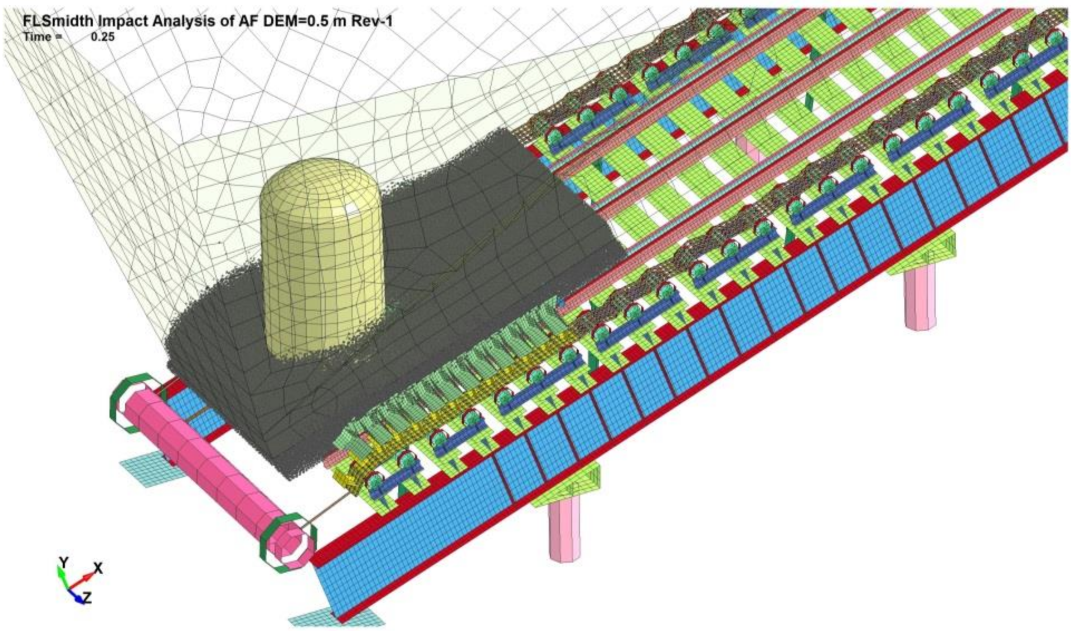
Predictive Engineering LS-DYNA DEM and SPH Simulation Project Work



Title:

Large Rock hitting bed of gravel (DEM) within apron feeder (FEA) used in open-pit mining

Keywords:

Femap, LS-DYNA, discrete element method (DEM), smooth particle hydrodynamics (SPH), finite element analysis, drop-test, bird strike analysis, hail impact analysis, DEM analysis of rock and sand, DEM calibration to experimental tests, finite element analysis, nonlinear analysis, FSI Analysis, DEM to FEA, ASCE 4-98, sloshing analysis of ASME Section VIII, Division 2 pressure vessel, off-shore platform mounted pressure vessels,

Project Overview

This case study presents several examples where we have used the discrete element method (DEM) and smooth particle hydrodynamics (SPH) to apply sand and rock, mineral, organic (bird) and fluid loading to complex nonlinear dynamic finite element models.

DEM and SPH are both visualized as small discrete spheres but that is about all they have in common since DEM is often used for modeling discrete particles such as rocks or pea pods while SPH is used for modeling continua such as fluids and solids. Where we have found DEM and SPH useful is as a method to apply dynamic loads to structures. For DEM simulations, the ability to simulate granular media from sand and rocks or to friable compressed mineral cake or to food products, has allowed us to create FEA simulations that are far more accurate than what can be achieved by any combination of time varying force, acceleration or pressure loading arrangement. With SPH and its ability to simulate the mechanical response of highly deformable media (e.g., hail or frozen birds) during impact or fluids sloshing within a tank with good accuracy and low numerical cost provides a ready means for performing bird strike analyses or hail impact analyses or fluid sloshing analyses.

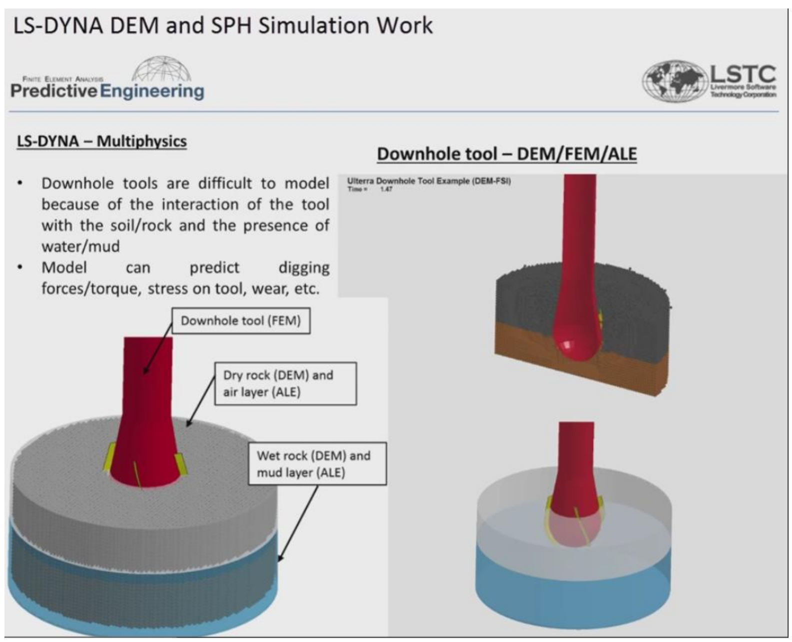
This case study is provided as a standalone document but is best accompanied by the video we have posted on YouTube which provides an overview of the DEM and SPH process and some examples of how we have used it at Predictive Engineering.

YouTube Video:

Predictive Engineering LS-DYNA Discrete Element Method (DEM) and Smooth Particle Hydrodynamics (SPH) Simulation Project Work

The video provides a graphical overview of the DEM and SPH process that has been used at Predictive Engineering with examples of project work with direct examples of:

- Using DEM as an integral part of a simulation to predict the cushioning effect of sand and rocks (DEM particles) when a very large rock (rigid body) is dropped onto an apron feeder (FEA) that is commonly used in an open pit mining operation;
- DEM impact simulation of dropped mineral cake onto conveyor;
- Mineral flow prediction on conveyor with knife gate with prediction of maximum forces onto the knife gate and if the gate would get buried by conveyed material;
- Virtual DEM angle-of-repose calibration to experimental test;
- SPH simulation of bird strike on composite radome;
- SPH fluid sloshing in ASME Section VIII, Division 2 pressure vessel.



