NONLINEAR SEISMIC ANALYSIS OF STEEL TANKS UNDER HORIZONTAL AND VERTICAL BASE EXCITATIONS

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The aboveground cylindrical steel tanks are the type of lifeline structures extensively used in water supply facilities, oil and gas refineries and nuclear power plants for various purposes. The major damage mechanisms of steel tanks observed in the past seismic events are the elastic buckling or elasto-plastic buckling of their shells that are called diamond buckling or elephant-foot buckling, respectively. The seismic behaviour of tanks under earthquake excitation is very complex mainly due to the effects of liquid-structure, material and geometrical nonlinearities. The main purpose of this study is the numerical investigation of the seismic behaviour of anchored cylindrical steel tanks with different aspect ratios (H/D) under tri-directional seismic input using finite element method. The finite element models include two anchored steel tank with different height to diameter ratio (H/D) subjected to tri-directional ground excitations. Also, the influence of the aspect ratio of the tank models, type of seismic ground motions and importance of simultaneous 3-directional action of seismic ground motion on the seismic behaviour of steel tanks is investigated.

In finite element modelling of the steel tank, four-node, doubly curved quadrilateral shell elements with reduced integration is used for modelling the surrounding wall, the bottom plate and the roof. Also two-node linear beam elements are used for modelling the roof rafters. The liquid is modeled using eight-node brick elements. The liquid element has only one pressure unknown as degree of freedom at each node. This elements is formulated based on the Laplace equation and describe liquid using just compression and expansion without any shear effect. Assuming the liquid is compressible and neglecting its viscosity. The interaction between liquid and tank was formulated based on a master-slave contact method, in which normal force is transmitted using tied normal contact between both surfaces through the simulation. Assuming the small-amplitude gravity waves on the free surface of the liquid, the sloshing waves are considered in liquid model.

The proposed finite element model is verified by the experimental results carried out by Manos and Clough (1982). The experimental results for the response parameters, i.e. the hydrodynamic pressure and sloshing wave height, are used as a reference measure to evaluate the accuracy of the numerical results obtained in this study. Also, the dynamic properties of tank-liquid model, i.e. the natural frequency of the impulsive and sloshing modes, are verified by those obtained of API 650 standard (2009).

The 3-D tank models considered in this study are the same as the shallow tank (model A) and tall tank (model C) used by Virella et al. (2006). The height to diameter ratio (H/D) for shallow tank (model A) and tall tank (model C) is 0.40 and 0.95 respectively. In the finite element model, both geometric and material nonlinearities are considered. The Rayleigh mass proportional damping considered for the steel tank models. The explicit time integration method is used to integrate coupled equation of motion for tank-liquid system. This method is based on explicit central difference integration rule and benefits from the lumped and diagonal mass matrix.

Four far-field and near-field pulse-like records with different frequency contents were considered in the nonlinear dynamic analysis to investigate the seismic behaviour of steel tanks. All the selected accelerograms are recorded on rock or stiff soil sites. The Pakfield and Northridge (Canyon station) are far-field records, while the San-Salvador and Northridge (Rinaldi station), are considered to be near-field records.

The simple criteria by Budiansky and Roth (1962) introduced to account for the dynamic buckling load of structures. Based on this criterion, the dynamic analyses of structure are carried out under different level of loadings, and the specific load at which there is a significant jump in the displacement response for a small load increment is considered as the critical dynamic buckling load. In this work, the same criterion was used to study buckling behavior of the tank models.

The incremental dynamic analyses of the tank models were carried out for the selected earthquake records scaled for several PGAs from 0.05g to 0.3g as a preliminary range of excitation intensities. The scale factor for an accelerogram computed based on the larger PGA of its two horizontal components. Then, all three components of the accelerogram are multiplied by the computed scale factor. The tank models were first subjected to gravity loads including hydrostatic and self-weight loads, before being exposed to seismic loadings. Two damage states for the tank models under seismic loading were found in this work. The material plasticity at tank wall and the elastic buckling of the tank wall were observed in liquid- tank systems.

The comparison on the critical peak ground accelerations for material plasticity and elastic buckling modes for tank models A and C for all selected accelerograms is presented in Figure 1.

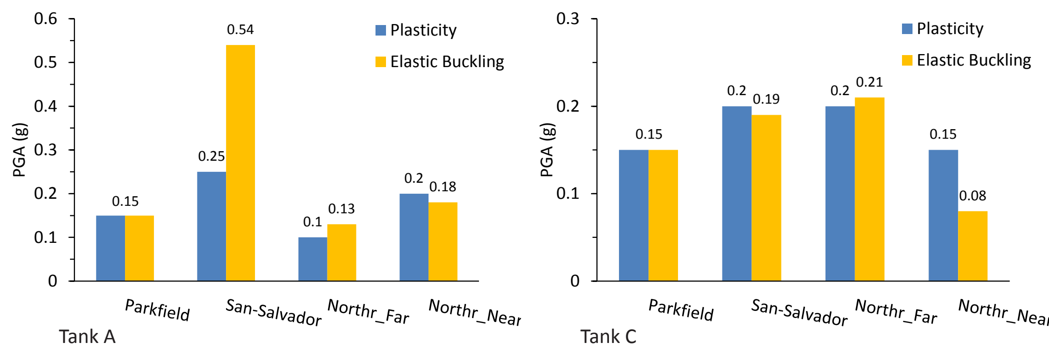

Figure 1. Critical PGAs for plasticity and elastic buckling for tank models A and C

The numerical results obtained indicate for most selected accelerograms, plasticity of tank shell occurred in shallow tank (H/D=0.40) for a PGA which less than or equal the PGA for elastic buckling at the top of the tank shell. Also, for shallow tank (H/D=0.40) subjected to near-field Northridge accelerogram, material plasticity at mid height of the tank shell widespread all round of the tank shell due to the influence of the vertical component of the near-field record. For most selected accelerograms, elastic buckling at the top of the tank shell occurred in tall tank (H/D=0.95) for a PGA which less than or equal the PGA for plasticity of tank shell. When both tank models A and C subjected to near-field earthquake accelerograms (San-Salvador and Northridge_Near), either the critical PGA for elastic buckling mode or the critical PGA for material plasticity for tank model C is less than corresponding critical PGAs for tank model A.

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