Seismic response analysis and damping method of spherical liquid storage tank

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Abstract. Earthquake is a natural disaster with outburst and ruinous in the world. The damage of spherical liquid storage tank due to earthquake can result in serious deaths and economic loss. In this thesis, the analysis of seismic response of spherical tank, which considering interior pressure, gravity, liquid sloshing and earthquake, is carried out. Seismic response analysis shows that the spherical tank rotates horizontally while rotating a small amount around the horizontal axis, mainly around the vertical axis. Time-history analysis of the tank under passive control is performed. The spherical tank model with dissipative bracing system installed has a very good damping effect by comparing the seismic responses of controlled and uncontrolled structures.

1. Introduction
Earthquake is a natural disaster with outburst and ruinous in the world. The damage of spherical liquid storage tank due to earthquake can result in serious deaths and economic loss [1-2]. Especially leak of flammability and exploded-prone medium deposited in tanks can cause Secondly disaster, which led to the serious destroy of the survival environment. The spherical liquid-storage tank is developing with high parameter and huge, analyze the seismic response of it and reduce seismic damage to the least has always become one of the most important researches, which becomes more outstanding in currently study of seismic protection of petrochemical facilities.

Structural vibration control technology is a burgeoning technology to take precautions against and to reduce natural calamities, apply which to seismic protection of petrochemical facilities is an innovative attempt [3-4]. In this task, the analysis of seismic response of spherical tank considering that it effect on interior pressure, gravity, liquid sloshing and earthquake. Then, applying passive control technologies of fluid damper to the support system of the tank, which is base on passive energy dissipated control technology, and compare the seismic response in order to investigate the effectiveness of the seismic protection system [5-7].

2. Description of structure
The structure analyzed in the present study, shown in Fig. 1, is a typical spherical liquid storage tank with a volume of 1000m³. The contained liquid is assumed to be refrigerated polypropylene with a density of 480kg/m³. The sphere has an inner diameter of 12.3m, an average shell thickness of 34mm and is constructed from a steel plate with Elastic Modulus of 2.1GPa, Poisson's ratio of 0.3 and density of 7850kg/m³. The equator of the sphere is 8.0m above ground. The sphere is supported by then circular columns with an outer diameter of 486mm and a wall thickness of 10mm. The spherical tank is laterally strengthened by pairs of diagonal braces between columns, i.e. 11 pairs in total, as shown in Fig. 1. The braces are made of steel pole with diameter of 56mm, the mechanical characteristics of
which are the same as those of the spherical container. Each brace is pin-connected to the adjacent columns, at 0.5m and 6m above the bottom level of the columns. All braces are considered to be tension-only elements since they buckle at very low compression levels.

![Figure 1. A typical spherical liquid storage tank.](image1)

![Figure 2. Finite element model of the tank.](image2)

### 3. Seismic response analysis of spherical liquid storage tanks

#### 3.1. Finite element model

The numerical analysis of the spherical storage tank structure is performed on the basis of detailed finite element model developed with the help of the routines available in the ANSYS Finite Element program, as shown in Fig. 2. The spherical shell and the supporting columns are modelled by 3310 four-node shell elements (SHELL181) with six DOFs per node. The eight node solid fluid element (FLUID80) with three DOFs per node has been chosen to model the incompressible fluid content. A total of 1023 or 1793 FLUID80 elements are used, respectively, for 89% tank fullness considered in this work.

In order to satisfy the continuity conditions between the fluid and solid media at the spherical boundary, the coincident nodes of the fluid and shell elements are constrained to be coupled in the direction normal to the interface, while relative movements are allowed to occur in the tangential directions. The uniaxial “tension only” behaviour of the braces is simulated by means of the 3-D spar elements LINK10, which feature a bilinear stiffness matrix, i.e. the stiffness is removed if the element goes into compression. The above finite element model of spherical tank is numerically analyzed by means of a full transient non-linear analysis. The governing equations of motion can be expressed in matrix form as

\[
[M]\ddot{u} + [C]\dot{u} + [K]u = \vec{F}(t)
\]

with \([M]\), \([C]\) and \([K]\) being the mass, damping and stiffness matrices of the structure, \(u\), \(\dot{u}\) and \(\ddot{u}\) being the displacement, velocity and acceleration of the structure, and \(\vec{F}(t)\) of the load applied to the structure. Eq. (1) is integrated directly in time using the Newmark-\(\beta\) method.

