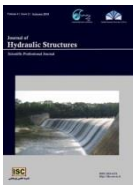
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Investigating the Behavior of Jacket Offshore Steel Structure under Blast Loading

Farhad Hosseinlou [*1]
Wissam Asaad Ibrahim [1]
Mojtaba Labibzadeh [1]

Abstract

Given the hostile nature of offshore environments, ensuring the structural stability of offshore platforms is crucial to their design. A computer program was developed for the preliminary stability analysis of offshore platforms under significant environmental loads. The program output was applied to a minimum facility platform under extreme storm conditions, providing insight into its structural resilience. A comprehensive framework for experimental studies of the platform's stability was also established using a scaled physical model. This research investigates the effect of blasting loads and the distance of explosions on Steel Jacket Type Offshore Platforms (JTOPs) in both air and water environments. Simulations were conducted using Abaqus 2023, where four blasting loads (1, 2, 5, and 10 tons) were applied at varying distances (10, 20, 50, and 100 meters) from the structure. Results indicate that in water, the blasting wave increased by over 11 times as the distance from the platform increased, highlighting the significant amplification effect of the water medium. In contrast, the influence of the blasting load was considerably reduced in air, suggesting a notable difference in the platform's response to underwater versus atmospheric explosions. The displacement over time for different blast scenarios. At 0.5 seconds, the main model (2,000 kg at 20 meters) recorded the highest displacement, around 1.65 meters. Case 1, 2, 3, and 4 follow with displacements of approximately 1.35 m, 1.2 m, 0.95 m, and 0.7 m, respectively. Results indicate that displacement increases with higher blast loads and proximity, particularly in the water medium.

Keywords: Blast Loading; Jacket Offshore Structure; Strengthening; Numerical Analysis; Shock Wave.

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[*] E-mail: F.hosseinlou@scu.ac.ir **(Corresponding Author)**
[1] Faculty of Civil Engineering and Architecture, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

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1. Introduction

The increasing demand for alternative energy sources has led to significant rivalry between fossil fuels and other renewable energy sources since fossil fuels are considered non-renewable [1], [2]. Nevertheless, several contemporary platforms have included advanced technology derived from the preexisting offshore platforms (OSP) utilized in gas and oil exploration [3], [4], [5]. Significant progress has been achieved in ocean engineering, including a diverse array of inventive offshore structure configurations spanning from stationary to buoyant platforms. The structures encompassed in this category consist of floating liquid natural gas vessels, units of mobile offshore production, floating drilling production storage and offloading, units of floating generation, units of floating storage, units of floating offloading and storage, floating offshore wind turbines, jack-up rigs, and deep-water semi-submersible platforms [6], [7].

In recent decades, significant focus has been placed on studying the behavior of engineered structures when subjected to blast or impact loads [8]. Terrorist organizations worldwide are increasingly using explosives to target civilian buildings and infrastructure, posing a rising concern in contemporary communities [9]. Explosive devices have decreased in size and risen in power over the years, resulting in greater mobility of the explosive material and expanded range effects. The casualties from an explosion are often caused not just by immediate deaths resulting from the direct release of energy but primarily by structural collapses that may develop and lead to significant loss of life [10].

The issue of structural resistance to likely to explode loads was extensively studied for several years and made significant progress within the military community [11]. For this reason, most of these discoveries are not available to the public and are limited to military usage. However, design engineers may access documentation that enables them to forecast the impacts of an explosive detonation [12], [13].

