



Effect of Explosion Under the Water On Fixed Offshore Platform at Distances 30 And 60 Meters

Nasser HassanKhani¹, Seyyed Shahab Emamzadeh²

^{1,2}Department of Civil Engineering, West Tehran Branch, Islamic Azad University, Tehran, Iran.

ABSTRACT

In the field of marine passive defense, because it stands in conflict can be attacked by troops and navigation, it is more likely to occur explosion around it. Given that the majority of rigs built in the Persian Gulf was a fixed base and the region of platform construction have a high degree of mine threat, so, in this thesis, the behavior of a hypothetical fixed offshore platform has been considered against explosion under the water and possible happening. Hypothetical platform has been defined similar to made platforms in the Persian Gulf. The effect of the wind-driven waves have been ignored. Only the weight of the platform and underwater blast loading platform is applied on the platform structure. Invasion scenario was defined by placing naval mines including a mass of 50 and 100 kg of TNT at medium distance (30 meters) and long (60 meters) from the platform. Upload waves caused by underwater explosions at a certain depth is applied in accordance Girz and Hunter swinging bubble model. The effect of inertia of the water around the base of the platform is intended by added mass method. Platform structure was modeled by finite element method and Abaqus software. The results showed that the blast wave caused localized damage to part of the platform that is level and endanger stable platform explosives; Therefore, risk assessment is potentially explosive in accordance with design codes and strengthen the and carrying out preventive measures is necessary on offshore platforms.

Key words: finite elements, water interaction and structure, explosion under the water, added mass, platform, sustainability.

Corresponding author: Nasser HassanKhani

INTRODUCTION

Field and historical observations show that platforms can use by troops and navigation forces in conflicts, so, it is possible that occur explosion around them. In this thesis, dynamic response of base offshore platform is considering against explosion under the water and its possible accidents. Explosion variables including depth of explosive, weight and distance of explosive from platform that is taking as internal information of numerical analysis. Dependent variables which is calculate as output, is malfunction indicator which is calculating based on deformation and tension build in platform members. In spite of the strategic importance of mineral platforms, a little understanding on how these structures respond to the explosion under the water and possible accidents after that.

It is assuming that deep or semi-deep explosion is occur in a depth that gas bubbles cannot come up or explosive material is close to surface adequately such that bubbles exit before the first contraction.

First information is about explosion under the water by U.S.A navy during World War II and was done after serious damages of American navy resulted in explosion under the water (Cole, R.H. "Underwater Explosions,1948). Since then, extensive studies have been done on underwater explosion and its impact on marine structures such as ships, submarines. But has done

research on the damage caused by the explosion of platforms and recognizing the specific reasons it has not been published. Considering the large number of platforms and offshore full recognition events occurred during the underwater explosion as well as damage to platforms in the process and offer solutions to cover the weaknesses seems necessary in light of the goals of marine passive defense.

There is a little understanding on how these structures respond to explosions under the water, in spite of the strategic importance of marine platforms. So far, the effects of underwater explosions have not been studied at different distances from the podium and various explosive weight. Definitions and underwater explosive loading is as an accidental loading of innovation of this research.

History of study

So far, a large study has been developed on offshore platforms and loading random letters Regulations to determine the loads. For example, it has raised a chapter called accidental loads, explosion and fire in the American standards API that in addition to defining different levels of risk, it has evaluated possible risk on platform by providing an algorithm (American Petroleum Institute (API),2002). The law states that random loads can cause partial or total damage to the platform and have risk of people death and environmental pollution; therefore, for the least cost, taking into account such loads in structural design is essential. Explosion into the water is one of the possible

phenomena that have been studied for years, but the regulations have not been paying particular attention to it (Cole, R.H. "Underwater Explosions,1948). In the standard Norwegian DNV, there is accidental loads that explosion is a part of it. It has suggested determining accidental load based on experience and designer's evaluation in this standard (Det Norske Veritas (DNV),2011). One of accidental loads which is payed attention less and less by designing standards is hydrodynamic waves pressure resulted in underwater explosion. research history goes back to World War II in terms of simulation of underwater blast wave propagation. At that time the analytical method and laboratory simulation of underwater blast wave propagation was proposed to solve the equations (Cole, R.H. "Underwater Explosions,1948). It has been mentioned to the selection of the methods in Meier article (Mair, H.U , 1999). The studies mainly were for animated floating objects such as ships and submarines military or defense purposes. So far, several empirical relationships presented for underwater explosion loading. In some of these relationships that are more accurate, due to fluctuation of the bubbles burst and its uptake is intended. Giers and Hunter model (Geers, T.L.; Hunter K.S, 2002). is one of such model that is used in this study.

In the '70s onwards, with the development of numerical methods, numerical simulation of wave propagation is first underwater explosion with finite difference method and finite volume method was evaluated and on this basis, it was prepared computer programs (Mair, H.U ,199). In recent years, many researchers focus on the development of numerical methods for solving the governing equations of the shock wave propagation. It can be cited from recent research in the field to spectral element method Sprague. He modeled the waves caused by underwater explosion by refine grid finite and increasing element shape functions and the level of water in the wave passes. He also defined criteria for pressure, cavitation due to the interaction of blast waves with structures studied (Sprague, M.A.; Geers, T.L,2006). The interaction of water and structures and issues related to the common border can also be cited recent research head. He calculated the forces of interaction between water and structure of non-conforming networks and compared with other methods (Ross, M.; Sprague M.A.; Felippa C.A.; Park K.C ,2009; Ross, M.; C.A. Felippa; K.C. Park and M.A,2008). by Lagrange multipliers defined position.