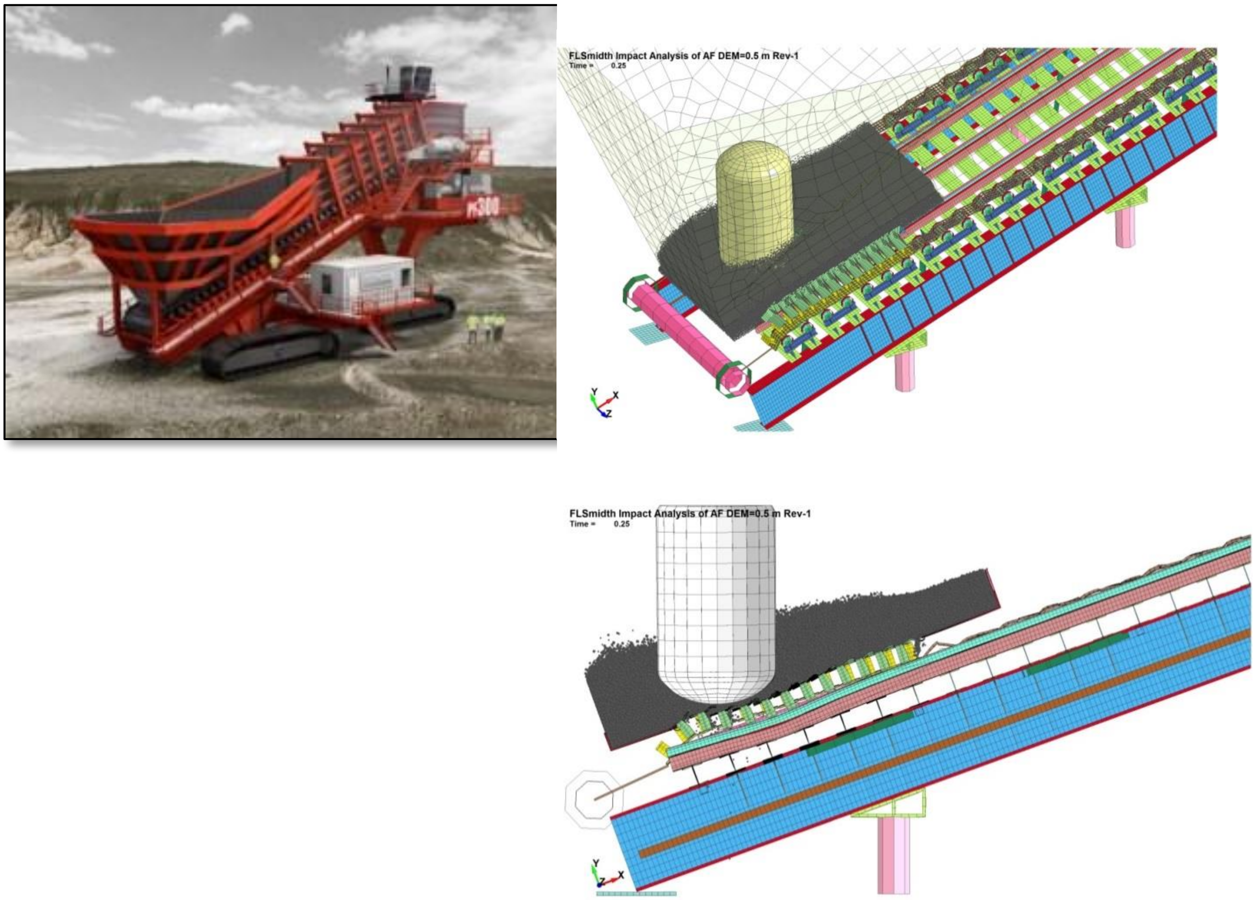


Figure 1: LS-DYNA was used in a combined structural / DEM model for the simulation of a large rock-drop on an apron feeder (AF) commonly used within the mining industry. Results show that if the AF is keep filled with material, the impact of large rocks is almost completely mitigated.