The Steel Jacket Type Offshore Platforms (JTOPs) rank as one of the most utilized structures within the offshore oil industry of today [14]. As part of its design, JTOPs are generally intended to endure physical loads caused by waves, currents, wind, and earthquakes associated with the environment. As terrorist attacks have increased in recent decades, engineers have tended to pay more attention when designing structures to carry specific loads, such as explosives. In design codes, explosive loads are not considered comprehensively [15]. A variety of factors influence the effect of explosions, including the type of structure and its location, as well as the type, location, and intensity of the explosion. In the design of modern structures, it is necessary to prevent progressive collapse because of blasts [16], [17], [18]. Therefore, in the design of modern JTOPs, progressive collapse due to blast must be considered. It is essential to design so that the economic effects of failure are minimized as much as possible. The use of non-linear analyses can assist the designers in identifying weak points in structural systems subjected to blast and wave loads and reduce the likelihood of unfavorable Jacket platform failures [19], [20]. Pile-supported JTOPs are essential components of oil and gas exploration and production. It is important to note that pile-supported structures may face many lateral loadings; in some cases, they may also be subjected to strong waves and blasts, making assessing such structures' performance under blast loads an essential factor [21], [22], [23]. Considering the recent increase in terrorist attacks worldwide over the past few decades, researchers have begun to pay closer attention to specific loads, such as blast loads [17], [24]. Understanding the precise behavior of JTOPs under blast loads is necessary for developing methods for designing and fabricating structures resistant to explosive loads [25], [26].

Numerous research studies have examined the dynamic deformations of applying explosive blast stress on plates. The classification of failure modes of structures under impulse loading,

ranging from significant inelastic deformation to ripping and shear failure at the supports, was emphasized by Neuberger et al. [27], [28]. Shock tubes are a preferable alternative to explosives for generating shocks, and they are widely employed in shock/blast simulation research. The impact of blast loading on E-glass fiber-based composites and other materials was experimentally investigated by Tekalur et al. [29], [30], [31] via shock tubes and controlled explosive tube loading. The findings indicated that the E-glass fiber composite gradually deteriorated when subjected to high-rate loading, similar to the conditions reported by Hoo Fatt and Palla [32]. This deterioration was characterized by a progressive failure of the front face owing to indentation, followed by the entire collapse of the core. The investigations have been consistently advanced by the identical research group, yielding significant outcomes. These investigations have extensively investigated several factors, including the dispersion of blast energy throughout the impact procedure and the preservation of structural integrity in sandwich constructions subjected to blast pressures.

In comparison with previous study, the current study considered the first article that presents a strengthening for offshore structure against blasting load. As well as investigate the effect of the distance away from blasting location on the structural behavior under the blasting. This research is innovative as it bridges this gap by examining the behavior of JTOPs under different blast loads and explosion distances in both air and water environments. Using Abaqus 2023, this study performs comprehensive simulations of explosive loads on JTOPs, analyzing not only the structure's immediate response but also the progressive collapse mechanisms that might occur due to underwater explosions. By incorporating both media (air and water), the research brings new insights into the disparity of blast effects in different environments, an area not sufficiently addressed in current literature. This work could have profound implications for improving the design and safety of offshore platforms, minimizing the risk of catastrophic failure under blast loading, and guiding future non-linear analysis techniques for designing blast-resistant offshore structures. Using a 3-D model of the HE4 Platform in the Persian Gulf provides a detailed and realistic representation of the structure, crucial for accurate simulations of its behavior under environmental loads and blasting impacts. This approach accounts for the unique conditions of the Persian Gulf, such as water depth and wave patterns, ensuring the findings are region-specific. The model captures complex interactions between the platform and its environment, including the effects of blasting in both air and water, which enhances the accuracy of the analysis. By incorporating detailed geometries and structural components, the 3-D model allows for precise stress distribution and deformation analysis, leading to better design optimization and improved safety. This comprehensive approach ensures the study's conclusions are both relevant and practical for enhancing offshore platform resilience. However; the current study aims to investigate the effects of blast loading located on the behavior of jacket offshore steel structures as well as changing the blasting load with changing the distance to identify which load will effects more (small load near to structure or high load away the structure) to apply this idea 4 loads have been used (1, 2, 5 and 10) ton at (10, 20, 50 and 100)m away from the structure, the main reason for applying load on various distances to identify the effect of displacement, deformation and strength as well as identify the load amplification in water based on the distances. The responses of JTOP structure that subjected to blast loads induced by explosions on the water surface using three-dimensional (3D) Finite Element modeling and analysis as well as investigate the effect of structure strengthening by steel plate the behavior of JTOP under blasting load (2 ton at 20 m distance). As a method for representing JTOP behavior realistically, the present study uses numerical simulations based on non-linear material models.