Lots of relations have been offered for underwater explosion loading. In some of these relationships, the oscillation bubble burst and its uptake is intended into the water table. One of these relationships is the Giers and Hunter model(Geers, T.L.; Hunter K.S,2002) that is used to determine the pressure wave of an explosion in the right are more. In this model it is assumed after the explosion of underwater bubbles that formed pressure and the pressure inside the bubble radius is a function of the depth of explosives. The dynamic analysis platform to Westergaard added mass method (Westergaard H. M,1933) of the dipped beams used to model truss platform and added mass of water to be added to the effect. It has used from limited components software of Abakose for numerical analysis (Tiantang, Y,2009).

1. METHODOLOGY

• Underwater explosion phenomenon

When strong explosives *TNT, RDX, HBX_1* are explode, explosives are become a gas with high pressure and temperature for several seconds. The shock wave which is started from the explosive material (detonator) spread around the explosive material, a chemical reaction is started by spreading pressure wave that create more pressure waves. Speed of pressure wave is increasing into the explosive solid

material to not exceed from sound speed. As it can be seen in figure 1, pressure is decreased with time in the explosion exponentially. Speed of propagation of acoustic waves in the sea water is variable with depth, salinity and temperature. While, the average of sound speed in the air is $340 \frac{m}{SEC}$, the average of sound speed in the water is about $1500 \frac{m}{SEC}$, which is several times to sound speed in the air. So, this speed is decreased to sound speed. Chart inverse function of distance is from the explosive shock wave pressure [2].

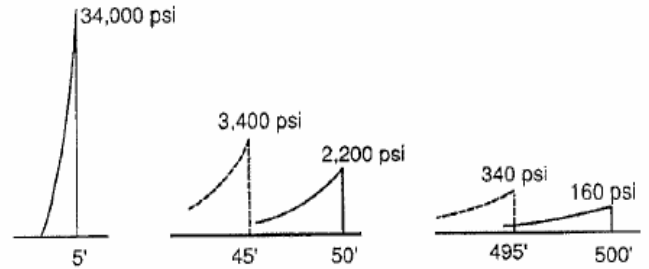


Figure 1 - SHIFT 300 pounds of explosives, the shock wave from the explosion [2]

Figure 2 show scheme of pressure to the time after the underwater explosion at points around the show. Negative pressure can be seen in the figure is due to backflow of water into the site of an explosion due to the contraction of the bubble. Shock wave reflected from the sea floor is a pressure wave that an additional load on the structure. The shock wave reflection from the sea surface reduces the pressure generated by the shock wave [2].

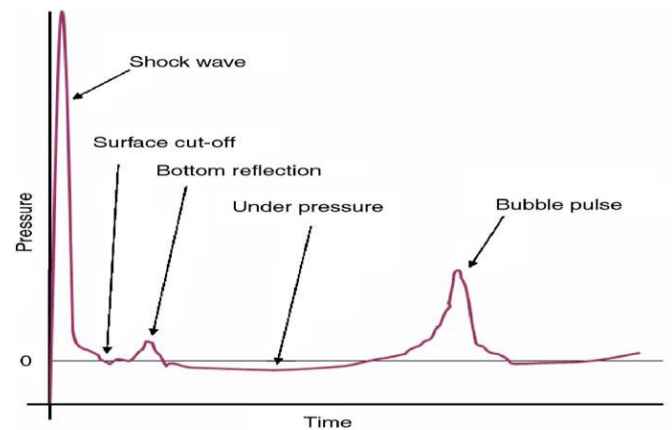


Figure 2 - Pressure graph - time underwater explosion [2]

• Temporal and spatial variations of shock waves caused by underwater explosion

Often the shock wave from the blast after a sudden increase in pressure at one point reduced exponentially with time. The spatial extension shock wave maximum amount of pressure reduction and increases its duration. For example, in a pressure - time curve that is obtained from barometers in different distances from 136 Kg cylindrical TNT material, maximum pressure from 40 MPa is reduced in 6 meters' distance from explosion center to 1MPa in 150 meters' distance from

explosion center. In addition, the time constant was increased from 500 microseconds to 900 microseconds. At the time of the next disorders is resulting reflection from the floor and does not affect water pressure [2].

The pressure after the shock front is in the form of Equation 1:

$$p = P_m e^{-\frac{t}{\theta}} \frac{lb}{in^2}$$

P_m = starting maximum pressure

θ = Time constant to decrease exponentially

$$P_m = k \left(\frac{W^3}{R} \right)^A$$

$$\theta = k W^3 \left(\frac{W^3}{R} \right)^A$$

• **Impulse function**

The effects of shock wave is dependent to impulse function $\int_0^t p(t)dt$ that is obtained from pressure - time curve. If the time of deposition of maximum structure is so more than duration pressure shock wave, impulse function is become important. Impulse function is stated as equation 2 after reaching shock wave:

$$I(t) = \int_0^t p(t)dt$$

In this equation, it should use from $p(t) - P_0$ in addition to hydrostatic pressure, but for more cases, shock wave pressure $p(t)$ is so great that this difference is tangible.

• **Density of energy flow**

The other characteristics of wave shock is cross energy flow from unit area for wave expansion (relations 3 to 5)

$$(3) E_f = \int_0^t \rho u \Delta \left[E + \frac{1}{2} u^2 + \frac{p}{\rho} \right] E_f = \int_0^t \rho u \Delta \left[E + \frac{1}{2} u^2 + \frac{p}{\rho} \right]$$

The relation of density of energy flow is as following by pressure:

$$E_f = \frac{1}{\rho c} \int_0^t (p - p_0)^2 dt + \frac{1}{\rho R} \int_0^t (p - p_0) \left[\int_0^t (p - p_0) dt \right] dt \quad (4)$$

$$E_f = \frac{1}{\rho c} \int_0^t (p - p_0)^2 dt + \frac{1}{\rho R} \int_0^t (p - p_0) \left[\int_0^t (p - p_0) dt \right] dt \quad (5)$$

Shock wave pressure is obtained for a significant rage of weight and different distances from explosive material during some tests as following:

Circle TNT: pressure from 500 $\frac{lb}{in^2}$ to 20000 $\frac{lb}{in^2}$ for explosive materials by weights from 48 to 76 pounds and density 1.52 $\frac{gm}{cm^3}$

Cylindrical Discount: pressure from 4000 $\frac{lb}{in^2}$ to 17000 $\frac{lb}{in^2}$ for weights 4 and 5 pounds, 0.93 $\frac{gm}{cm^3}$

• **Bubbles of explosive gas products and load pulse burst bubble**

The chemical reaction caused by a gas explosion at a very high temperature and pressure generated. Gas pressure is achieved quickly and move water around the compression of the radial induction. Experimental statement is as relation 6 for the first terms of explosion of gas bubble (T) and maximum radius (A_{maximum}) [2]:

$$T = K_5 \frac{W^{\frac{1}{3}}}{(D + 33)^{\frac{3}{6}}}$$

$$A_{\text{max}} = K_6 \left(\frac{W^{\frac{1}{3}}}{(D + 33)^{\frac{1}{3}}} \right)$$

That T is gas bubble period in second, D is depth in Foot. Values K_5, K_6 is obtained from following table:

Table 1 - Product gas bubble parameters of explosives [2]

Description	Parameter	Explosive type		
		HBX-1	TNT	PETN
Bubble period	K_5	4.761	4.268	4.339
Bubble radius	K_6	14.14	12.67	12.88

About 47 percent of the energy generated gas bubbles burst the bubble rate and pressure can produce injuries in the explosion extent. Bubbles drift upwards effect and can lead to the collapse of the bubble near the target, When the bubble radius near the radius of maximum deep low-pressure gas is even lower air pressure. Clearly, if the depth of the explosion close to the greatest size of the bubble, so what will happen. When bubble is reach to surface, air is attacked by atmosphere pressure to the bubble cavity that has less pressure, hydrostatic pressure compass existing air for closing cavity, air act as padding and doesn't allow to close. It is clear that exiting bubble is required to less explosion depth than bubble maximum radius. Experience has shown that if explosion depth is between 50 to 80 percent of maximum radius, then results will be satisfactory [2].

$$(\varepsilon = 408.6 \text{ and } \delta^2 = 0.57): \text{time(a) } t=0.00, (b) t=0.29, (c) t=0.69, (d) t=1.19, (e) t=1.32, (f) t=1.38 \text{ and } (g) t=1.49$$

• **Introducing explosion pressure function underwater**

If maximum pressure of explosion front wave underwater is p_m , pressure changes with time will described as relation 7, as it has said in relation 1:

$$p(t) = p_m e^{-t/\theta}$$

Constant θ is when explosion pressure reduce to $\frac{p_m}{e}$.

Entered impulse is stated by shock wave I as figure 3:

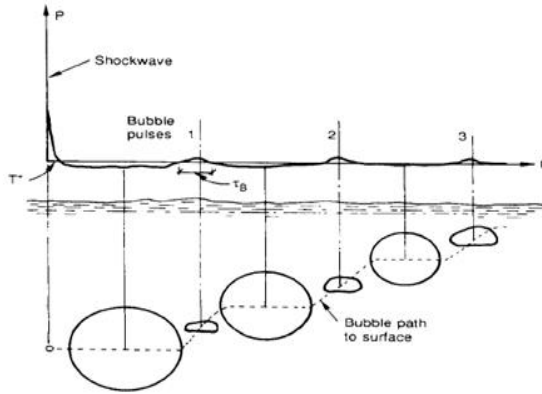
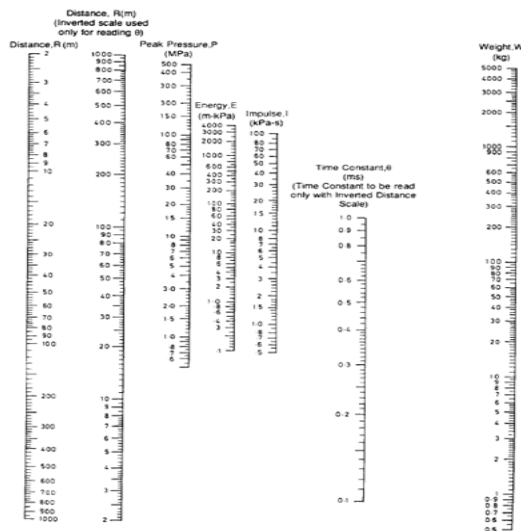


Fig. 3 history of pressure - time for shock wave and pulse of underwater explosion bubble [18]

Changes of main parameters shock wave can be provided on a calculation table as it has shown in figure 4. Weight of explosive material is given on Kilogram of TNT in the explosion at air. For other explosives, converted by TNT is a step before using nomogram. Use figure 4 has been described well using an



example [2].

Figure 4 - Chart nomogram to get the shock wave parameters [2]

K and a are experimental constant for explosive material. The empirical constants are given in Table 2 was to evaluate in terms of MPa.

Table 2 - Characteristics of explosives to calculate the maximum pressure

Explosive material	K	α	Validity range (MPa)
TNT	52/4	1/13	138 to 3/4
Pentolite	56/6	1/14	138 to 3/4
H-6	59/2	1/19	10/3to138

• **Dynamic Analysis of Platform**

To show explosive analysis, a stool wellhead platform with six floors in the semiconductor and board a water depth of 75 m is considered as shown in Figure 5. The platform is similar to the original design of offshore South Pars. Deck dimensions 32 x 40 mm and weighs 1,000 tons. Distance between bases jacket at deck 22.5 x 30 meters. Jackets base has a slope 1:10. The base of the platform depends on the load, different diameters from one to two meters and thicknesses ranging from three to ten centimeters. Braces podium pipe diameters from 0.3 to 1.2 mm and are made from a thickness of between two to eight centimeters. Steel deck truss members of the Elastoplastic ST37, the current tension of 2400 kg cm to 3700 kg cm and the tension built. Explosive mass of 100 and 50 kg at an average distance of 30 meters and 60 meters away from the podium and in-depth 35.5 m of surface water intended and the platform of the blast wave behavior has been studied. Water inertia effects connected to the base by the added mass is considered. The deck is intended to be rigid. Dead and live load is applied in accordance with the proposed edit the twentieth API (American Petroleum Institute (API),2002). Environmental loads, wave, wind and earthquakes when an explosion is neglected. Although hydrostatic pressure could strengthen lateral force is too small explosive charge than to simply discard it was calculated. Connection of the platform bases to the seabed is considered as fixed.

