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Investigating the Seismic Vulnerability of Urban Water Reservoirs Based on Economic Justification

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Abstract:- Liquid storage tanks are included in the group of industrial (non-building) structures, which are made of different types of steel and concrete and in different shapes, including cylindrical, cubic, conical, and spherical, on the ground and in the air, and with different uses, including liquid fuel storage tanks in Factories, oil and gas facilities, and the like, up to drinking water and firefighting tanks are divided into industrial towns and urban residential areas. Special structures such as water tanks are of such importance that they must have high safety not only in normal and operating conditions but also in critical conditions such as earthquakes. As a result, the design of these structures against seismic loads and their proper performance during an earthquake is very important. This study aimed to investigate and evaluate the seismic behavior of concrete tanks with fluid (water) in different states. For this purpose, 5 concrete tanks with different dimensions were investigated and parameters such as displacement, shear stress, soil settlement and displacement in a specific path were analyzed. By checking the displacement of these tanks, it was found that this parameter is the most optimal for tank number 4.

Keywords: Industrial structures, seismic evaluation, liquid tanks, concrete tanks, optimization

Introduction

1. Introduction

Today, the upward trend of the increase of the earth's population on the one hand and the limitation of natural resources on the other hand has forced mankind to think of solutions and take various measures in order to save, optimize productivity and future vision of these resources. Water is one of the essential needs of humans, although it occupies two-thirds of the earth's surface, due to its time and space limitations on the one hand and the small amount of fresh and accessible water on the other hand, today it is necessary to manage and plan it. This subject is so important that some thinkers consider future human wars as water wars [1, 2]. Special structures such as water tanks are of such importance that they must have high safety not only in normal and operating conditions but also in critical conditions such as earthquakes. The heavy life and financial consequences caused by the destruction of water reservoirs lead engineers to design such structures in such a way that they can withstand strong earthquakes with minimal damage [3, 4]. On the other hand, because the two fluid environments and the structure are in direct contact with each other and the overall response of the system depends on the size between them; The modeling of these structures should be in such a way that it expresses the real behavior of the interconnected fluid-structure system. Such structures, especially when their rupture leads to the destruction of tanks are of special importance. This has created a lot of enthusiasm among researchers to develop new modeling methods for seismic dynamic analysis. Damage to fluid storage tanks under the influence of recent earthquakes such as Lomapritai in the United States, Lausanne in the Philippines, Hokkaido in Japan, Erzincan in Turkey, Northridge in the United States, Kobe in Japan, Izmit in Turkey, and Haiti in the United States caused many researchers to study and conduct laboratory and analytical studies in this field. Therefore, the use of efficient and cost-effective methods to reduce the impact of gravity waves caused by earthquakes can improve the performance of the structure and fluid system and lead to a reduction in construction costs. Today, the managers of every country are facing challenges in several ways. Due to the expanding economic pressures, they must ensure the sustainable use of natural resources and the survival of the quality of resources. The society and officials are increasingly demanding the establishment of an effective strategy for the management of these valuable resources. Safe water is one of the serious challenges before us. For a water sector manager, a correct understanding of natural systems and physical laws governing each component of the hydrological cycle in nature is important. The non-linear behavior of structures during an earthquake causes a considerable amount of input energy of the earthquake to be lost as damping and residual energy, as a result, the design of structures against seismic loads and their proper performance during an earthquake is of great importance. Unfortunately, most of the densely populated areas of our country are located in earthquake-prone areas. Because most of the big cities are built at the foot of heights that are separated from the plain by important and often complete faults. Throughout history, Khorasan region has always been one of the most active earthquake-prone regions in the country. One of the faults of Mashhad is the northern fault of Mashhad. This fault is a continuation of the Toos fault, which branches off from the Kashafroud fault in the north of Toos city and passes through the northern corner of Mashhad along the northwest-southeast direction. Due to the importance of these structures in urban and industrial service networks, their safe operation in an earthquake to respond to the water needs of citizens, avoiding fire and environmental damage is of particular sensitivity. Ensuring the proper functioning of these structures during an earthquake requires more studies in terms of their behavioral complexity. This complexity, on the one hand, , the need to understand the economy of the tank and water during loading and designing the structure, under the influence of the factors in the structure, on the other hand, doubles the need to provide simple and optimal methods in the regulations. This study aimed to evaluate the seismic vulnerability of water reservoirs in Mashhad, Iran so that by knowing the current situation of urban water reservoirs in Mashhad city and determining the level of vulnerability of the reservoirs and also investigate general economic solutions regarding the improvement of the current conditions. The hypotheses of this study were: urban water reservoirs of Mashhad city have seismic vulnerability and it is effective to identify and provide economic solutions regarding the future planning of the reservoirs.

2. Literature Review

2.1 Classification of ground concrete tanks in terms of geometric shape and dimensional specifications

Ground concrete water tanks are usually built in cylindrical and rectangular cube shapes, although they can be built in any beautiful and appropriate geometric shape. In general, cylindrical tanks are superior to rectangular cubic tanks in terms of technical aspects and passive defense considerations. In areas where the soil load factor is suitable, bowl tanks are also a suitable option for large volumes.

2.2 Structural system resistant to earthquake forces in ground concrete tanks

To evenly distribute the earthquake force and prevent any concentration of force due to large torsional anchors, it is necessary for the tank to have a uniform distribution of hardness on the horizon.

