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Investigation of Damage and Deformation of above-Ground RC Tanks under the Effect of Blast Load

Majid Alipour [1)], ***Mojtaba Hosseini*** [2)*], ***Hamidreza Babaali*** [1)], ***Mehdi Raftari*** [1)], ***Reza Mahjoub*** [1)]

[1)] *Department of Civil Engineering, Khorramabad Branch, Islamic Azad University, Khorramabad, Iran.*
E-Mail: majidalipour.2024.1980@gmail.com
[2)] *Associate Professor, Department of Civil Engineering, Lorestan University, Khorramabad, Iran.*
** Corresponding Author. E-Mail: hosseini.m@lu.ac.ir*

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ABSTRACT

The primary purpose of designing various structures, regardless of their intended use, is to create convenience, comfort, and security for users. Due to operational restrictions, it is not always possible to design and build a buried or semi-buried tank. Thus, in such a condition, the construction of above-ground tanks is considered the only available option. Therefore, the main goal of this research is to investigate the damage and deformation of the above-ground cylindrical and cubic tanks under the effect of blast loads, taking into account the power of the blast and the distance between the explosive materials and the tank. ABAQUS finite element software was used to simulate the RC cylindrical and cubic tanks. MATLAB software was also used to investigate the damage behavior of the concrete. For this purpose, the main variables in the current research include the amount of explosive materials (500 kg and 1000kg), the distance of explosives from the ground (0-15 meters), and the geometrical shape of the cross section of the concrete tank (circle and square with equivalent area). Also, the responses studied include maximum von Mises stress, maximum displacement, and damage created in the tank. The results show that with an increase in the explosive substance, the responses of maximum stress, maximum displacement, and damage have increased by 33%, 44.4%, and 13.3%, respectively. Also, as the distance of the explosion source from the ground increases, the amount of damage to the concrete tank does not change noticeably, indicating that the amount of damage index does not depend on the height of the explosion source. Other results show that by changing the cross-section of the concrete tank from circular to square, the damage rate has increased by approximately 40% to 50%.

Keywords: RC cylindrical and cubic tanks, Blast loading, Von Mises stress, Maximum displacement, Damage, ABAQUS and MATLAB software.

INTRODUCTION

Creating convenience, comfort, and security for users is the most important goal and philosophy of designing and producing various types of structures, regardless of the type of use. Human needs are not the same in different situations and cover a wide spectrum. In times such as war, drought and water shortage, fire, and the need to access a high-pressure water source, conditions change in such a way that the peace and life of the citizens of a city depend on providing a source and reservoir with a suitable capacity. Due to operational restrictions, it is not always possible to design and build a buried or semi-buried tank. Thus, in such a condition, the construction of above-ground tanks is considered the only available option. It should be noted that the probability of damage caused by blast loading in above-ground tanks due to not being covered is much higher compared to buried and semi-buried concrete and steel tanks. Therefore, in this research, numerical investigation and behavior of above-ground RC tanks under blast load have been studied. Today, according to the progress of cities and industries, water tanks are still part of the necessary urban and industrial facilities, and it is necessary to maintain their usability after unexpected events, such as earthquakes and explosions, in order to meet the needs of water supply, sanitation, and firefighting. Reservoirs are one of the important structures in the storage of fluid for storage and use in transmission networks, which usually have fixed shapes in plan and height. They are designed and calculated according to input flow rate, construction site conditions, and the type of static and dynamic loads. Therefore, a detailed investigation of the behavior of tanks under the blast load is highly essential to study. Thus, by accurately identifying the behavior of an important structure, such as an RC above-ground tank under the effect of blast load, a correct understanding of the performance of the structure exposed to blast load can be achieved. This knowledge ultimately leads to identifying the weak points of the structure. By strengthening and covering the weak points of the structure, an ideal engineering design can be achieved, which can ensure the safety of the structure and reduce the financial and life losses of the structure in crises. The most important variables affecting the behavior of RC above-ground tanks that are considered in this study are: the geometrical shape of the cross-section, the amount of explosive materials, and the distance of explosive materials from the tank.

RC above-ground water tanks are usually built in cylindrical and rectangular shapes, although they can be built in any appropriate geometric shape. In general, cylindrical tanks are superior to rectangular cubic ones in terms of technical and passive defense considerations. In the areas where the soil load factor is suitable, bowl tanks are also a suitable option for large volumes. From the viewpoint of exploitation and passive defense, tanks are usually considered as twins. But, in the absence of special limitations, the most suitable geometric dimensions for rectangular cubic tanks are obtained in terms of economy, where the ratio of the length to the width of the tank is 2-3. In twin cylindrical tanks, the most suitable mode is to use two independent tanks with equal volume. In practice, in order to save money and time for the analysis and design of tanks, codes and analytical relationships are used. These regulatory relationships are mainly based on mechanical models. The famous mechanical models are:

- Two-mass model of Housner;
- Three-mass model of Haroun;
- Simple method of Malhotra.

Rectangular and circular RC tanks with fixed and flexible foundations, as well as air tanks with supporting foundations, are considered at ACI350.3. In the NZSEE code, circular and rectangular concrete ground tanks with rigid and flexible foundations, as well as concrete air tanks, are considered and evaluated. In Eurocode 8, circular and rectangular tanks with girder base and air tanks have been evaluated. Also, in Iranian code named publication 123, RC circular and rectangular concrete tanks have been analyzed and investigated, as well as concrete air tanks. Therefore, it can be seen that a large percentage of the mentioned codes are related to RC tanks. Different codes have presented various relationships in order to calculate the period time of tanks in different conditions (Khanmohammadi et al., 2014). The explosion is a very rapid release of energy in the form of light, heat, sound, and shock waves. When an explosion occurs, energy is released suddenly and in a very short time (a few milliseconds), and the effect of this energy is seen in the form of thermal radiation and propagation of waves in space. Explosives are classified according to their material state into solid, liquid, and gas types. Usually, the solid type is more useful in bombs and produces stronger waves. In terms of excitability and reaction initiation, they are divided into primary and secondary types, where the primary type reacts quickly and due to the smallest stimulus, such as a spark or shock (Zou, 2017).