2. Numerical Model and Simulation

2.1. Model Description

A case study is conducted using a 3-D model of a recently developed jacket platform in the Persian Gulf, known as the HE4 Platform. The platform's design and analysis adhere to the guidelines outlined in [33]. Given that several jacket platforms worldwide adhere to same design specifications, the findings of this study have the potential to be extrapolated to other comparable offshore platform behaviors. The water depth at the platform's position is 74.6 meters.

The vertical distance between the mudline elevation (elevation Ω74.4 m) and the top of the jacket elevation (elevation 9.2 m) of the jacket section of the platform is 83.6 m. Figure 1 depicts the configuration of the jacket as modeled in the ABAQUS program, as described by [34]. The platform under consideration is a jacket with four legs, exhibiting a damaged ratio of 1:10 in one row and a straight configuration in the other row. The absence of batter in a single row of legs is attributed to the presence of a Jack-up drilling platform in addition to the stationary platform [35]. The platform under consideration is representative of platforms often found in the Persian Gulf region [35], [36], [37].

The platforms used in other places have a similar arrangement of legs [38]. The jacket is comprised of four compartments that are reinforced. The jacket plan exhibits a square form at the working point level, measuring 23 m x 23 m. It is further expanded to 23 m x 31.53 m at the mudline height using the batter. A grouted section is formed by filling the space between the pile and leg with grout, resulting in a composite section. The cans and brace ends serve to enhance the structural integrity of all significant joints inside the jacket.

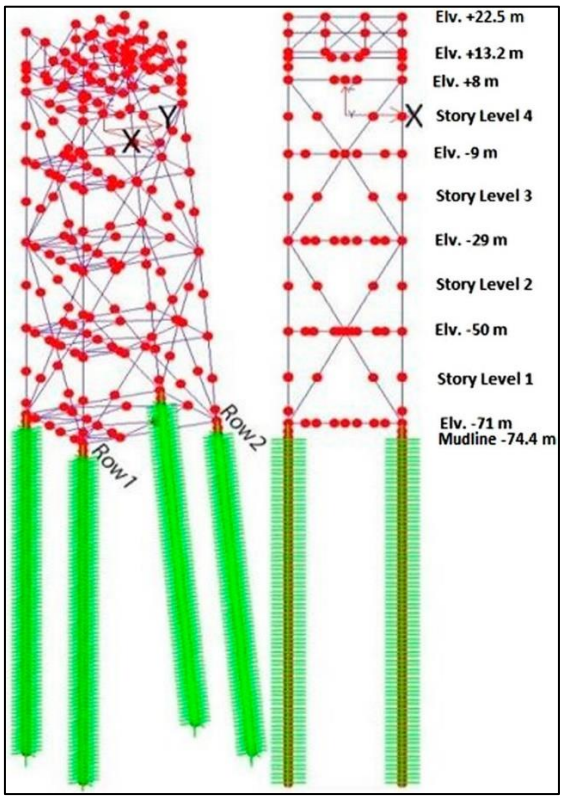


Figure 1. The configuration of the platform modeled in ABAQUS.

Four piles, each having a diameter =1.32 m and a wall thickness=5.5 cm, are used to support the jacket. It is significant to state that the analysis model utilizing ABAQUS software only includes the main structural features. The weight of the jacket under consideration in the analysis encompasses several components, such as the jacket construction, pile within legs, Boat Landing, Barge Bumpers, Anodes, and Mudmats. The weight of the deck encompasses several elements such as structural components, mechanical systems, electrical systems, instrumentation, and pipelines. These components are subjected to intense loads at all nodes of the deck.

2.1.1. Model Validation

It is crucial to comprehend both the UNDEX stresses and the reaction mechanisms of buildings that are most suitable for withstanding or reducing the impact of an explosion. The response of plates to a UNDEX event depends on many characteristics, including the peak pressure of the shock wave, the exponential decay, the effects of cavitation, the secondary and subsequent pulse loading, and the spatial and temporal fluctuation of the shock pulse on the structure. An intricate difficulty arises when attempting to describe and analyze the impact of UNDEX loads on structural elements/systems due to the combination of intense impact loading and a nonlinear structural response that includes both geometric and material non-linearities. Additionally, the characteristics of the material, including its sensitivity to strain rate, the influence of temperature, and metrics related to rupture and damage, change when subjected to dynamic loading and reaction.