2.3 Related literature

Since the late 1940s, extensive research on the dynamic response of liquid storage tanks during earthquakes has begun. Sekins and Jagbein (1982) [5] provided the first report on the experimental and analytical observations of rectangular tanks under excitation caused by a simulated horizontal earthquake. Hausner (1972) [6] used the mass and spring simulation for the liquid inside the rectangular tank by assuming the wall to be rigid. Graham and Zhedri Goz (2003) [7] have presented methods involving higher bodies for rigid tanks by increasing the number of oscillating masses added. Based on the Hausser model, Epstein (2002) [8] provided design curves for estimating the bending moment and overturning resulting from hydrodynamic pressure for cylindrical and rectangular tanks. All the models presented at that time were derived by assuming the wall to be rigid. Young (1994) [9] considered the effect of wall flexibility on the magnitude and distribution of hydrodynamic pressures in cylindrical tanks and calculated the resulting forces on the tank. Veltsos and Young (2000) [10] concluded that the impact pressure distribution is similar for rigid and flexible tanks, although the magnitude of the pressure depends greatly on the ductility of the tank wall. For a more detailed analysis of the dynamic response of the liquid storage tank, Balendra and Nash (2006) [11] solved the problem by modeling the tank with a thin elastic shell and using the finite element method and ignoring the effect of turbulence. Minowa (1984) [12] investigated the effect of tank wall flexibility on the hydrodynamic pressure applied to the tank wall. Haroun (1980) [13] has done many theoretical and experimental studies on the dynamic behavior of liquid storage tanks. He used the fluid-shell system, in which the shell wall is divided into cylindrical finite parts and the fluid boundary, which behaves as a continuous medium, has been investigated by boundary value problem solving methods. Harun and Hausner (1981) [14] modified this model for flexible wall by adding a mass and spring to Hausser's model in cylindrical tanks. Haroun (1984) [15] also presented a detailed analysis method for various loading systems in rectangular tanks. By completing Hausner's theory for cylindrical tanks, Haroun and Elaithy (1985) [16] described a simplified model in which the position of concentrated masses and springs as well as their related parameters were calculated in such a way that the response value in the simplified model and the analytical model were the same. Haroun and Tayel (1985) [17] have used the finite element method for the dynamic analysis of liquid storage tanks exposed to vertical movement of the earth. Veltsos and Tang [18] analyzed cylindrical liquid storage tanks subjected to vertical ground motion, on rigid and flexible supports. Haroun and Abou-Izzaddin (1991) [19] investigated the effect of several factors on the soil interaction of the structure with a parametric study under vertical and horizontal vibrations. Veltsos and Tang (1987) [20] presented a paper in which the Laplace equation governing the fluid medium for a cylindrical tank was solved analytically. Then they presented a simplified model in which the contribution of higher modes of system response turbulence is included. Veltsos et al. (1992) [21] presented a modified method for calculating shock and vibration components of cylindrical tanks. They concluded that the oscillatory component of the response does not depend on the flexibility of the tank wall and the underlying soil and can be calculated by assuming the tank and underlying soil to be rigid. Malhotra (2000) [22] presented a simplified model by considering the horizontal component of the ground excitation, in which the effect of higher vibration and impact modes is also included in the structural response calculations. Park et al. (1992) [23] conducted a research study on the dynamic response of rectangular tanks. They use the boundary element method. They used the finite element method to calculate the hydrodynamic pressure and the solid wall analysis. Kim et al. (1996) [24] used an analytical method to investigate the horizontal and vertical vibration of rectangular tanks. They presented formulas to calculate the hydrodynamic pressures of a three-dimensional reservoir. They applied Rayleigh-Ritter's method using hypothetical allowed functions (hypothetical vibration modes of a rectangular plate with appropriate boundary conditions for dynamic analysis. Subhash Babu and Bhattachryya (1996) [25] using Finite elements presented a numerical method to calculate fluid displacement due to turbulence and fluctuating pressure in a flexible reservoir. Koh et al. (1998) [26] performed a combined finite element-boundary element method (BEM-FEM) including free surface turbulence for the analysis of three-dimensional rectangular tanks with four flexible walls subjected to horizontal ground motion. Degangun et al. (1996) [27] and Degangun and Liva Glu (2004) [28] investigated the vibration response of liquid-filled rectangular storage tanks using analytical methods as well as the finite element method, by the commercial structural analysis computer program SAPIV. Chen and Kianouh (2005) [29], considering the flexibility of the wall and neglecting the effect of liquid turbulence, used a sequence method to calculate the hydrodynamic pressure in rectangular tanks in a two-dimensional space. Kianoush et al. (2006) [30] introduced a new numerical method for seismic analysis of rectangular tanks in a three-dimensional space, in which the effect of shock and vibration components, both in the time domain, are considered. Ghaemmaqami and Kianoush (2010) [31] have used finite elements in two-dimensional space to investigate the dynamic behavior of rectangular concrete tanks. Livaoglou (2008) [32] evaluated the dynamic behavior of the rectangular-pit reservoir fluid system with a simple seismic analysis method in the frequency domain. The results showed that the displacements and shear forces of the foundation decrease with the decrease of soil hardness. Seismic analysis of reservoirs containing multiphase fluids (fluid non-uniformity effects) and their effect on hydrodynamic pressure was carried out by Shivakumar and Veltsos (1995) [33]. One of the modern methods of seismic safety of liquid storage tanks is to separate the structure from its foundation by seismic isolation systems. Seismic isolation is the provision of flexibility in the foundation level of the structure in a horizontal plane and at the same time placing dampers to limit the range of motion caused by earthquakes. In this case, the superstructure has almost linear elastic behavior even in the range of severe earthquakes. Chalhoub and Kelly (1990) [34] conducted a laboratory investigation on two similar cylindrical liquid storage tanks. Kim and Lee (1995) [35] studied the isolated cylindrical liquid storage tank system with multilayer rubber cushion for different types of separator stiffness and different tank geometries. The effect of lead-rubber isolators on the vibration response of flexible cylindrical tanks has been investigated by Bo and Jia-Xiang (1994) [36]. Malhotra (1997) [37, 38] used a ground-based cylindrical liquid storage tank seismic isolator system with the walls of the tanks discontinuous from the base plate and mounted on a collar made of horizontally flexible isolators. Shrimali and Jangid (2002) [39] investigated the response of narrow and wide underground liquid storage tanks under earthquake motion in two directions simultaneously, to study the effects of isolators. Shekari et al. (2009) [40] used finite elements to model the tank structure and boundary elements to model the fluid inside the tank. Friction pendulum system (FPS) has been used for separation of liquid storage tanks by Tsai et al. (2000) [41] and Wang et al. (2001) [42] and Abali and Uckan (2010) [43]. This system can effectively reduce the shock pressure while not having much effect on the dynamic pressure fluctuation. For liquefied natural gas storage tanks, Eibl et al. (1994) [44] conducted tests on layered steel separators with high damping. Baumann and Boehler (2001) [45] compared different methods to describe the nonlinear behavior of seismic isolators. Three models were developed and the effect of Jed If on the seismic response for several earthquakes was investigated. Computer simulation of rubber isolators with high damping was done by Baumann et al. (1998) [46]. Their results confirmed the usefulness of depreciation due to cyclic damping for the overall behavior of the dynamic system. Fornl (2005) [47] conducted shaking table tests to investigate the effectiveness of new devices (fiber-reinforced isolators and buckling-reinforced braces) in holding liquid-filled structures (liquefied natural gas tanks and spherical product storage tanks). In the past years, many researchers have analyzed reservoirs under the influence of earthquakes. Livaoglu and Cakir (2009-2010) [48, 49] presented a model that is a simplified analytical model to determine the modal characteristics of the embankment-wall-reservoir-fluid system, which includes soil-wall and fluid-wall interaction for a variety of soil conditions. They found that the frequency values of the wave modes obtained from the analysis are not different for different situations. Therefore, the wave modes do not change significantly with the change of soil-wall interaction effect. Chen and Kianoush (2009) [50], who have conducted several studies in the field of water storage tanks, presented a simplified method for estimating the dynamic response of rectangular fluid storage tanks using the general SDOF system. Minowa (1984) [51] investigated the effect of earthquakes on the response of these tanks using a seismic table test on a variety of water tanks made of plastic. Akyildiz and Unal (2005) [52], investigated the distribution of hydrodynamic forces on a rectangular tank and concluded that the presence of breakwaters inside the tank greatly reduces fluid movement. Many researchers inside and outside the country have investigated this issue using numerical methods and finite element software. Reza Naderi et al. (2008) [53] analyzed the vibrations of a buried concrete tank with regard to the effect of the interaction between the soil and the structure. The results of this study showed that the maximum tensile stress and displacement occurs in the middle of the tank wall. They also showed that with the increase in depth, the effect of earthquake force and the stress values of the tank wall and its deformation increase.

3. Method

In this research, a rectangular concrete tank with different dimensions (5 different dimensions) was subjected to seismic investigation, and according to the results, one of these tanks, which had the optimal condition in terms of displacement (stability), was selected, and the tank was selected in three conditions. It was investigated: 1) the tank is buried, 2) the tank is partially buried, and 3) the tank is on the surface. Then, the selected tank, which had specific dimensions and had a more optimal mode than the others in terms of displacement under seismic load, was modeled and evaluated in two other modes. In fact, in the first case, the 5 tanks that were investigated were in semi-buried conditions. Then the selected tank was analyzed in the second stage with the following conditions: 1) The tank is completely buried, 2) The tank is completely placed on the soil surface. The investigated parameters in the present study included: displacement of selected points in all three directions, displacement in the selected path in different directions, base cutting of reservoirs and soil settlement. The results extracted from the Abaqus software [54] were presented through different graphs and the analysis method was performed in a non-linear dynamic manner.

3-1 Specifications and parameters of tanks

Tables 1 to 5 show the characteristics of the study reservoirs. In choosing the dimensions of the reservoirs, it has been tried to use the experiences of previous studies to consider the ratio of different dimensions for the length and width of the reservoir, so that a better view of the effects of the earthquake on it can be obtained. For this purpose, 5 different reservoirs have been used in this research.

Table 1. Specifications of the tank 1

Tank (meter)			Soil (meter)		
Depth	Width	length	depth	width	length
17	20	40	200	200	400

Table 2. Specifications of the tank 2

Tank (meter)			Soil (meter)		
Depth	Width	length	depth	width	length
17	28.3	28.3	200	200	400

Table 3. Specifications of the tank 3

Tank (meter)			Soil (meter)		
Depth	Width	length	depth	width	length
17	23.1	34.6	200	200	400

Table 4. Specifications of the tank 4

Tank (meter)			Soil (meter)		
Depth	Width	length	depth	width	length
17	34.6	23.1	200	200	400

Table 5. Specifications of the tank 5

Tank (meter)			Soil (meter)		
Depth	Width	length	depth	width	length
17	10	80	200	200	400

The considered water depth in the reservoirs is 8 meters.

3.2 The characteristics of the modeled soil

Table 6. Characteristics of the modeled soil

Poason Coefficient (v)	E (pa)	Density
0.3	124000000	2400 (kg/m3)

The material used in the construction of the tank is based on studies and the principles of concrete tank construction are taken into account. The specifications of the concrete used were also selected based on the design made by Chen and Kianoush (2009) [55].

3.3 The specifications of concrete used in tanks

Table 7. Concrete specifications modeled in the software

Poason Coefficient (v)	E (pa)	Density
0.17	21e9	2400 (kg/m3)

3.4 The specifications related to meshing for soil, reservoirs and water

Table 8. Specifications related to the meshing performed in the software for different elements

Mesh Size	Types of elements	
2 critical zone	C3d8r	soil
2	S4r	Tank
1	Acoustic	water

Also, in this research, the acceleration map of the Mashhad (Sefid Sang) earthquake in 2016 was used. The selected accelerometer in terms of distance is the far field record. The selected record in the y direction (or 2 in the software) was imported into the reservoirs. Diagram 1 shows the accelerogram related to this record.