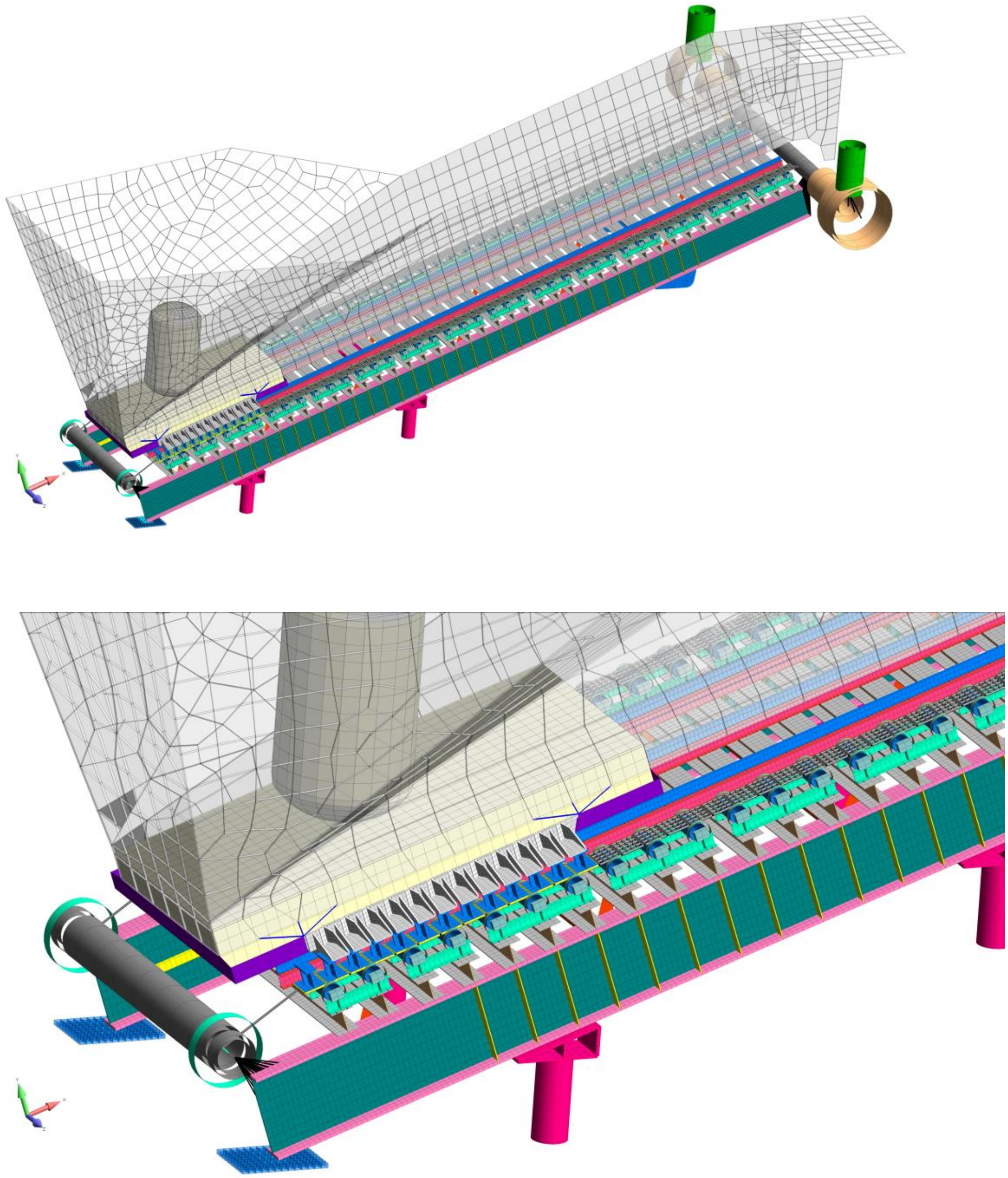
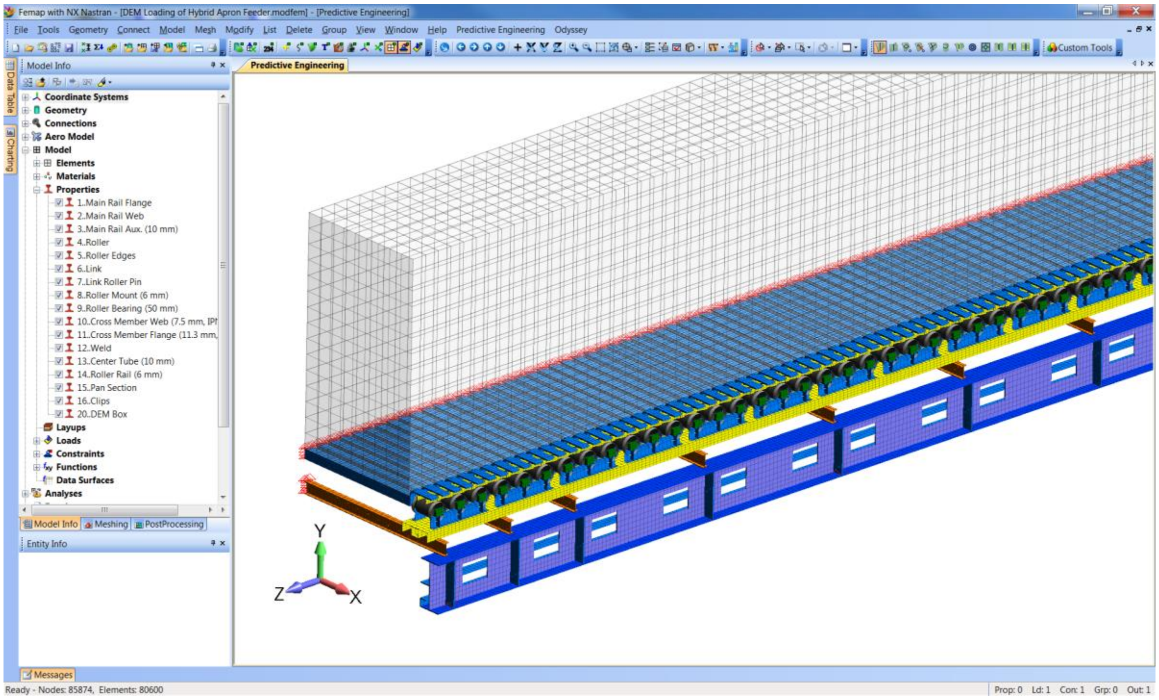


Figure 2: The Femap FEA model of the apron feeder system was constructed using a carefully mapped mesh of quad plate elements with beam elements for the chain and roller system. The DEM particles were automatically created within LS-PrePost.

This application of DEM was one of our most interesting projects where the DEM particles were used to simulate the mixed rock bed within a large open-pit mine apron feeder. The rock bed of DEM particles was created using a mix feed of different sized DEM particles. This mixed bed was then vibrated to settle the particles and then transferred to the final LS-DYNA model. The FEA part was built in Femap and then exported to be combined within LSTC's LS-PrePost (LSPP) within the DEM particles. The load case for this analysis was the 5 meter drop of a large rock. The rock was given its corresponding initial velocity and then allowed to impact against the rock bed within the apron feeder. Simulations were run with no protective covering of rocks (i.e., DEM particles) and then at various depths. The simulation allowed the client to conclusively and quantitatively show the importance of keeping the apron feeder loaded during operation.



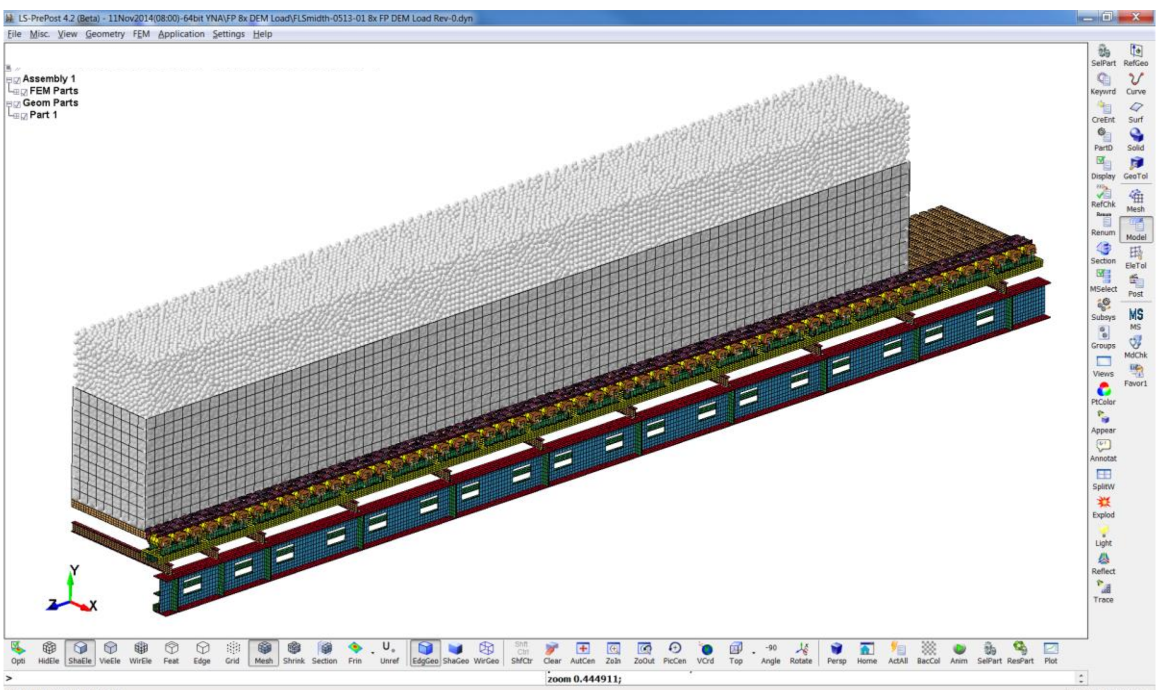


Figure 3: DEM particles were used to simulate the processed mineral cake onto conveyer belt feeder with a knife gate at the far end. The model was built in Femap and then exported to LSPP for the addition of the DEM elements.