#### 3.2. Seismic wave selection

The selected Tianjin wave is suitable for the third and fourth types of sites. The duration is taken from the first 10 seconds of the Tianjin wave record. The reading interval is 0.02 seconds. The time history is shown in Fig. 3.

In this paper, the seismic fortification intensity to be 8 degrees, the peak value of X to Tianjin wave acceleration is adjusted to 0.20g, the corresponding Y-direction peak is 0.29g, and the Z-direction peak is 0.20g.
3.3. Time history analysis of 89% full spherical tank

Enter the three-direction seismic wave. Fig. 4 and Fig. 5 show the x-direction and y-direction displacement time history of the apex and bottom points of the spherical shell. The maximum x-direction displacement of the apex (up) and bottom (low) of the spherical tank is 53mm and 50mm, respectively, and the maximum difference in the time course is 3mm. The maximum y-direction displacement of the apex (up) and bottom (low) of the spherical tank is 18 mm and 17 mm, respectively, and the maximum difference in the time course is 1 mm. It shows that the spherical tank rotates horizontally while rotating a small amount around the horizontal axis, mainly around the y axis.

Fig. 6 shows the horizontal displacement cloud of the spherical tank when the seismic wave is input for 5.3s while the maximum displacement occurs. The equivalent stress of the spherical shell, the tensile stress of the rod and the vertical reaction force at the bottom of the column also appear at this time. Fig. 7 shows the stress distribution of the spherical shell at this moment. In the position where the pillar and the spherical shell are connected, the stress level is high because the displacement of the casing is resisted to satisfy deformation coordination.

4. Damping method study

4.1. Finite element model

A viscous damper is a device that uses viscous fluid to dissipate energy through an orifice or a gap between a cylinder and a piston to generate viscous damping [8-9]. Replace all tie rods in the original structure with a viscous damper. In this paper, only the simplest model is used for analysis. Therefore, the linear viscous damper is selected, and its viscous damping coefficient is 600kN/(m/s).
The viscous fluid damper devices are modelled using the 1-D non-linear damper elements COMBIN37. The above finite element model of spherical tank is numerically analyzed by means of a full transient non-linear analysis. The governing equations of motion can be expressed in matrix form as

\[
[M] \ddot{u} + [C] \dot{u} + [K] u = [M][\ell] \{\ddot{u}_g(t)\}
\]

with \([\ell]\) being an influence coefficient matrix, and \(\{\ddot{u}_g(t)\}\) the ground acceleration. Eq. (2) is integrated directly in time using the Newmark-\(\beta\) method. The nonlinear, introduced by the “tension-only” behaviour of the conventional braces and by the viscous fluid damper devices, require an iterative solution with incremental load steps. In the present study the iterative Newton-Raphson approach is employed.

The seismic response of the spherical liquid storage tank with and without the dissipative bracing system is investigated by performing two types of analyses: time domain analysis. The problem is solved for 89% fullness of tank.

The seismic response of the spherical tank structure with a dissipative bracing system is compared to that of the tank with conventional bracing in order to investigate the effectiveness of the seismic protection system. The time history analysis corresponds to the TJ earthquake ground motion, the ground acceleration of which has a duration of 10sec and a peak ground acceleration (PGA) of 0.4g, applied in horizontal x-direction of the tank.

4.2. Result analysis

The time variation of the displacement in the x-direction at the top of the sphere, the total base shear and the vertical fluid displacement at the intersection of the fluid free surface are shown in Figs 8, 9 and 10. Figs 8 and 9 reveal a significant reduction in horizontal movement and base shear of the tank, implying the effectiveness of the seismic protection system.

More specifically in Fig. 8, the maximum horizontal displacements at the top of the sphere are reduced from 10.6cm when conventional braces are used to 3cm when dissipative ones are employed. Similarly in Fig 9, the total base shear peak responses are reduced from 401kN to 196kN.

On the other hand, the sloshing vertical displacements of the fluid content, shown in Fig. 10, remain almost the same, as expected, for both bracing systems. This is due to the fact that the natural frequency of sloshing liquid mass (2.3sec) is well apart from the dominant natural frequencies of the structure and corresponds to negligible portion of the seismic excitation in Fig. 11 the hysteretic loop of the viscous damper had effective absorbed the energy of earthquakes.
5. Conclusions

Seismic response analysis shows that the spherical tank rotates horizontally while rotating a small amount around the horizontal axis, mainly around the y axis. Time-history analysis of 89% of the tanks under passive control is performed. The spherical tank model with two dampers installed has a very good damping effect by comparing the seismic responses of controlled and uncontrolled structures.

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