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Interaction study of factors on the effect of explosion on vertical and horizontal pressure vessels using response surface method

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ABSTRACT

Oil, gas, and petrochemical facilities are strategic industry facilities, and their passive defense issues are of high priority in every country. Explosions due to sabotage or aerial bombardments are the most critical factors in considering issues related to passive defense in the abovementioned facilities. This study investigates the effect of blast loading on pressure vessels. The research issue is the study on the interaction between factors that affect on responses of pressure vessels under blast loading. For this purpose, the response surface method and central composite method were used for numerical design tests. Four factors were selected, type of pressure vessel (vertical or horizontal), the thickness of vessel body, the yield strength of steel vessel, and the amount of explosive material. Two responses were studied, the maximum displacement of pressure vessels and the residual displacement of pressure vessels. The result shows that the quadratic equation is the best model for equations. Then for two responses according to the four factors presented equations. These equations are practical, and straightforward for engineers and researchers. The result shows that for both of the selected responses, the role of body thickness and type of steel in the stronger explosion is the same, but in the weaker explosion, the role of yield strength increased. In addition, it was found that role of the amount of explosive material is more than another parameter. And the interaction of material explosive by other parameters in vertical type is more than horizontal pressure vessels.

1. Introduction

Today Due to the increase of potential for attacking civilian areas and the heavy damage. As a result, studying the safety and stability of structures under the loads caused by explosions or accidental shocks has been considered; so understanding the explosion phenomenon and analyzing the behavior of structures in the reaction is essential.

In 1970 in Port Hudson[1], a breakdown in a pipeline released a large amount of propane, and an explosion of the steam led to heavy destruction upon buildings and structures nearby. In this accident, the estimated peak pressure was 1 Bar. Four years later, in 1974, a temporary failure in a gas pipeline released about 100 tons of cyclohexane in Flixborough[2]. Emission of the gas caused significant damage to structures inside the site. In the above incident, the blast mechanism involved a transition from deflection to detonation, and peak pressure is estimated in the range of 1 to 10 bars.

A critical incident happened on an offshore platform and led to numerous researches is Piper Alpha [3] incident in 1994. In this incident, 167 people died in the fire or because of carbon monoxide inhalation trapped inside restrooms.

In 2005 a very important accident also occurred at an oil reservoir site in Buncefield. This incident started due to overfilling one of the reservoirs with gas, leading to reservoir overflow. In combination with the air, the spilled gas formed a vapor cloud. As a result of the vapor explosion, about 20 reservoirs in that field were on fire and tallow explosions (Domino effect) Which caused enormous financial and human losses[4], [5].

The sudden release of energy from an explosion process turns the explosive into gases with very high pressure and temperature. The compressive front of high-pressure gas is radially propagated in the atmosphere as a strong shock wave that is driven and supported by hot gas. The shock wave That is called an explosion wave is determined by an almost instantaneous increase from ambient pressure to maximum pressure collision (p_{so}).

This increase in pressure or shock front moves radially from the point of the explosion at a decreasing speed. As the shock front expands to larger volumes in the diffusion medium, the maximum impact pressure on the fronts decreases, and the duration of pressure increases[1].

Regarding the effects of the explosion, major data provided in the guidelines and regulations are related to the pressures resulting from the explosion of spherical uncoated TNT. These data can be used for other explosive materials by correlating the explosive energy of the effective weight of these materials with values such as the weight equivalent to TNT. In addition to the resulting energy, other factors may affect the equivalent of materials compared to TNT. These factors include a Figure of the material (flat, square, round, etc.) Number of Explosive (various) materials, enclosed Explosive material (sheath, enclosure, etc.), and Considered pressure range (close range, medium, Or far) [1] .

Giglio [2] Investigated the internal explosion of a spherical tank under pressure. He presented an analytical model for calculating the above mechanical facilities. Mazaheri and Mirzaei [3] researched the effect of internal explosion load on the transient response of pressure pipes. They provided an analytical model for that conditions. Also, the above analytical model results have been compared with laboratory results. In another article Mirzaei [6]examines the rupture of a gas cylinder during an internal explosion. Also, Mirzaei did another research [7] in which he investigated the amplification of the blast wave caused by the explosion inside the pressurized pipe. In this research, he has used analytical and numerical models. John Dyer [8] has studied the effect of the external explosion on pressurized tanks and has examined the important points about the design of those tanks against explosion. Mirzaei and Malekan [9] discussed the effect of the internal explosion on the CNG fuel pressure tank. In the above research, the finite element numerical method has been used. Yaseri [10] presented a relationship to obtain the external explosion pressure distribution around vertical pressure vessels by conducting laboratory studies.

Xu-dong Zhi [11] discussed the pressure distribution characteristics of hemispherical shell structures subjected to external explosion.

B.Y. Zhang wo[12] discussed the effect of the external explosion on the spherical storage tanks.

In another article Kun Hu[13] present a novel approach to distinguish the uniform and non-uniform distribution of blast loads in process industry. Shengzhou Lu [14] work on Behaviors of Thin-Walled Cylindrical Shell Storage Tank under Blast Impacts.

In the occurrence of engineering phenomena and the appearance of a specific answer for the system, several factors often identify all the factors affecting this phenomenon, and how these factors interact with each other is one of the common topics in research today. One way to identify the factors affecting the phenomena is to use test design methods. Methods in which all possible factors are considered by performing designed experiments. By measuring the response of the system and its statistical analysis, it is possible to obtain acceptable results regarding the effect of each of the considered factors, how each of these factors interacts with each other, and the optimal amount of each of these factors to achieve the desired amount of response.

Response Level Method is widely used, a set of statistical and mathematical methods for modeling, analyzing, and analyzing problems in which the responses are affected by several variables. Second-order equations are widely used in the response level method, which is one of the advantages of this method. This advantage allows the proposed model to have the appropriate flexibility and accuracy and close to the correct response level. It is also easy to estimate the parameter in the quadratic model using a central composite scheme. Central design methods are widely used to construct quadratic response TNT. They are among the most important experimental design methods for optimization studies [15], [16] .

Articles mentioned often study the phenomenon of an internal explosion in pressurized tanks that have been addressed, and the issue of the external explosion has been neglected. Also, the articles that have done research in the field of the external explosion have not discussed the interaction between the effective parameters due to the explosion on the pressurized tanks.

Therefore, to point out the past research challenges, the following can be mentioned

1- Past research has often addressed the phenomenon of internal explosions in pressurized tanks, and external explosions have been neglected. Also, the articles that have done research in the field of the external explosion have not discussed any interaction between the parameters affecting the effect of the explosion on pressure vessels.