Another useful example of DEM to structure application was this analysis for the loading of a heavy duty conveyor. The load was processed mineral filter cake that was dropped from three meters onto the bed of the conveyor. The DEM particles represent a fully-loaded bed that was given an initial velocity to simulate the impact of the filter cake. This worst case scenario can be seen in the YouTube video montage. The structure (FEM) was allowed to fully contact the DEM particles and plastically deform to failure.

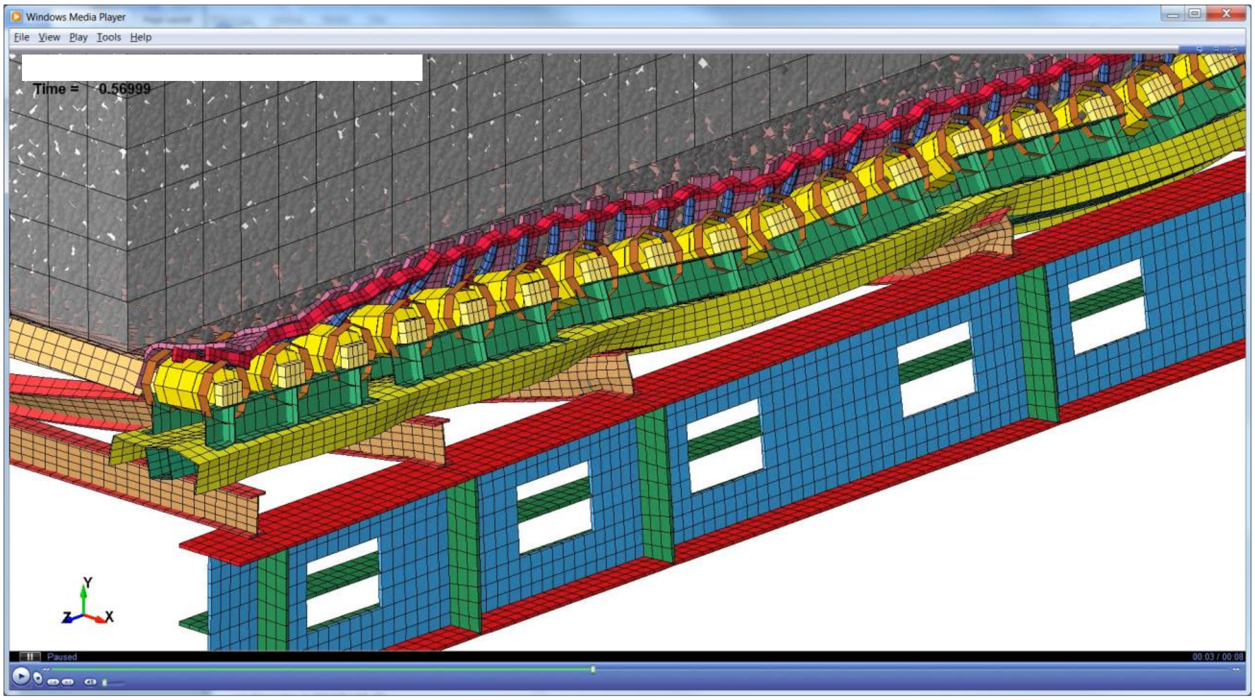


Figure 4: DEM particle impact loading on conveyor

To simulate minerals and organic media accurately, one can create virtual laboratory to match your real laboratory results. This technique is described in the paper: Improving the Precision of Discrete Element Simulations through Calibration Models.

As the abstract says: "*The Discrete Element Method (DEM) is fast becoming the numerical method of choice for modelling the flow of granular material. Mining, agriculture and food handling industries, among many others, have been turning their attention towards this powerful analysis technique. In this paper, we present three simple calibration modeling tactics that should be the starting point for every DEM simulation of dry and semi-dry granular material. The three tests are designed to be as simple as possible in order to minimize the run time of the test simulations. The tests are developed to be run in a specific order, providing a sequential calibration procedure that does not involve multiple unknown variables in each test.*

Other standard testing methods are briefly discussed, such as the rotating drum and the shear cell (Jenike) tests. The complexity of these tests does not lend itself well to initial numerical model calibration as each test involves many unknown variables. However, they are mentioned as an extension of the three basic test models. The paper will help analysts to increase the precision and validity of their discrete element modelling work."