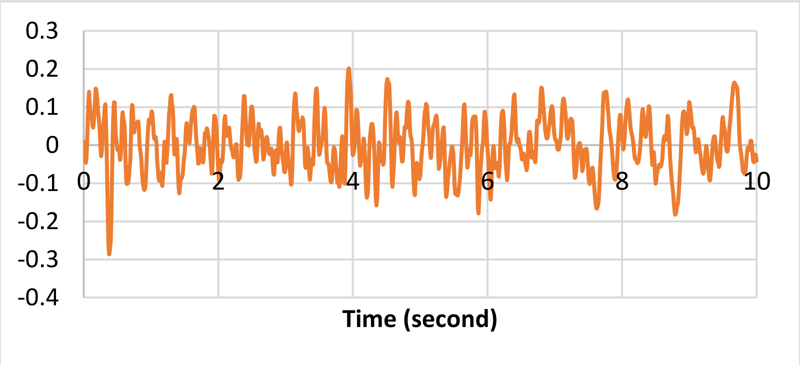

Diagram 1. Accelerometer related to the selected record

Acceleration (G)	**Time (second)**	**Acceleration (G)**	**Time (second)**	**Acceleration (G)**	**Time (second)**
0.01	0	-0.03	3.5	0.02	7
-0.01	0.05	-0.03	4	-0.08	7.5
0.08	1	0.16	4.5	0.02	8
0.02	1.5	-0.08	5	-0.1	8.5
-0.07	2	-0.05	5.5	0.11	9

Acceleration (G)	Time (second)	Acceleration (G)	Time (second)	Acceleration (G)	Time (second)
0.1	2.5	-0.01	6	0.07	9.5
-0.04	3	-0.02	6.5	-0.04	10

Table 9. Accelerometer related to the selected record

3-5 Validation

From the point of view of exploitation and passive defense considerations, tanks are usually considered as twins. For example, instead of building a 5000 cubic meter tank, two 2500 cubic meter tanks are built next to each other or attached to each other. The dimensions of the tanks depend on the characteristics of the land and environmental conditions, but in the absence of special limitations, the most economically suitable geometric dimensions for rectangular cubic tanks are obtained in conditions where the ratio of the length to the width of the tank is 3:2. These dimensions express the optimal state from an economic point of view according to the clauses of the regulation "Regulations and criteria for the design and calculation of ground water reservoirs".

4. Results

We calculated the parameters such as displacement in all three directions and values of base shear and soil settlement. Also, a ridge was defined as a path on the wall, and the displacement on this path was also investigated in all three directions. Figure 1 shows how to model and also the different directions of the coordinate system.

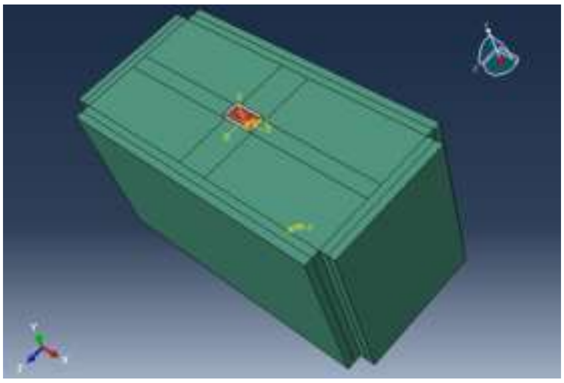

Figure 1. Modeling method and considered directions in Abaqus software

In this device, the coordinates of the x direction is the same as the 1st direction, the y direction is the same as the 2nd direction, and the z direction is the same as the 3rd direction. The chosen point for evaluating displacement in different directions is the center point of the surface at the bottom of the tank.

4-1 Displacement in direction 1 for the desired point

Diagram 2 show displacement values for direction 1 at the drawn study point. Due to the large difference in the range of values for the study reservoirs, three graphs were used to display the values. Diagram 2 shows the displacement diagram for tanks number 2, 3 and 4, Diagram 3 shows the displacement diagram for tank number 1, and Diagram 4 shows the displacement diagram for tank number 5.

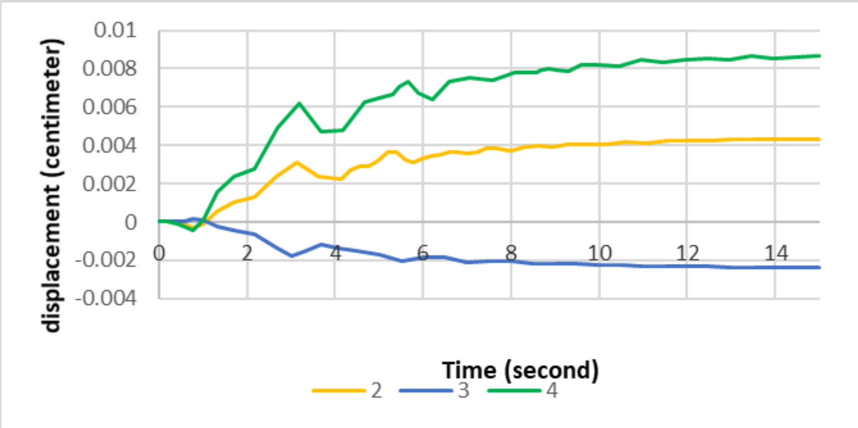

Diagram 2. Displacement diagram in direction 1 for reservoirs 2, 3 and 4

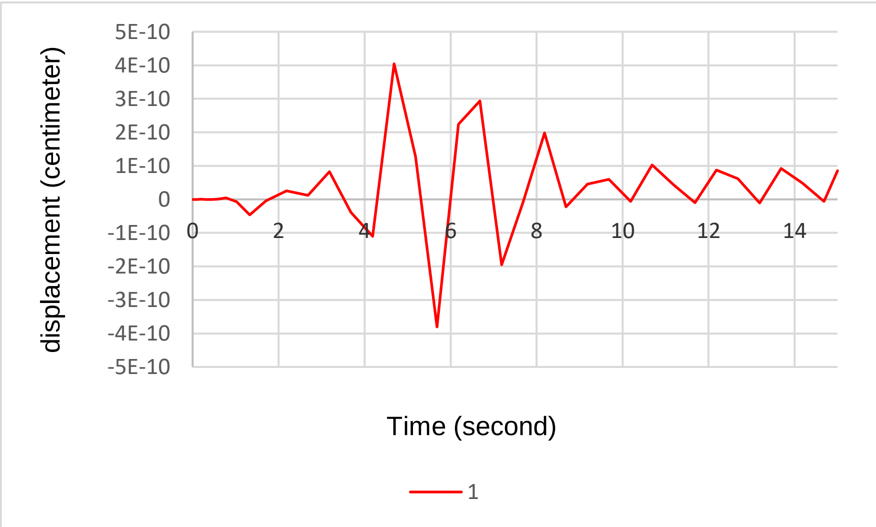

Diagram 3. Displacement diagram in direction 1 for tank 1

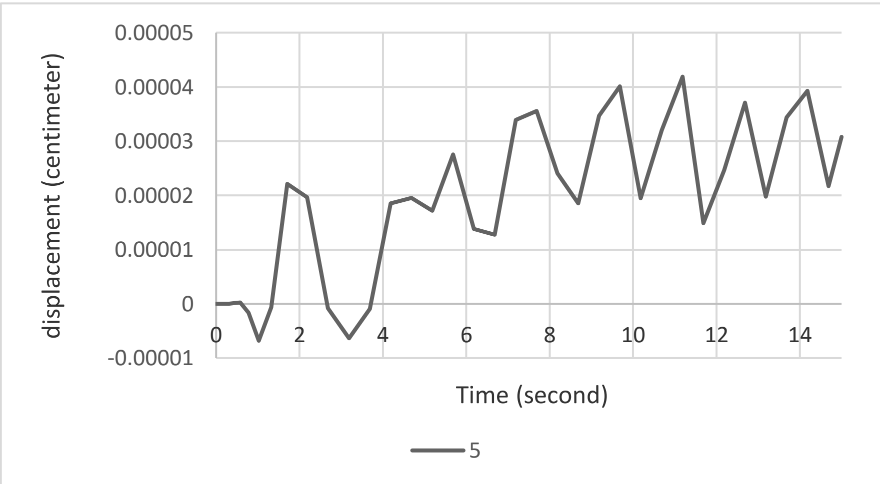

Diagram 4. Displacement diagram in direction 1 for tank number 5

As can be seen, for the displacement parameter in direction 1, the highest values correspond to tank number 4. Its maximum value is about 0.0084 cm for tank number 4. On the other hand, the lowest values are related to tank number 1. In fact, the graph related to this tank shows that moving in direction 1 for tank number 1 has a more optimal state than other tanks. From the comparison of the graphs, it is clear that in tank 1, the permanent displacement values are lower than other tanks. While tanks 2, 3, 4, and 5 have large permanent displacement values at the desired point, and in the meantime, tank number 4 has the highest permanent displacement value. The values obtained for tank number 3 are in the opposite direction to other tanks, which can be justified considering the reciprocating nature of earthquake movements.

4.2 Displacement in direction 2 for the desired point

As it is clear from the diagram 5, the changes of these values at different times for all reservoirs are approximately the same and the change process is the same. The maximum value for this parameter in direction 2 according to the above diagram is approximately 4.5 cm, which has a negative direction in all cases of the study tank. On the other hand, in this direction (direction 2) it is observed that the desired parameter has permanent displacement values. The following diagram shows the values of this parameter at different times for all the reservoirs.