2-Previous research has not provided an empirical formula for calculating the tank's response to the explosion load for engineering applications.

3-In previous research, the factors affecting the structural response and the effect of each on the final response have not been discussed.

Therefore, the present study aimed to investigate the effect of the external explosion on vertical and horizontal pressure vessels in order to obtain dynamic response as well as the performance of the tank and its structural support against the external explosion load caused by explosives is strong; In the following, based on the response level method, different models are compared to obtain the interaction between the effective factors, and at the end, simple and practical relationships for engineers to use in the design of pressure vessels are presented. Therefore, as an innovation of this article, the following can be mentioned:

1. Investigation of the effect of the external explosion on pressure vessels and the support of their structures.
2. Investigation of the interaction of effective parameters due to external explosion under different scenarios on horizontal and vertical pressure vessels.
3. Introducing a model for predicting the response of tanks under explosion load for use in engineering applications.

2-Materials and methods

2-1- Pressure tanks

According to standard [1], the pressure tank reservoirs are said to have a design pressure greater than 15 psi and less than 3000 psi. These metal tanks are usually cylindrical or spherical for storing or performing chemical processes of liquids or gases that have the ability to withstand various loads (internal pressure or external pressure and vacuum inside). The main application of these tanks is in the oil and gas industry. Pressure tanks are designed to operate safely at specific pressures and temperatures, called design pressure and the design temperature. The design and construction of such pressure equipment without principles and design codes and standards will be very dangerous and accidental.

In theory, any material with high and specific tensile stress tolerance and suitable tensile properties can be used in the construction of tanks, but construction standards make a list of the best materials and their temperature and pressure limits. In addition to good mechanical strength, current world standards force companies to use an iron with high impact resistance, and also for environments and fluids that cause corrosion of carbon steel. it is necessary to use materials with corrosion resistance. Pressurized tanks can be divided into two types of tanks in terms of shape And spherical.

A- Cylindrical tanks: They are often made in the form of a cylinder with two lens heads. These types of tanks are the most common type of tanks. Tall cylindrical tanks may be vertical or horizontal. Basically, the operational need of a tower specifies its type to be horizontal or vertical. For example, towers requiring gravity to separate the phases are installed vertically, while heat exchangers can be installed horizontally and vertically. In the case of heat exchangers, this choice is usually made by the heat transfer method. In storage tanks, the installation location is mainly the selection factor (Figure 1).

B - Spherical tanks: Due to the inherent strength of the spherical shape of these tanks, they are used mainly for high pressures. Large storage tanks are usually spherical or quasi-spherical in shape under medium pressure (Figure 1).

Figure 1 Sample of two horizontal, vertical pressure vessels and spherical cylinders

2 -2- Model validation

To validate the numerical simulation, the experiment performed by Xu-dong Zhi in 2019 has been used. A hemispherical shell structure as a typical large-span space roof structure with a rise–span ratio of 1/2 was selected in this study.

Considering the actual buildings and test sites, the model was constructed from a 20-mm thick steel plate and was sufficiently robust to withstand repeated blast loading without deformation. Moreover, the scaled model was welded directly to a square-shaped steel pipe height of 80 mm and was fixed on the concrete ground by six expansion bolts to avoid deviation and vibration, as shown in Figure 2. The processing technology only guaranteed that the inner diameter of the hemispherical shell was kept as 900 mm so that the actual diameter of the test model was 940 mm.

To understand the spatial pressure distribution characteristics of the hemispherical shell structure, five pressure transducers were used at key areas along the model to measure the reflected overpressure time at a different scaled distance, as shown in Figure 2. To validate the reflection and diffraction effects generated by several numerical methods, the peak positive reflected pressure from several numerical data was compared with the blast trials' experimental test data. Figure 3 shows the typical pressure-time from the experiment and numerical simulation at a stand-off of 1 m and 58-g TNT equivalent charge package

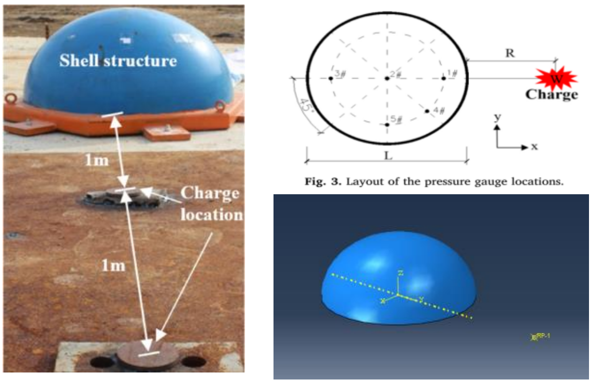


Figure 2 Experimental test[11] and numerical model

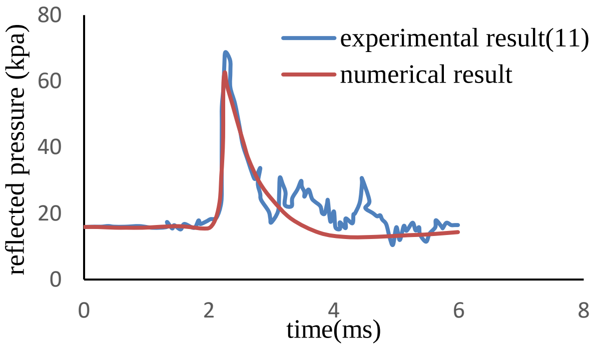


Figure 3 Numerical validation model for gauge 2#

2 -2- Tanks understudy

One of the reservoirs studied in this research is a separating reservoir with a diameter of 2 meters and a length of 6.065 meters. The tank is of horizontal cylinder type. The above reservoir on the deck of offshore platforms of the South Pars project is responsible for separating the compounds extracted from the well. The tank is placed on two bases that are welded at 3 meters from each other. The above bases are fixed on the platform deck beams (Figure 4). The second tank is a vertical cylindrical tank with a diameter of 1.75 and a height of 4.512 meters. It is located on four bases on the ground (Figure 5). The above pressure tank is widely used in petrochemical industries.

Table 1 Physical characteristics of the studied tanks

Type	Diameter (meters)	Length (meters)	Thickness (meters)	Internal pressure (load)
Cylindrical Hor.	2	6/560	0.07	124
Cylindrical Vert.	1/75	4/512	0.07	124
Spherical	3	-	0.05	124

2-3- Numerical Simulation

As mentioned in the previous sections, two pressure tanks were examined. The first type is a vertical pressure tank, and the second type is a horizontal pressure tank. Studies show that four parameters can affect the responses independently.

