SAND2008-2502C

EVALUATION OF THE EDS USING THE ASME CODE CASE FOR IMPULSIVELY LOADED VESSELS

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Introduction – The Explosive Destruction System (EDS) was developed by Sandia National Laboratories for the US Army Product Manager for Non-Stockpile Chemical Materiel (PMNSCM) to destroy recovered, explosively configured, chemical munitions. PMNSCM currently has five EDS units that have processed nearly 1000 items. The system uses linear and conical shaped charges to open munitions and attack the burster followed by chemical treatment of the agent. Extensive modeling and testing were done to qualify the EDS vessel for explosive containment. In the eight years that the EDS has been in operation, the requirements and applications for the system have grown considerably. The size of munitions, the quantity of explosives in the munitions, the number of munitions destroyed in each operation, and the frequency of use have all increased. The EDS is now used in essentially continuous operations treating up to six munitions at a time. These changes have been supported by additional testing, computer simulation, and fracture mechanics analysis to better understand the loads that are generated and the response of the vessel.

As part of this effort, Sandia has participated on The ASME (American Society of Mechanical Engineers) Task Group on Impulsively Loaded Vessels. This task group has developed a Code Case under Section VIII Division 3 of the ASME Boiler and Pressure Vessel Code. The Code Case now provides a set of specific, well-defined, independently-derived criteria for defining the capacity and life of impulsively loaded vessels. In this paper, the explosive capacity of the EDS P1 vessels are investigated against the ASME criteria. Results from recent explosive overtests using small, geometrically scaled vessels are presented to corroborate the analysis.

EDS Description – The main component of the EDS is a thick-walled cylindrical vessel shown in Figure 1. The vessel, which contains the explosion and the subsequent chemical treatment, consists of a deep cup with a flat door. The material for both the vessel and the door is forged 316 stainless steel. The door is sealed with a Grayloc™ metal gasket and secured with 4140 steel clamps and hydraulic nuts.

A fragment suppression system (FSS) protects the vessel walls from high velocity fragments. There are different FSS designs for different munition configurations. Each FSS consists of two large half cylinders that sit above and below the munitions. The momentum of the fragments is transferred to the heavy FSS pieces, which impacts the vessel wall at a relatively slow speed. The FSS also holds the munition and the shaped charges in the proper location and it protects the vessel from back spray from the linear shaped charges. Figure 2 shows the FSS for six German Traktor Rockets in the P2 system.

Two sizes of vessels are in use. The volume of the P1 vessels is about 189 liters and the larger P2 vessels about 620 liters. Figure 3 shows the two vessels side by side. The vessels are geometrically similar with a linear scaling factor of 1.5. Consequently, data and analysis from one vessel can be applied to the other with reasonable accuracy using principles of geometric similitude. The explosive scaling factor is 1.5^3 or 3.375. In other words, one pound of explosive in a P1 vessel will produce the same strain as 3.375 pounds in a P2 vessel.

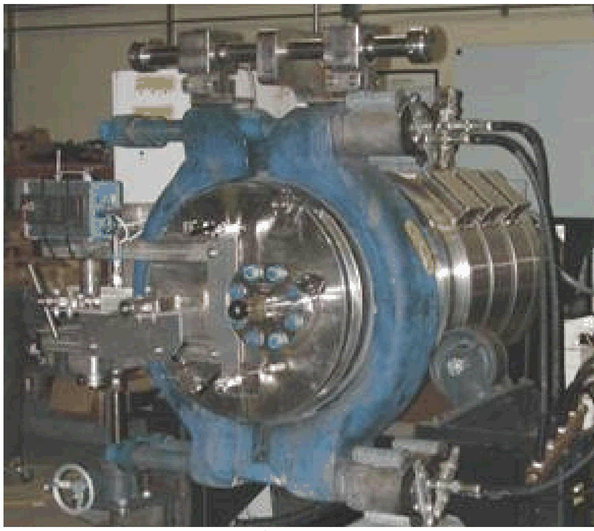

Figure 1: EDS P1 Vessel

Figure 2: FSS for 6 German Traktor Rockets

Figure 3: Comparison of EDS P1 and P2 Vessels

In the absence of the code case or other independently derived criteria, Sandia has rated the P1 vessel for 1.5 pounds of explosives (TNT equivalent) for 500 operations. The P2 vessels are rated for 4.8 pounds. None of the vessels has reached the limit of 500 uses. One goal of the current work is to determine how to recertify the vessels after that point.