The significant global conflicts of the world wars played a crucial role in advancing research related to UNDEX. Consequently, many controlled experiments were carried out aboard ships and submarines, with the results being systematically documented. Cole [39] provided one of the first extensive accounts, including experimental findings, theoretical assessments, and formulas to characterize the explosion and its pressure history. Shock Factor= 0.794, Charge mass=0.08kg, Standoff distance=0.15m. The current study dependent on Cole [39] to simulate the blasting load which is already taken from real explosion and the validation of the current structure under the selected blasting load is shown in Figure 2.

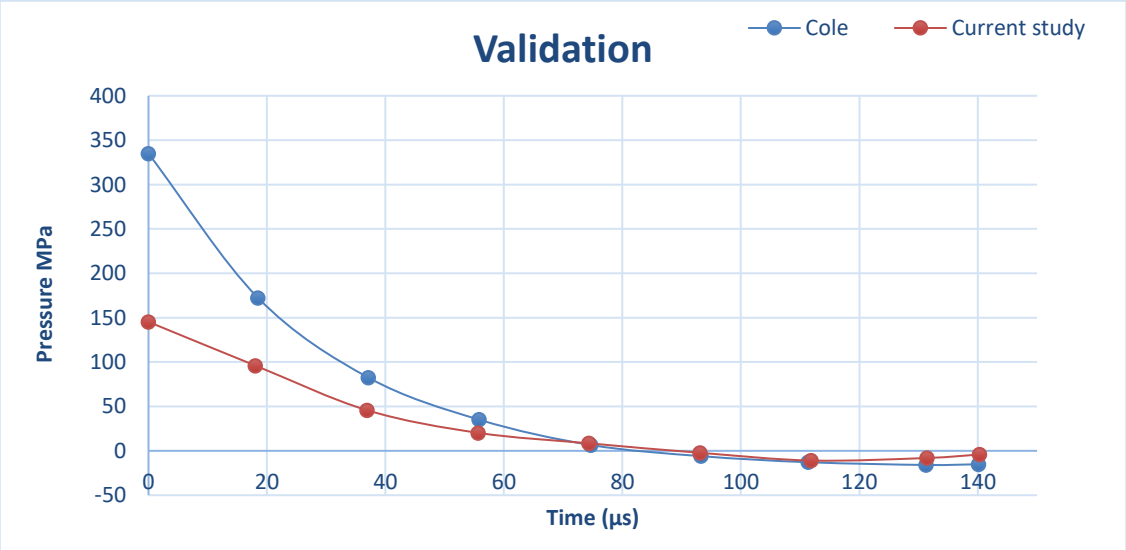


Figure 2. The validation model has been conducted based on Cole [39].

2.1.2. Finite element modeling

A Finite Element model of a newly deployed jacket platform in the Persian Gulf is used as a case study in this research. A numerical model of the experimental specimen is developed in ABAQUS, which is compared with the results in literature to validate the numerical model. A finite element model created in Abaqus is illustrated in Figure 3. Our next step was to mesh the model using B31 elements (A 2-node linear beam in space).