Jacobsen has focused his studies on cylindrical tanks with a rigid wall, and Hausner has modeled the rigid cylindrical and rectangular tanks system in a form that has practical application for civil engineers. In Hausner's model, liquid pressure is divided into two parts. The first one is the impact part, which is caused by a part of the liquid that has an acceleration equal to the wall acceleration, and the second one is the transfer part, which is caused by the liquid sway movement. Epstein has determined the maximum forces caused by an earthquake by presenting a series of equations and tables assuming that the transfer component acts in the upper part of the liquid (Epstein, 1976). In 2010 and 2011, Ghaemmaghami and Kianoush investigated the dynamic behavior of rectangular ground concrete tanks by the finite element method in two and three dimensions. In other studies, dynamic analysis of the RC tanks was performed using the finite element method with modal and time-history analysis, and the effect of different elements on the dynamic responses was investigated (Ghaemmaghami & Kiamoush, 2010; Kiamoush & Ghaemmaghami, 2011). Khoshmood et al. (2014) analyzed the sensitivity of retrofitting buried concrete tanks and the effect of soil type and distance from the explosion site. They used a soil model of 100 meters in length and 50 meters in width. They used the Drucker-Prager model in their study. The results of the study showed that the explosive response of the buried tank is highly sensitive to the characteristics of the location and site of the structure. Based on the elastic and plastic parameters, as the soil softens, the displacement and stress created in the tank wall increase, so that the stress and displacement in the tank wall in soft soil compared to stiff soil are 62% and 42% higher, respectively. In other words, the behavior of a concrete tank buried in less stiff soil is more critical, and building a tank in soft soil should be avoided. Lin and Li (2017) investigated the performance of RC tanks under severe seismic excitation. They evaluated the safety of the structure based on two specific limit states, including the serviceability limit state and the ultimate limit state. The results obtained from their numerical analysis showed that the concrete tanks are placed in the serviceability state for acceleration records with PGA equal to 0.8-1.1, and for PGA in the range of 1.2-1.7, they pass the ultimate state. Safa and Shabdiz (2015) investigated the effect of an explosion on above-ground floating roof tanks. Explosive loading has been investigated in their study on two widely used tank samples with two types of floating roof. The non-linear dynamic analysis of the structure under the effect of load caused by the explosion has been carried out using a numerical method for 30 different cases of explosive loads. Explosions on two types of tanks are modeled by the air blast model in the software and analyzed based on Brad relations. In this way, when the explosion occurs, more pressure is applied to the body of the tank. The explosion scenarios applied to the tanks are based on the two parameters of the distance and the amount of the explosive charge. The distance was assumed to be 5, 15, and 25 meters from the closest point of the tank body to the source of the explosion. Regarding the amount of explosive charge according to the type of attack in 5 cases, the weight of the explosive TNT equal to the values of 5, 20, 100, 500, and 1000 kg has been considered. The results show that the investigated tank body is vulnerable to some explosive loading scenarios and will be damaged based on the standard failure criteria of API650. In the following part, suggestions to prevent economic and environmental losses, as well as necessary measure, such as retrofitting, passive defense, and crisis management after destruction, are discussed. The summary of the results obtained from their study can be expressed as follows:

- Among the two types of tanks presented in their study, the tank with a diameter of 50 meters, compared to the tank with a diameter of 32 meters, has a more suitable behavior in terms of absorbing and dissipating energy. Because the larger tank has more liquid volume, it can dissipate the energy under favorable conditions.
- The pressure on the elements of the tank decreases with the square of the distance from the explosion site.
- The behavior of the tank is very sensitive at a distance of about 5 meters, and up to this distance, explosions of less than 5kg can be tolerated. As a result, above-ground tanks are relatively resistant to light terrorist attacks.

Burkacki and Robert (2014) investigated the seismic behavior of steel tanks using a shaking table test. According to the laboratory limitations of the tank sample, it was converted to the scale of 1 to 33.33; the diameter and height of the tank were 1.5 m and 0.7 m, respectively. The weight of the tank was 86kg, the thicknesses of the bottom plate and roof were 3mm and 1.2mm, respectively. The tested tank was examined for four states: empty, filled with water up to the height of 162mm, filled with water up to the height of 324mm, and filled with water up to the height of 486mm. In all cases, it was investigated under the earthquake records of Suwalki, El Centro, and Polcois Minigtermore.

After that, the recorded signals have been subjected to data processing and analysis using a computer program. Then, the results of the response of the structure have been provided in the form of an acceleration-time diagram under the mentioned earthquakes. According to the results, the response of the structure has increased in the form of time acceleration in a tank that is completely full.

Despite the considerable amount of studies conducted regarding the analysis and evaluation of the behavior of RC tanks against the application of various types of loading (Wu et al., 2011; Tabatabaiefar & Massum, 2010), until now, a comprehensive investigation has not been conducted regarding the analysis and evaluation of the behavior of above-ground RC tanks against blast loads, especially it has not been carried out with consideration of geometric characteristics of the tank section. Therefore, in this study, the behavior of two circular and square RC tanks for two amounts of explosives and at two different distances from the explosion site has been investigated and evaluated.

Jamalvandi and Amiri (2021) studied the influence of seismic isolation systems on the behavior of fluid inside thin-walled steel tanks. In their study, the maximum dynamic parameters of tanks, including the vertical displacement of the surface fluid (sloshing), the horizontal displacements of the fluid (convective), and the base seismic isolator, were investigated. Using non-linear dynamic analysis under the seismic excitation near the fault, three types of tanks having fixed and the same heights and different diameters, titled as broad, moderate, and slender tanks, were investigated. The tanks are selected in different supporting conditions, including an isolated base with and without seismic isolation lead rubber bearings (LRBs), in two different states of fixed welded roof and open roof, and in different states of liquid height level. According to the results, it was observed that the contribution of the convective component to the total response has a significant effect on the seismic response of the tanks and that the maximum fluid height (sloshing) increases in isolated base tanks. In addition, base isolation significantly reduces the horizontal displacements of the fluid compared to the fixed base tanks.

Qi et al. (2020) studied the dynamic response of a high liquid level plate shell integrated concrete liquid storage structure under long-period ground motion**.** In their study, 6 long-period ground motions and 6 common ground motions are selected, and the time-domain and frequency characteristics are analyzed. The dynamic response of a high liquid level plate shell integrated concrete liquid storage structure (PSICLSS) to long-period ground motion is studied. The results showed that ground motion does not cause intense shaking of the liquid at the bottom of the storage structure. Under the action of long-period ground motion, the sloshing height of the liquid will be far higher than the design dry string height, but it will not cause damage to the structural components. Under the action of common ground motion, the sloshing height of the liquid meets the design requirements, but rare earthquakes will cause local damage to the PSICLSS.

Qsymah and Ayasrah (2024) conducted finite element analysis of two-way reinforced concrete slabs strengthened with FRP under flexural loading. Their research showed that CFRP provides the highest strength enhancement with a 34.5% increase in the ultimate load, while PET-FRP provides the lowest improvement with an increase of 11.2%, compared with the unstrengthened slab. The results also showed that the concrete compressive strength (f_c') has a moderate influence on the ultimate load.

Moghadam et al. (2022) studied the dynamic analysis of reinforced concrete water tanks under blast loading, considering fluid-structure interaction. Alipour et al. (2025) conducted research on the evaluation of the behavior of reinforced concrete above-ground tanks subjected to blast loading. Huang et al. (2023) studied the dynamic response of steel cylindrical tanks subjected to sequential loadings of earthquake and explosion. Zhou et al. (2023) conducted research on blast test and probabilistic vulnerability assessment of a shallow buried RC tunnel considering uncertainty.