ASME Code Case Criteria – The code case requires use of an elastic-plastic analysis to demonstrate that the following criteria are met:

- The design margin against a plastic instability state for the specified impulsive load shall be 1.732
- The maximum in-plane equivalent plastic strain during the transient, averaged through the thickness of the vessel, as a result of the design basis impulsive loading shall not exceed 0.2%.
- The maximum in-plane equivalent plastic strain during the transient, linearized through the thickness of the vessel, as the result of the design basis impulsive loading, shall not exceed 2 % (1 % at welds).
- The maximum peak equivalent plastic strain during the transient at any point in the vessel, as the result of the design basis impulsive loading, shall not exceed 5 % (2.5 % at welds).
- A fracture mechanics fatigue evaluation shall be conducted.
- It shall be verified that fragment-induced damage to the inner surface of vessels subjected to multiple impulsive loading events is not more severe than the flaws assumed in the fatigue evaluation.

The EDS fatigue analysis has been documented previously. We are currently reviewing that analysis, but it will not be discussed here. The FSS provides protection against fragment damage which satisfies the last criterion. The analysis described here covers the other criteria. In a normal analysis, the design basis loads are specified and then these criteria are applied to design the vessel. Since the EDS vessels already exists, the process is reversed. Our intent is to find the maximum design basis impulsive load for which the existing vessel meets the criteria.

P1 EDS Vessel Analysis – The explosive load in the vessel includes the munition bursters and the shaped charges. Clearly the locations of the different explosive components and their relative detonation times affect the vessel loads. Consequently, every configuration of munitions and shaped charges has a different loading function, which quickly becomes unwieldy for analysis. However, instrumented tests and computer simulations with a variety of different munitions show that a single, centrally-located, bare charge with the same total explosive weight produces equal or greater strain in the vessel than the distributed bursters and shaped charges of the actual configuration as long as the munitions are properly placed in the FSS. This analysis of the EDS, therefore, is based on computer simulations of the detonation of a bare charge of explosive at the center of the vessel.

First the Eularian shock wave code, CTH, was used to calculate TNT detonation pressures inside the vessel wall. Figure 4 shows a typical pressure/time history at one point in the vessel with a three pound detonation. The pressure histories were then transferred to LS-Dyna as input loads to determine the structural response of the vessel. Only the initial impulse up to about 0.4 msec was considered. Figure 5 shows the mesh. The door seal was not modeled. The LS-Dyna material model *MAT_PLASTIC_KINEMATIC [4] was used for the 316 stainless steel vessel body. The effective stress and effective plastic strain were extracted from the simulation (Fig. 4) to assess the performance of the vessel.

Simulations were done with 1, 2, 3, 4, 6, and 10 pound charges. Figure 6 shows the specific impulse as a function of the charge weight. Figure 7 shows the peak strain from a 3 pound charge and a 10 pound charge. The highest strain occurs around the waist of the vessel.