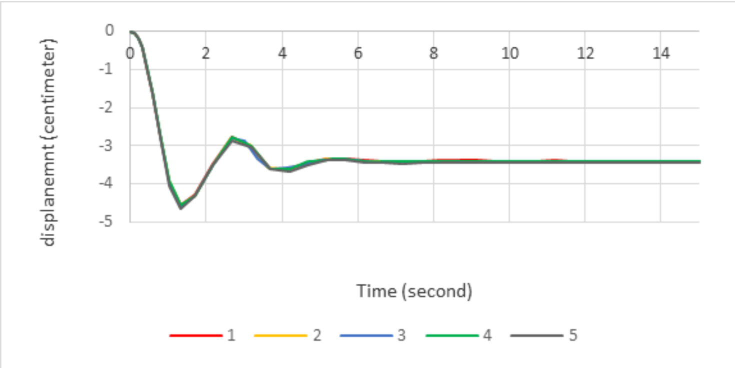

Diagram 5. Displacement diagram in direction 2 for all reservoirs

4.3 Displacement in direction 3 for the desired point

The diagram below shows the different values of displacement during earthquake loading in the 3rd direction at the desired point and in all tanks.

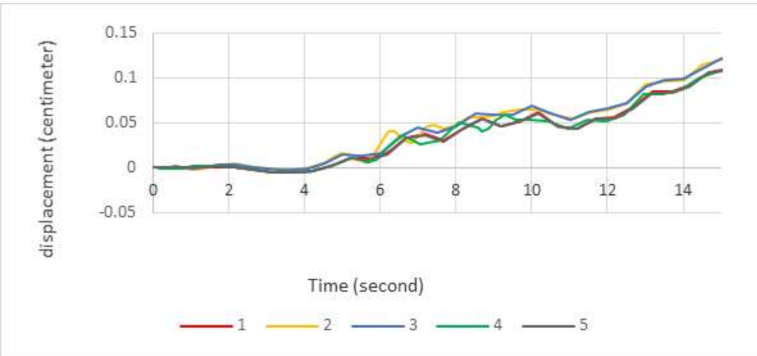

Diagram 6. Displacement diagram in direction 3 for all reservoirs

According to the diagrams in the above figure, it is clear that the trend of displacement parameter changes in the direction is similar in different reservoirs. In other words, the values of this parameter in tanks 2 and 3 are very similar to each other, and the same values are very similar in tanks 1, 4 and 5. The maximum values of displacement parameter in direction 3 occurred in tanks 2 and 3. In other words, these values are close to each other in all the reservoirs, but in these two reservoirs, they have approximately the highest values. The displacement parameter in direction 3 has constant values in all tanks. The values of permanent displacement in this case are not high, but according to the trend and range of changes of this parameter in the desired time period, it is relatively high. Table 10 shows the comparison of the maximum displacement values for different tanks:

Table 10. Comparison of maximum displacement values related to different tanks (in centimeters)

	Direction 1	Direction 2	Direction 3
Tank 1	4.04e-10	-4.54	0.109
Tank 2	0.0043	-4.55	0.120
Tank 3	-0.0023	-4.57	0.122
Tank 4	0.0087	-4.54	0.108
Tank 5	4.19e-5	-4.66	0.108

According to the above table, it is determined in which reservoirs the minimum values in each direction were created. In direction 1, the minimum value has occurred in tank 1. In direction 2, the minimum value has occurred in tank 1 and 4. In direction 3, the minimum value has occurred in tank 4 and 5.

For tank 1 we have:

$$\sqrt{(4.04e-10)^2+(-4.54)^2+(0.109)^2}=\sqrt{20.623481}=4.54131$$

For tank 4 we have:

$$\sqrt{0.0087^2+(-4.54)^2+0.108^2}=\sqrt{20.62334}=4.541293$$

Therefore, considering that we are looking for an optimal state in terms of displacement, it can be seen that this value was obtained according to the above calculations for tank number 4. Therefore, to change the depth in two different modes, tank number 4, which has dimensions, will be used. Also, considering that in the publication of criteria and criteria for the design and calculation of ground water tanks (revision of publication 123), it is stated that in the absence of special restrictions, the most economically suitable geometric dimensions for rectangular cubic tanks are obtained in conditions where the ratio of length to width The tank should be 2 to 3. Therefore, it can be seen that in the current research, the most optimal dimensions of the tank in terms of displacement were obtained with the best condition in terms of economy. Therefore, these dimensions (reservoir number 4) are used to analyze different depths.

4.3.1 Fluid Por-Pressure check

The figures 2 and 3 shows the Por-Pressure values of the desired fluid in tank number 2 related to the acoustic model.

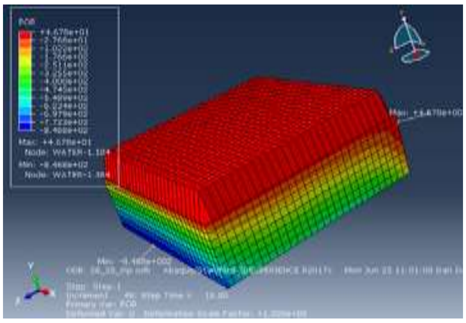

Figure 2. Por-Pressure values of the desired fluid (water) in tank number 2 related to the acoustic model

Figure 3 shows the path selected for this research:

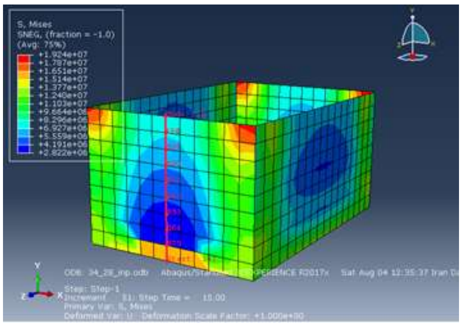

Figure 3. Display of the selected path to check the displacement parameters on the path

4.3.1.1 Move in direction 1 for the desired path

Diagram 7 shows the diagram related to the trend of displacement changes in direction 1 in the desired path for the study reservoirs:

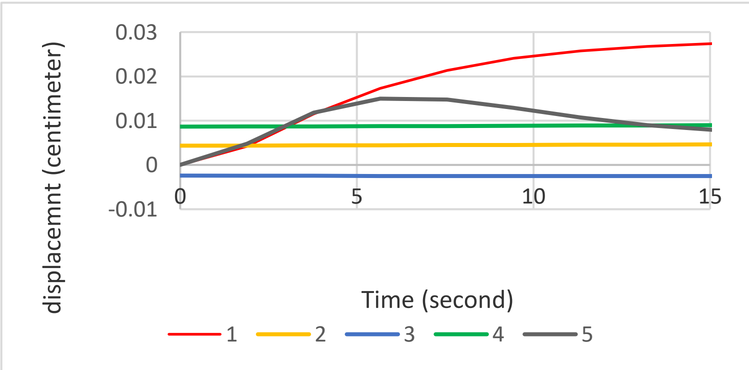

Diagram 7. Displacement diagram in direction 1 related to the selected route for all tanks

As can be seen, the trend of changes for reservoirs 1 and 5 are similar to each other until about second 4, and the trend of changes of these values in reservoirs 2, 3 and 4 is also similar. According to the above diagram, the maximum value of this parameter happened in the desired path in tank 1. On the other hand, its lowest values occurred in tank 3. Also, according to the obtained results, the change process for tanks 2, 3 and 4 is almost a linear and constant process. Of course, if we draw the graphs individually, according to the scale of each graph, the shape of the process of changes will be different. For example, the diagram below is related to tank number 3, which is different in appearance from the previous diagram.

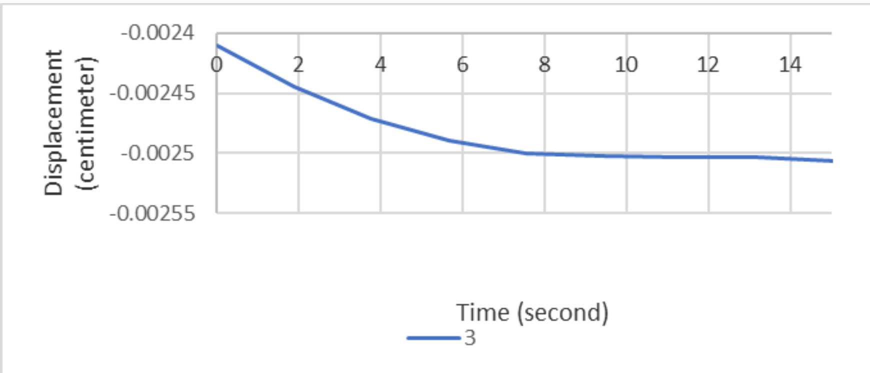

Diagram 8. Displacement diagram in direction 1 related to the selected route for tank number 3

Of course, you should pay attention to the range of changes. The displacement values for tank number 3, as seen in the above diagram, range from -0.0024 to -0.0025. Due to the presence of other reservoirs in the first diagram and their change interval is greater than that of reservoir No. 3, the changes of this reservoir seem to be in the form of a fixed line. While, according to the second diagram, despite the short interval of changes, the process of changes is not constant.