The first parameter is the type of tank (horizontal or vertical).

The second parameter is the thickness of the tank body. The thickness of the tank body during operation may be due to factors such as corrosion and etc. Decrease. They also consider different thicknesses for different uses.The pressurized tanks used today have thicknesses between 4 and 7 cm. Therefore, the second parameter to be considered is the thickness in the range of 4 cm to 7cm.

The third parameter to be considered is the type of steel used to construct the body and foundations. According to the steels available in the market, the yield stress of the above steels is between 3600 MPa to 6300 MPa . Therefore, the yield stress of the consumed steel is considered representative of the stiffness of the steel.

The fourth parameter is the amount of explosive charge. Explosive amount of 30Kg Up to 2000Kg It is based on explosives.

Two answers are considered for the above analytical system. The first answer is the maximum displacement of the event at the top of the reservoir and the second answer is the permanent displacement of the event at the top of the reservoir. Therefore, four factors have been examined, and two answers have been selected.

Design expert software has been used to design numerical experiments. According to the introduction, the design of experiments using the RSM method and CCD algorithm.

2-4- Finite element model

In the previous section, we discussed the effect of the interaction between different parameters on the degradation of pressure vessels. For this purpose, four effective parameters and three responses were analyzed.

In reservoirs, the first response parameter is the permanent displacement, and the second response parameter is the maximum displacement.

The horizontal pressure tank is shown in Figure 6, and the vertical pressure tank is shown in Figure 7 when the blast load is specified. As it turns out, most of the displacement has occurred at the top of the reservoirs. For this reason, this point is used for further investigation. Figure 6 shows the time-displacement diagram for the horizontal tank top, and Figure 9 shows the time-displacement diagram for the vertical tank top.

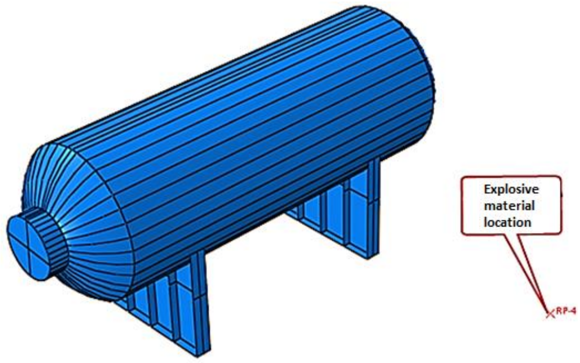


Figure 4 Reservoir Horizontal cylinders modeled in software.

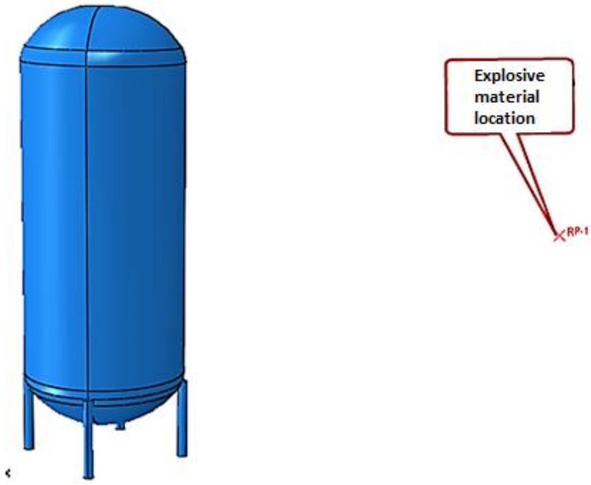


Figure 5 Reservoir vertical cylinders modeled in software.

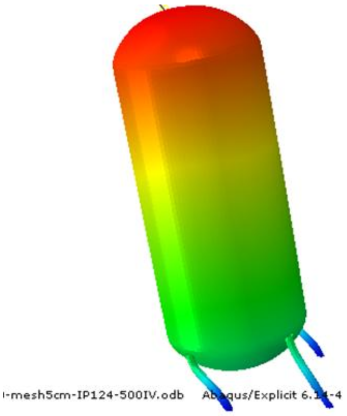


Figure 7 The site of the most displacement under the explosion of 2000 kg of TNT

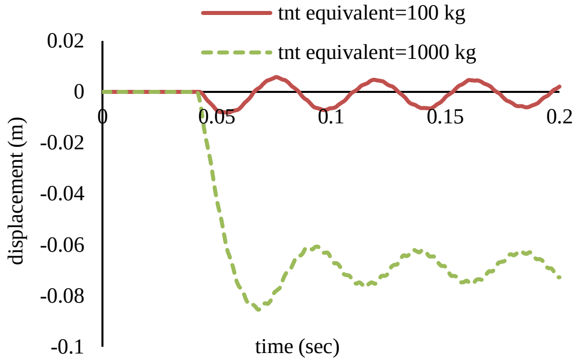


Figure 8: Chart of the time history of the top of horizontal reservoir deformation under two explosion scenarios

3-Results and Discussion

The interaction of different parameters on the degradation of pressure vessels was discussed in the previous section. Four effective parameters and three responses were analyzed for the above purpose.

The first response parameter is the permanent displacement and the second response parameter is the maximum displacement at the top of the reservoirs.

The horizontal pressure tank is shown in Figure 6, while the vertical pressure tank is shown in Figure 7. As it turns out, most of the displacement has occurred at the top of the reservoirs. For this reason, this point is used for further investigation. Figure 8 shows the time-displacement diagram for the horizontal tank top, and Figure 9 shows the time-displacement diagram for the vertical tank top.