METHODS AND MATERIALS

Finite Element (FE) Modeling of the Tank

According to the title of the study, which is: Investigation of Damage and Deformation of above-Ground RC Tanks under the Effect of blast load, the steps of the research can be described as follows:

Modeling of two categories of square and circular above-ground RC tanks in the ABAQUS environment: In this step, a square tank with the ratio of length to height (L/H) equal to 2 has been modeled using ABAQUS finite element software. Also, a circular cross-section tank was modeled with the ratio of diameter to height (D/H) of 2.25.

Applying different loading scenarios caused by explosion in ABAQUS software to the model built in the previous stage using the Conwep method: At this stage, each of the primary models will be subjected to explosive loading for different amounts of explosive material (2 numerical values) and different distances (2 distinct distances) from the explosion site (totally 4 different states).

In order to ensure the correctness of the considered models, the verification process has been carried out using the results of another research. After validation, the results are evaluated in different modeling modes and compared with each other. In this study, validation was conducted based on one of the models studied by Ghaemmaghami and Kianoush (2010). It should be noted that the responses studied in this study are:

- Stress contours created in above-ground RC tanks under the effect of blast load.
- Displacement created in above-ground RC tanks under the effect of blast load.
- Diagrams of distributed energy in above-ground RC tanks for explosive loading.
- Park-Ang failure index.

It should be mentioned that the stiffness of the soil is considered infinite in the present study, and the effects of soil-structure interaction are practically neglected. Also, the variables used can be introduced as follows:

Geometry of above-ground tank: One of the variables in the current study is the geometry of the above-ground tank. The cross-sectional shape of the tank and the height of the structure are considered as two geometrical variables. Therefore, the RC tank will be studied and evaluated in two circular and square geometries with a cross-sectional area equal to 900 m^2. The dimensions of the cross-section of the square tank are equal to 30m and its height is equal to 15m. Thus, for a square tank, the ratio of the length to the height (L/H) will be equal to 2. Also, in the case of the tank with a circular cross-section, the ratio of the diameter to the height of the tank (D/H) will be equal to 2.25 (in this case, the diameter of the tank is equal to 33.85m and the height of the tank is equal to 15m).

Explosive-material amount: As mentioned before, the loading studied here is the explosive loading type. Therefore, one of the effective factors in causing damage is the magnitude of the force caused by the explosion, and the amount of explosive material is one of the variables. Two numerical values of 500kg and 1000kg of explosive material are used in this study.

Blasting Position: The blasting distance from the tank is 25m. Also, the height of the explosives from the ground surface varies from 0 to 15 meters. In explosion modeling in ABAQUS software using the Conwep method, the model is an airy blast.

Nuclear weapons, chemical weapons, and biological weapons are notorious for causing large-scale mass destruction. Weapons that do not cause such large-scale mass destruction and yet are capable of causing significant damage to life and property are generically referred to as conventional weapons. These weapons typically include land mines, non-nuclear bombs, shells, rockets, missiles, ... etc. The threat from such weapons is measured by the mass of the explosive, or the charge mass, and the distance of the explosion from the vulnerable structure or the stand-off distance. The charge mass used in conventional weapons is typically measured in kilograms of TNT. For comparison, nuclear weapons release energy equivalent to that released by millions of conventional explosives, and their charge mass is generally referred to in kilotons of TNT.

Detonation of an explosive involves chemical reactions that cause rapid heating and expansion of the detonated products. This rapid expansion causes abrupt compression of the surrounding medium, leading to a strong shock wave, commonly known as a blast wave, which propagates away from the source with high velocity. The state of the medium, described by its pressure, density, temperature, and velocity, is discontinuous across the shock front. The states before and after the shock are related by the conservation of mass, momentum, and energy, which are collectively expressed as the well-known Rankine-Hugoniot jump condition. The blast waves are typically supersonic (moving with a speed faster than the fastest speed of propagation of any perturbation in the medium). Hence, the medium remains unperturbed until the advent of the shock front, with the pressure just ahead of the shock (away from the source) remaining close to ambient pressure.

As the shock propagates away from the source, this over-pressure reduces, causing the pressure of a region behind the shock to drop below ambient pressure, which causes transport of debris far away from the explosion source. The pressure distribution at different time levels is qualitatively shown in Figure 1(a). A typical time history of the pressure inflicted by a blast wave at a fixed distance from the source is shown in Figure 1(b).

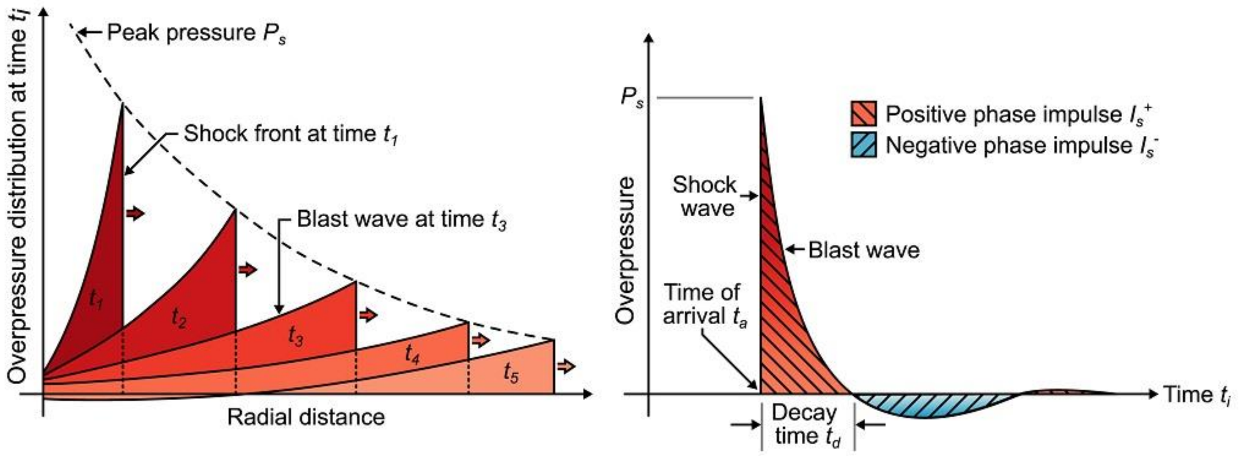

Figure (1): (a) Pressure distribution at different time levels, (b) Time history of pressure due to a blast wave

This qualitative model has been known and developed by several researchers, directly or indirectly working for defense organizations. Much of their work has remained classified information and is not available for public access. Later, the model developed by Kingery and Bulmash (1984), more commonly known as the CONWEP model, has been widely used for free explosions in air (Kigery & Bulmash, 1984). It has previously been implemented in the ABAQUS software. The CONWEP model can be briefly described by expressing the free-field pressure–time response by a modified Friedlander equation (Dharmasena et al., 2008).

$$P(t) = (P_{max} - P_{atm})[1 - \frac{t-t_a}{t_d}]e^{-(\frac{t-t_a}{t_d})} \quad (1)$$

$$P_{max} = \begin{cases} \frac{6.7}{Z^3} & : P_{max} > 10\ {kg}/{cm^2} \\ \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019 & : 0.1 < P_{max} < 10\ {kg}/{cm^2} \end{cases} \quad (2)$$

$$Z = \frac{R}{\sqrt[3]{W}} \quad (3)$$

where P_{atm} is the atmospheric pressure, $(P_{max} - P_{atm})$ is the over-pressure, t_a is the time of arrival of the shock front, t_d is the duration of the positive phase, R is the distance from the center of the explosion, W is the weight of TNT explosive. The time of arrival, the duration of the positive phase and the impulse of the blast depend on the distance of the location from the source, the charge mass and other parameters defined in the CONWEP model.