4.3.2 Move in direction 2 for the desired route

Diagram 9 shows the displacement parameter in the desired path in direction 2 in terms of time:

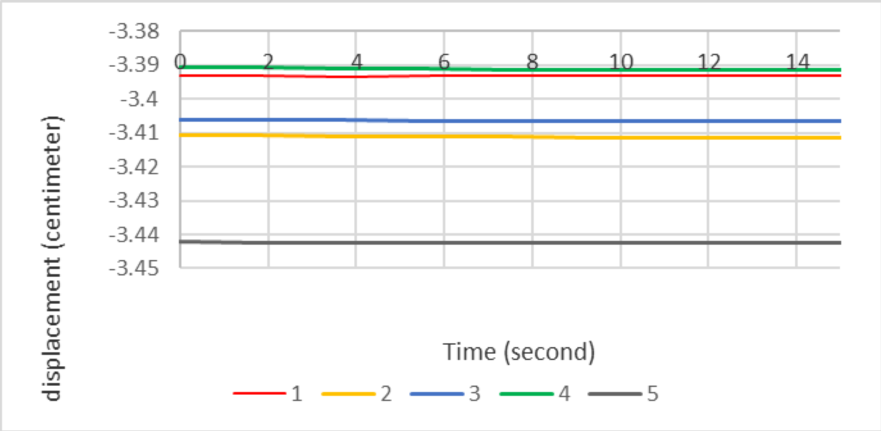

Diagram 9. Displacement diagram in direction 2 related to the selected path for all tanks

According to the above diagram, the range of changes related to the displacement parameter on path 2 is small for all 5 tanks, and in terms of the range of changes, if we want to check in general, they have relatively constant values in this regard. While the process of their changes has not been constant. To further investigate this issue, the graph related to this parameter was drawn separately for tank number 1 and 2:

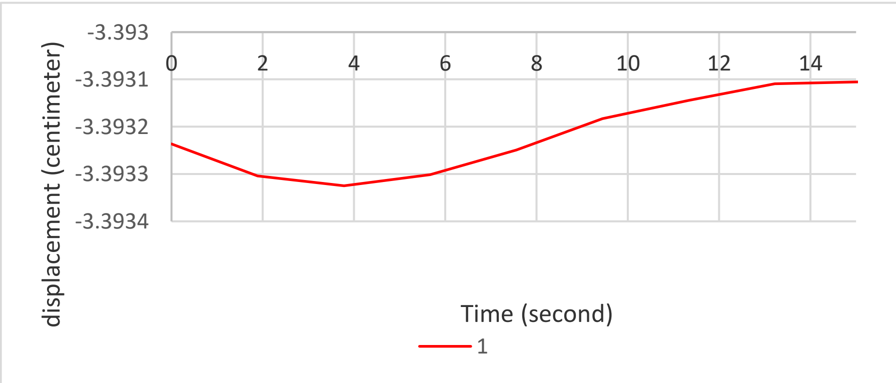

Diagram 10. Displacement diagram in direction 2 related to the chosen path for tank 1

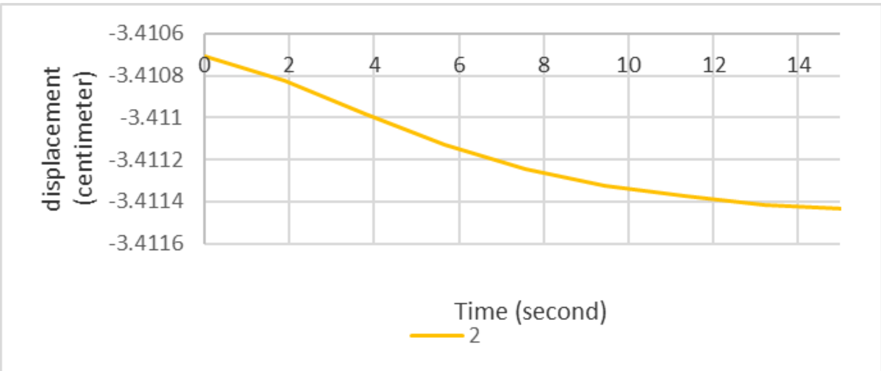

Diagram 11. Displacement diagram in direction 2 related to the selected route for tank number 2

It can be seen that the trend of changes of this parameter in these two tanks is not constant, but due to the proximity of the minimum and maximum values in each of the tanks, its range of changes is very small. For example, in tank number 2, the values of this parameter have changed from -3.4107 to -3.4114, which shows that its changes are small. By checking the first graph for the values of this parameter in route 2, it is clear that the maximum values for displacement occurred in tank number 5. While the lowest values of this parameter occurred in tank number 4.

4.3.2.1 Move in 3 directions for the desired path

Diagram 12 shows the graph related to this parameter for the desired route in direction 3:

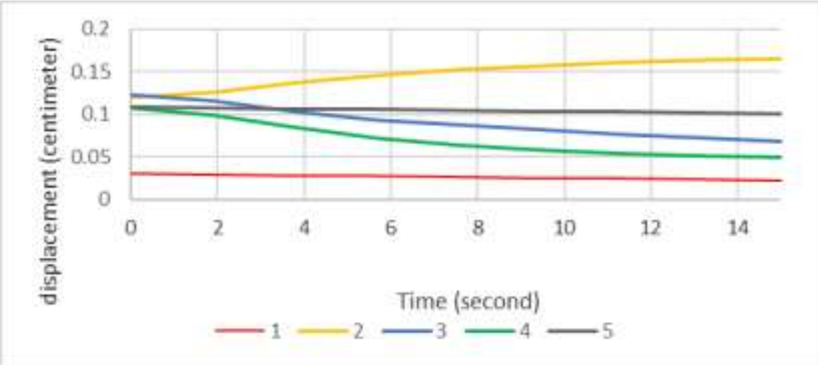

Diagram 12. Displacement diagram in direction 3 related to the selected path for all tanks

A separate chart for tank number 5 is also given below.

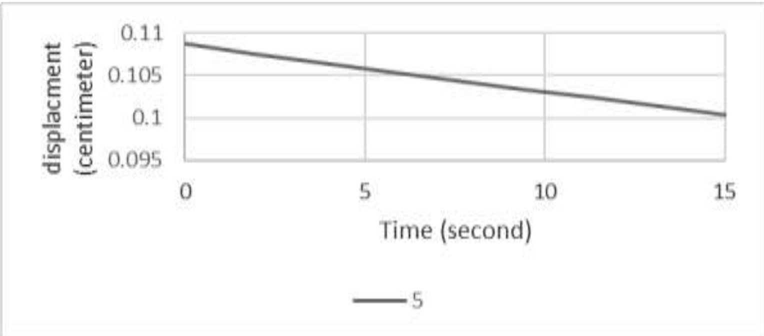

Diagram 13. Displacement diagram in direction 3 related to the chosen route for tank number 1

By examining the results related to displacement in this route for different tanks, it is clear that the highest values of this parameter are for tank number 2 and the lowest are related to tank 1.

4.3.3 Investigation of soil settlement in the study model

Considering that the vertical direction in this modeling is y or direction 2, therefore the meetings also occurred in direction 2. Figures 4 to 8 show soil settlement in 5 tanks:

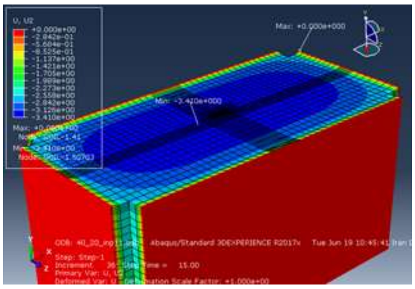

Figure 4. The soil settlement related to tank number 1

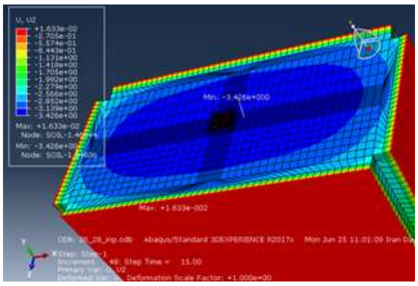

Figure 5. The soil settlement related to tank number 2

According to the above figure, the maximum amount of settlement in this case was 3.426 cm and its location is also specified in this figure.

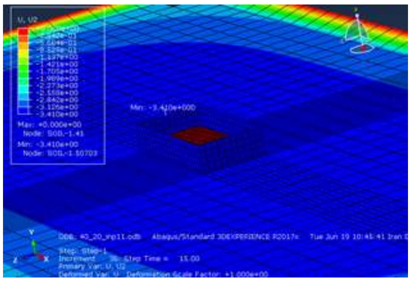

Figure 6. The soil settlement related to tank number 3

According to the above figure, it is clear that the maximum value in this case was equal to 3.41 cm and the location of this value is also specified in the above figure.