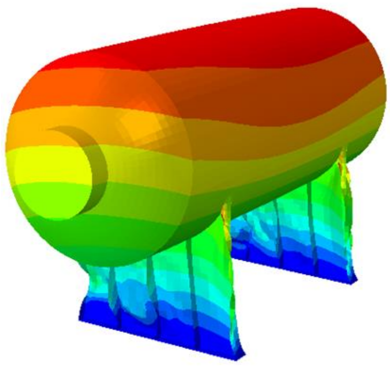


Figure 6 The site of the most displacement under the explosion of 3000 kg TNT

Table 2 Parameters studied along with the results of numerical analysis

	Factor 1	Factor 2	Factor 3	Factor 4	Response 2	Response 3
Run	A: THK	B: TNT EQ	C: Fy	D: vessel	max displacement	residual displacement
	Cm	kg	(MPa)		cm	cm
1	5.5	30	4950	Horizontal	0.420273	0
2	4.75	1507.5	5625	Horizontal	16.6789	12.85
3	4	1015	4950	Horizontal	12.3838	8.7
4	7	1015	4950	Horizontal	7.41688	5.4
5	5.5	2000	4950	Horizontal	22.2517	18.6
6	5.5	1015	4950	Horizontal	9.61624	6,945
7	5.5	1015	3600	Horizontal	10.5709	8.3
9	4.75	1507.5	4275	Horizontal	18.3257	(14.8)
9	5.5	1015	4950	Horizontal	9.61624	7
10	6.25	522.5	5625	Horizontal	3.51266	1.13
11	6.25	522.5	4275	Horizontal	4.13791	2.05
12	4.75	522.5	4275	Horizontal	5.33128	2.8
13	5.5	1015	4950	Horizontal	9.61624	7
14	5.5	1015	4950	Horizontal	9.61624	6.95
15	4.75	522.5	5625	Horizontal	4.63694	1,745
16	5.5	1015	6300	Horizontal	8.59868	5.55
17	6.25	1507.5	4275	Horizontal	14.6431	11.8
18	6.25	1507.5	5625	Horizontal	13.3136	0.85
19	5.5	1015	4950	Vertical	43.1465	43
20	5.5	30	4950	Vertical	0.781155	0.01
21	6.25	522.5	5625	Vertical	13.2216	13.25
22	5.5	1015	4950	Vertical	43,143	43
23	5.5	2000	4950	Vertical	113,999	118
24	6.25	1507.5	4275	Vertical	69.7208	70
25	4	1015	4950	Vertical	54.4142	55
26	5.5	1015	6300	Vertical	37.2737	37.5%
27	7	1015	4950	Vertical	35.1264	34.5
28	4.75	1507.5	4275	Vertical	88.4992	88
29	6.25	522.5	4275	Vertical	16.7934	17.3
30	5.5	1015	4950	Vertical	43,143	43
31	4.75	522.5	5625	Vertical	18.8076	18.35
32	6.25	1507.5	5625	Vertical	62.9481	62
33	5.5	1015	3600	Vertical	49.5478	50
34	4.75	1507.5	5625	Vertical	81.3081	80
35	4.75	522.5	4275	Vertical	22.6261	22.5
36	5.5	1015	4950	Vertical	43,143	43
37	4	50	3600	Horizontal	0.82	0.005
38	4	50	3600	Vertical	0.63	0.84
39	7	70	6300	Horizontal	1.98	0.035
40	7	70	6300	Vertical	1.65	6.25

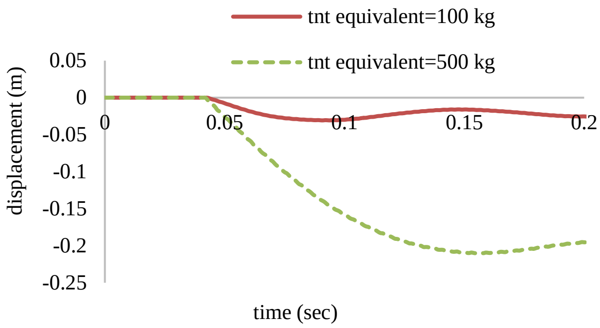


Figure9 Time history diagram of vertical tank top deformation under two explosion scenarios

Table 2 shows the tested parameters along with the three analyzed responses. The table above contains a total of 40 analyzes.

3 - 1 Residual displacement response

Table 3 shows the results of some statistical parameters related to the proposed models. Parameter p-value For all three linear models, 2FI and the second degree is less than 0.05, which means that all three models for data above are usable. Also, the sum of squares parameter means the sum of squared deviations from the mean calculated. Therefore, the lower the rate, the better the performance model. Among the three possible models, grade two less has the sum of squares, and in this respect, it is a better match with the rest of the proposed model's data. As it is specified, the parameter of detection coefficient in models 2FI and Quadratic The conditions are very good, and the resulting models are well matched to the results.

Table 3 Summary of statistical results of permanent displacement response

Press	R-Squared	P-value Prob> F	Sum of Squares	Source
10179	0.77	<0.0001	24320	Linear
1957	0.97	<0.0001	6531	2FI
1690	0.98	0.0014	308	Quadratic.

So following what before mentioned and as predicted, the quadratic model matches the results best and provides the relationship .

Figure 8 shows the accuracy of the proposed model. As it turns out, the points are neatly scattered around the line at an angle of 45 degrees.

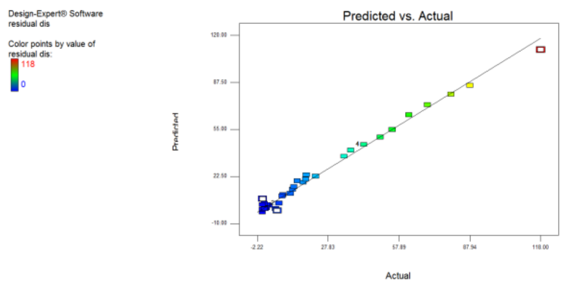


Figure 10 Compare the predicted value for the permanent displacement response based on the model and the actual value

Therefore Notes said Predictable model of permanent displacement at the top of the tank based on three parameters of equivalent tensile strength, tank body thickness, and yield stress of consumed steel and with Benefit of the method CCD is presented in Table 4.

Table 4 The relationship coefficients provided for the displacement response Lasting

type of vessel = horizontal	type of vessel = vertical
Response = residual displacement	Response = residual displacement
-3.13954	7.50777
-0.059241 * THK	-3.10885 * THK
0.039981 * TNT EQ	0.086498 * TNT EQ
-7.03E-04 * Fy	-8.04E-04 * Fy
-6.21E-03 * THK * TNT EQ	-6.21E-03 * THK * TNT EQ
-4.59E-04 * THK * Fy	-4.59E-04 * THK * Fy
-3.02E-06 * TNT EQ * Fy	-3.02E-06 * TNT EQ * Fy
0.50057 * THK ^ 2	0.50057 * THK ^ 2
9.65E-06 * TNT EQ ^ 2	9.65E-06 * TNT EQ ^ 2
3.09E-07 * Fy ^ 2	3.09E-07 * Fy ^ 2

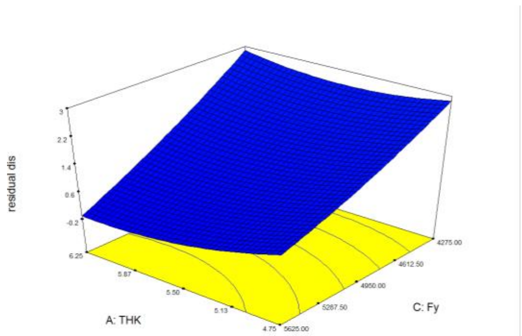
Figure 11 shows the interaction between the thickness of the tank body and the steel used in the amount of material displays the maximum displacement for a response. The following results are obtained from Figure 11:

A: In the amount of 560 kg TNT, thickness About Not effective, and whatever steel be the displacement response increased.