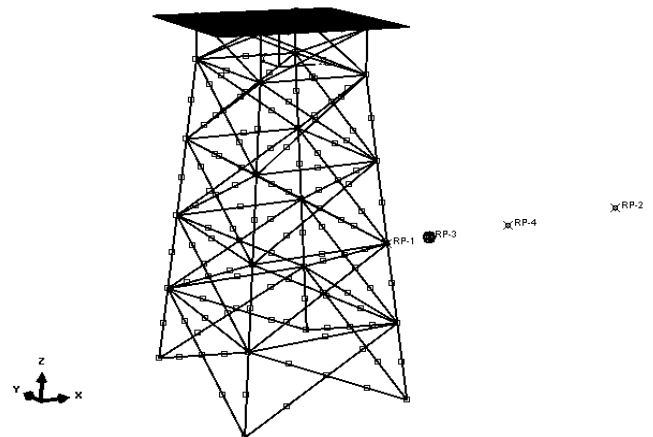


Figure 5. Location of explosives and point of reference on the podium

• **Model of limited components of platform**

It has used from Abaqus 6.12.1 software to build finite element model. According to Table 3, for the effect of both explosive weight for weight amount of explosives is considered. TNT explosive material in two different scenarios 50 and 100 kilograms. Detonation time a millisecond and underwater explosions called UNDEX defined in Abaqus is used for loading explosive. In this model the explosive situation at a given point. In all models, the explosive is in depth of 37.5 meters from the

water. This depth is equal to half the depth of the water around the platform. Total time modeling is considered to half a second (500 milliseconds).

Table 3 - geometry and sections of the wellhead platform

Water depth	75 m
Jacket height	85 m
Jacket dimension at deck level	30 × 22.5 m
Deck dimension	32 × 40 m
Total No. of jacket legs	4
Section of legs(+0~-18.75)	Φ1000×20mm
Section of legs(-18.75~-37.5)	Φ1250×20mm
Section of legs(-37.5~-56.25)	Φ1500×20mm
Section of legs(-56.25~-75)	Φ2000×20mm
Section of horizontal brace(+0)	Φ600×20mm
Section of horizontal brace (-18.75)	Φ600×20mm
Section of horizontal brace (-37.5)	Φ500×20mm
Section of horizontal brace (-56.25)	Φ500×20mm
Section of diagonal brace (+0~-18.75)	Φ400×20mm
Section of diagonal brace (-18.75~-37.5)	Φ400×20mm
Section of diagonal brace (-37.5~-56.25)	Φ500×20mm
Section of diagonal brace (-56.25~-75)	Φ500×20mm

In the present model, the density of seawater on average is considered equal to 1025 kilograms per cubic meter. The speed of sound in water 1,500 meters per second, which is almost five times the intended speed of sound in air. Other features are shown in Figures 6 and 7. Due to the proximity of explosives to blast wave from the podium changes the source of the explosion is spherically defined. Profile of explosives and related coefficients is applied according to the JWL equation for TNT in Figure 6. In this figure, TNT density of 1600 kilograms per cubic meter and a mass of 100 kg is imported.