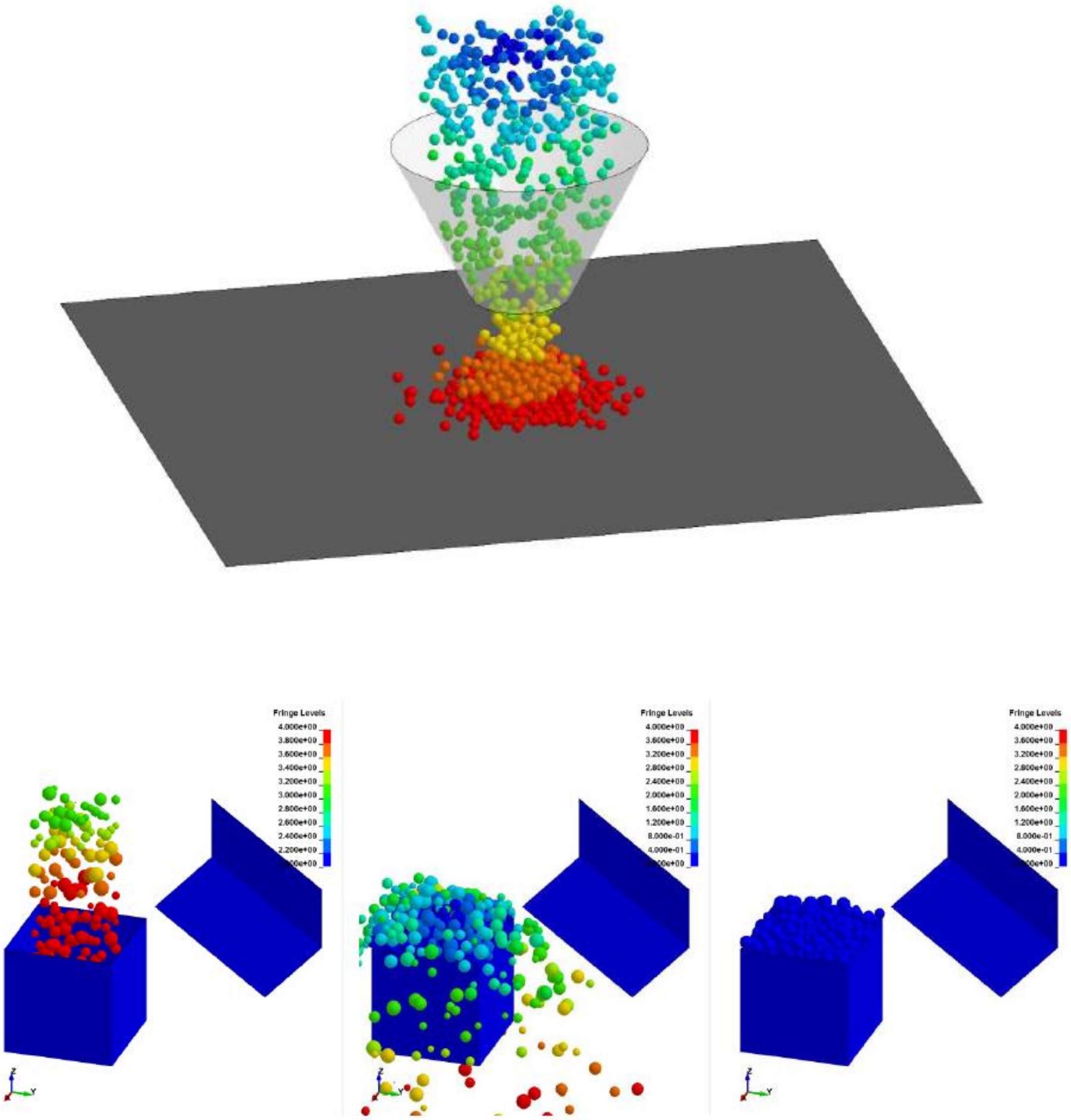
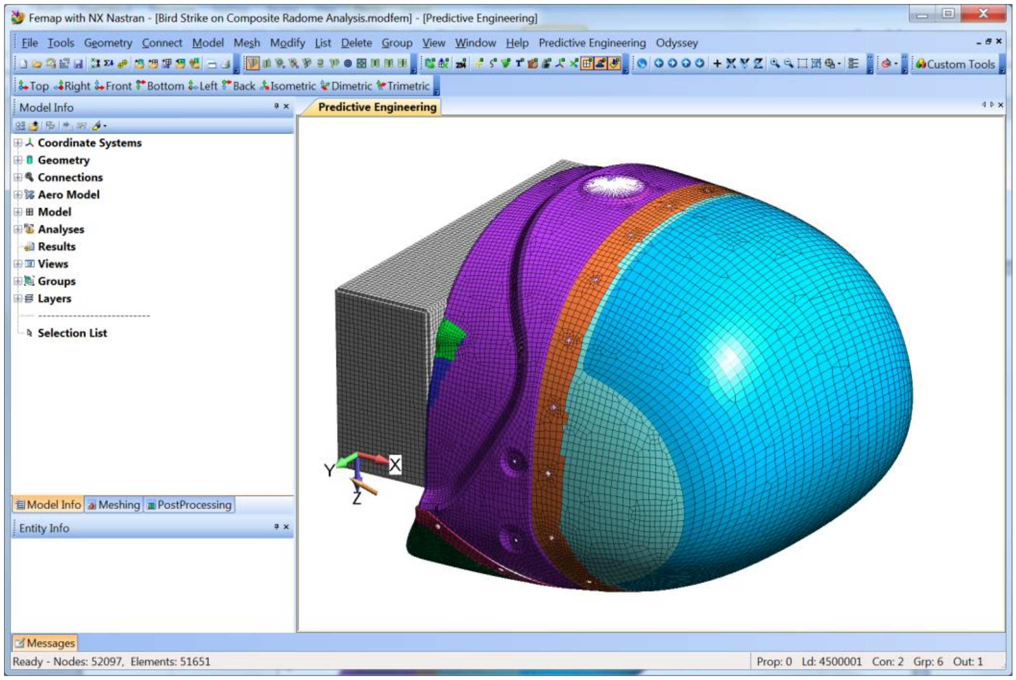


Figure 5: DEM angle of repose and surface friction test (angle to induce flow) simulations



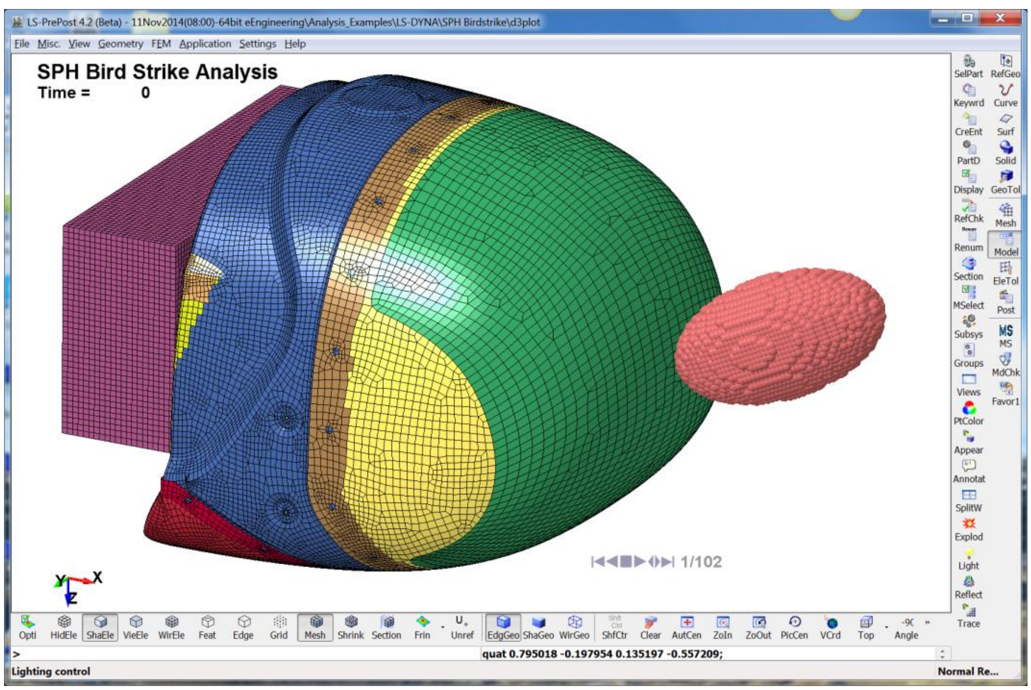


Figure 6: Femap model of composite radome structure translated out to LSTC's LS-PrePost Interface with SPH bird added to the simulation