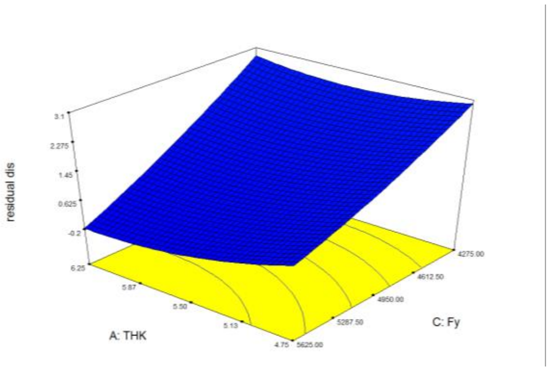
B: At 575.74 kg TNT, the thickness starts to affect very little, but again the weakness of the steel causes many deformations.

A: In the amount of 820 kg TNT, the role of thickness and strength of steel in response to permanent displacement has been almost equalized.

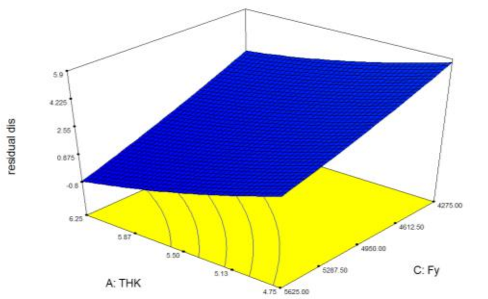
D: At 1507.5 kg TNT, the role of thickness and strength of steel in the permanent displacement response is almost the same.



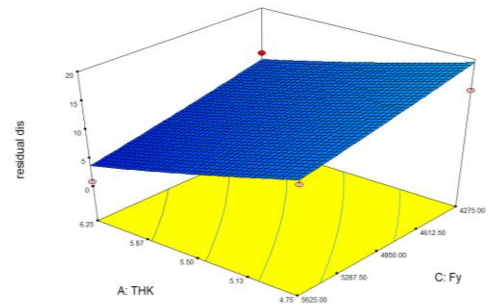
A: 560 kg



B: 74.575 kg of explosive



A: 820 kg of explosives



D: 5/1507 kg of explosive

Figure 11 Interaction of sustained displacement response for horizontal tank against a range of explosive

Figure 12 shows the interaction between the thickness and the amount of explosive for a sustained displacement response. As it turns out, the impact of the sustained displacement response on increasing the amount of explosive is much greater than the effect of decreasing the thickness. Another point that can be seen in Figure 12 is the increase in the effect of thickness reduction if the number of explosives increases. This result was also taken from Figure 11 and reported.

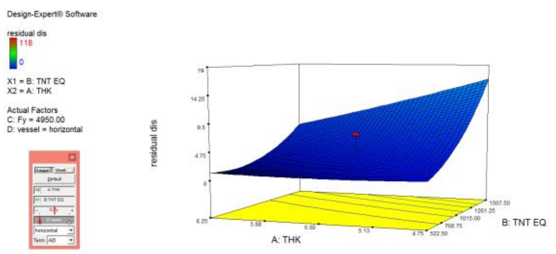


Figure 12 Interaction of thickness and amount of explosive for permanent displacement for horizontal tank

Figure 13 shows the interaction of different parameters in conditions where they are all on their central value. As previously stated and shown in Figure 13, the effect of the explosive parameter is much greater than the other parameters, and the other two parameters, the thickness and strength of the steel used, have almost the same effect. The same analysis can be provided for the vertical reservoir (Figure 14). The difference is that the impact of explosives in the vertical tank is much greater than the horizontal tank, and this is due to the greater vulnerability of the vertical tank to lateral pressures.

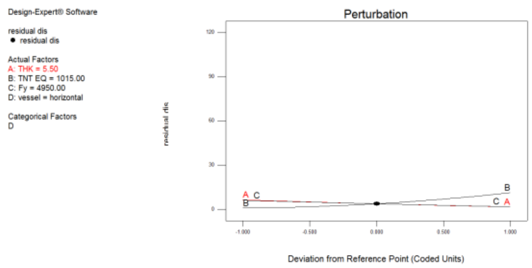


Figure 13 Interaction of different parameters on the response of permanent displacement of horizontal reservoir

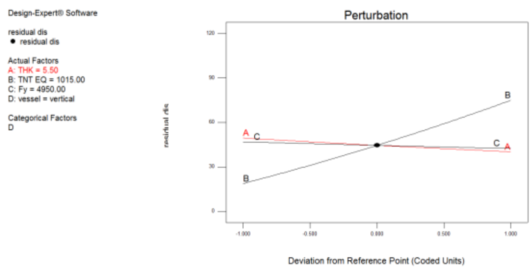


Figure 14 The interaction of different parameters on the permanent displacement response of the vertical tank

Regarding the interaction between the three parameters, the amount of explosive, the yield stress of the consumed steel and the thickness of the tank body, according to the simulations, the following points can be mentioned:

Interaction between the thickness of the horizontal tank body and the amount of explosive: These two parameters have a relatively large interaction with each other in obtaining a permanent displacement response.

Interaction between the steel strength of the horizontal tank body and the amount of explosive: These two parameters have little interaction in obtaining a permanent displacement response.

Interaction between horizontal tank body thickness and steel resistance of horizontal tank body: These two parameters have little interaction in obtaining a permanent displacement response.

Interaction between the steel strength of the vertical tank body and the amount of explosive: These two parameters have a relatively high interaction in obtaining a permanent displacement response.

The interaction between the thickness of the vertical tank body and the amount of explosive These two

parameters have a relatively large interaction in obtaining a permanent displacement response.
Interaction between vertical tank body thickness and steel resistance of vertical tank body: These two parameters almost do not interact in obtaining a permanent displacement response.