In the present study, the FEM is used for the analysis of the base-isolated liquid storage tank of radius R and liquid height H, as shown in Figure (2). The water contained in the tank is modeled using the eight-node 3-D continuum acoustic element AC3D8R with reduced integration and hourglass control, for acoustic wave propagation having only pressure degree-of-freedom at each node. The flexible tank walls are modeled using the four-node quadrilateral and triangular 3-D shell elements S4R and S3R, respectively, with reduced integration and hourglass control and steel reinforcing elements are also of the T3D2 type, as shown in Figure (2). The rigid tank wall is modeled using the shell elements same as for the flexible tank wall, but a very large modulus of elasticity of the shell material is assigned to account for tank rigidity. Thus, a modulus of elasticity twenty times greater than flexible shell material is used. The interaction between the tank wall and acoustic liquid elements is defined using a surface-based tie constraint. The acoustic surface in the constraint is designated to be the slave surface; the tank internal surface is defined as the master surface. The mesh size in all elements is considered to be 1000 mm.

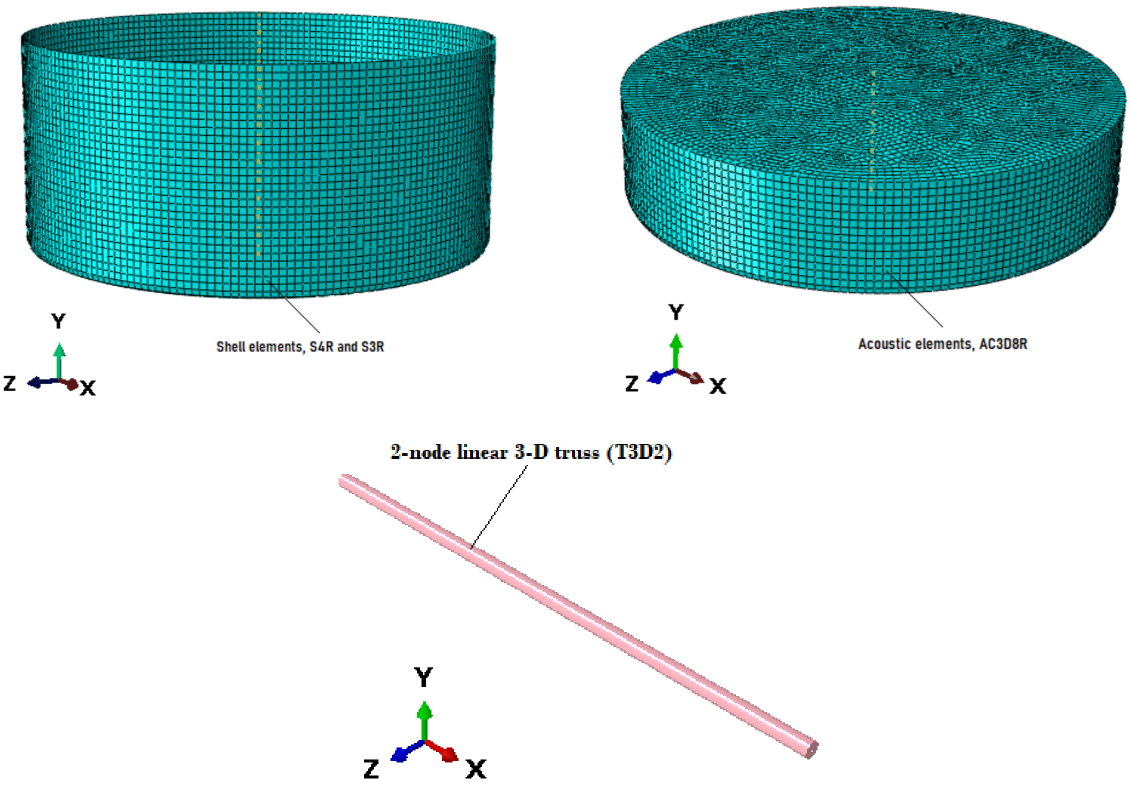

Figure (2): Finite element (FE) model of cylindrical liquid storage tank

The Process of Modeling and Validation

To build an RC tank, the specific weight of the concrete is considered as 2500kg/m^3, Poisson's ratio is 0.2, and the modulus of elasticity is 2000000kg/m^2. After assigning the materials to the parts, the parts will be assembled, and the size and distance of the explosive material will be defined using the CONWEP method. Therefore, the considered points will be defined as reference points using an offset from the point, and then, the amount of explosive material will be defined. It should be noted that the bottom of the tank has a fixed support and is completely fixed modeled. In order to ensure the accuracy of the modeling carried out in the current study, the results have been verified using the results presented in a scientific reference. For this purpose, one of the Ghaemmaghami and Kianoush (2010) models was simulated, and the results have been compared. The geometry of the square tank modeled for verification is shown in Figure (3). In this figure, Lx = 15 m, Lz = 30 m, H_w = 6m, H_1 = 5.5m, and t_w =0.6m. In order to ensure the validity of the present results, the response investigated in this study is the changes in the response of hydro-dynamic pressure along the height of the tank. Figure (4) compares the hydro-dynamic pressure response of the fluid for different heights of the tank with the results of Ghaemmaghami and Kianoush (2010). As can be seen, by increasing the height of the tank, the hydro-dynamic pressure of the fluid has decreased. The maximum difference between the results of the current research and the results of Ghaemmaghami and Kianoush (2010) is obtained at zero height level. Also, it can be seen that the maximum hydro-dynamic pressure obtained based on the study of Ghaemmaghami and Kianoush in the 11-meter tank is equal to 26kPa. The numerical value of the hydro-dynamic pressure at such a depth of the tank in this study is equal to 24.8 kPa. As can be observed in Table 1, the maximum difference between the results of this study and the results of Ghaemmaghami and Kianoush (2010) was obtained at a depth of 7.3m, which is 4.7%. This insignificant difference indicates the desired accuracy of the modeling in the present study.

