May 2020

TANK SLOSH ANALYSIS

DJH Engineering Technical Newsletter

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- Improved simulation of tank sloshing using Eulerian elements

Tank Slosh Analysis Challenges

It is important to accurately analyze a liquid-filled tank to keep the need for expensive prototyping and testing costs low. With many tanks transitioning from metal to plastic, tooling costs can prohibit the ability to iterate and test designs. This means it is vital to be able to accurately simulate a tank and the effect of fluid sloshing within the tank. There are a few quick and low-cost ways to analyze a tank. One popular method is to apply a hydrostatic pressure distribution on all internal surfaces in contact with the fluid, see Figure 1. Another common method is to apply the pressure over an estimated wetted surface from the slosh vector generated by gravity and the tank lateral inertia, see Figure 1. These are a few simple ways to analyze the damaging effects of fluid slosh on the tank walls and the tanks ability to handle inertial loading, but there are many assumptions and simplifications in this method that tend to reduce their accuracy. A few limitations of this method are the inability to determine the dynamic effects of fluid slosh and the effects of baffles on the sloshing. These limitations can be seen in the hydrostatic load contour plots in Figure 4 when compared to Figure 5. The strains around the tank baffle are artificially low due to the inability to accurately model the loading on the baffle. Another method to analyze tank slosh is to use Eulerian elements to model the fluid material in a dynamic simulation. The tanks structural integrity can be accurately analyzed along with the dynamic effects of the fluid slosh and any effects a baffle may have on the sloshing.

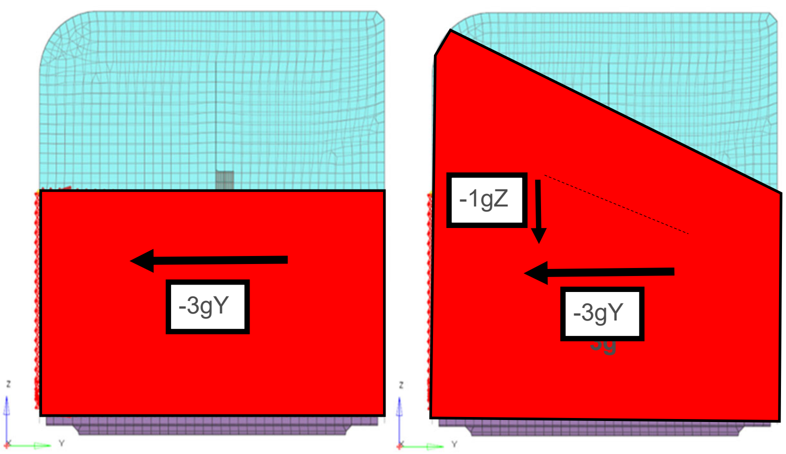

Figure 1. (Left) Model of –3gY Hydrostatic Load

Introduction to Eulerian Elements

A traditional Lagrangian analysis uses nodes to make up elements that are fixed within a material; these elements displace and deform as the materials displace and deform. Lagrangian Elements are fully comprised of one material and lose accuracy when highly distorted. For Eulerian analysis, the nodes are fixed in space and never displace or deform, the material flows through the elements. Thus, elements may not be comprised of a single material, they can be empty or partially empty. Eulerian mesh is effective at handling extreme deformation much like fluid slosh. A Eulerian material can interact with a Lagrangian element using a Eulerian-Lagrangian contact. This interaction allows Eulerian materials to combine with a traditional Lagrangian analysis to effectively and inexpensively analyze tank slosh. The model can be seen in Figure 2.

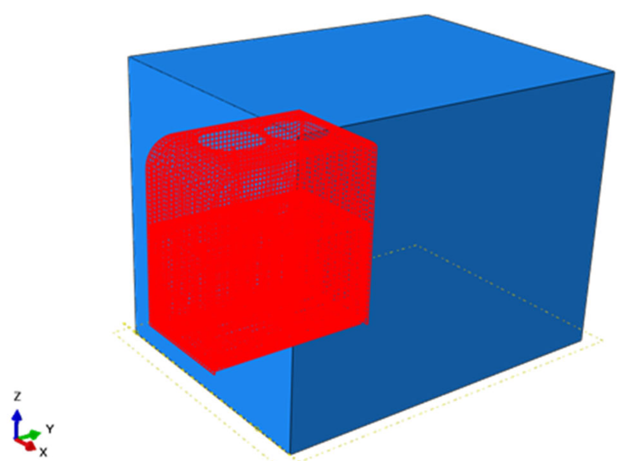

Figure 2. Tank in a Eulerian Elements Mesh

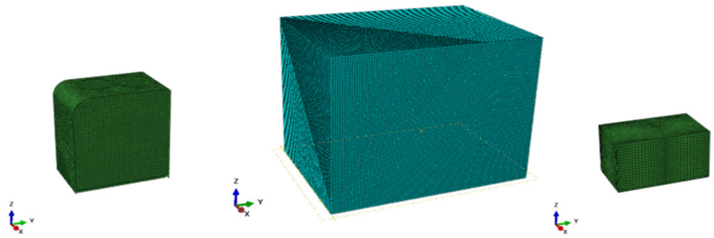

Figure 3. (From Left to Right) Lagrangian Tank Mesh, Eulerian Mesh, and the Dummy Fluid Mesh

Tank Slosh Analysis Process

A Coupled Eulerian-Lagrangian (CEL) dynamic analysis is comprised of 3 components: (1) The Tank: A standard mesh using Lagrangian elements and the tank material properties: (2) The Eulerian mesh: Must be large enough to account for any tank/fluid movement during the analysis; and (3) The Dummy Fluid: Mesh for the volume fraction calculation to reference during the analysis. See Figure 3 for the components. A contact is added between the fluid and tank mesh. This coupling can be made between anything that may contact the fluid, for example, a baffle or any internal component. The analysis is run by displacing the tank through the fluid resulting in a horizontal inertial load.