3 - 2 Maximum displacement response

Table 5 The results show some statistical parameters related to the proposed models. According to what was stated about the maximum displacement response, four statistical criteria are the sum of squares, p-value ، R-Squared, And press Has been studied.

Table 5 Summary of statistical results of maximum displacement response

Press	R-Squared	P-value Prob> F	Sum of Squares	Source
9008.76	0.7824	<0.0001	22875.02	Linear
1315.67	0.9831	<0.0001	5867.87	2FI
1155.81	0.9905	0.0015	218.01	Quadratic.

Therefore, following what has been mentioned before and as predicted, the Quadratic model best fits the results and is selected to provide the relationship. Figure 15 shows the accuracy of the proposed model. As it turns out, the points are neatly scattered around the line at an angle of 45 degrees.

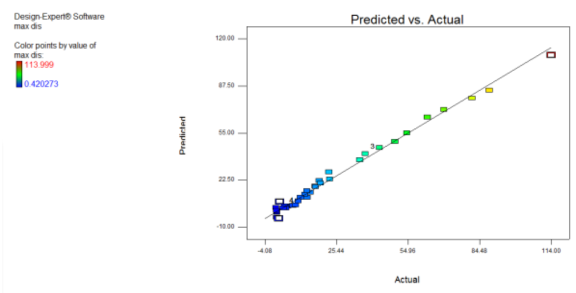


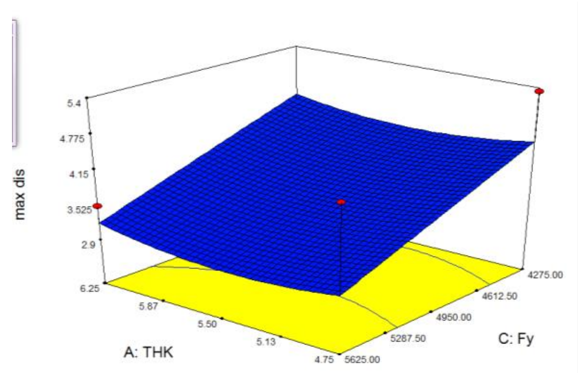
Figure 15 Compare the predicted value for the maximum displacement response based on the model and the actual value

According to the above points, the model predicts maximum displacement at the top of the tank based on three parameters: equivalent tensile strength, tank body thickness, and yield stress of consumed steel, and using the method CCD is presented in Table 6.

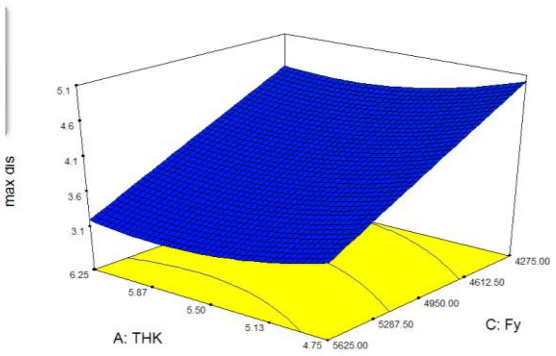
Table 6 The relationship coefficients provided for the maximum displacement response

type of vessel = horizontal	type of vessel = vertical
Response = maximum displacement	Response = maximum displacement
-1.20279	+15.98046
-1.19419 * THK	-4.73470 * THK
+0.035227 * TNT EQ	+0.079550 * TNT EQ
+ 6.79422E-006 * Fy	-1.13344E-003 * Fy
-5.43173E-003 * THK * TNT EQ	-5.43173E-003 * THK * TNT EQ
+ 3.29695E-005 * THK * Fy	+ 3.29695E-005 * THK * Fy
-1.85783E-006 * TNT EQ * Fy	-1.85783E-006 * TNT EQ * Fy
+0.35592 * THK ^ 2	+0.35592 * THK ^ 2
+ 8.06971E-006 * TNT EQ ^ 2	+ 8.06971E-006 * TNT EQ ^ 2
-2.01685E-008 * Fy ^ 2	-2.01685E-008 * Fy ^ 2

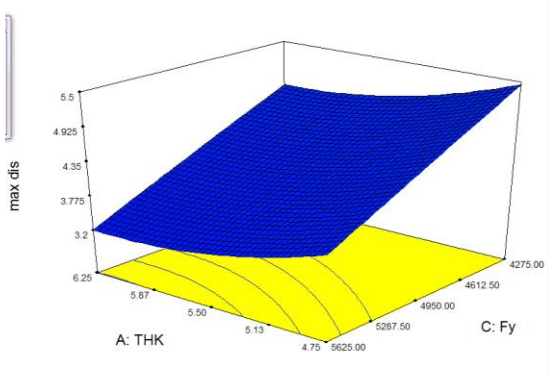
Figure 16 shows the interaction between the tank body thickness and the steel used in different explosives and for maximum displacement response. The following results are obtained from Figure 16:
A: In the amount of 522.2 kg TNT, the thickness is almost ineffective, and the weaker the steel, the higher the displacement response.
B: In the amount of 575.574 kg TNT, the thickness is affected, but not too much, and again the weakness of the steel causes many deformations.
A: At 615.68 kg TNT, the above trend continues, and the role of thickness increases, but the role of steel strength is more effective.
D: In the amount of TNT 820 kg, the role of thickness and strength of steel in the displacement response has been maximized to a maximum.
E: At TNT 1100 kg, the process of equalization of the role of thickness and strength of steel in the displacement response continues in almost the same way.
And: in the amount of TNT 1507.5 kg, the role of thickness is more than the role of steel stress. Therefore, it can be said that in this amount of TNT, the thickness of the body plays a more effective role than the role of steel resistance in the amount of displacement that occurs at the top of the tank.



