Using Base Isolation Method to Mitigate the Seismic Response of Liquefied Natural Gas

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During the last 20 years, part of the research work has focused on the seismic analysis of Liquefied Natural Gas (LNG) tanks, due mainly to (1) the increasing number of LNG tanks constructed in seismically active regions, resulting from the adoption of LNG as an environmentally friendly fossil fuel, and (2) the catastrophic environmental impact, associated with a potential local or total failure of such tanks, caused by the earthquake motion.

Seismic isolation is a well-known method to mitigate the earthquake effects on the structures by increasing their fundamental natural periods at the expense of larger displacements in the structural system. In this study, the seismic response of isolated and fixed base vertical, cylindrical, liquid storage tanks is investigated using a numerical model, taking into account the fluid-structure interaction effects. The numerical model is validated by the comparison of its results with the experimental measurements of small-scale tank under harmonic and seismic excitations. The comparison reveals that the use of the considered model provides enough accuracy for evaluating the seismic behavior of nonlinear isolated and non-isolated tanks.

Three vertical, cylindrical tanks with different ratios of height to radius (H/R = 2.6, 1.0 and 0.3 as the representatives of slender, medium and broad tanks) are analyzed and the results of response-history analysis, including base shear, overturning moment and free surface displacement are reported for isolated and non-isolated tanks. The isolated tanks are equipped with lead rubber bearings isolators, and the bearings are modeled by using a non-linear spring in numerical model. Long period ground motion is the main parameter that can significantly affect the seismic response of isolated tank.

It is observed that the seismic isolation of liquid storage tanks is quite effective and the response of isolated tanks is significantly influenced by the system parameters such as their fundamental frequencies and the aspect ratio of the tanks. The average reductions of base shear forces of isolated tanks are 71%, 70% and 50% for broad, medium and slender isolated tanks. It seems that the effectiveness of base isolation system to mitigate the base shear force is not significantly affected by changing of tank aspect ratio. In terms of overturning moment, the average reductions of the order of 71%, 69% and 47% for broad, medium and slender tanks is obtained due to applying of isolation system. Therefore, overturning moment is considerably mitigated by the reduction of the tank aspect ratio. The effectiveness of base isolation considerably reduces for exerted earthquake records including long period motion. Especially for slender tanks, base isolation may even increase the overturning moment.

However, the base isolation does not significantly affect the surface wave height, and even it can cause adverse effects on the free surface sloshing motion. The results of free surface displacement for both isolated and non-isolated tanks have quite similar trends for considered tanks. The errors between the maximum sloshing wave height of fixed base and isolated tank are less than 8% for most of the considered cases. Even, the sloshing height is slightly amplified in some cases. Therefore, the base isolation system can cause adverse effects on the free surface sloshing motion.

It can be concluded that the effectiveness of the base isolation method is very sensitive to the physical and geometrical parameters of the considered tanks. This suggests that a careful selection of isolators with a certain limit on the mechanical properties of the isolators is required for the optimal seismic isolation design of liquid storage tanks.

Keywords: LNG; Storage Tanks; Numerical Model; Base Isolation