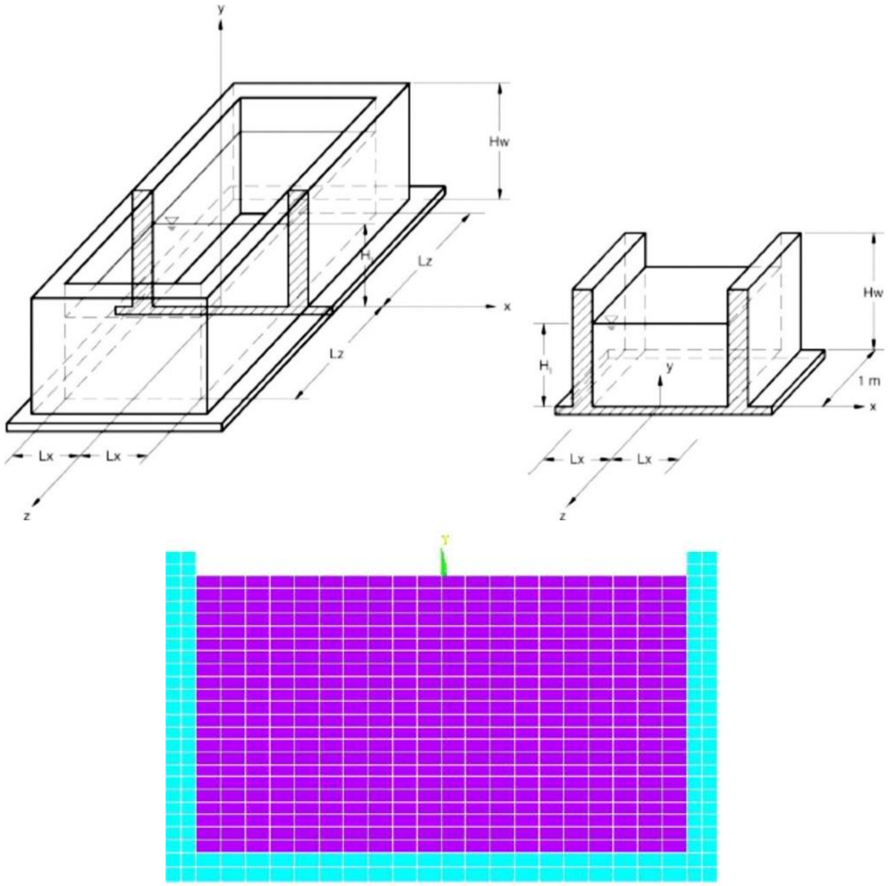

Figure (3): Schematic configuration of rectangular liquid tank and 2D finite-element model of rectangular liquid tanks (Ghaemmaghami and Kianoush, 2010)

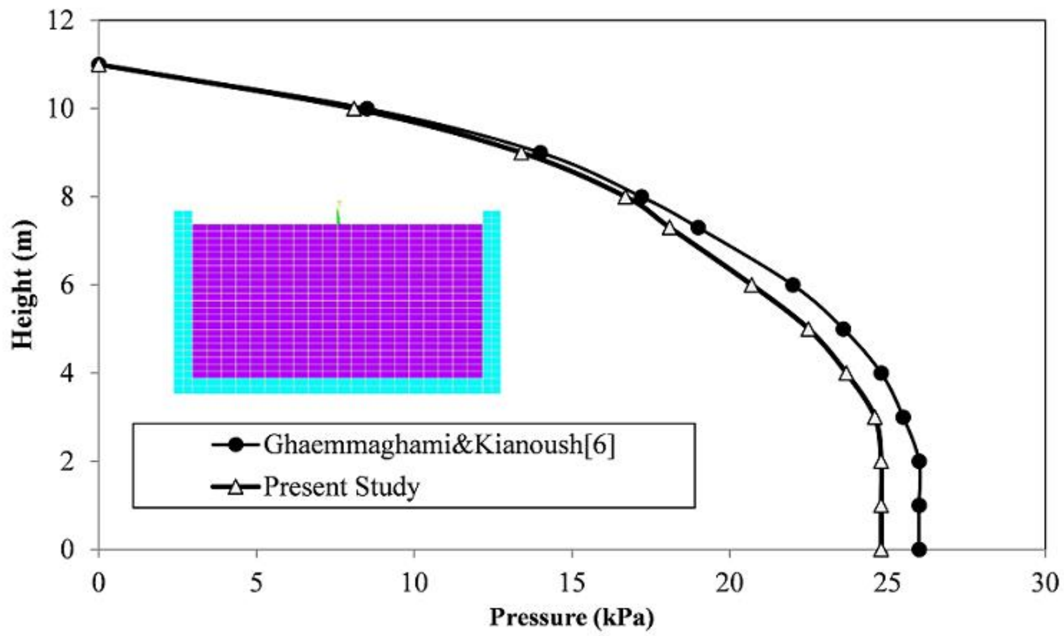

Figure (4): Comparison of the response of the hydro-dynamic pressure distribution of water in the tank in this study and the responses of Ghaemmaghami and Kianoush (2010)

Table 1. The detailed results of verification

Pressure (kPa)	Ghaemmaghami and Kianoush (2010)	This study	Difference%
Depth of 8m	17.2	16.7	2.9
Depth of 7.3	19	18.1	4.7
Depth of 0	26	24.8	4.61

RESULTS AND DISCUSSION

To answer the research questions and achieve the goals of the study, the effect of each mentioned variable on the behavior of the above-ground RC tank will be investigated. In this situation, other variables will be considered constant. This process will be repeated for each variable, and the effect of all variables on the response of the structure will be studied and evaluated. Therefore, in the following sub-sections, the effect of each of the variables of the geometrical shape of the section, the amount of explosive material, and the distance of the explosive material on the overall response of the above-ground tank under the effect of blast load has been investigated and evaluated. The scenarios studied in the current research are named according to Table 2.

Table 2. Scenarios studied in the current research

Model name	Geometry of cross-section	Amount of explosive material (kg)	Explosive distance (m)	Explosive height (m)
V_1	Circular	500	25	7.50
V_2	Square	500	25	7.50
V_3	Circular	1000	25	7.50
V_4	Circular	500	25	15.00
V_5	Circular	500	25	0.00

Effect of Geometric Shape on the Behavior of the RC Tank

To investigate the effect of the cross-sectional geometric shape of the RC tank, other variables were considered constant. Therefore, the considered variable in this case will be only the geometric shape of the tank section. In the first case, the cross-section of the tank is circular, and in the second case, it is considered square. In the circular state, the diameter of the section is equal to 33.85m, and the height of the tank is 15m. In the square state, the length of the sides of the section is 30m and the height of the tank is 15m. In this condition, 500kg of explosive materials are placed at a distance of 25m from the tank.

Figures (5) and (6) show the distributed stress in V_1 and V_2 models, respectively. The only difference between these two models is the geometric shape of the tank section. It can be seen that the stress distributed in the circular section is uniform and spread on all the peripheral surface of the tank. But, if the cross-section of the tank is square, the stress concentration will be observed. In other words, if the cross-section of the tank is circular, the stress is distributed on the entire peripheral surface of the cross-section, but in the square tank, the stress is created only in the wall opposite to the explosion, and the other sides of the square have a considerable stress. The maximum stress created in the circular and square sections is 590MPa and 649MPa, respectively. Therefore, using a circular section for the tank compared to a square section will reduce the maximum stress distributed in the wall of the concrete tank by 9.1%.

