QUANTITATIVE SAFETY EVALUATION OF THE VALVE GUARD USED FOR TANK VEHICLES

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Abstract - Tank vehicles are widely used in the industries for transporting liquid cargos. A valve guard is usually a necessary device mounted on the vehicle for protecting the valves from the damages possibly caused by the transportation and operation of the tank and the vehicle. This research intents to assessing the safety and reliability of valve guard used for tank vehicles via a quantitative approach. A numerical model with finite element method is established in the research, and numerical analyses are performed with consideration of various loading conditions reflecting the operation of the tank and the tank vehicle. The tank design and manufacturing follow the corresponding ASME codes and safety assessment is conducted as per the regulation CSA B620, specified for highway tanks and TC portable tanks for the transportation of dangerous goods. The research results provide the engineers and researchers a methodology and a practically sound technique for quantitatively evaluating the safety of the valve guards used for transporting liquid cargos which can be hazardous in practice.

Keywords - Safety Assessment, Finite Element Analysis, Tank Vehicle Valve Guards, Damage Protection, CSA B620, Tank Vehicles, Pressure Vessels

I. INTRODUCTION

For transporting liquid cargos, tank vehicles play an important role. The liquid cargos carried by the tank vehicles can be hazardous or flammable in many cases, especially for transporting compressed gases. Many valves are commonly mounted on the tanks of the vehicles and they therefore need to be properly protected, for obvious safety reason. The valve guard, a structure usually presented at the bottom of a tank, is hence a necessary device equipped with the tank and vehicle. The tanks on the vehicles are pressure vessels which are well governed by ASME codes especially in the jurisdictions of North America. Some standards, such as CSA B620 in Canada, can be used for designing and manufacturing the valve guards. However, in design practice, safety assurance of the valve guard may still be a concern due to the geometry complexity of the valve guards and loading conditions for serving different tanks and vehicles or for meeting different operation requirements. More significantly, the load considered in the standards are commonly steady state loads rather than dynamic loads which are usually the case in the tank vehicle operations. Another drawback of existing studies is that the existing studies were performed with low aptitude of force, hence it cannot be used as a guideline for this kind of analysis with cargo tanks.

Limited works are found for quantitatively studying the design, safety and reliability of the valve guards of the tank vehicles. In these limited works, the loads applied on the valve guards are merely based on steady state loading conditions [1]. Some studies based on impact loading conditions, but the guard dimensions considered are small as these are based on passenger vehicles instead of cargo tank vehicles used in industries for carrying dangerous or hazardous liquids [2]. An approach that meets the standards or jurisdictional requirements and can be used to systematically and quantitatively evaluate the safety and reliability of the valve guards equipped with the cargo tank vehicles is therefore in demand and has significant value in industrial applications.

II. METHODOLOGY

The present research focuses on the evaluation of the valve guard mounted on TC 331 tank, a highway tank for transporting liquefied compressed gases such as LPG and NH3. A typical tank and associated tank vehicle is selected for demonstrating the methodology of the present research. This tank has a design pressure of more than 690 kPa (100 psi) and less than 3450 kPa (500 psi). The material used to construct the vessel and guard is either steel or aluminum. [3]

Figure 1 shows the sketch of TC331 tank, which mounted on a truck trailer. The valve guard is presented at the bottom of the tank and is responsible to protect the valves and fittings which may contain hazardous or dangerous liquids. The governing body for these types of transportation tanks is Canadian Standards Association (CSA) and the regulations used for this analysis is taken from CSA B620: Highway tanks and TC portable tanks for the transportation of dangerous goods.