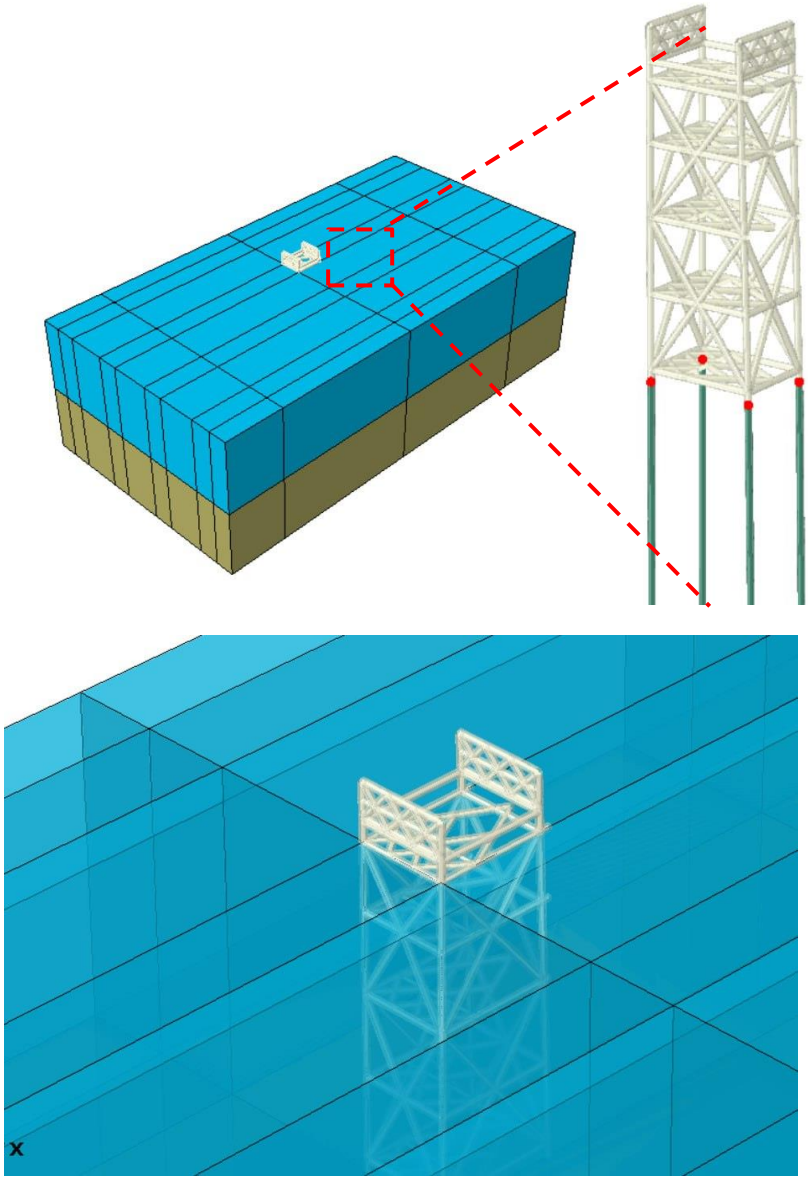


Figure 3. A finite element model designed in Abaqus.

The UNDEX Loading

Noncontact underwater explosions pose a significant risk to maritime vessels, including submarines and ships. Submerged structures may be classified into two groups based on the distance between the exploding charge and the target (standoff distance): far-field explosion and near-field explosion [40].

The pressure versus time history plot in Figure 3 illustrates the many events that took place throughout the UNDEX event [41]. Underwater explosions may result in many loading processes, such as hull cavitations, bulk, bubble-pulse loading, gas bubble oscillation, bottom reflection waves, free surface reflection waves and incident shock waves [42]. The compression wave resulting from the shock wave reflection from the ocean floor imposes an extra stress on the structure. The pressure generated by the shock wave is diminished due to the reflection of the shock wave from the surface of the open ocean [43], [44]. The shock wave generated by the UNDEX charge is referred to as the incident wave. The acoustic field produced by the interaction between the incident wave and the submerged structure is referred to as the dispersed wave. A spherical incident shock wave is used to describe the initial shock wave. This shock wave is delivered as a transient load on both the structural meshes and acoustic at their common surfaces, known as the wetted interface. The shock wave's distribution onto the plate is determined utilizing the incident pressure wave formulas, as illustrated in reference [45].