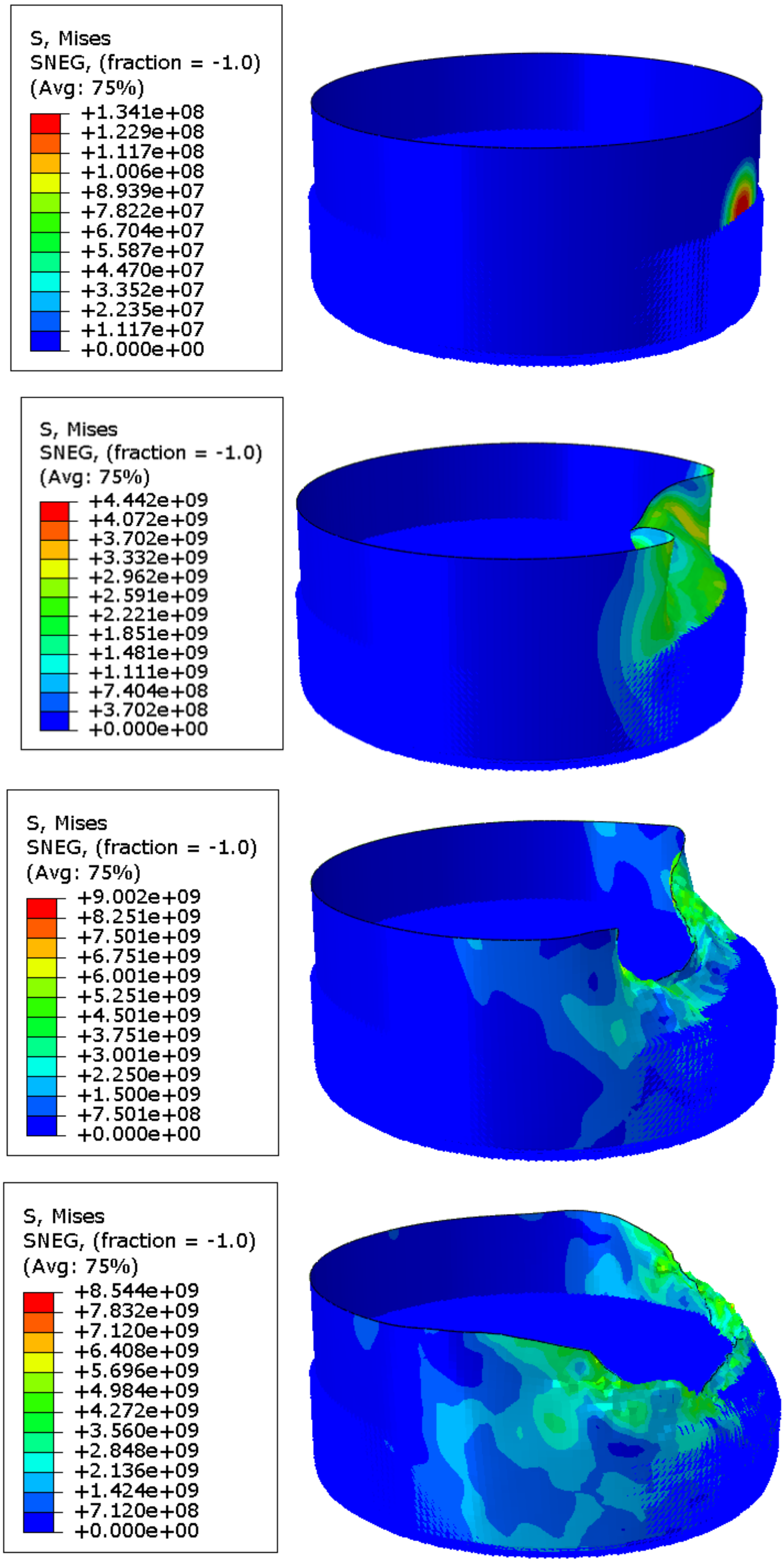

Figure (5): Von Mises stress distributed in the V_1 model

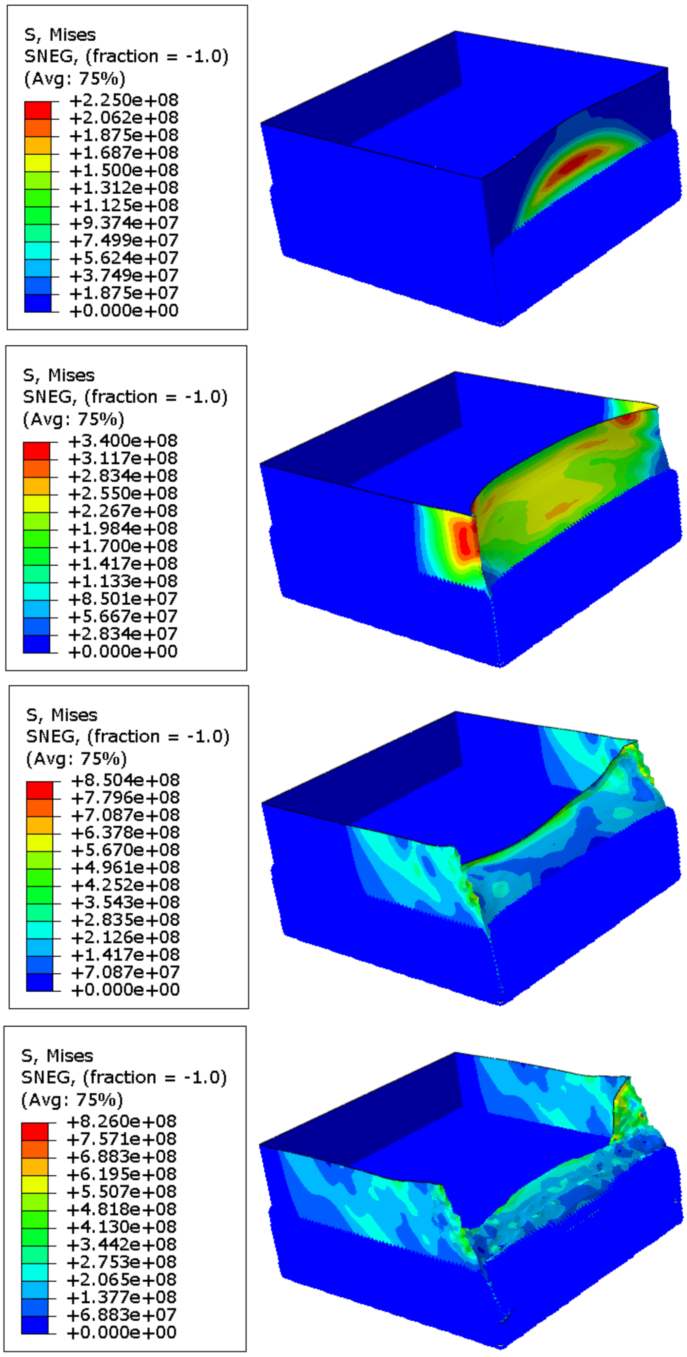

Figure (6): Von Mises stress distributed in the V_2 model

Figures (7) and (8) show the maximum displacement created in the V_1 and V_2 models, respectively. It can be seen that the uniform stress distribution in the circular tank, compared to the square section, caused the displacement created in the concrete wall of the circular tank to be less than that of the square section. The maximum displacement created in the circular and square tanks is 7.5mm and 11.7mm, respectively. Therefore, it can be seen that by changing the cross-section of the tank from circular to square, the displacement will be increased by 35.9%.