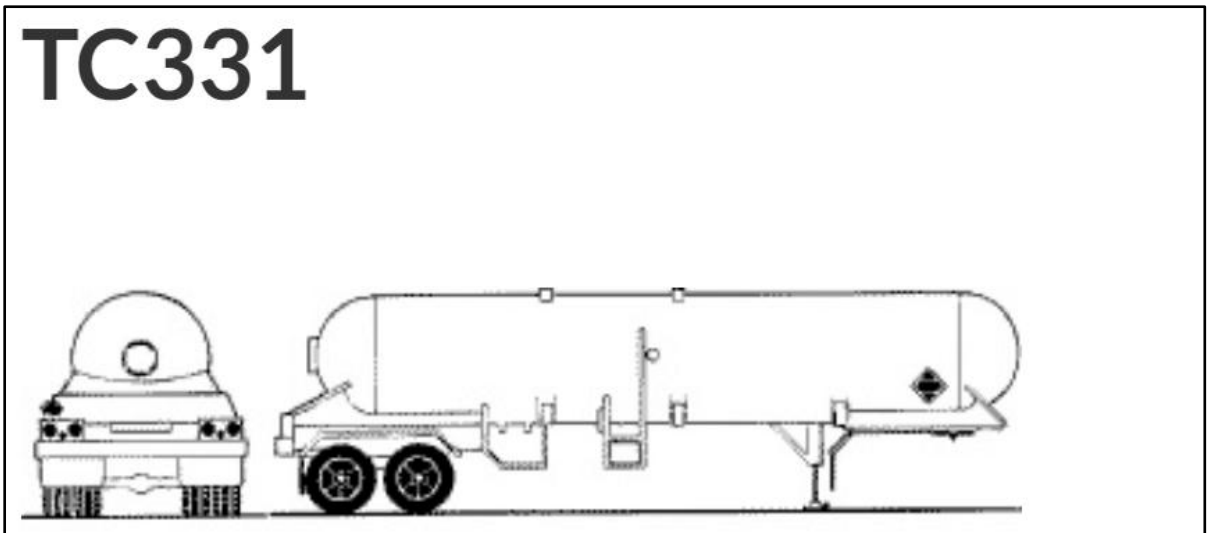


Figure 1: A schematic drawing of a TC 331 tank

To better describe the methodology proposed by the present research for evaluating the safty and reliability of the valve guard considered, a flowchart is prepared as shown in Figure 2, which outlines the framework of the evaluation.

