiness characteristics. The interaction between the rigid tank car body, higher GRL, and trucks could cause truck warping, undesired large amplitude oscillations such as hunting, and accelerated wear within truck components. The result is a higher potential for derailments. To verify vehicle performance, applicants must provide analytical, and as necessary test evidence, demonstrating that the vehicle characteristics of the tank car body and the suspension are in accordance with AAR M-1001, Chapter XI, Sections 11.7, 11.8, and Appendix A.

5. Service equipment

5.1 Valves and fittings

A review of the FRA / AAR accident statistics clearly shows that service equipment without protection has a greater likelihood of damage in an accident than those that have protection. As an illustration, the data show that for every 100 Class 111A tank cars without top-fitting protection involved in an accident, 12 release a product through a top fitting. This compares unfavorably to Class 105A tank cars having top-fitting protection where only 2 for every 100 involved in an accident release product. Another way to quantify the benefits of top-fitting protection is through a source distribution of accident-caused releases. A source distribution of accident-caused releases shows that damaged top fittings account for more than 50 percent of the total number of releases, although the amount of lading loss is about 1 / 3 of that from other sources.

It is without considerable investment then, that the National Transportation Safety Board recommended improvements in fitting design to ensure that closure fittings maintain their integrity in accidents typically survivable by the rail tank.[3] In addition to the Safety Board, the FRA and TC also have voiced their concern with respect to the vulnerability to damage of service equipment in accidents. While not

[3] “*Head-on Collision Between Iowa Interstate Railroad Extra 470 West and Extra 406 East with Release of Hazardous Materials near Altoona, Iowa on July 30, 1988*” (NTSB / RAR-89-04).

totally as a result of the government's concern with respect to the frequency of top-fitting damage in accidents and the quantity of product lost, the industry has adopted standards for the protection of top discontinuities (See AAR's Tank Car Manual Section E10.00). As a matter of clarification, while the industry publishes a standard for top-fitting protection, there is no mandate to apply it to any tank car or commodity combination. To reduce the consequences of an accident, applicants for an exemption or permit must demonstrate that all top and bottom discontinuities have adequate protection.

5.2 Pressure relief devices

In addition to the vulnerability of top-fittings to damage in an accident and the subsequent release of product, pressure relief devices are also vulnerable to pressure surges and account for a large number of product releases. Over the last decade, Federal and industry research dollars have targeted improvements in the design of and improvements to non-reclosing pressure relief devices (safety vents). Improvements include dampening hydraulic pressure surges to the rupture disc by means of baffles and an increase in the burst pressure of the disc. Despite these improvements, the rupture disc simply remains a fuse that once broken, requires replacement. As an example, during the 1991 through 1996 period, the RSPA / AAR statistics for non-accident releases show 1,713 disc failures.[4] Recent changes in Federal law that requires a higher-rated burst pressure for the rupture disc and the industry's efforts to require surge baffles and to report incidents through its Non-Accident Release Program have caused a downward trend in the number of such releases. However, any such reduction may not outweigh the benefits derived from the use of a reclosing pressure relief device (safety valve) having a start-to-discharge pressure setting sufficient to prevent it from functioning during a pressure surge from yard impacts and in-train forces.

The potential for railroad employee injury is high if a rupture disc in a non-reclosing pressure relief device fails near the employee. To compound this issue, there is no telltale indicator, other than product splashing out of the tank car, to reveal that a disc has failed. It is probable that a failed disc will not be discovered in transit until an employee witnesses a release of a product, is a victim of a release of product, or sees product on the tank car.

For these reasons, applicants must use reclosing pressure relief devices for any tank car operating above 263,000 pound GRL, unless the applicant can demonstrate that the use of such a device will decrease the level of safety below that afforded by a non-reclosing pressure relief device.

6. Service reliability and maintenance management

Maintenance management of an asset requires car owners to develop a quantitative approach to maintaining the minimum level of performance of each component on a tank car. Knowledge of the environment and the behavior of the structure within the environment, e.g., fatigue, corrosion, wear, is essential to identify appropriate areas of inspection and the inspection method. A basic understanding of the failure mode of a component and the elements that contribute to the failure mode of the component are essential to the preparation of an adequate life-cycle maintenance program. The plan should be seen as a living document intended to be periodically improved and amended based on continuous

[4] During the same period, there were 461 occasions where a reclosing pressure relief device functioned.

monitoring and assessment of the results of in-service inspections and other non-routine data and a comparison against expected or predicted performance levels.

Recently, the AAR issued Casualty Prevention Circular CPC-1098, "*Life Cycle Inspection Program*," for public comment that provides guidance on the development of a maintenance program for managing a fleet of tank cars.[5] The circular requires the development of a manual that identifies the required inspection items, inspection methods, acceptance criteria, and inspection frequencies. In addition, the circular letter requires written procedures (work instructions) that ensure that the work on the tank car conforms to Federal, industry, and the tank car owner's requirements.

The applicant for an exemption or permit must provide documented evidence that the builder and tank car owner have initiated development of such a manual and a program to analyze inspection results. Before the first renewal of the exemption or permit, the applicant must have completed and filed the manual with the Federal Railroad Administration and Transport Canada.

For more information on reliability, see the following materials:

Handbook of Reliability Engineering and Management, W. G. Ireson, McGraw Hill, 1996;

Reliability-Centered Maintenance, F. S. Nowlan and H. F. Heap, Final Report for Contract MDA 903-75-C-0349, Office of Assistant Secretary of Defense, Washington, D.C., 1978;

Reliability-Centered Maintenance, A. M. Smith, McGraw Hill, 1992;

Reliability-Centered Maintenance, J. Moubray, Industrial Press, 1997;

Reliability in Engineering Design, K.C. Kapur and L. R. Lamberson, John Wiley & Sons, 1977.

Risk-Based Management: A Reliability-Centered Approach, R. B. Jones, Gulf Publishing Company, 1995; and

SAE Standard JA 1011, Reliability-Centered Maintenance

The industry and the government have expended considerable research on DTA to support maintenance management efforts. Although a DTA is not required to receive an exemption or permit, the applicant should plan to initiate an analysis of the tank car structure in accordance with the guidelines provided by Southwest Research Institute to support the portion of a life-cycle inspection and maintenance program related to the detection of cracks.

7. Maximizing safety and weight

Current industry practice is to design railroad equipment at pre-established GRL criteria. For most rail equipment, the pre-established threshold provides economies and standardization. On the other hand, tank cars transport products with varying degrees of hazards, with varying density, and various physical states. For these reasons, applicants must evaluate the increased GRL of a tank car against the risk posed by the potential quantity and form of the product released. When evaluating an application for an exemption or permit, the government will compare the level of safety introduced by the proposed increase in GRL against the level of safety provided by the current regulation.

[5] See AAR CPC-1098, September 7, 1999.

Any request for an increase in GRL requires the applicant to address and demonstrate that there is at least an equal of safety of transporting more product in a given tank car. Applicants must show risk minimization by addressing all the elements outlined in this paper.