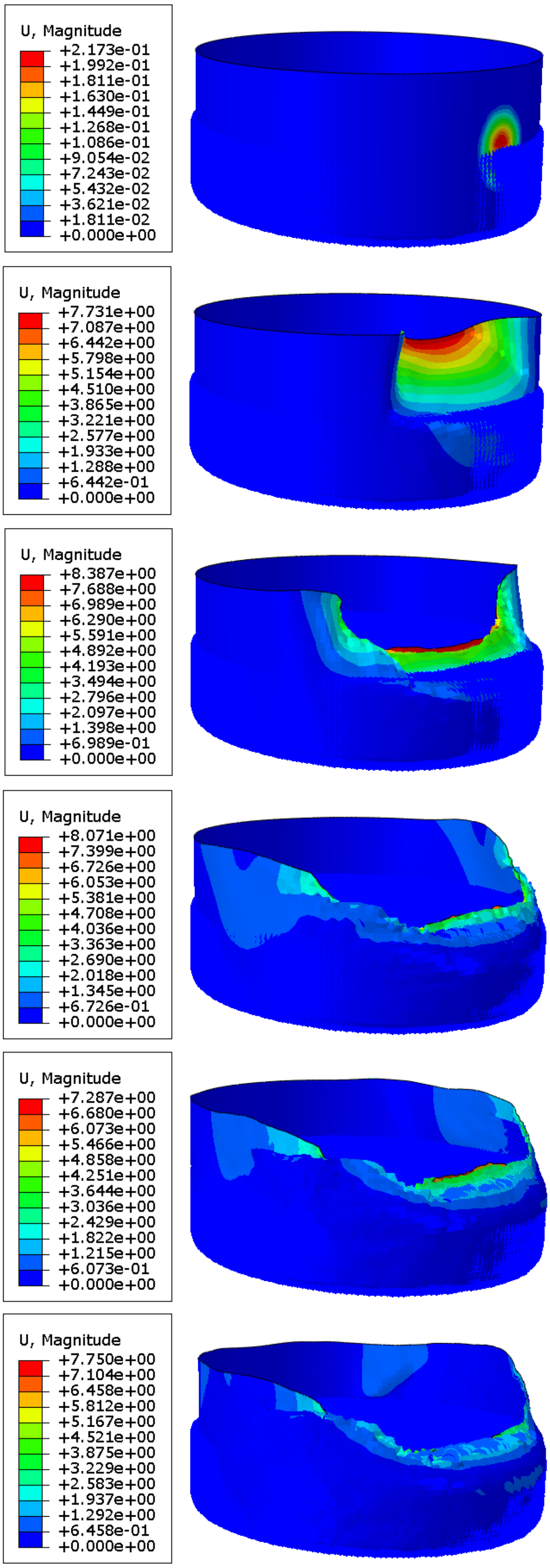

Figure (7): Displacement in the V_1 model

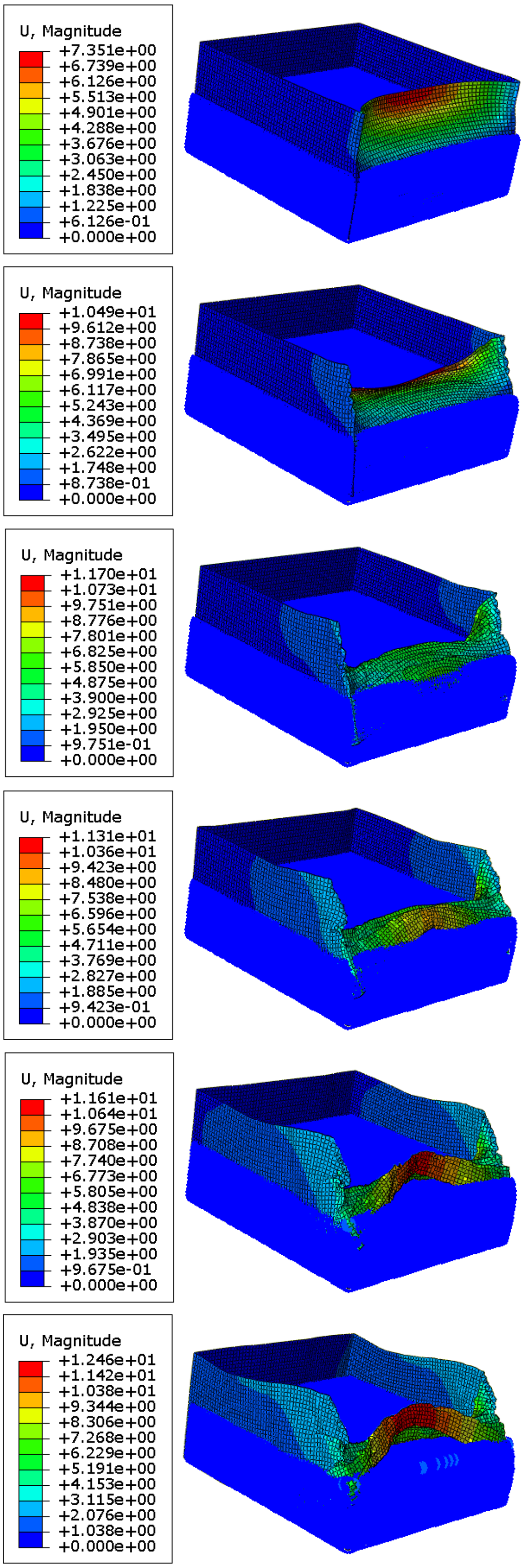

Figure (8): Displacement in the V_2 model

Figure (9) shows the plastic damage in V_1 and V_2 models. One of the most famous composite indices is the Park-Ang failure index, which is considered a linear combination of damage caused by the deformation of each member and the effects of repeated loading. This index changes between zero (not damaged) and one (complete failure). In this study, in order to compare and understand the failure conditions in different models, the numerical values of the failure have been normalized in such a way that all responses are divided by the maximum numerical value of failure. It is clear that in concrete tanks with a circular cross-section, the damage distribution is not uniform, but in tanks with a square cross-section, the damage distribution is uniform in different directions.