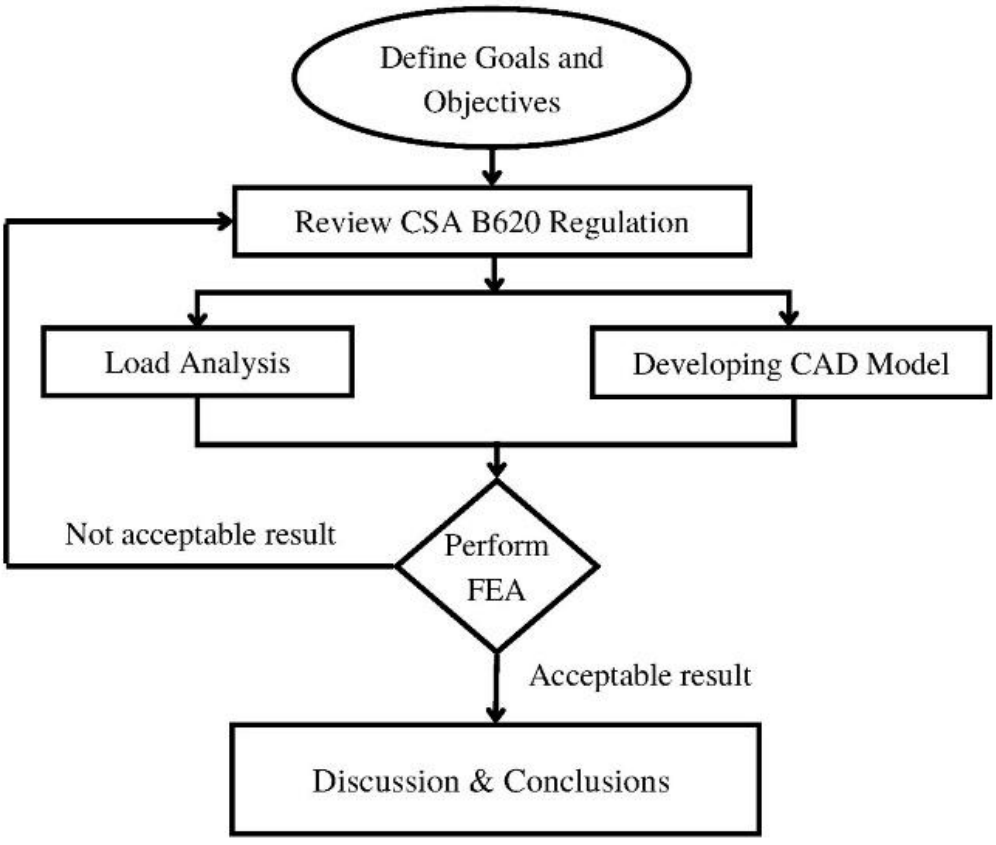


Figure 2: Framework of the study

Load Analysis

The loading on the guard is to applied to simulate the behavior of the guard in the event of a collision or an accident of the tank. As per the CSA B620 regulations [4], the determination of the weight of the tank when it is filled with the hazardous goods has to be done first. The tank in this study has two units, one with the capacity of 10,174 USWG and other with the capacity of 8,886 USWG. As a worst-case scenario, this report is generated with considering the capacity of the vessel as 10,174 USWG. The vessel is filled up to 85% of total capacity and the product density is given as 5.2 lbs/USWG, hence weight of the product can easily be calculated as 45,000 lbs. The dead

weight of the tractor & axle weight is given as 19,500 lbs. Therefore, the total weight of the tank when filled with the material comes out to be of 64,500 lbs.

III. COMPUTER AIDED DESIGN MODEL

A typical valve guard mounted at the bottom of the tank is selected and a CAD model is generated for this research. To reduce the running time of the model and to ease the meshing process, the model is divided into two parts as per the ZX symmetrical plane, which will not have any other adverse effect in the results. Figure 3 shows the symmetric plane as well as the half model.The whole base frame is imported in the assembly module and all the remaining parts fits on the frame, resulting in the final model as presented in the Figure 3. The materials of the guard is carbon steel with density 0.2836 lbm in^{-3}, ultimate strength 66,717 psi, modulus of elasticity 2.9008e+007, and Poisson's Ratio 0.3.

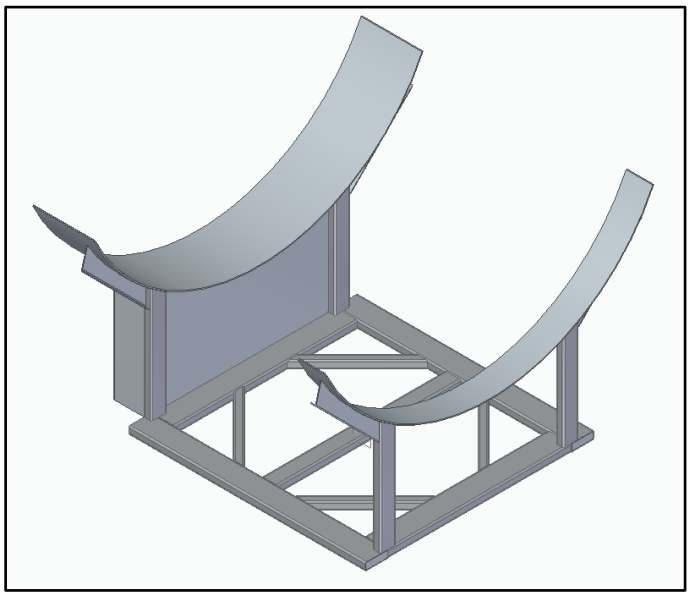


Figure 3: A model of typical valve guard for tank vehicle

IV. FINITE ELEMENT ANALYSIS

Steady-State Structural analysis

The FEA is divided into two parts. In the first part the steady state analysis is performed, which has two sections: side and bottom part. The regulation states that the front and rear part of the guard is being protected by the truck's chassis and suspension system. In next section, the static analysis of the side part is discussed.

A CAD model is established by implementing ANSYS design modeler. To reduce the running time of the model and to ease the meshing process, the model is divided into two parts as per the ZX symmetrical plane, which will not have any other adverse effect in the results. The Figure 4 shows the Symmetric plane as well as the half model. The meshing of the model is also shown in the figure.