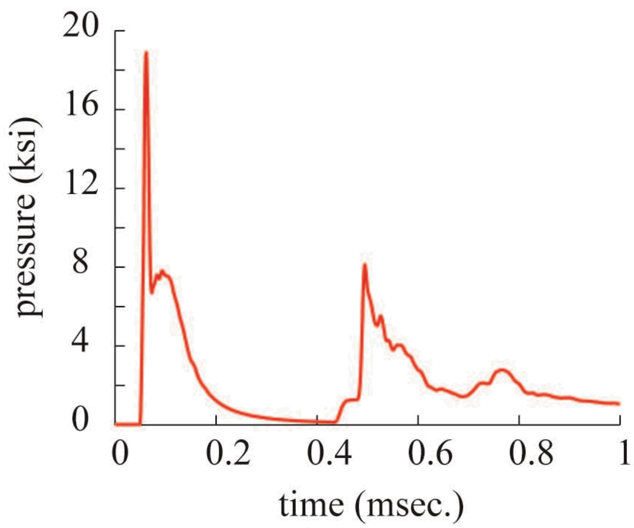

Figure 4: Typical Pressure History for 3 Pound Detonation

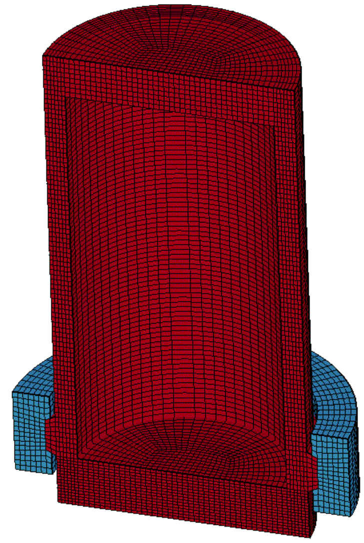

Figure 5: Mesh for Analysis

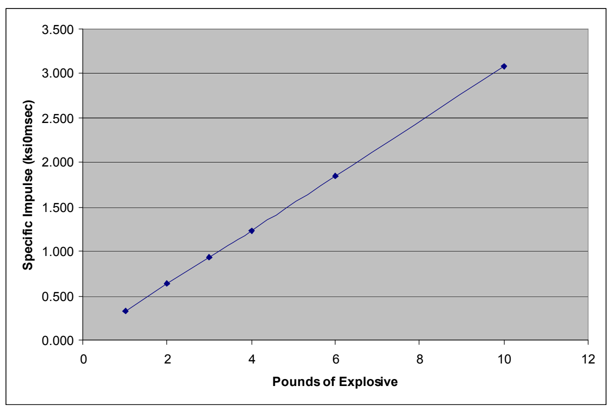

Figure 6: Specific Impulse vs. Explosive Weight

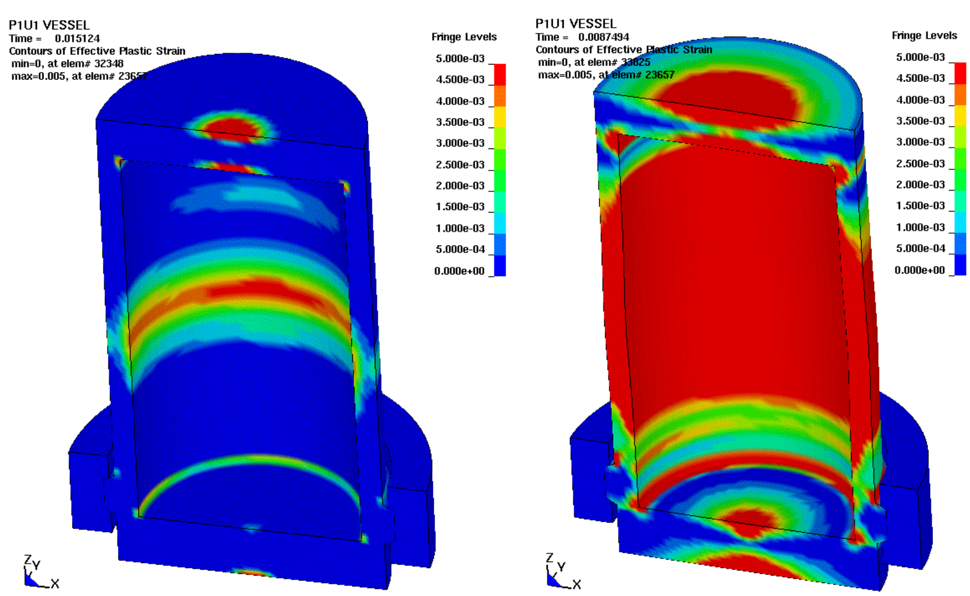

Figure 7: Maximum Strain for 3 Pound and 10 Pound Simulations

Figure 8 shows the strain at the inner and outer wall at the waist. At about 3.1 pounds, plastic yielding (0.2 % strain) extends through the wall, resulting in a plastic hinge. Applying the design margin of 1.732 for the plastic instability state to that level, the explosive limit for the EDS P1 vessel per the code case is 1.8 pounds TNT equivalent. This is the limiting criterion. Based on the limit for average maximum in-plane equivalent plastic strain, the rating would be about 2.5 pounds. The other design criteria all lead to higher values.

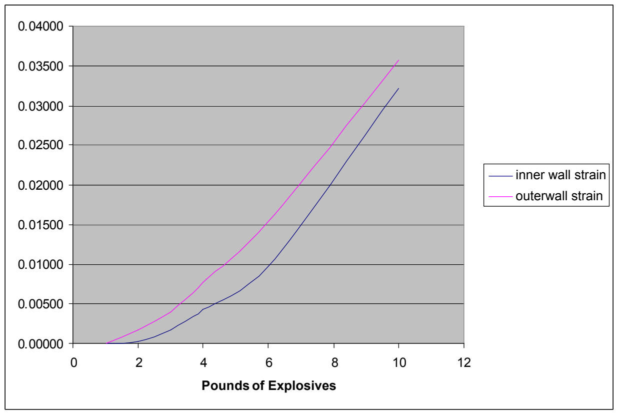

Figure 8: Peak Strain at Inner and Outer Wall

For the plastic instability analysis, the material is assumed to be ideally plastic (non-strain hardening). In fact, 316 stainless steel experiences significant stain hardening, which adds an additional factor of safety for plastic instability.

Subscale Vessel Testing – To supplement the analysis, we have begun a series of extreme overtests using subscale vessels. One of these vessels is shown in Figure 9. As described earlier, results from these tests can be scaled based on geometric similitude to predict the behavior of the full-size EDS vessels. The scaling factor is 1:33 meaning, for example, that 0.1 pounds of explosive in the subscale vessel would produce vessel response similar to 3.3 pounds in the EDS P1 vessel. In these tests, through the wall plastic yielding first occurred with 0.21 pounds of explosive. This is the scaled