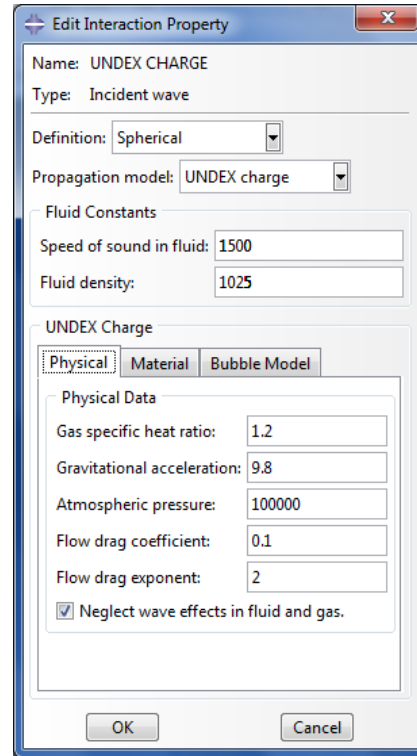


Figure 6 - data relating to the physical characteristics of explosives

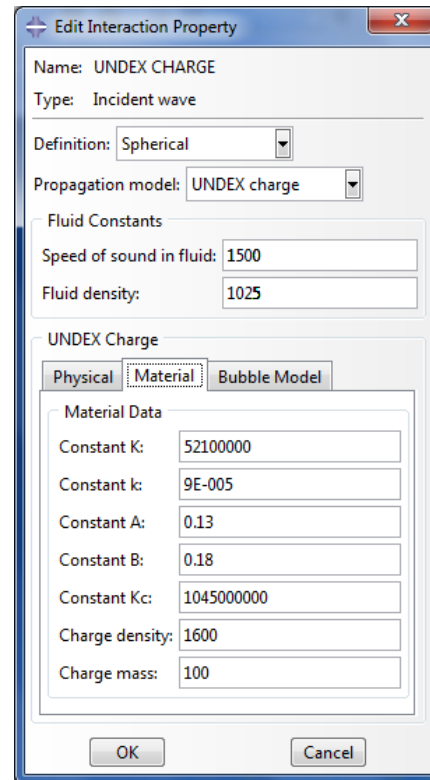


Figure 7 - Data related to explosives

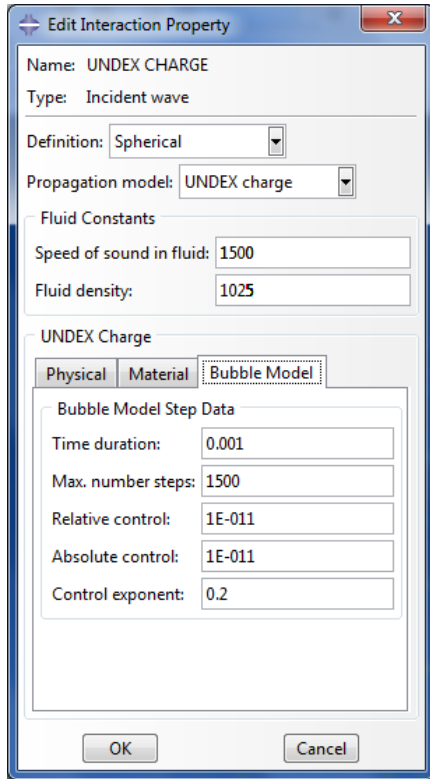


Figure 8 - Data on the bubble bursts

Explicit dynamic was performed by analysis method with variable time steps. This time steps are determined based on dynamic stability appointed stepwise analysis. Example of steps used are presented in Table 4.

Table 4 - variable timely steps in analysis of clear dynamic

Step	Increment	Total Time	CPU Time	Step Time	Stable Time Inc	Kinetic Energy	Total Energy
1	166	0.0250143	0.3	0.0250143		1.16433e+12	1.0512e+10
1	362	0.0501127	0.6	0.0501127		1.15298e+12	1.0451e+10
1	493	0.0661342	0.9	0.0661342		2.53773e+12	1.42334e+12

Totally, six dynamic analyses were done to study the effect of underwater explosion. In each analysis, explosive weight and distance has changed according to table 5. Model of limited component of platform has consisted of 1106 nodes and 1144 elements that 340 elements are related to deck and 804 elements are related to deck.

Table 5 - recognition the models

Explosive weight	Distance from platform	Z(m)	Sample ID
Kg 100	Average	30	M-100
	Round	60	F-100
Kg 50	Average	30	M-50
	Round	60	F-50

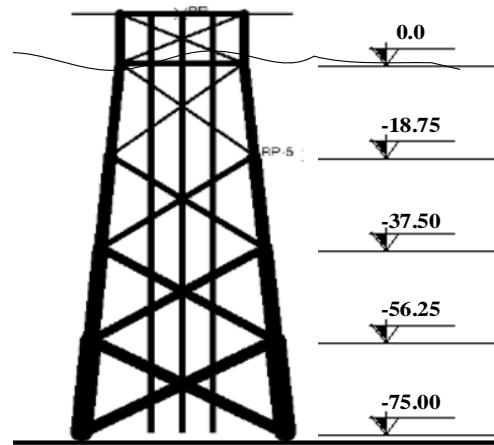


Figure 9 - level reference for the dynamic response of platform

2. Data analysis

1. Explosion 100 kilograms of explosives at an average distance of the platform M-100

In this section, exploded 100 kg of explosives TNT is checked in the 30-meter platform. Model podium and explosive position is shown in Figure 10.

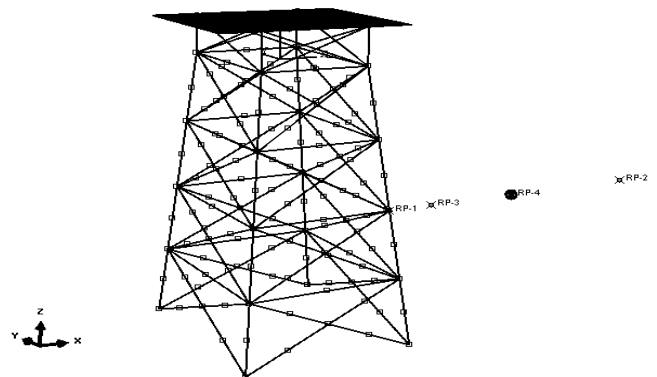


Figure 10. Model of platform and explosives at a distance of 30 meters from the surrounding

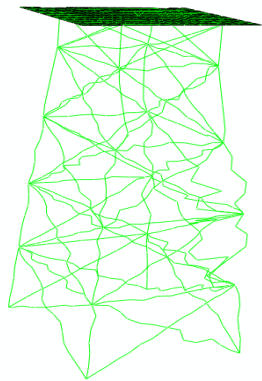


Figure 11 - Change the platform at half a second after the explosion

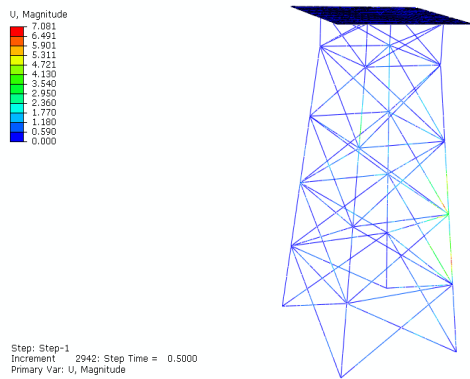


Figure 12 - Contour transformation in the last step analysis

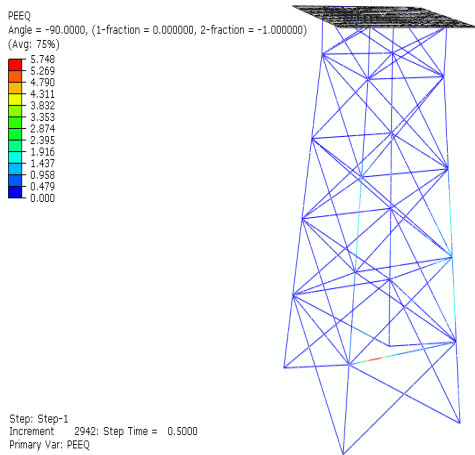


Figure 13 - Contour plastic strain in the last step analysis

Base cutting is created for explosion of platform in its bases. Base cutting change is shown in figure 14. Most base cutting has obtained after explosion during 0.03 second (30 mill seconds) and trend to zero after that.