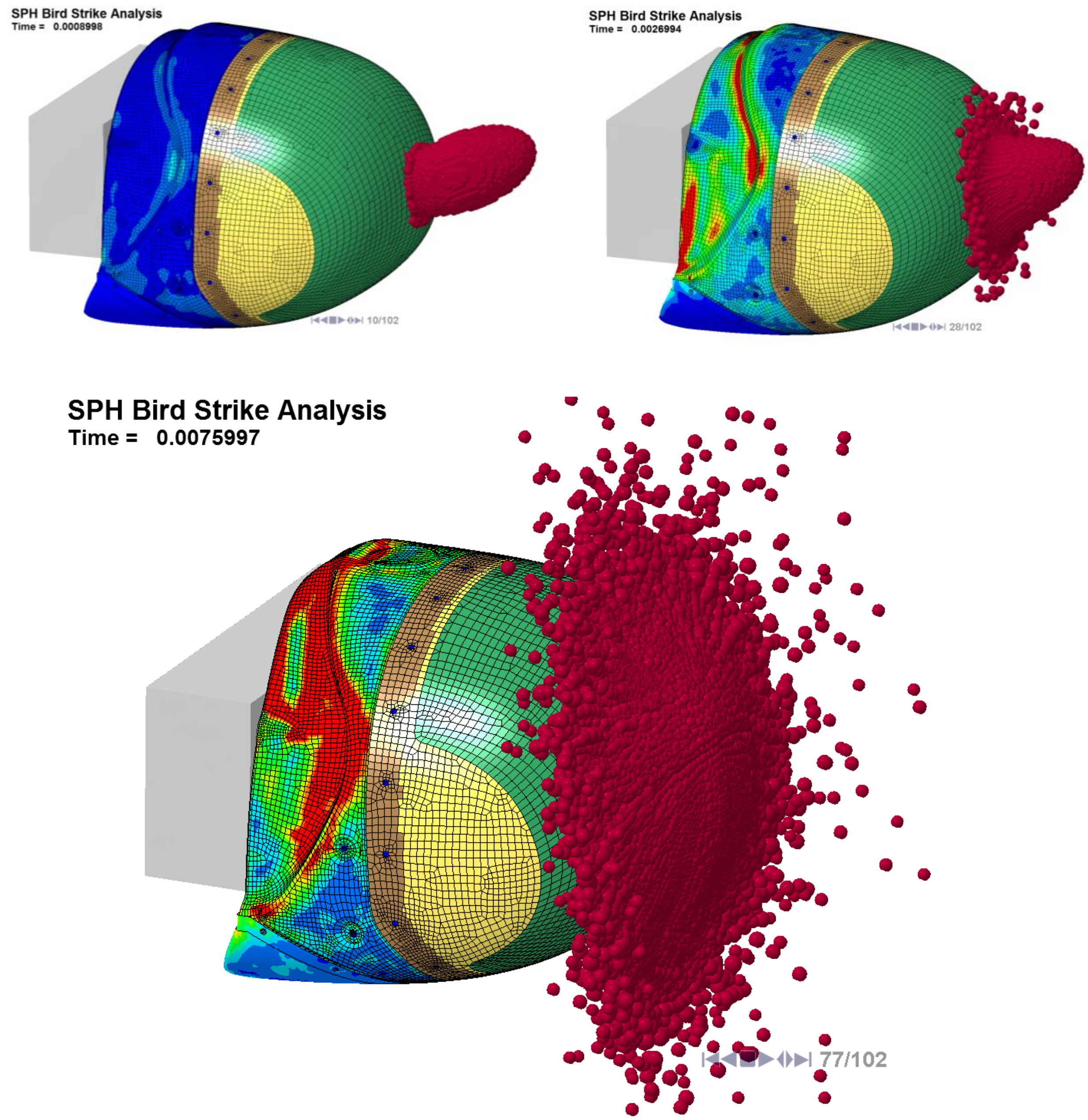
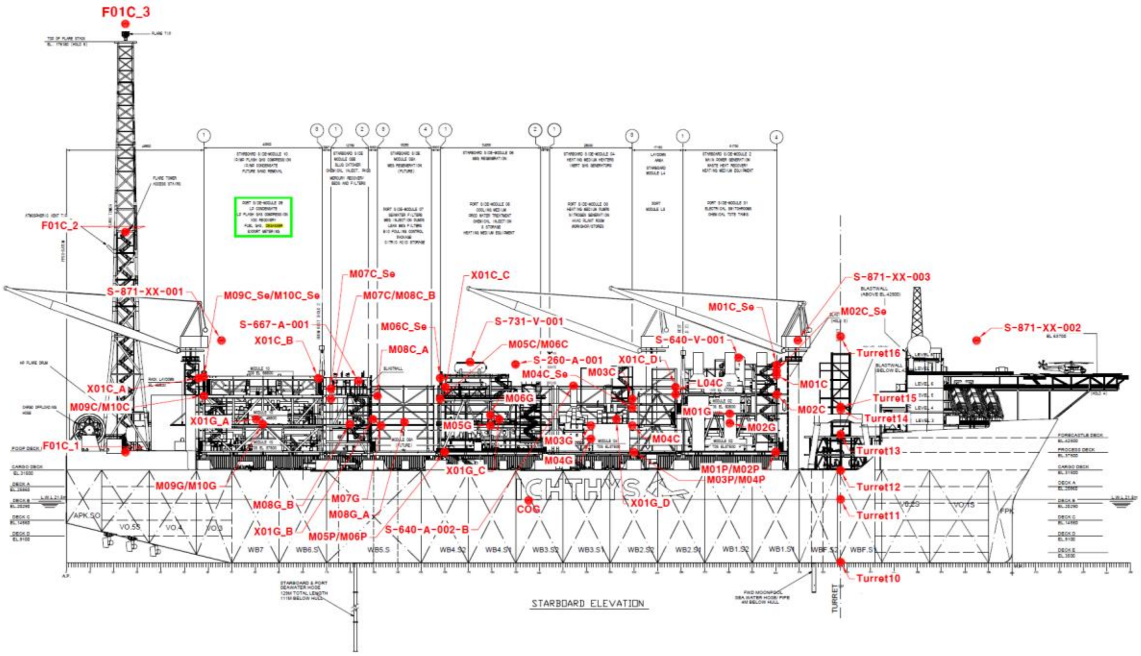


Figure 7: The SPH bird disintegrates upon impact with the radome

The smooth particle hydrodynamic (SPH) modeling of bird strike is not that difficult given that the material formulation or material law for virtual birds is that somewhat similar to a viscous fluid and modeling parameters can be leverage from work done by the LS-DYNA Aerospace Working Group Modeling Guidelines Document. The document provides a complete section on Bird-Strike with a Bird Material Model based on the standard formulation of *MAT_NULL and *EOS_TABULATED.

