Abstract

Present work focuses on developing a three-dimensional finite element formulation for the dynamic analysis of cylindrical composite liquid containers considering fluid-structure interactions. Cylindrical tanks are the most widely used liquid storage tanks, and their dynamic analysis is of great practical importance. Sloshing of liquid in cylindrical containers can cause severe damage to the containers. Hence free vibration and forced vibration analysis of the sloshing behaviour of liquid-filled containers are necessary. The elasticity of tank material plays an important role on the sloshing behaviour, thus, the tank material needs to be taken into consideration while analysing the sloshing. Composite materials are rapidly replacing conventional isotropic materials due to their superior strength, durability, tailorability, and ease of maintenance.

3D degenerated shell elements are used to model the composite tank structure due to their clear advantages over other elements. The element is developed by using the degenerated solid approach based on Reissner–Mindlin assumptions. Thus, the shear deformation and rotary inertia effect have been considered, and the 3D field has been reduced to a 2D field in terms of mid-surface nodal variables. These elements are not based on any shell theory, thus making them free from the limitations of the structure's geometry.An 8-noded degenerated shell element with a natural coordinate system (ξ, η, ζ), defined by the element geometry in the global coordinate system has been considered for the present study. A new model to analyse delaminated plates has been developed using proposed 3D degenerated elements to show the accuracy and efficiency of the developed element. New results are generated using the proposed method for different boundary conditions, ply orientations, size of delamination, and the location of delamination, which will serve as a benchmark for future research. Furthermore, parametric study of free vibration and forced vibration of cylindrical composite tanks have been performed using the developed element.

A pressure-based three-dimensional finite element model is developed using 20-noded brick elements to analyse the liquid inside the tank. An experimental setup is demonstrated to validate the developed numerical model. Results for free vibration as well as forced vibration analysis of liquid inside a cylindrical container are generated using the developed numerical model.

Finally, direct coupling between the developed structure and fluid model is performed for the fluid-structure interaction of the cylindrical composite tank. The coupled model is then validated, and new results are generated using the coupled model. Free vibration analysis of composite tank for various ply orientations, tank thicknesses, tank height to radius ratios, water heights, etc., are performed, and results are generated to better understand the behaviour of natural sloshing frequency for different parameters. Also, forced vibration of the composite tank is performed to generate maximum slosh height, maximum tank deflection, hydrodynamic pressure on tank, and maximum tank base moment under harmonic and seismic loading for a deep understanding of the behaviour of these parameters. It is observed that the tank stiffness in the radial direction of the tank affects the sloshing parameters much more significantly than the overall stiffness of the tank. The radial stiffness can be increased by changing the ply orientation of the composite tank. This phenomenon further strengthens the importance of the use of composite materials instead of conventional materials for liquid tanks.

Keywords: Degenerated shell elements, Delaminated plates, Composite tank, Cylindrical tank, 3D sloshing, Direct coupling, Harmonic loading, Seismic loading.