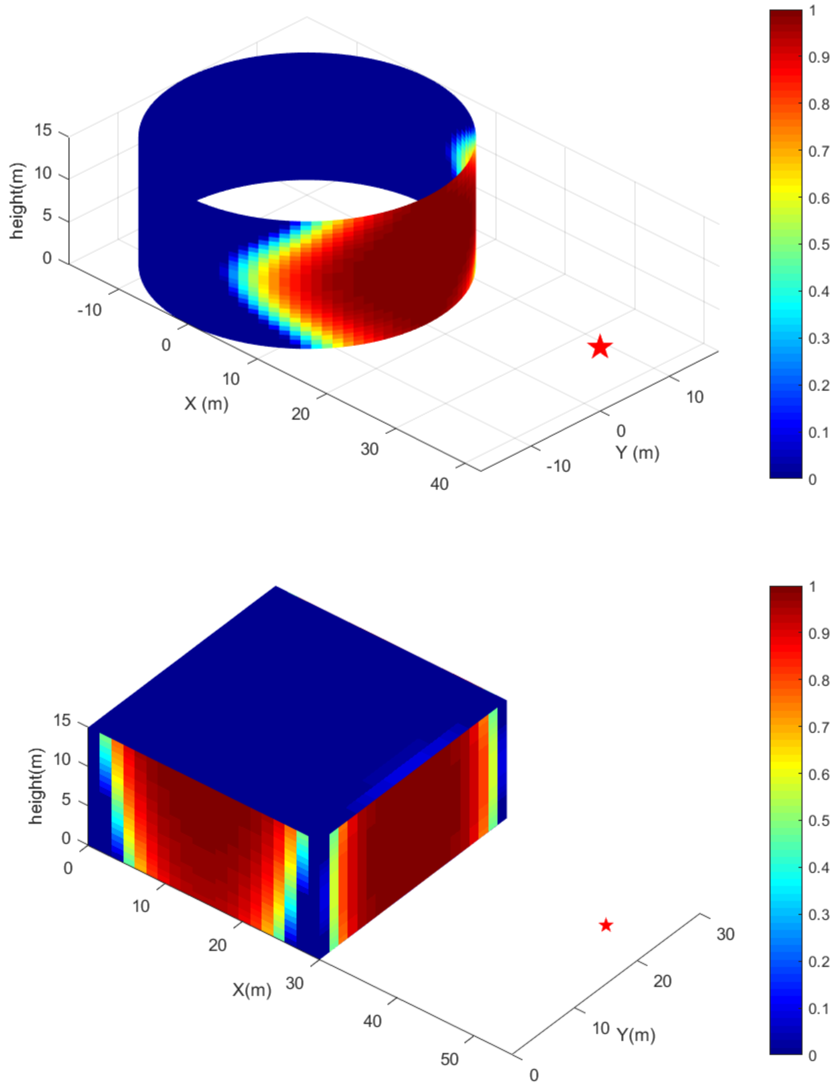

Figure (9): Effect of the geometrical shape of the section on the damage

The Effect of the Height of Explosive above Ground on the Behavior of the RC Tank

Figure (10) shows the damage in the V_4 and V_5 models with a 100% decrease in the height of the TNT explosive from the ground, based on a study of the behavior of concrete tanks against explosions, it is observed that the height of the explosion does not have much effect on the amount of damage to the tanks, and its only effect is excessive damage in the direction of the tank and the explosion location.

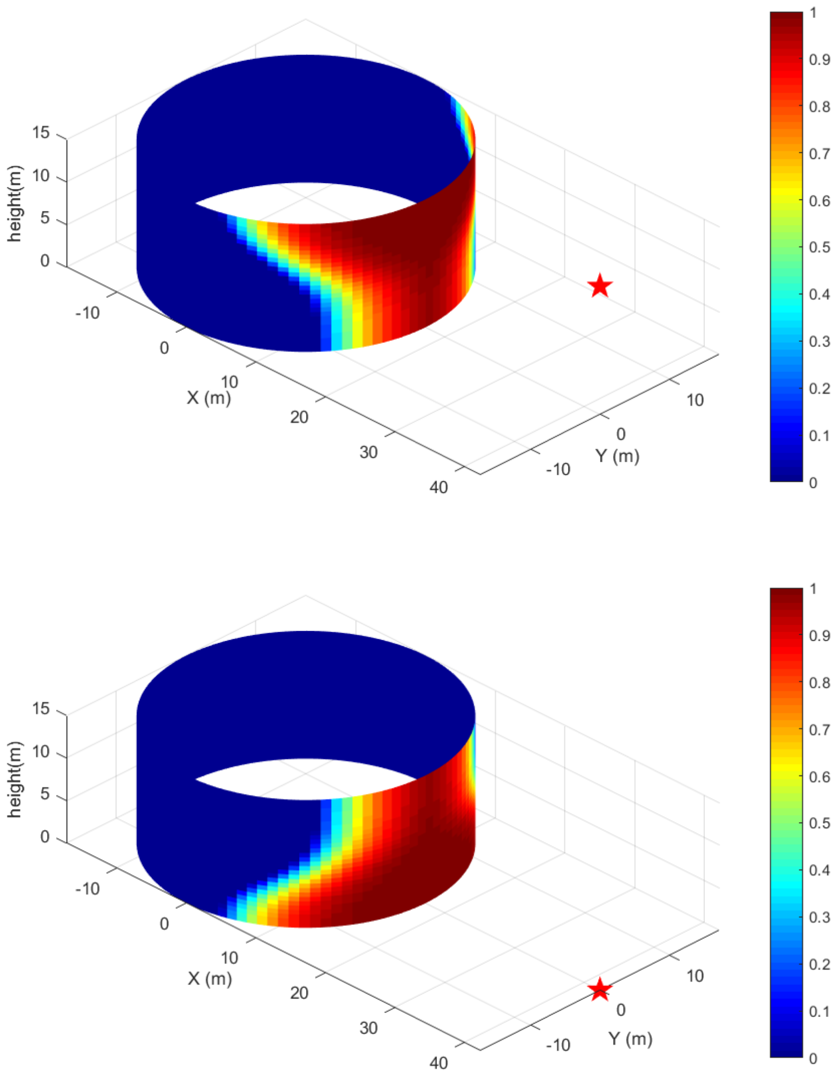

Figure (10): The effect of the height of explosive material from the ground on the damage

CONCLUSIONS

Based on the analysis carried out in this study, the results can be summarized as follows:

- By changing the cross-section of the tank from circular to square, the maximum stress distributed in the tank will be increased by 9.1%. This can be justified due to the stress concentration formed in the corners of the square section.
- By increasing the amount of explosive material, the maximum stress distributed in the wall of the RC tank has increased by 33%.
- By changing the cross-section of the tank from circular to square, the maximum displacement created in the tank will be increased by 35.9%.
- With the increase in the amount of explosive material, the maximum displacement created in the wall of the RC tank has increased by 44.4%.
- By changing the cross-section of the tank from circular to square, the damage index of the tank will be increased by 3.7%.
- With the increase in the amount of explosive material, the damage index in the tank wall has increased by 13.3%.

Data Availability

The data used to support the findings of this study is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors have no conflicts of interests to declare.

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