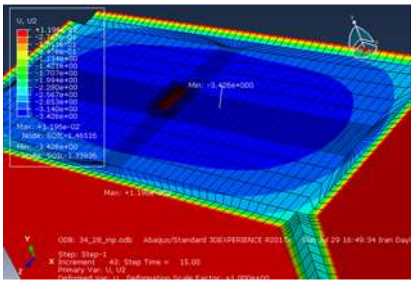

Figure 7. The soil settlement related to tank number 4

According to the above figure, the maximum value in this model was also 3.426 cm, which occurred in the place specified in the above figure.

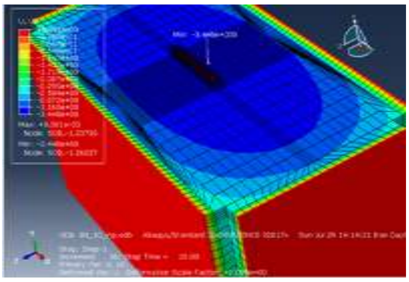

Figure 8. The soil settlement related to tank number 5

It can be seen that the maximum amount of settlement related to tank number 5 was equal to 3.448 cm and the place of occurrence of the maximum amount is known in the figure above.

4.3.4 Check the values of shear stress at the desired point

Diagram 14 shows the desired parameter for different reservoirs during the desired earthquake record.

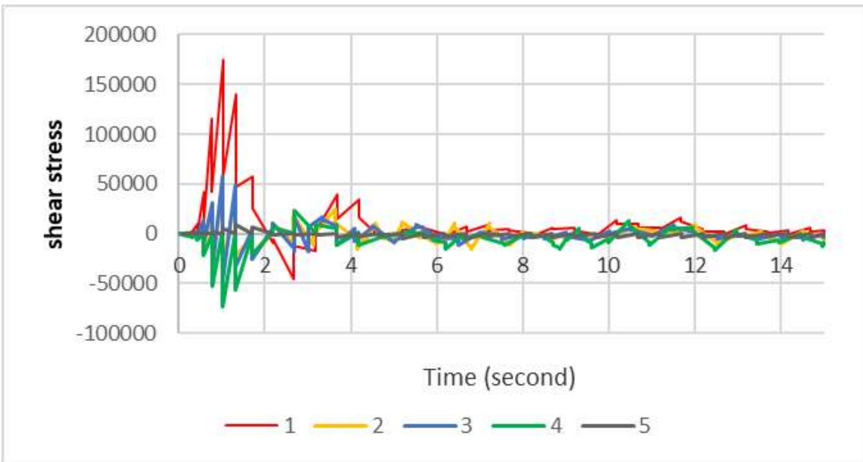

Diagram 14. Shear stress diagram for the center point of the surface under the tank (related to all tanks)

According to the above diagram, the shear stress parameter had the maximum values in the initial times of the acceleration mapping of the intended earthquake for all states of the reservoirs. In other words, most of the desired values for different situations occurred in the first 2.5 seconds. Also, the highest values for the shear stress parameter among the tanks were obtained for tank number 1. The lowest range of changes for this parameter has occurred in tank number 5, and as a result, after the fourth second, the range of changes of the shear stress parameter at the desired point has decreased, and in addition, the change process has become more uniform.

4.3.5 Investigating the buried state and the state on the tank soil

Considering that tank number 4 was chosen as the optimal tank in terms of handling and economy, the tank in question was checked in the following 2 situations: in the case where the tank is placed completely on the ground, when the tank is completely placed in the soil (mode buried). Diagram 15 shows the values of displacement at different times of tank No. 4 in the buried state and the state that is placed on the ground:

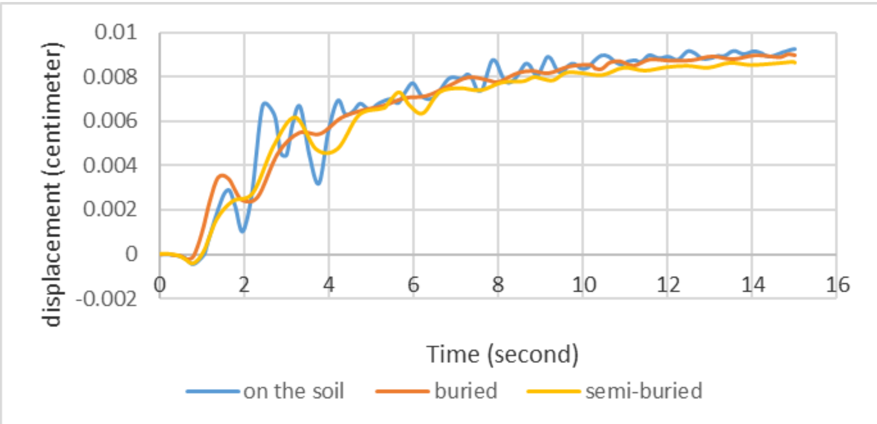

Diagram 15. Displacement diagram in direction 1 for tank number 4 in buried, on soil and semi-buried states

According to the diagram, the process of changes in both cases is almost the same. Of course, in the initial times, especially 2 to 4 seconds, the changes related to the buried state were more. Also, in most of the time, it was found that the state on the soil had relatively higher values. Also, the case where the tank was completely on the ground had a more uniform displacement process. Diagrams 16 and 17 show these values over time for direction 2, 3:

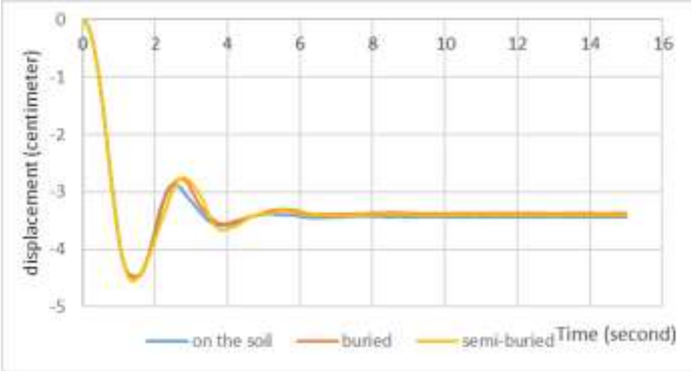

Diagram 16. Displacement diagram in direction 2 for tank number 4 in buried, on soil and semi-buried states

It can be seen that the values of the displacement parameter in direction 2 in terms of time in both tank placement modes had the same trend, and at some times, the values related to the buried mode were higher.

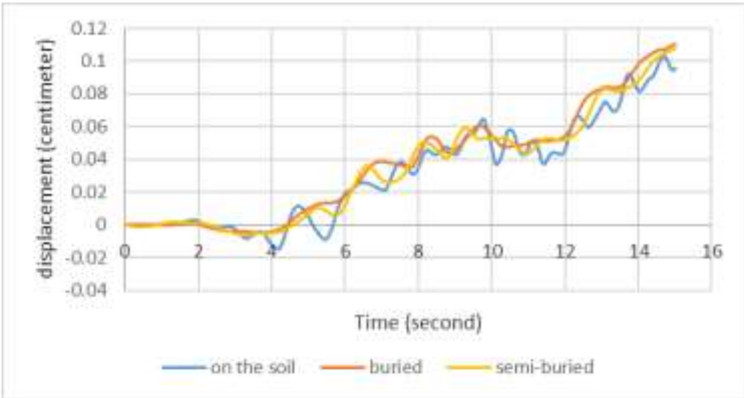

Diagram 17. Displacement diagram in direction 3 for tank number 4 in buried, on soil and semi-buried states

According to the diagram, the trend of displacement parameter changes at different times for all three states, buried, semi-buried, and on the soil, were very similar. It can also be seen that the maximum values usually occurred in the buried state. According to the results, the range of displacement changes in the desired point did not differ much in different modes, but it can be said that the process of changes was different.

4.3.6 Move in 1, 2, and 3 directions for the desired route

Diagrams 18 to 20 show the displacement on the selected path in directions 1, 2, and 3 for tank number 4 in buried, on soil, and semi-buried states:

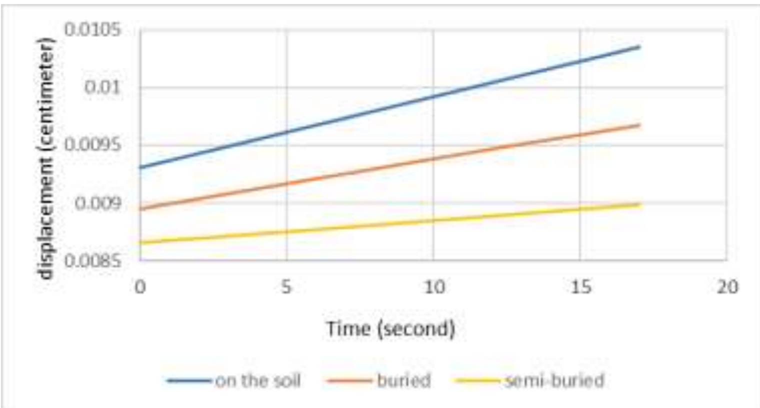

Diagram 18. Displacement diagram on the selected path in direction 1 for tank number 4 in buried, on soil and semi-buried states