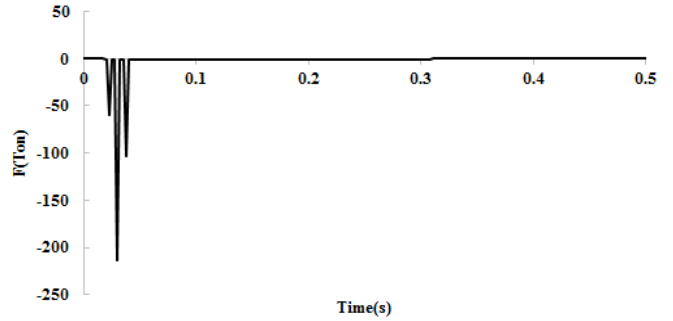


Figure 14 - Time History of Force for Base cutting platform

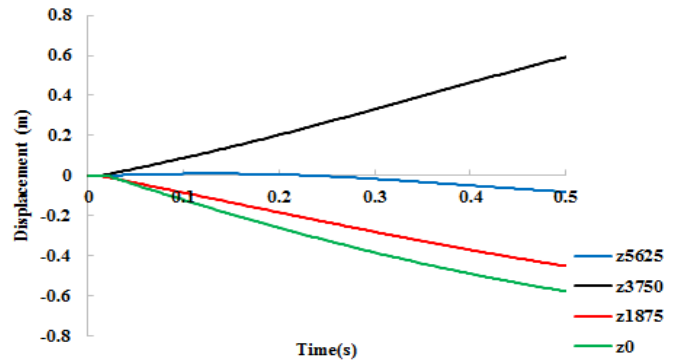


Figure 15 - Time History of different levels of deformation of the base platform

2. The explosion of 100 kg of explosives at a distance away from the stands F-100

In this section, explosion effect of 1 tons of explosives TNT is checked in the 60-meter platform. Model of platform and explosive position is shown in Figure 16.

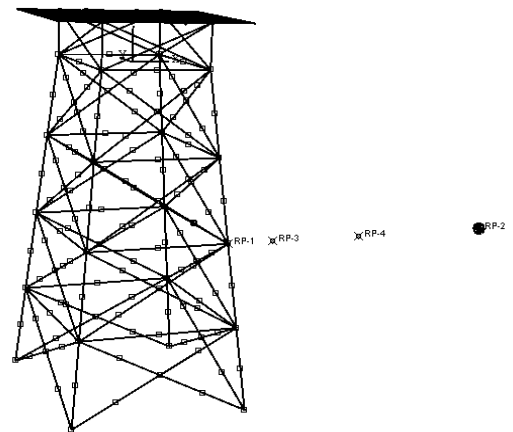


Figure 16 - Model of platform and explosives at a distance of 60 meters around it

Base cutting is created for explosion of platform in its bases. Base cutting change is shown in figure 17. Most base cutting has obtained equal to 3000 tons that is obtained after explosion during 0.03 second (30 mill seconds) and trend to zero after that.

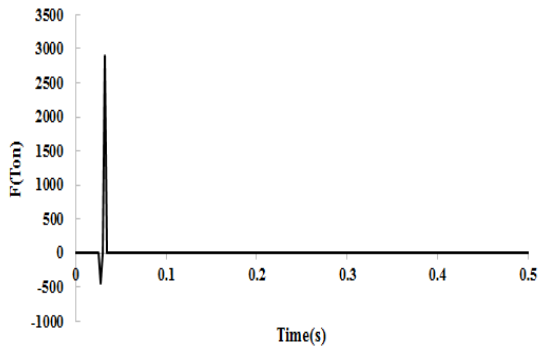
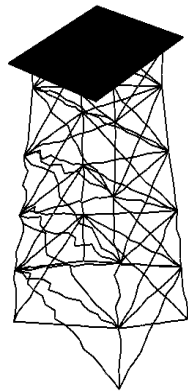


Figure 17 - History shear force base platform support



Step: Step-1
 Increment 2600: Step Time = 0.5000
 Deformed Var: U Deformation Scale Factor: +1.000e+00

Figure 18 - deformation at the last step of analysis

Figure 19 shows the movement of the platform at various levels. Most displacement is obtained about 10 cm that is about 0.4 seconds (400 mill seconds) after explosion. This replacement is related to zero scale. It means a scale from platform that is in the same level of water.

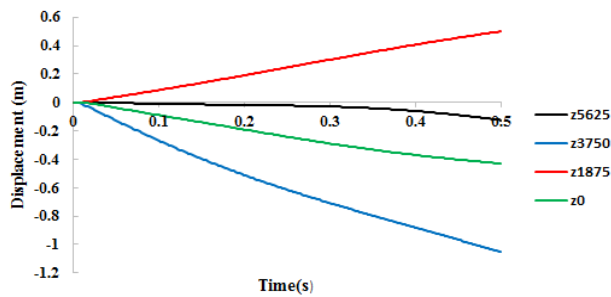


Figure 19 - Time History of different levels deformation of the base platform

3. Explosion 50 kilograms of explosives at an average distance of the platform M-50

In this section, explosion effect of 50 kilograms of explosives TNT is checked in the 30-meter of platform. Model of platform and explosive position is shown in Figure 20.