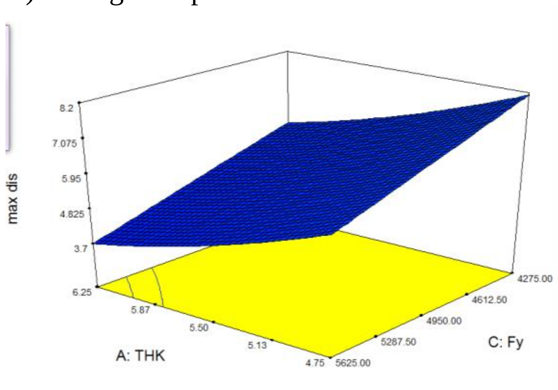
A) 522 kg of explosive



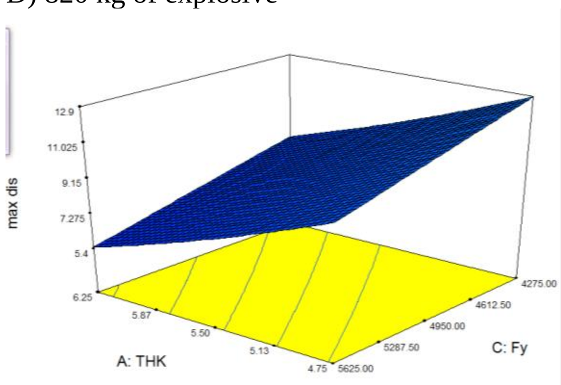
B) 74.575 kg of explosive



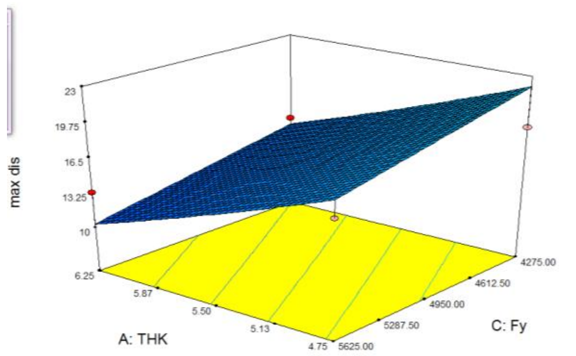
C) 615 kg of explosive



D) 820 kg of explosive



E) 1100 kg of explosive



F) 1507 kg of explosive

Figure 16 Maximum displacement response interaction for horizontal tank versus the range of explosive

Figure 17 shows the interaction between the thickness and the amount of explosive for the maximum displacement response.

As it turns out, the effect of the maximum displacement response from increasing the explosive amount is much greater than the effect of decreasing the thickness. Another point that can be seen in Figure 17 is the increase in the effect of thickness reduction if the amount of explosive increases.

Also, according to Figure 18, the interactions between the strength of the steel and the amount of explosive for the maximum displacement response, the following analyzes can be presented:

The effect of the amount of explosive is much greater than the effect of the strength of the steel used

Also, with increasing the amount of explosive, the effect of reducing the resistance of steel in increasing the displacements increases.

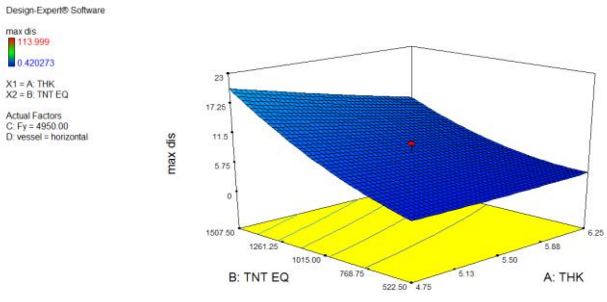


Figure 17 Interaction of thickness and amount of explosive for maximum displacement for horizontal tank

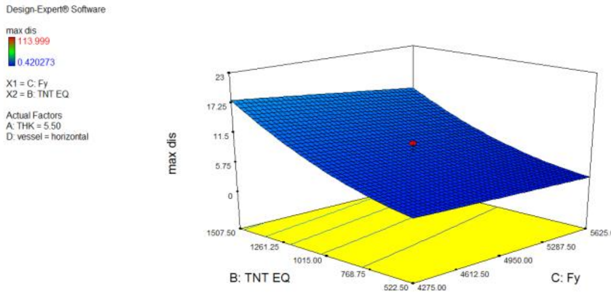


Figure 18 Interaction of steel type and amount of explosive for maximum displacement for horizontal tank

Figure 19 shows the interaction of different parameters in conditions where they are all on their central value. As previously stated and shown in Figure 19, the effect of the explosive parameter is much greater than the other parameters, and the other two parameters, the thickness and strength of the steel used, have almost the same effect. The same analysis can be provided for the vertical tank (Figure 20) with the difference that the impact of explosives in the vertical tank is much greater than the horizontal tank, and this is due to the greater vulnerability of the vertical tank to lateral pressures.

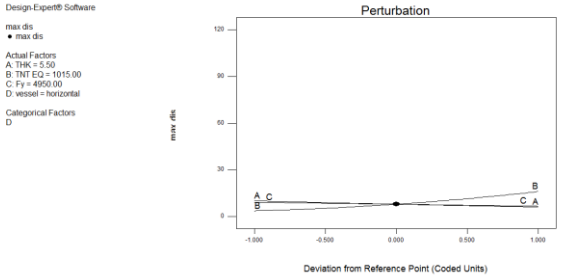


Figure 19 Interaction of different parameters on the displacement response of the maximum horizontal reservoir

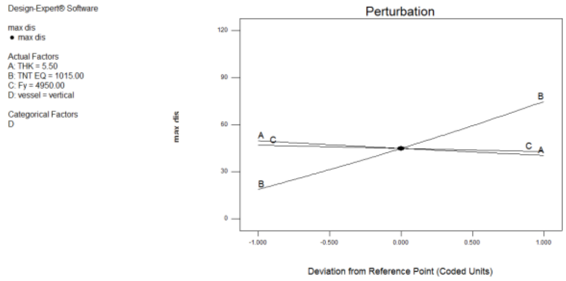


Figure 20 Interaction of different parameters on the displacement response of the maximum vertical tank

In the following, the interaction between different parameters in horizontal reservoir conditions is reported based on what was specified in the simulations.

Interaction between the thickness of the horizontal tank body and the amount of explosive: These two parameters have a relatively large interaction in obtaining the maximum displacement response.

Interaction between the steel strength of the horizontal tank body and the amount of explosive: These two parameters have little interaction in obtaining the maximum displacement response.

Interaction between the horizontal tank body thickness and the steel strength of the horizontal tank body: These two parameters have little interaction in obtaining the maximum displacement response.

Interaction between the steel strength of the vertical tank body and the amount of explosive: These two parameters have little interaction in obtaining the maximum displacement response.

Interaction between the thickness of the vertical tank body and the amount of explosive: These two parameters have a relatively large interaction in obtaining the maximum displacement response.

Interaction between the thickness of the vertical tank body and the steel strength of the tank body: These two parameters have very little interaction in obtaining the maximum displacement response.

4-Conclusion

Oil facilities, gas, and petrochemicals are very sensitive and expensive. The need to investigate issues related to the passive defense of the equipment used in the above facilities is important. Pressure tanks are of special importance because they can cause multiple failures in case of failure and explosion.