In this study, gravitational loading was considered as a critical factor in the overall structural analysis of the jacket offshore platforms. Gravitational loading, primarily due to the platform's self-weight and the additional weight of equipment and materials, was modeled as a constant vertical load acting on the structure. This includes both dead loads (permanent structural and equipment weight) and live loads (temporary or variable loads such as operational equipment and personnel). The gravitational load was incorporated in the simulations alongside other environmental forces (e.g., wave, wind, and blast loads) to assess the combined effects on the platform's structural performance. This approach ensures a comprehensive evaluation of the platform's stability, considering the influence of both static and dynamic loads on its integrity and resistance to collapse. Based on the API RP 2A-WSD (American Petroleum Institute) provides specific guidelines on calculating gravitational loads, which have been considered in this study. Furthermore, the ISO 19902 standard also addresses the treatment of gravitational forces in the design of offshore steel structures.

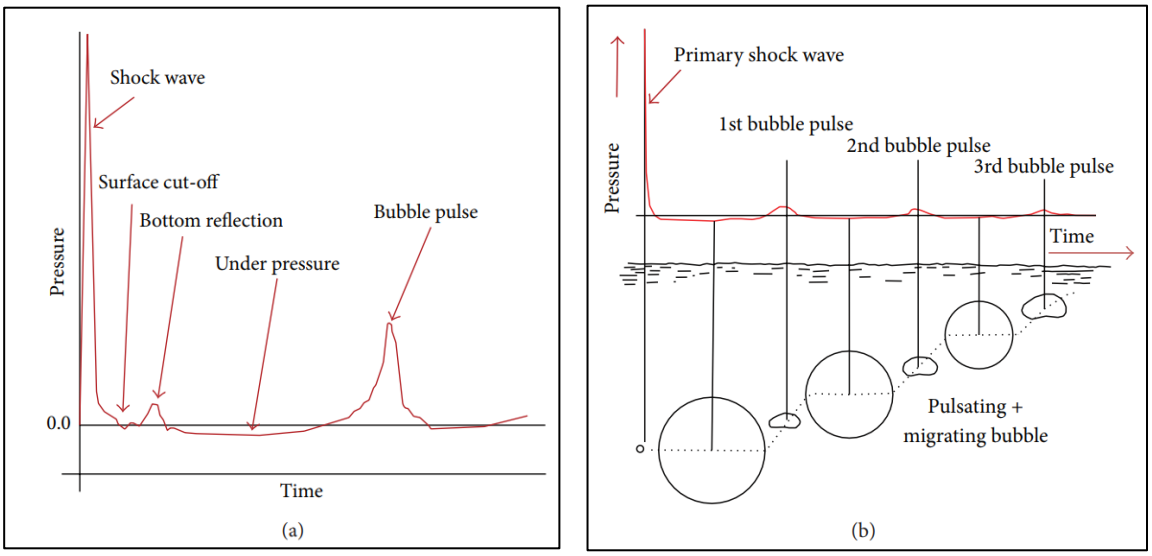


Figure 4. UNDEX Phenomenon: high pressure bubble and shock wave [41].

The pressure history of the shockwave at a stationary position, denoted as P(t), begins with an immediate pressure peak, P_{max}, and then a subsequent decrease that is often represented by an exponential function. The pressure profile equation, as obtained by empirical methods [39], [40], [46], may be expressed in a way that follows.:

$$P(t) = P_{\max} e^{-((t-t_1)/\theta)} (\text{MPa})\ t \geq t_1 \tag{1}$$

Whereas
t refers to the duration elapsed after the charge detonation in (msec)
t_1 refers to the arrival shock wave duration to the target after the charge detonation (msec);
$P_{\max}$ refers the peak pressure value (MPa) at the front wave shock;
θ refers to the decay duration constant that depicts the exponential decay in (m.sec) and is equal to the duration detected by the peak pressure to fall to $1/e$ durations its initial magnitude.