Analysis Conclusion

As seen in Figure 4 the strains around the baffle in the hydrostatic pressure analysis are much lower than the Eulerian analysis shown in Figure 5 with strain differences exceeding 40%. This is due to the hydrostatic pressure not accurately simulating the loads the fluid generated on the tank and included baffle. The Eulerian analysis gives greater accuracy on how the fluid sloshes within the tank and can be used to better determine the external effects. Correlation with test has proven this to be a more effective analysis approach to accurately simulate the fluid slosh. Another benefit of the Eulerian analysis is the output of a strain time history during the sloshing event which demonstrates how the sloshing affects different sections of the tank at different time slices throughout the load step. Fluid displacement over various time increments can be seen in Figure 6. Eulerian dynamic analysis provides the opportunity to quickly iterate on a tank design reducing the need for prototype builds and allowing for a design that meets the requirements on the first pass.

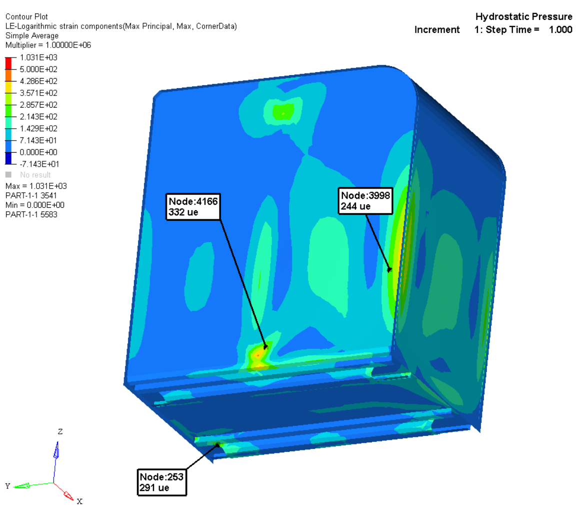

Figure 4. Contour Plot of the Hydrostatic Pressure Load Case

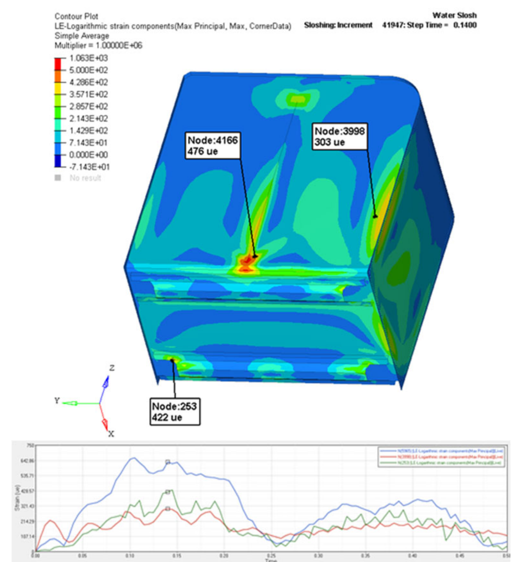

Figure 5. Contour Plot and Strain Time History of the Tank Eulerian Analysis

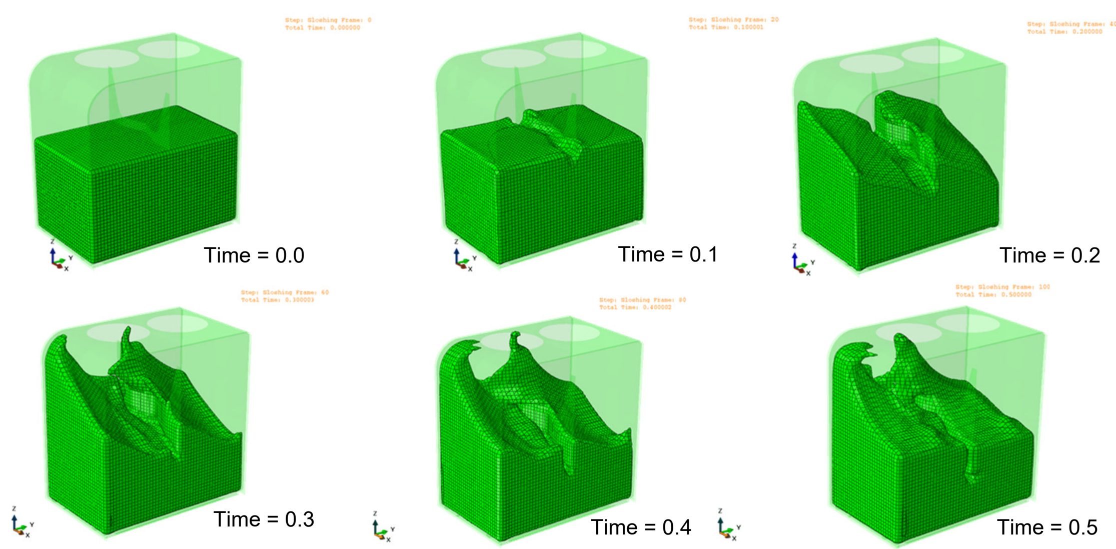

Figure 6. Eulerian Time Increments of Fluid Sloshing in the Tank