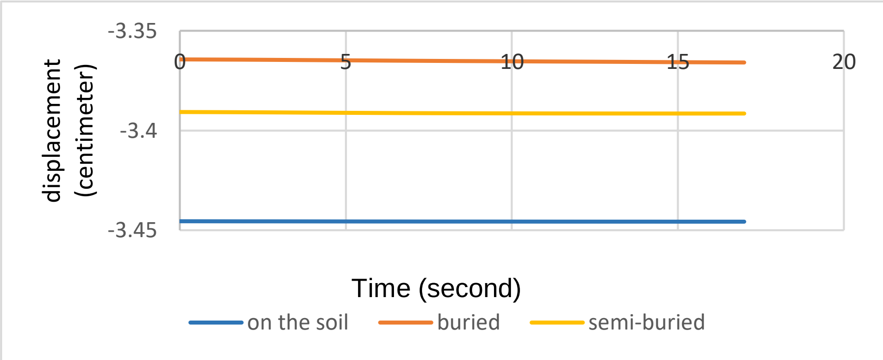

Diagram 19. Displacement diagram on the selected path in direction 2 for tank number 4 in buried, on soil, and semi-buried states

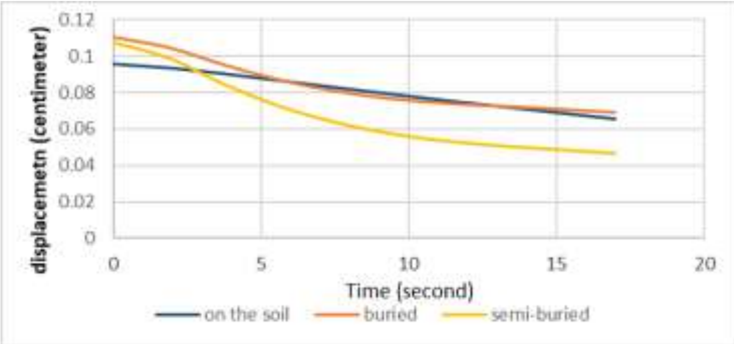

Diagram 20. Displacement diagram on the selected path in direction 3 for tank number 4 in buried, on soil and semi-buried states

In the first diagram, it is clear that the change process of the displacement parameter in direction 1 is the same in all three cases and the range of their changes is different. It can be seen that this parameter has higher values in the case where the tank is located on the soil, and the lowest values were obtained in the half-buried case. The values of this parameter in direction 2 are very different in different situations. In this direction, the highest values occurred for the state on the soil and the lowest value occurred for the buried state.

In direction 3, the buried tank has larger values, and on the other hand, the range of changes of the semi-buried tank is greater than other modes. In this case, it can be seen that the tank is more uniform when it is on the ground than in other cases.

4.3.7 Investigation of soil settlement in buried models and on soil

Figures 9 and 10 show soil settlement in two different states (buried tank and tank on soil) in tank number 4:

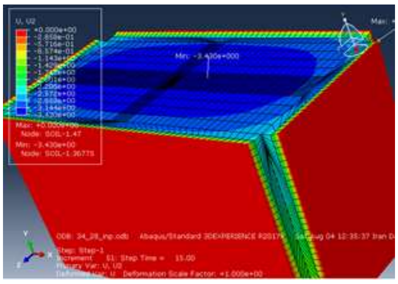

Figure 9. The soil settlement in tank number 4 in the buried state

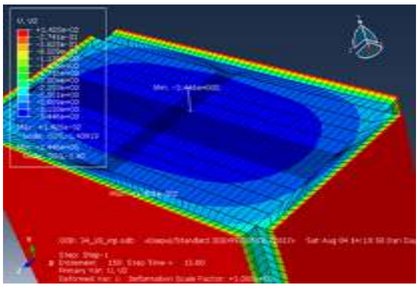

Figure 10. The soil settlement in tank number 4 when the tank is on the ground

According to the results, in the buried state, the maximum amount of settlement was equal to 3.43 cm. In the state on the soil, the maximum amount of settlement was 3.446 cm, which is more than the previous state.

4.3.8 Examining shear stress values in the buried state and on the soil

Daigram1 shows the shear stress parameter at the center of the surface of the tank floor in different situations for tank number 4:

Diagram 21. Comparison chart of shear stress values at the center point of the surface (under the tank) for tank number 4 in buried, semi-buried, and placed on the soil

According to the results, the shear stress values in tank number 4 were the highest when the tank was completely on the ground and the lowest when it was buried.

5. Conclusion

In this research, the seismic behavior of concrete tanks with fluid (water) in different situations was investigated. For this purpose, 5 concrete tanks with different dimensions were investigated and parameters such as displacement, shear stress, soil settlement and displacement in a specific path were analyzed. By checking the displacement of these tanks, it was found that this parameter is the most optimal for tank number 4. Then, this reservoir was selected and analyzed at different depths. In this order, it was examined in two cases, completely buried and completely on the soil. The results showed that tank number 4, which has dimensions of 23.1 and 34.6, has an optimized state in terms of displacement. By examining the shear stress parameter in different tanks, it was found that this value is the highest in tank number 1. Also, this parameter has the lowest value in tanks number 2 and 5. It should be noted that this parameter has been investigated for the point located in the center of the tank's bottom surface. By examining the parameter of soil settlement in reservoirs with different dimensions, it was found that the lowest value of this parameter occurred in the cases of reservoirs 1 and 3. Also, the highest values related to tank 5 have been obtained. By examining the displacement parameter for tank number 4 in buried, semi-buried and completely on the ground, it was found that this parameter has higher values in the case where the tank is completely on the ground. Also, by examining the parameter of soil settlement in tank number 4 at different depths and analyzing it, it was found that the highest value for this parameter also occurs when the tank is completely on the soil. It is suggested to investigate more about the effect of fluids, to conduct this research with another fluid and compare the results. Also, in addition to the concrete tank used in this research, a cylindrical tank is also modeled and its results are evaluated. It is suggested that the seismic evaluation of this research be done with an emphasis on earthquakes in the nearby area. It is suggested to use steel tanks instead of concrete tanks for modeling and analysis.

References

[1] Pérez-Nava J, Hernández-Aldana F, Martínez-Valenzuela C, Rivera A. Pseudomonas sp Isolated from Wastewater and their Interaction with Microalgae. J Biochem Technol. 2021 Apr 1;12(2):1-5.
[2] Bubunets EV, Zhigin AV, Esavkin YI, Panov VP, Grikshas SA, Salikhov AA, et al. Temperature Factor in the Cultivation of Juvenile Anadromous Sturgeons in Warm-Water Farms. J Biochem Technol. 2022;13(1):45-9.
[3] Thuy VVT, Ngoc HD, Ngoc TN, Le HA. Cash Flow and External Financing in The Covid Pandemic Context and Financial Constraints. J Organ Behav Res. 2022;7(2):109-19.
[4] KHUC AT, DO LH, NGO XT. Determinants Influencing the Intention to Cause the Moral Hazard of Vietnam Commercial Banks' Staff. J Organ Behav Res. 2022;7(1):125-37.
[5] Sekins, A., and Jagbein, H., (1982). "Buckling of cylindrical liquid storage tanks under earthquake loading", Earthquake Engineering and Structural Dynamics, Vol. 10, pp. 107- 122.
[6] Haunser, G.P., (1972). Concrete Reservoirs and Tanks, Concrete Publication.
[7] Graham, J., and Zedri Koz, L., (2003).Dynamic Response of Concrete Rectangular Liquid Storage Tank. M.S. thesis, Dept. of Civil Engineering, Ryerson University, Toronto, Canada.
[8] Epstein, M.K., (2002). "Seismic response of liquid storage tanks isolated by sliding bearings", Engineering Structures. Vol. 24, pp. 909-921.
[9] Young, Z., (1994). "Uplifting Analysis of Base Plates in Cylindrical Tanks", ASCE Journal of Structural Engineering, Vol. 120, pp. 3489-3505.
[10] Veltsos, A.S., and Young, Z., (2000). "Simple procedure for seismic analysis of liquid storage tanks", Structural Engineering International., Vol. 20, pp. 197-201.
[11] Balendra, M., and Nash, R., (2006). "Seismic Performance of Industrial Facilities Affected by the 1999 Turkey Earthquake", Journal of Performance of Constructed Facilities © ASCE, Vol. 47, No. 1, pp. 28-36.
[12] Minowa, C., (1984). "Experimental studies of seismic properties of various type water tanks." Proc., 8th WCEE, pp. 945–952.
[13] Haroun, M.A., (1980). Dynamic analyses of liquid storage tanks. EERL 80-4, California Inst, of Tech., Pasadena, California.
[14] Haroun, M.A. and Housner, G.W., (1981). "Seismic Design of Liquid Storage Tanks", Journal of Technical Councils, ASCE, Vol. 107, pp. 191-207.
[15] Haroun, M.A., (1984). "Stress Analysis of Rectangular Walls under Seismically Induced Hydrodynamic Loads", Bulletin of the Seismological Society of America, Vol.74, No. 3, pp. 1031–1041.
[16] Haroun, M.A. and Ellaithy, H.M., (1985). "Model for flexible tanks undergoing rocking", ASCE Journal of Engineering Mechanics., Vol. 111, pp. 143-157.
[17] Haroun, M.A. and Tayel, M.A., (1985). "Response of tanks to vertical seismic excitations", Earthquake Eng. Structural Dynamic, Vol. 13, pp. 583–595.
[18] Veletsos, A.S. and Tang, Y., (1986). "Dynamics of vertically excited liquid storage tanks", J. Structural Engineering, Vol. 112, No. 6, pp. 1228–1246.
[19] Haroun, M.A. and Abou-Izzeddine, W., (1992). "Parametric study of seismic soil tank interaction. I: Horizontal excitation", J. Structural Engineering, ASCE, Vol. 118, No. 3, pp. 783-797.
[20] Veletsos, A.S. and Tang, Y., (1987). "Rocking response of liquid storage tanks", ASCE Journal of Engineering Mechanics., Vol. 113, pp. 1774-1792.
[21] Veletsos, A.S., Tang, Y. and Tang, H.T., (1992). "Dynamic response of flexibly supported liquid storage tanks", J. Struct. Eng., Vol. 118, pp. 264–283.
[22] Malhotra, P.K., Wenk, T. and Wieland, M., (2000). "Simple procedure for seismic analysis of liquid storage tanks", Structural Engineering International., Vol. 10, pp. 197-201.