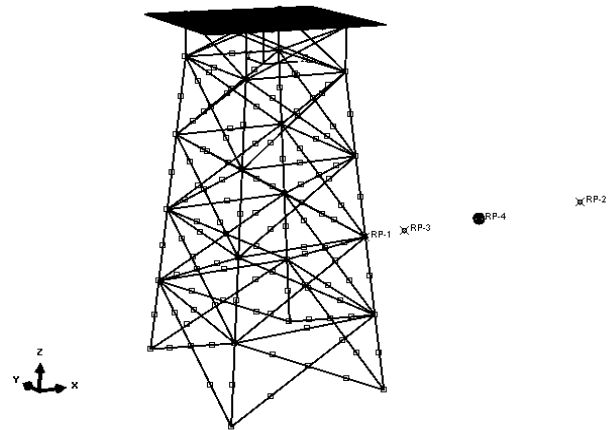


Figure 20 - Model of platform and explosives at a distance of 30 meters around it

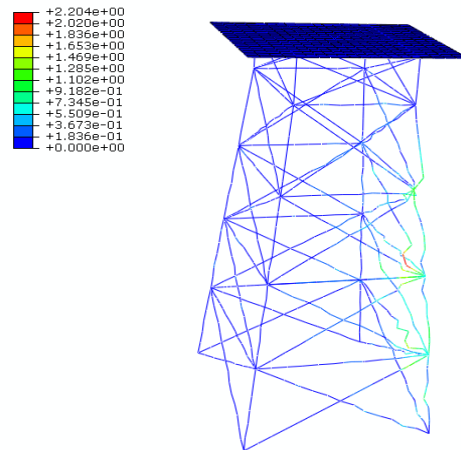


Figure 21 - Contour plastic strain in the last step analysis

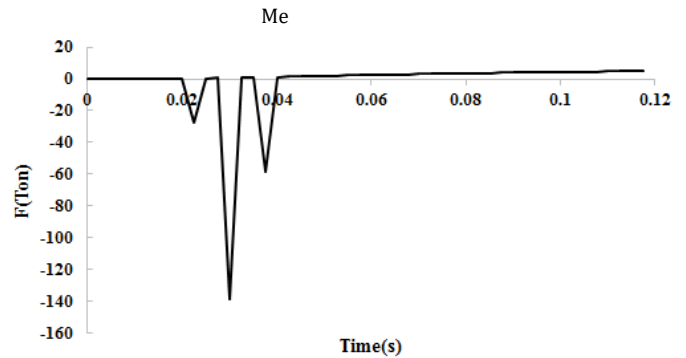


Figure 22 - Time History of shear force of platform bases

1-1-1 The explosion of 50 kg of explosives at a distance from the platform F-50

In this section, explosion effect of 50 kilograms of explosives TNT is checked in the 60-meter of platform. Model of platform and explosive position is shown in Figure 23.

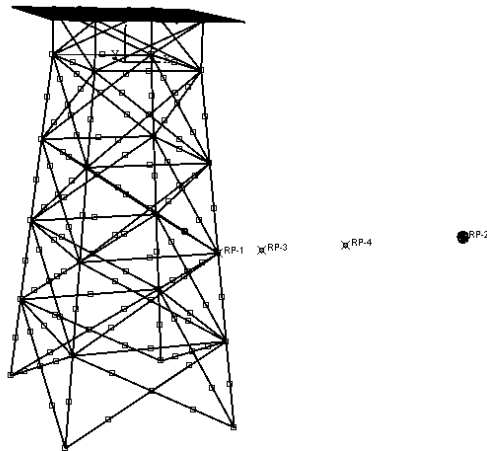


Figure 23 - Model of platform and explosives at a distance of 60 meters around it

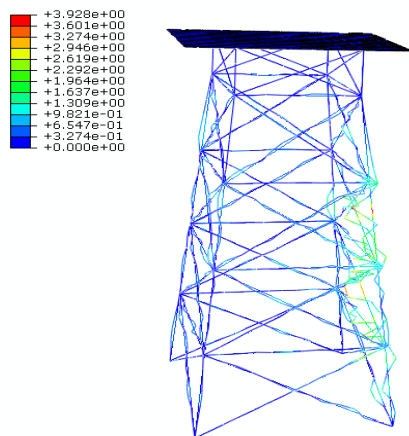


Figure 24 - Contour deformation in half a second after the explosion

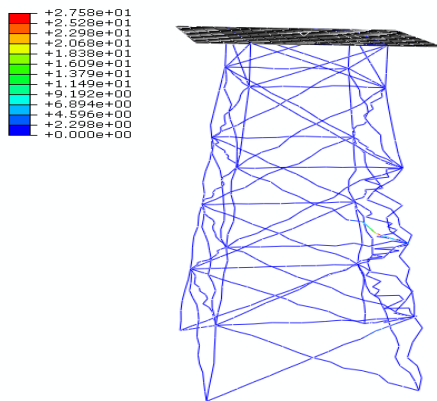


Figure 25 - Contour of plastic strain in half a second after the explosion

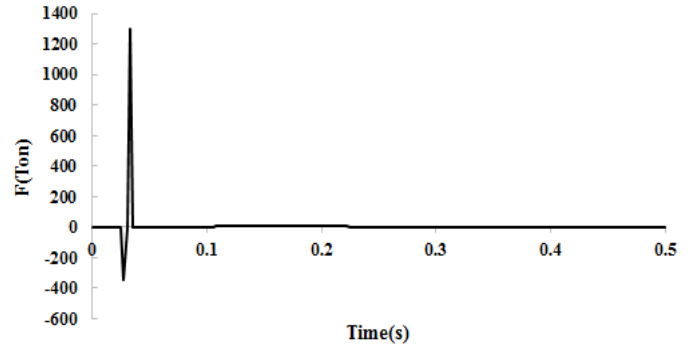


Figure 26 - Time History of Force Base cutting platform

4. Conclusion

In this study, the effects of underwater explosions were studied on offshore platforms Fixed base. Explosive material was placed within walking distance and the average of the platform. Steel consumption of elastic behavior was considered and assuming that connecting to the platform is to the sea floor as clamped. It was used from added mass method to modeling water around platform and after the construction of the finite element model, the stepwise explicit dynamics equations were analyzed in the time domain. In addition, carried out findings of research offered in relation to the objectives, hypotheses and research questions.

