*Journal of Ferdowsi Civil Engineering, Vol.34, No.1, 2021.*

# Exploring the Seismic Behavior of the On-ground Bipartite Elliptical Liquid Storage Tanks

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## 1. Introduction

Tank is a structure that is used for the storage of various liquids and in the on-ground, elevated, concrete and steel types, has a wide usage in the water plants, refineries and factories. Regarding the application of vast dynamic and hydrodynamic forces on a large tank in the event of earthquake and great importance of complete function continuation of the structure in critical conditions, the study of its seismic behavior is of high importance.

It is notable that various static and dynamic analyses and also experimental and mathematical studies have been done on various on-ground and elevated tanks of rectangular and circular shapes. However, neither in the collection of research articles nor in the collection of design codes, no work has been done on the elliptical tanks, so the study of the seismic behavior of the elliptical tanks is an innovation of this research.

The elliptical tank in flexible condition has more stiffness than the rectangular tank, hence in experiences less deformation and cracking in earthquakes. The elliptical tank also experiences much less stress concentration rather than rectangular tank, because of the absence of the sharp corners. Moreover, from passive defense aspect, the ellipse curved form works better than rectangle linear form.

Bipartite elliptical tank is an elliptical tank that has elliptical and annular internal parts. Generally, dividing tanks into two parts with equal volume increases their efficiency from operation and loading aspects. From operation aspect, during discharge of a part for its repair or cleaning, the fullness of another part preserves the operation ability of the tank. From loading aspect, the convective pressure on the tank, resulting from water sloshing in the event of earthquake is decreased because of the decrease of water horizontal dimensions in each part.

Slenderness and prolateness factors have much usage in elliptical and circular tanks and are defined as following.

Slenderness factor of the bipartite elliptical tank is calculated from following equation:

$$\lambda = \frac{h}{L} \qquad (1)$$

Where h and L are height of water in tank per meter and external length of tank per meter respectively.

Prolateness factor of the bipartite elliptical tank also is determined from following equation:

$$\eta = \frac{L}{B} \qquad (2)$$

Where B is external width of tank per meter.

In this study, monoplete and bipartite on-ground elliptical tanks, in various conditions of tank slenderness and prolateness, have been dynamically analyzed simultaneously under longitudinal and transverse components of Cape and Tabas earthquakes. Then, maximum impulsive pressure and maximum wave height parameters have been compared with each other in corresponding conditions.

## 2. Method

In this study, time history method has been used for dynamic analysis of the system in FLUENT software. For doing this work, the longitudinal and transverse velocigrams of each earthquake have been applied on the system simultaneously, in the longitudinal and transverse directions of the tank, respectively. It is notable that time increments number has been selected equal to 1000 to obtain sufficient accuracy and reasonable time for dynamic analysis.

Moreover, ka epsilon method was used for modeling of accelerated motion of the liquid in rigid tank and determination of maximum impulsive pressure and maximum wave height. In this method, density and viscosity and damping coefficient of the water in the tank were assumed equal to 1000 kg/m3 and 0.001 Pas and 0.5%, respectively.

The boundary conditions of the tank base and tank walls were defined as fixed and rigid, respectively. The tank lacks a roof, hence its top surface was defined as pressure outlet type. Moreover, the water sliding on the surface parallel to surfaces of the tank walls and tank base was provided by the use of standard wall option.

After geometric modeling and materials and boundary conditions definition and earthquake velocigram application on monoplete and bipartite tanks with various slendernesses and prolatenesses in FLUENT software, the transient seismic analysis was simultaneously done on them in the longitudinal and transverse directions.

It is notable that the maximum impulsive pressure of water under simultaneous longitudinal and transverse earthquakes, occurs in bottom of wall and in end of the diameter parallel to resultant earthquake. Moreover, the maximum wave height of water under simultaneous longitudinal and transverse earthquakes, occurs in water free surface and in end of the diameter parallel to resultant earthquake.

Decrease percent of the maximum impulsive pressure per percent, is calculated from following equation:

$$P_p = 100\left(1 - \frac{\alpha_d P_d}{\alpha_e P_e}\right) \qquad (3)$$

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Where $P_d$ and $P_e$ are maximum impulsive pressure of bipartite and monoplete rigid elliptical tanks per Pascal, respectively. Moreover, $\alpha_d$ and $\alpha_e$ are magnification factor of impulsive pressure of bipartite and monoplete flexible elliptical tanks, respectively.

It is notable that the tank flexibility increases liquid impulsive pressure rather than rigid tank condition, so the mentioned effect is entered into the calculations using the impulsive pressure magnification coefficient.

Regarding the sameness of material and thickness of walls and base of monoplete and bipartite tanks under study, the magnification factors of impulsive pressure of monoplete and bipartite flexible elliptical tanks become equal, so the equation 3 is simplified as follows:

$$P_p = 100\left(1 - \frac{P_d}{P_e}\right) \quad (4)$$

Also, decrease percent of the maximum wave height per percent, is determined from equation 5:

$$P_h = 100\left(1 - \frac{h_d}{h_e}\right) \quad (5)$$

Where $h_d$ and $h_e$ are maximum wave height of bipartite and monoplete elliptical tanks per meter, respectively.

To study the slenderness effect of elliptical tank on the internal wall efficiency, on-ground monoplete and bipartite elliptical tanks with fixed base, 20m long and 10m wide with various water heights, have been analyzed dynamically by FLUENT software under Cape and Tabas earthquakes in longitudinal and transverse directions simultaneously.

It is notable that in calculation of liquid maximum impulsive pressure, earthquake peak acceleration has maximum effect, so in calculation of liquid maximum impulsive pressures, Cape earthquake that has maximum peak acceleration, has overruled.

Moreover, in calculation of liquid maximum wave height, earthquake peak pseudodisplacement has maximum effect, so in calculation of liquid maximum wave heights, Tabas earthquake that has maximum peak pseudodisplacement, has overruled.

**3. Conclusion**

The results revealed that generally, in on-ground elliptical tanks, the efficiency of elliptical internal wall in the decrease of liquid sloshing is higher in more slender tanks. Moreover, it was revealed that generally, in on-ground elliptical tanks, the efficiency of elliptical internal wall in the decrease of liquid sloshing is higher in more prolate tanks.

From liquid maximum impulsive pressure calculation viewpoint, earthquake that has maximum peak acceleration, overruled on design (Cape earthquake with peak acceleration equal to 14.973 m/s2). From liquid maximum wave height calculation viewpoint, earthquake that has maximum peak pseudodisplacement, overruled on design (Tabas earthquake with peak pseudodisplacement equal to 2.131 m).Based on implemented studies in this research, due to tank partitioning, the following quantitative conclusions were obtained:

1. The maximum reduction percentage of maximum impulsive pressure of liquid, equal to 5.9 %, occurred in the amount of slenderness ratio equal to 0.25.
2. The maximum reduction percentage of maximum wave height of liquid, equal to 30.8 %, occurred in the amount of slenderness ratio equal to 0.2.
3. The maximum reduction percentage of maximum impulsive pressure of liquid, equal to 9.2 %, occurred in the amount of prolateness ratio equal to 3.5.
4. The maximum reduction percentage of maximum wave height of liquid, equal to 44.4 %, occurred in the amount of prolateness ratio equal to 3.