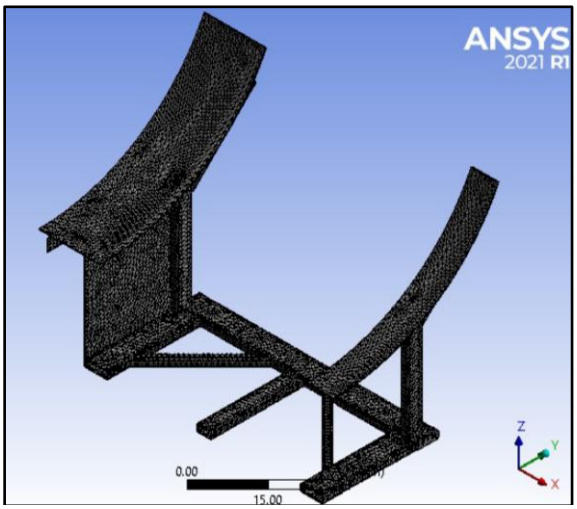


Figure 4: Symmetry region ZX plane with meshing

The element type selected for meshing is Tetrahedrons, because they fit better in the complex geometry and the element size selected is 1.0 inch. The element size is chosen based upon the geometry dimensions and it has been verified by performing convergence test in the deformation section of the analysis.

The boundary conditions and applying force to the model are as shown in Table 1 below. As the guard is presented at the bottom of a tank, the padding of the model remains in touch with the vessel and is welded with the valve guard through the pads. Hence, these landing leg and valve guard pads are selected as a fixed support for the analysis.

ObjectName	FixedSupport	Force
State	FullyDefined	
Scope		
ScopingMethod	GeometrySelection	
Geometry	2Faces	3Faces
Definition		
Type	FixedSupport	Force
Suppressed	No	
DefineBy		Vector
AppliedBy		SurfaceEffect
Magnitude		64500lbf
Direction		Defined

Table 1: Boundary conditions and loading applied for side impact

V. RESULTS AND DISCUSSION

Steady-State Structural analysis

5.1 Side Impact

The Table 9 summarizes the deformation and stress exerted on the valve guard in the case of a side impact. The key thing to notice here is that the maximum deformation is of 0.028 inches and the maximum stress resulted is greater than the breaking point of the material. These results suggest that the valve guard is going to break from the side impact and will have a maximum deformation of 0.028 inches, which is within the regulation of the CSA B620. Moreover, the average stress calculated is around 5235 psi, which is way less than the yield strength of steel of 36,259 psi. This is the static analysis, hence the time, load step and iteration all have numerical value of one.

The Figure 5 illustrates the maximum deformation and stress experienced by the valve guard in the event of a side impact. The deformation is maximum at the point where there is a less padding available and the breaking point of the guard is in the middel of the base frame as per seen in the below figure.