[23] Park, J.H., Koh, H.M. and Kim, J., (1992). "Liquid-structure interaction analysis by coupled boundary element-Finite element method in time domain", Proc., 7th Int. Conf. on Boundary Element Technology, C.A. Brebbia and M.S. Ingber, eds., Computational Mechanics, Southampton, U.K, pp. 89–92.

[24] Kim, J.K., Koh, H.M. and Kwahk, I.J., (1996). "Dynamic response of rectangular flexible fluid containers", J. Eng. Mech., Vol. 122, No. 9, pp. 807–817.

[25] Subhash Babu, S. and Bhattachryya, S.K., (1996). "Finite element analysis of fluid-structure interaction effect on liquid retaining structures due to sloshing", Computer Structural, Vol. 59, No. 6, pp. 1165–1171.

[26] Koh, H.M., Kim, J.K. and Park, J.H., (1998). "Fluid-structure interaction analysis of 3D rectangular tanks by a variationally coupled BEM-FEM and comparison with test results", Earthquake Eng. Structural Dynamics, Vol. 27, pp. 109–124.

[27] Dogangun, A., Durmus, A. and Ayvaz, Y., (1996). "Static and dynamic analysis of rectangular tanks using the lagrangian fluid finite element", Computers & Structures., Vol. 59, No.3, pp. 547-552.

[28] Dogangun, A and Livaoglu, R., (2004). "Hydrodynamic pressures acting on the walls of rectangular fluid containers", Structural Engineering and Mechanics, Vol. 17, No.2, pp. 203- 214.

[29] Chen, J.Z. and Kianoush, M.R., (2005). "Seismic response of concrete rectangular tanks for liquid containing structures", Can. J. Civ. Eng., Vol. 32, pp. 739–752.

[30] Kianoush, M.R., Mirzabozorg, H. and Ghaemian, M., (2006). "Dynamic analysis of rectangular liquid containers in three-dimensional space", Can. J. Civ. Eng., Vol. 33, pp. 501–507.

[31] Ghaemmaghami A.R. and Kianoush M.R., (2010). "Effect of Wall Flexibility on Dynamic Response of Concrete Rectangular Liquid Storage Tanks under Horizontal and Vertical Ground Motions", Journal of Structural Engineering ASCE, pp. 441–451.

[32] Livaoglu, R., (2008). "Investigation of seismic behavior of fluid-rectangular tank-soil/foundation systems in frequency domain", Soil Dynamic Earthquake Eng., Vol. 28, No.2, pp, 132–146.

[33] Shivakumar, P. and Veletsos, A.S., (1995). "Dynamic response of rigid tanks with inhomogeneous liquid", Earthquake Engineering and Structural Dynamics. Vol. 24, pp. 991-1015.

[34] Chalhoub, M.S. and Kelly, J.M., (1990). "Shake table test of cylindrical water tanks in base isolated structure", Journal of Engineering Mechanics ASCE., Vol. 116, pp. 1451–1472.

[35] Kim, N.S. and Lee, D.G., (1995). "Pseudo-dynamic test for evaluation of seismic performance of base-isolated liquid storage tanks", Engineering Structures., vol. 17, pp. 198–208.

[36] Bo, L. and Jia-Xiang. T., (1994). "Vibration studies of base-isolated liquid storage tanks", Computers and Structures, Vol. 52, pp.1051–1059.

[37] Malhotra, P.K., (1997). "Method for seismic base isolation of liquid-storage tanks", ASCE Journal of Structural Engineering., Vol. 123, pp.113–116.

[38] Malhotra, P.K., (1997). "New method for seismic isolation of liquid-storage tanks", Earthquake Engineering and Structural Dynamics., Vol. 26, pp.839–847.

[39] Shrimali, M.K. and Jangid, R.S., (2002). "Seismic response of liquid storage tanks isolated by sliding bearings", Eng. Struct., Vol. 24, pp. 907–19.

[40] Shekari, M.R., Khaji, N.and Ahmadi, M.T., (2009). "A coupled BE–FE study for evaluation of seismically isolated cylindrical liquid storage tanks considering fluid–structure interaction", Journal of Fluids and Structures, Vol. 25, pp. 567–585.

[41] Tsai, C.S., Chen, C.S., Chen, B.J. and Chiang, T.C., (2000). "Seismic Behavior of Oil-storage. Tank, Equipped with Friction Pendulum System", ASME Pressure Vessels and Piping Division, Vol. 402, pp. 107–111.

[42] Wang, Y.P., Teng, M.C. and Chung, K.W., (2001). "Seismic isolation of rigid cylindrical tanks using friction-pendulum bearings", Earthquake Engineering and Structural Dynamics., Vol. 30, pp. 1083–1099.

[43] Abalı, E. and Uckan, E., (2010). "Parametric analysis of liquid storage tanks base isolated by curved surface sliding bearings", Soil Dynamics and Earthquake Engineering., Vol. 30, pp. 21–31.

[44] Eibl, J., Hehn, K.H. and Schwartz, D., (1994). "Performance tests of high damping steel laminated seismic isolation bearings for LNG storage tanks", Proceedings of the Second International Conference on Earthquake Resistant Construction and Design, Berlin, Germany, June 15–17, Vol. 2, pp. 963–973.

[45] Baumann, T. and Boehler, J., (2001). "Seismic design of base-isolated LNG-storage-tanks, Structural Engineering International", Journal of the International Association for Bridge and Structural Engineering (IABSE), Vol. 11, pp. 139–144.

[46] Baumann, T., Lieb, M. and Boehler, J., (1998). "Sensitivity of seismic response with regard to the computational modeling of the nonlinear characteristics of isolators", Proceedings of the ASME Pressure Vessels and Piping Division, Seismic, Shock, and Vibration Isolation, San Diego, CA, USA, Vol. 379, pp. 9–17.

[47] Fornl, M., (2005). "Shaking table tests on a spherical tank mock-up provided with seismic isolation and flexing piping connections", Proceedings of the ASME Pressure Vessels and Piping Conference, Denver, CO, USA, July 17–21, Vol. 8, pp. 123–129.

[48] Livaoglu, R., Cakir, T., (2009). An analytical approach for the determination of backfill effects on rectangular drinking water storage tanks. Sakarya International Symposium of Earthquake Engineering, Sakarya.

[49] Livaoglu, R., Cakir, T., (2012). Fast practical analytical model for analysis of backfill-rectangular tank-fluid interaction systems. Soil Dynamics and Earthquake Engineering 37, 24–37.

[50] Chen, J.Z., Kianoush, M.R., (2009). Generalized SDOF system for seismic analysis of concrete rectangular liquid storage tanks. Engineering Structures 31, 2426–2435.

[51] Minowa, C., (1984). Experimental studies of seismic properties of various type water tanks. In: Proceedings of the Eighth WCEE, San Francisco, pp.945–952.

[52] Akyildiz, H., Unal, E., (2005). Experimental investigation of pressure distribution on a rectangular tank due to the liquid sloshing. Ocean Engineering 32, 1503–1516.

[53] Naderi, R., Yousefi Samangani, A., & Taleb Pour, M. H., (2008). Analysis of vibrations of buried cubic concrete tanks according to the effect of soil and structure interaction. The first national conference on crisis management: earthquake and vulnerability of vital places and arteries, Tehran.

[54] ABAQUS 6.11.1, Analysis User's Manual "Explicit dynamic analysis," Section 6.3.3 "Adaptive meshing," Section 7.16, 2011.

[55] Kianoush, M.R., Chen, J.Z., (2009). Generalized SDOF system for seismic analysis of concrete rectangular liquid storage tanks. Engineering Structures 31, 2426–2435.