THREE-DIMENSIONAL BWR SUPPRESSION POOL SEISMIC SLOSHING ANALYSIS

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SUMMARY

Liquid sloshing in a moving container is commonly analyzed by an equivalent mechanical model in terms of springs-masses, and results are available only for containers of simple geometries and with one direction (e.g., horizontal) excitation. In this paper, a mathematically precise procedure is developed for the determination of the dynamic responses of the liquid in a rigid container subjected to three-directional excitations. This procedure can be conveniently programmed for computer calculation. The method used is a combination of "separation of variables" and the finite element method, and can be applied to a system made of a cylindrical tank, having cross-sections of any shape, and containing liquid with a flat free surface.

Application is made to the analysis of the liquid motion in a BWR suppression pool under three-directional seismic excitations, with example solutions solved for a typical suppression pool system within a Mark II type containment modeled by a rigid annular circular cylindrical tank containing a pool of water. Parameter indicating the relative importance of the plate stiffness is evaluated to justify the rigid tank assumption for this particular problem. Mathematical model incorporating liquid structure interaction by the finite element method is suggested for further investigation.

The liquid motion is described by the Laplace equation subjected to linearized boundary conditions, for incompressible, and irrotational flows. The method of separation of variables is used to separate spatial eigenfunctions in three cylindrical coordinates, namely, r, θ, and z, from equations governing the liquid motion. The free surface oscillation mode (i.e., eigenfunction) along r-direction is determined by finite element method. By the use of normal mode expansions, a second order dynamic equation under a combination of forced and parametric excitation is obtained for each mode. With given seismic ground excitation time-histories, the free surface oscillation profiles, and the pressure and velocity fields in the pool are then calculated by superposition of modal responses as time-histories. The above procedure is derived for systems having circular symmetry. For tanks having cross-sections of other shapes, the eigenfunctions are not separable in the r and θ directions. Variational functional is provided for such cases to determine the free surface oscillation modes by the finite element method.

Results indicate that the vertical container motion is of secondary importance in determining free surface deflections, but has its main contribution in the pressure loads on tank boundaries. Surface deflection has its maximum value at the region near the inner radius, occurring after earthquake terminates. It was also found that the most important free surface oscillation mode is the second mode with natural frequency of about 0.3 Herz for a typical BWR suppression pool and that even-numbered modes are more important than odd-numbered modes. This is in contrast to that of a circular cylindrical tank where the first mode dominates and higher modes are generally of monotonically decreasing importance.