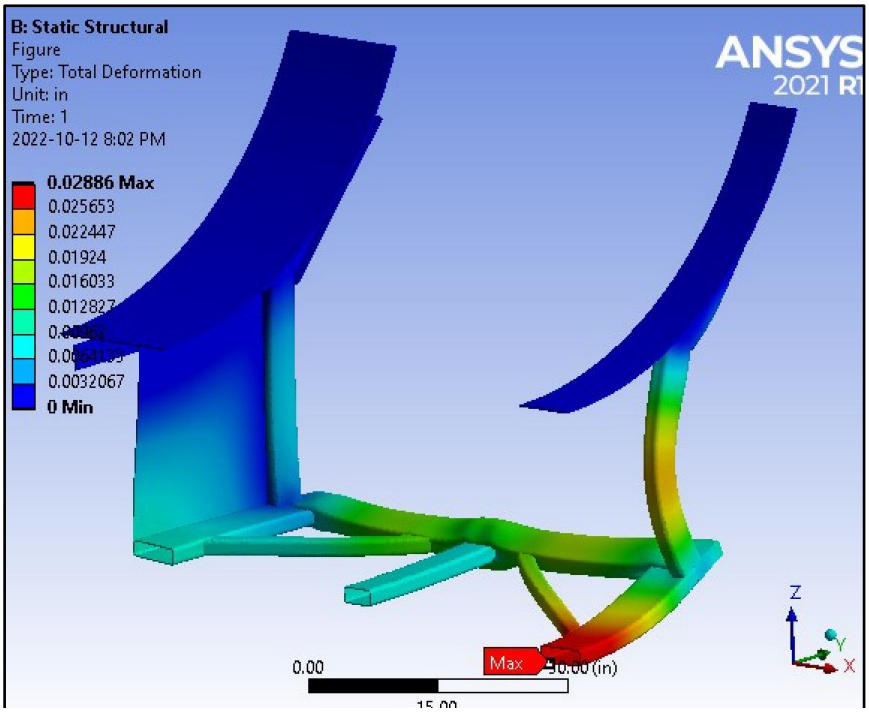


Figure 5: Maximum deformation from side impact

5.2. Bottom Impact

The point to remember is the fact that the greatest deformation is 1.92 inches, and the highest stress produced is higher than the material's breaking point. These results indicate that the valve guard will fracture from the bottom impact and will experience a maximum deflection of 1.92 inches, which falls within the CSA B620 limit. Furthermore, the deformation achieved here is greater than that obtained from a side hit, demonstrating that the bottom impact is more severe than a side impact on the guard.

Figure 6 illustrates the maximum deformation and stress experienced by the valve guard in the event of a bottom impact. The deformation is maximum at in the middel of the base frame as per seen in the below figure and the breaking point of the guard is also in the bottom where the bottom tubing meets the vertical tubing in the base frame.

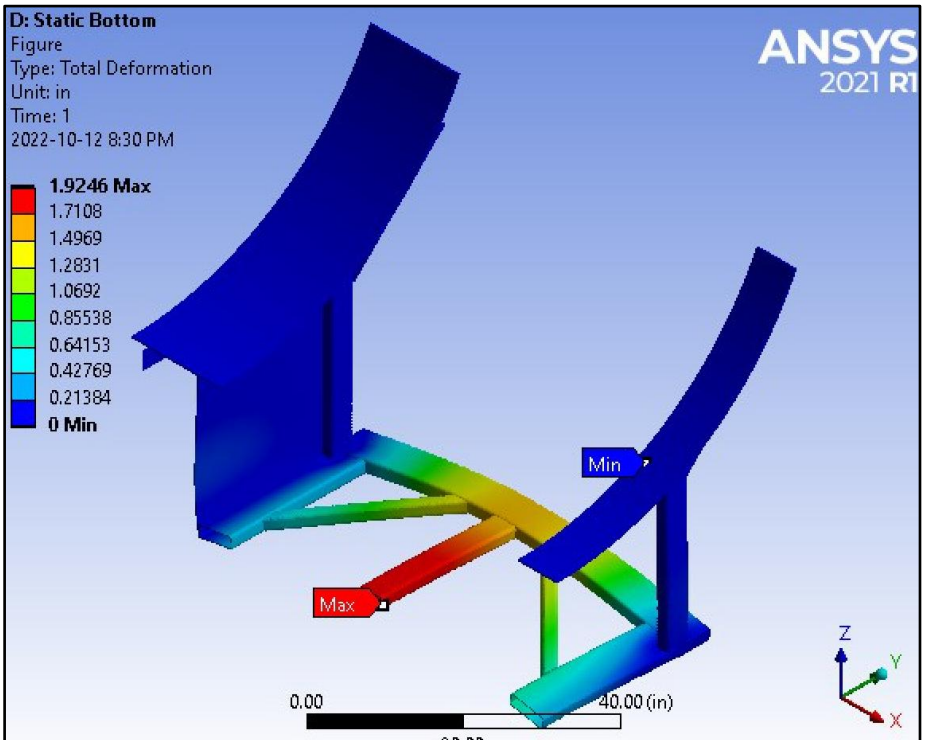


Figure 6: Maximum deformation from bottom impact

VI. CONCLUSIONS

This research provides a methodology for quantitatively assessing the safety of the valve guards used with the cargo tank vehicles for transporting hazardous liquid cargoes. The procedures of conducting the assessment are presented with a demonstration for a typical valve guard commonly used in the industries in North America. The assessment is along the line of the regulations established by CSA B620 standards. The safety of the side and bottom parts of the valve guard are investigated with consideration of various loading conditions. The significance of this research is that it can become a useful guideline as there have not been many studies on the subject. This research will give direction to academics and engineers as a foundation for advancing quantitative analysis in the sector of tank vehicle design and manufacturing. The step-by-step guide on how to conduct the assessment for the valve guards is provided, such that the engineers or technicians in practice may directly use them for evaluating the safety as well as the stability of the valve guards used in the field.

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