The aim of this study was to simulate the behavior of offshore platforms Fixed base against underwater explosions and possible events after that. The main question in this study was how is the effects of underwater explosion on the offshore platform fixed base. For the purpose of answering the research questions and a sample from offshore platforms in the Persian Gulf region a variety of explosive were studied. In short, the explosion was different at different distances of platform. In the field with more distance, because more part of platform is influenced by explosive waves, so total degradation is occurring. While it was observed partial degradation in the closer field.

After modeling and numerical analysis of a sample made offshore platform in the Persian Gulf, the numerical results obtained were analyzed and the results are as follows.

- Part of the platform is in the vicinity of explosives may have been damaged and increases deforming in a short time, speed and acceleration of this part of the platform.
- The impact of the explosive and its distance was significant from the platform in the amount equivalent plastic strain.
- Very low podium last time before destruction, and destruction is done.
- Platform last time under various scenarios were calculated and the results showed a significant increase in survival time compared to a distance is closer distances.
- Considering the fact that the regulations have not addressed the structural design of offshore underwater explosion load, therefore, it is necessary to develop a risk assessment is carried out first offshore platform and identified the level of threat and by the way that was considered in this thesis, the vulnerable points of platform is recognized and act to reinforce it.

In previous studies it was observed that the blast was more localized and only for the range of structures located in the vicinity of explosives will be destroyed. For example, one can note the studies on the effects of underwater explosion on the ship in 2002. Sheen Yang (Ghanaat, Y., 1993). The study examined the speed of the hull. In the present study due to the discrete structure of the continuous deck truss structure for hull deformation shell was used instead of speed. Because after the destruction of the very high speed platform of the members was not achieved with reality.

Recently, it is published dynamic analysis against a concrete dam underwater explosion by Tian Tong Yu (Zhang, Sherong et al., 2014). In this analysis, in view of Euler equations that govern the reservoir dam is written in Lagrangian approach. In the analysis, shock wave propagation and interaction between the dam and reservoir have been considered by Euler-Lagrange involved. It was used from LS-DYNA software for numerical calculations. In a research position at the upstream of the dam was destroyed. This result is similar to results obtained for the destruction caused by the explosion underwater platform. In the studied platform model, it was observed that a number of truss members of platform bases have lots of deformations and they are destructed.

Proposals

In relation to results from study for completion and development of present study, following cases is proposed for next studies.

- Measure the accuracy of obtained results by definition case study of similar platform
- Make a lab model from case study of marine platform of present study
- Definition of a destruction scale for platform

Following cases is offer for future studies to complete and develop the present study.

- Consider the response of platform to surface, average and deep explosion
- Consider the response of platform to average and far explosion
- Designing based on performance of marine platforms

REFERENCES

1. Abaqus Documentation
2. American Petroleum Institute (API). "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms-WSD"; 20th Edition; Chapter 18; 2002.
3. Cole, R.H. "Underwater Explosions"; Princeton University Press, 1948.
4. Det Norske Veritas (DNV). "Structural Design of Offshore Units (WSD Method)"; Section 8; 2011.
5. Geers, T.L.; Hunter K.S. "An Integrated Wave-Effects Model for an Underwater Explosion Bubble"; J. Acoust. Soc. Am., 111(4), 1584-1601, 2002.
6. Ghanaat, Y., (1993). Graphics based Dam Analysis Program, US army corps of engineers, waterway experiment station, vickborg, Missisipi.
7. Jae-Hyun Kim, Hyung-Cheol Shin, Application of the ALE technique for underwater explosion analysis of a submarine liquefied oxygen tank, Ocean Engineering, Volume 35, Issues 8-9, June 2008, Pages 812-822
8. Mair, H.U., "Benchmarks for Submerged Structure Response to Underwater Explosions"; Shock and Vibration, Vol. 6, 169-181, 1999.
9. Mair, H.U., "Hydrocodes for Structural Response to Underwater Explosions"; Shock and Vibration, Vol. 6/2, 81-96, 1999.
10. Ross, M.; C.A. Felippa; K.C. Park and M.A. Sprague, Treatment of acoustic fluid-structure interaction by localized Lagrange multipliers: Formulation. Comput. Methods Appl. Mech. Engng, 197, 3057-3079. 2008.
11. Ross, M.; Sprague M.A.; Felippa C.A.; Park K.C. "Treatment of acoustic fluid-structure interaction by localized Lagrange multipliers and comparison to alternative interface-coupling methods". Comput Method Appl Mech. Engng, 198, 986-1005, 2009.
12. Sprague, M.A.; Geers, T.L. "A Spectral-Element/Finite-Element Analysis of a Ship-Like Structure Subjected to an Underwater Explosion"; Comput. Methods Appl. Mech. Engng. 2006; 195, 2149-2167, 2006.
13. Tiantang, Y. (2009, March 31 2009-April 2 2009). Dynamical Response Simulation of Concrete Dam Subjected to Underwater Contact Explosion Load. Paper presented at the Computer Science and Information Engineering, 2009 WRI World Congress on.
14. Westergaard H. M., Water Pressure on Dams During Earthquakes, ASCE, 1931. Transactions of the American Society of Civil Engineers, Vol. 98, No. 2, February 1933, pp. 418-433.
15. Y.S. Shin, "Ship Shock Modelling and Simulation for Far-Field Underwater Explosion", in B.H.V. Topping, Z. Bittnar, (Editors), "Proceedings of the Third International Conference on Engineering Computational Technology", Civil-Comp Press, Stirlingshire, UK, Paper 36, 2002. doi:10.4203/ccp.76.36
16. Zhang, Sherong et al. "Numerical Simulation of Failure Modes of Concrete Gravity Dams Subjected to Underwater Explosion." Engineering Failure Analysis 36 (2014): 49-64. Web.