Composite modeling using LS-DYNA is straightforward and allows for an in-depth study of damage effects within the composite laminate using cohesive elements or just a damage model.



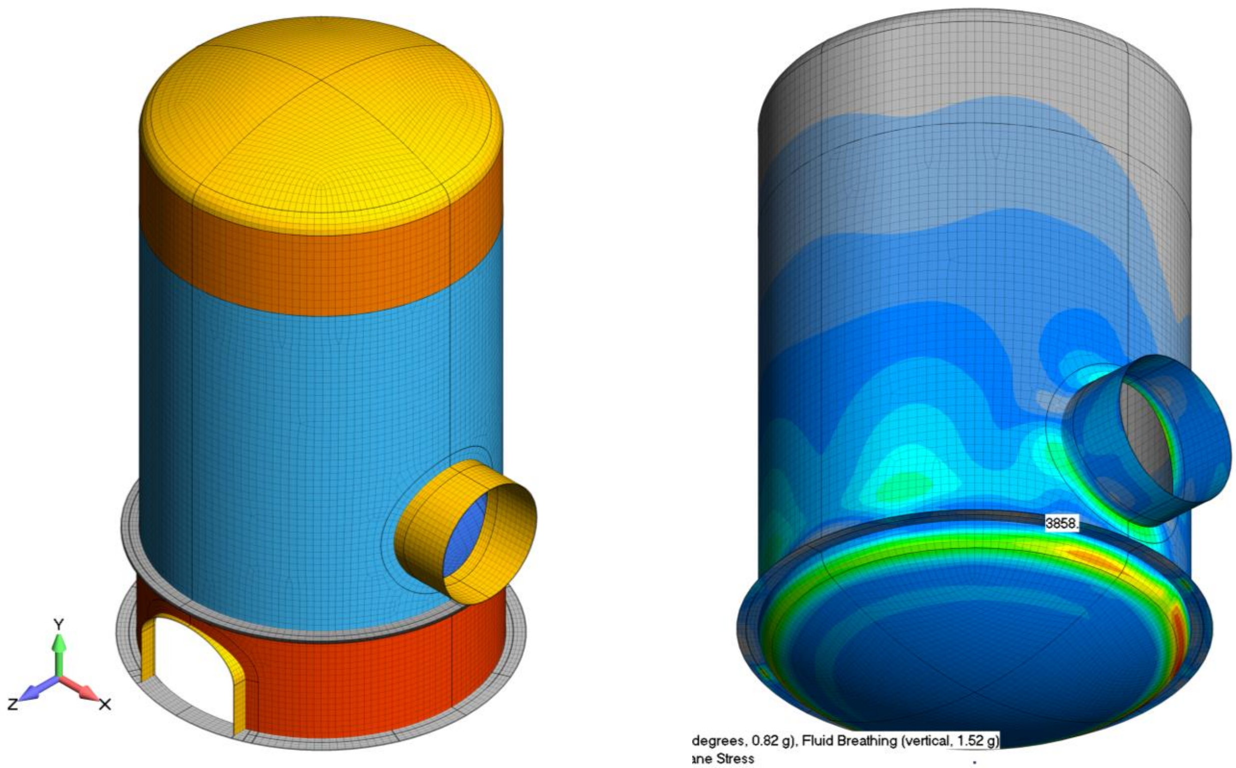


Figure 8: The sloshing analysis was performed to meet ship-board specifications per S930-AS-CAL-10007 with the work tied to ASCE 4-98. The pressure vessel was built in Femap and then prepared for SPH sloshing analysis using LSTC LS-PrePost.