equivalent of 7 pounds of explosive in the P1 vessel, which is much higher than the calculated value. This is an area of continued investigation. The difference is probably related to errors in scaling since the clamps and seal on the subscale vessel could not be scaled proportionately.

The center picture in Figure 9 shows the subscale vessel after a test with 0.71 pounds of explosive. Assuming the vessels scale accurately, this would be equivalent to over 23 pounds of TNT in the EDS P1 vessel or 78 pounds in the EDS P2 vessel. The subscale vessel failed on the following test with 0.775 pounds of explosive as shown in the final picture in Figure 9. Because the plastic strain from these tests is cumulative, the failure level for a single detonation in a pristine vessel is expected to be higher. However, repeated detonations at a lower level could eventually cause failure due to ratcheting. Future tests will evaluate this further.

 TO BE ENTERED

Figure 9. Subscale Vessel Before Testing, After 0.71 Pound Tests, and After Failure

Conclusions and Future Work – Sandia has an ongoing effort to better understand the capabilities and limitations of the EDS vessels. Based on the criteria in the ASME Code Case for Pressure Vessels Subjected to Impulsive Loads, the EDS P1 Vessels would be rated for 1.8 pounds of TNT. This corroborates the safety and robustness of the vessel. The currently specified rating of the P1 vessels is 1.5 pounds. In the near future we expect to expand this work with several related activities including:

- Additional fracture mechanics analysis to evaluate vessel life.
- Evaluation of the P2 vessels against the code case.
- Continued subscale testing.
- Analysis of vessel response with real munition configurations rather than bare charges.
- Destructive explosive testing of the original EDS P1 vessel.

References –