Explosions caused by sabotage or aerial bombardment are among the most important factors influencing the investigation of passive defense issues in the above facilities. This research examines the effect of explosions caused by powerful explosives TNT etc. on two types of more common pressure tanks in Iranian oil plants.

In this research, the effect of the external explosion on horizontal and vertical pressure vessels has been investigated. Four parameters of pressurized tank type (horizontal or vertical), tank body thickness, the yield stress of consumed steel, and explosive amount were selected as effective parameters.

the two responses of maximum displacement occurred, and permanent displacement in the reservoir was investigated. A numerical method for designing experiments Response level and central composite design algorithm was used. A total of 40 experiments were designed.

The results show that the quadratic adaptation equation is a suitable model to present the relationship between the effective parameters and the specified responses.

In the continuation of the research, based on the quadratic equation, simple and practical relations for calculating the maximum displacement and permanent displacement at the top of the tank are presented by considering the parameters of tank thickness, tank type, explosive amount, and yield stress of consumed steel.

The simulation results show that for both sustained displacement responses and the maximum displacement occurred at the top of the horizontal and vertical reservoirs, the thickness of the reservoir body has very little effect on the responses in weaker explosions. As a reason, it can be pointed out that in weak explosions, the displacements are limited to the bases, and the connection of the bases to the tank's body does not play a role in the overall displacement of the tank and causes more displacement. This is not true of the strength of the steel used, because in any case, the type of steel used plays an important role in the displacements.

It was also found that the effect of the explosive amount was much greater than the thickness of the body parameters and type of steel.

It was also found that the impact of displacement of the vertex of the vertical reservoir against the explosion load is higher than the vertex of the horizontal reservoir because the vertical reservoir is weaker against lateral

loads and responds more to interaction with the power they have an explosion charge.
In addition, it was determined interaction there is a high relationship between the amount of explosion load with the two parameters of tank body thickness and yield stress of consumed steel. Still, the two parameters of body thickness and type of steel have little interaction with each other.

References

[1] UNIFIED FACILITIES CRITERIA (UFC), "Structures To Resist the Effects of Accidental Explosions Approved for Public Release; Distribution Unlimited," no. May 2005, 2005, [Online]. Available: http://dod.wbdg.org/.

[2] M. Giglio, "Spherical vessel subjected to explosive detonation loading," *Int. J. Press. Vessel. Pip.*, vol. 74, no. 2, pp. 83–88, 1997, doi: 10.1016/S0308-0161(97)00024-0.

[3] K. Mazaheri, M. Mirzaei, and H. Biglari, "Transient dynamic response of tubes to internal detonation loading," *J. Sound Vib.*, vol. 297, no. 1–2, pp. 106–122, 2006, doi: 10.1016/j.jsv.2006.03.027.

[4] R. Dezvareh, "Application of Soft Computing in the Design and Optimization of Tuned Liquid Column–Gas Damper for Use in Offshore Wind Turbines," *Int. J. Coast. offshore Eng.*, vol. 2, no. 4, pp. 47–57, 2019, doi: 10.29252/ijcoe.2.4.47.

[5] R. Dezvareh, "Upgrading the seismic capacity of pile-supported wharfs using semi-active liquid column gas damper," *J. Appl. Comput. Mech.*, vol. 6, no. 1, pp. 112–124, 2020, doi: 10.22055/jacm.2019.28242.1466.

[6] M. Mirzaei, "Failure analysis of an exploded gas cylinder," *Eng. Fail. Anal.*, vol. 15, no. 7, pp. 820–834, 2008, doi: 10.1016/j.engfailanal.2007.11.005.

[7] M. Mirzaei, "On amplification of stress waves in cylindrical tubes under internal dynamic pressures," *Int. J. Mech. Sci.*, vol. 50, no. 8, pp. 1292–1303, 2008, doi: 10.1016/j.ijmecsci.2008.05.007.

[8] J. N. Dyer, A. P. Raibagkar, M. Kolbe, and E. Salzano, "Blast damage consideratons for horizontal pressure vessel and potential for domino effects," *Chem. Eng. Trans.*, vol. 26, pp. 87–92, 2012, doi: 10.3303/CET1226015.

[9] M. Mirzaei, M. Malekan, and E. Sheibani, "Failure analysis and finite element simulation of deformation and fracture of an exploded CNG fuel tank," *Eng. Fail. Anal.*, vol. 30, pp. 91–98, 2013, doi: 10.1016/j.engfailanal.2013.01.015.

[10] S. Yasseri, "Blast Pressure Distribution," no. July, 2015.

[11] X. dong Zhi, S. bo Qi, and F. Fan, "Temporal and spatial pressure distribution characteristics of hemispherical shell structure subjected to external explosion," *Thin-Walled Struct.*, vol. 137, no. August 2018, pp. 472–486, 2019, doi: 10.1016/j.tws.2019.01.021.

[12] B. Y. Zhang, H. H. Li, and W. Wang, "Numerical study of dynamic response and failure analysis of spherical storage tanks under external blast loading," *J. Loss Prev. Process Ind.*, vol. 34, pp. 209–217, 2015, doi: 10.1016/j.jlp.2015.02.008.

[13] K. Hu, G. Chen, R. Abbassi, Z. Zhou, T. Zeng, and Y. Yang, "A novel approach to distinguish the uniform and non-uniform distribution of blast loads in process industry," *Process Saf. Environ. Prot.*, vol. 134, pp. 416–428, 2020, doi: 10.1016/j.psep.2019.10.037.

[14] S. Lu, W. Wang, W. Chen, J. Ma, Y. Shi, and C. Xu, "Behaviors of Thin-Walled Cylindrical Shell Storage Tank under Blast Impacts," *Shock Vib.*, vol. 2019, 2019, doi: 10.1155/2019/6515462.

[15] B. Ebrahimi, S. A. Shojaosadati, S. O. Ranaie, and S. M. Mousavi, "Optimization and evaluation of acetylcholine esterase immobilization on ceramic packing using response surface methodology," *Process Biochem.*, vol. 45, no. 1, pp. 81–87, 2010, doi: 10.1016/j.procbio.2009.08.007.

[16] Y. Moradi and R. Dezvareh, "Volume2 , Issue 6 (June 2012) ISSN : 2250-0588 SEISMIC ANALYSIS OF CUBIC BURIED TANKS REGARDING SOIL Volume2 , Issue 6 (June 2012) ISSN : 2250-0588," vol. 2, no. 6, pp. 24–34, 2012.