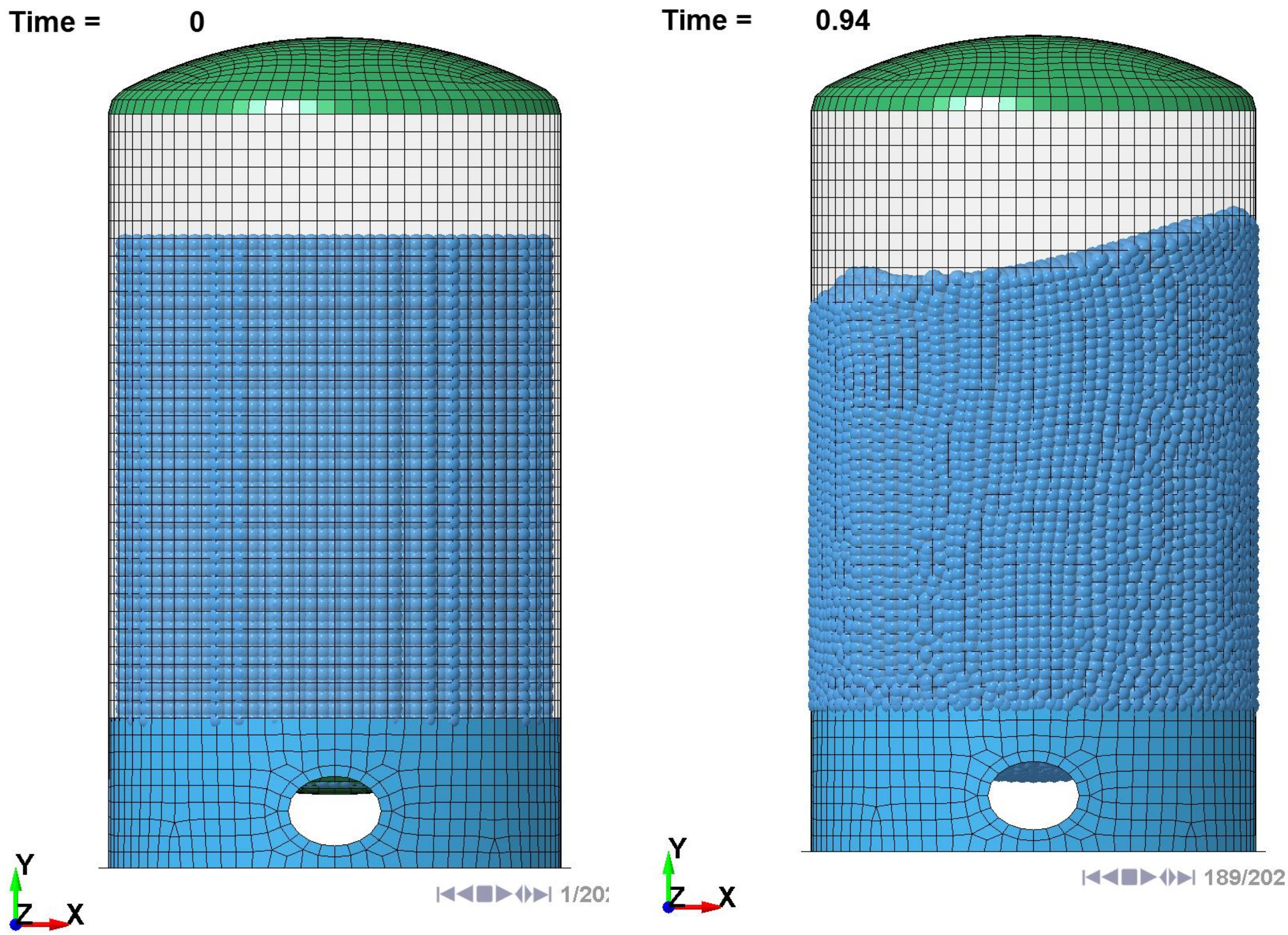


Figure 9: The shell mesh of the pressure vessel was used to generate the SPH particles within the pressure vessel. The EOS was for standard water. Sloshing was done by accelerating the vessel from the base of its skirt.

The sloshing loads for this vessel were calculated per ASCE 4-98, *Seismic Analysis of Safety-Related Structures*. From these calculations, loading conditions were quantified and applied to the FE model. The SPH sloshing results were compared against those analytical methods to determine the maximum base ring forces for the vessel subjected to the given acceleration specifications. It was satisfying to see that the hand-calculations correlated very well with the SPH results.

C3.5.4.2 Horizontal Impulsive Mode

C3.5.4.2.1 Effective weight of fluid - Impulsive mode

D/H

$$\frac{\mathrm{Diameter_{Shell}}}{\mathrm{FluidHeight_{High}}} = 0.811 \qquad \frac{\mathrm{Diameter_{Shell}}}{\mathrm{FluidHeight_{Operating}}} = 1.207 \qquad \frac{\mathrm{Diameter_{Shell}}}{\mathrm{FluidHeight_{Low}}} = 2.365$$

If D/H < 1.333

High Fluid Level

$$W_{TH} := \mathrm{FluidWeight_{High}} \qquad H_H := \mathrm{FluidHeight_{High}} \qquad D := \mathrm{Diameter_{Shell}}$$

$$W_{1H} := W_{TH}\left[1 - 0.218\cdot\left(\frac{D}{H_H}\right)\right] = 1.251 \times 10^{4}\cdot\mathrm{lbf}$$

$$X_{1H} := H_H\left[0.500 - 0.095\cdot\left(\frac{D}{H_H}\right)\right] = 39.844\cdot\mathrm{in} \qquad X_{1Hb} := X_{1H} + 14.4\mathrm{in}$$

Operating Fluid Level

$$W_{TO} := \mathrm{FluidWeight_{Operating}} \qquad H_O := \mathrm{FluidHeight_{Operating}} \qquad D := \mathrm{Diameter_{Shell}}$$

$$W_{1O} := W_{TO}\left[1 - 0.218\cdot\left(\frac{D}{H_O}\right)\right] = 7.313 \times 10^{3}\cdot\mathrm{lbf}$$

$$X_{1O} := H_O\left[0.500 - 0.095\cdot\left(\frac{D}{H_O}\right)\right] = 24.394\cdot\mathrm{in} \qquad X_{1Ob} := X_{1O} + 14.4\mathrm{in}$$

If D/H > 1.333

Low Fluid Level

$$W_{TL} := \mathrm{FluidWeight_{Low}} \qquad H_L := \mathrm{FluidHeight_{Low}} \qquad D := \mathrm{Diameter_{Shell}}$$

$$W_{1L} := W_{TL}\cdot\frac{\tanh(0.866)\cdot\left(\frac{D}{H_L}\right)}{0.866\cdot\left(\frac{D}{H_L}\right)} = 3.753 \times 10^{3}\cdot\mathrm{lbf}$$

$$X_{1L} := H_L\cdot 0.375 = 12.112\cdot\mathrm{in} \qquad X_{1Lb} := X_{1L} + 14.4\mathrm{in}$$

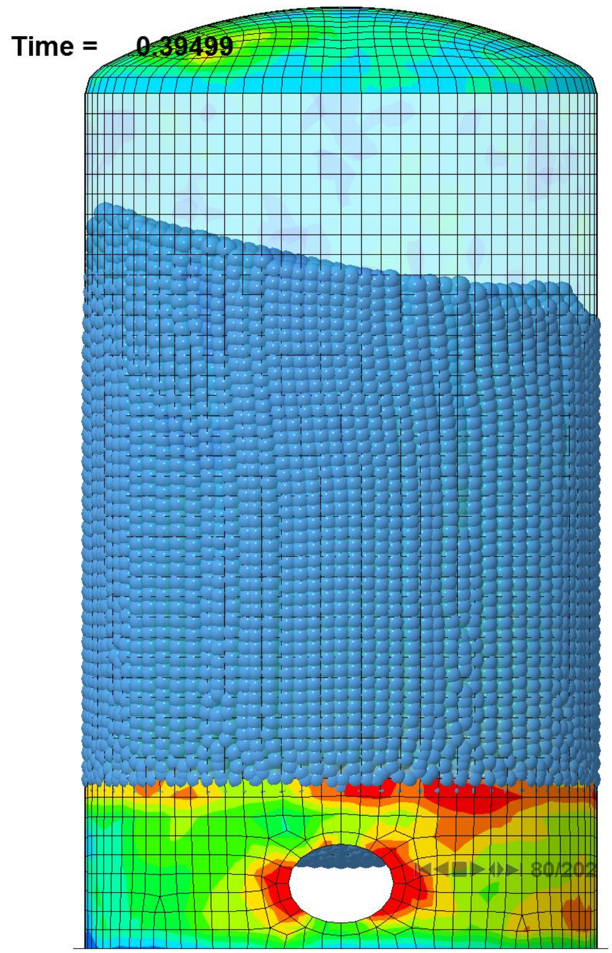


Figure 10: Hand-calculations using ASCE 4-98 is the industry standard for sloshing analysis but the SPH method provides a full-field color simulation of the event with stress and base skirt reaction forces.

Contact

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