The magnitude of the blast and the distance from the charge where the pressure is recorded determine the decay constant and peak pressure. The expression for the peak pressure, denoted as $P_{\max}$, and the decay constant, denoted as θ, is as following [47]:

$$P_{\max} = K_1 \left(\frac{W^{1/3}}{R}\right)^{A_1} (\text{MPa})$$
$$\theta = K_2 W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{A_2} (\text{millisecond (msec)}) \tag{2}$$

The max bubble radii of exploding gas, $R_{\max}$, and the initial pulsation periods, T, are presented in the case of TNT charge [48]:

$$\begin{aligned} R_{\max} &= 3.38\left(\frac{W}{(D+10.3)}\right)^{1/3} \text{ (m)} \\ T &= 2.1\frac{W^{1/3}}{(D+10.3)^{5/6}} \text{(sec)}, \end{aligned} \tag{3}$$

The constants K1, K2, and A1, A2 are contingent upon the kind of explosive charge used in the utilization of various explosives. The input constants listed in Table 1 [49] are as follows. The explosive charge weight is denoted as W in kilograms (Kg), the charge depth is represented as D in meters (m), and the distance between the exploding charge and the target is denoted as R in meters (m). In addition, Cole [39] offered more details on the methodical exposition of physical consequences linked to underwater explosives.

Table 1: The variables of shock waves for different exploding charges.

Constants	Explosive material kind			
	HBX-1	TNT	PETN	Nuclear
K1	53.51	52.12	56.21	1.06E4
A1	1.144	1.180	1.194	1.13
K2	0.092	0.0895	0.086	3.627
A2	-0.247	-0.185	-0.257	-0.22

Taylor's plate theory may be used to precisely forecast the reflecting pressure on the fluid-structure interaction surface once pressure from an underwater explosion impacts a flexible surface, including the hull of a surface ship [40]. In the case of an air-supported plate with a mass per unit area (m) and exposed to an incident plane shockwave, denoted as $P_i(t)$, a pressure reflection wave, denoted as $P_r(t)$, exits the plate while it is in motion at a velocity $v_p(t)$. The application of Newton's second law of movement,

$$m \cdot \frac{dv_p}{dt} = P_i + P_r \tag{4}$$

The velocities of the fluid particles behind the incident and reflected shockwave are denoted as $v_i(t)$ and $v_r(t)$, respectively. Consequently, the velocity of the plate is determined.

$$v_p(t) = v_i(t) - v_r(t) \tag{5}$$

The incident shockwave pressure $P_i = \rho_f c v_i$, whereas the reflecting shockwave pressure $P_r(t) = \rho_f c v_r$. In this equation, ρ_f represents the fluid density and c represents the acoustic velocity. By replacing the pressure in equation (4) and solving it with equation (1), the value of $P_r(t)$ is obtained.

$$P_r(t) = P_i(t) - \rho_f c v_p = P_{\max} e^{-((t-t_1)/\theta)} - \rho_f c v_p \tag{6}$$

Equation (4) can then be rewritten as

$$m \cdot \frac{dv_p}{dt} + \rho_f c v_p = 2P_{\max} e^{-((t-t_1)/\theta)} \tag{7}$$

Differentiating (7) yields the following expression for plate velocity, where $\psi = \rho_{fC\theta}/m$ and $t > 0$. The total pressure on the plate is

$$P_t(t) = 2P_i(t) - \rho_f c v_p = \frac{2P_{\max}}{1-\psi}\left[e^{-((t-t_1)/\theta)} - \psi e^{-\psi(t-t_1)/\theta}\right] \tag{8}$$

A shock factor (SF), which is proportional to the energy density of the shockwave arriving at a structure, due to various combinations of charge weight and standoff distance is derived by

$$\mathrm{SF} = \frac{0.45\sqrt{w}}{R}\left(\frac{\mathrm{Kg}^{1/2}}{\mathrm{m}}\right) \tag{9}$$

The study simulates underwater explosions (UNDEX) using Abaqus software, modeling the impact of varying blasting loads (1, 2, 5, and 10 tons) and explosion distances (10, 20, 50, and 100 meters) on the offshore structure. Key parameters include the magnitude of the blast, the distance from the structure, and the medium (air or water) to assess how these factors influence the impact. The simulation models the pressure waves generated by the explosion and their interaction with the platform. It also analyzes the structural response, focusing on stress distribution and deformation to evaluate stability and potential damage. This approach provides a comprehensive understanding of how different explosion scenarios affect the structural integrity of offshore platforms.

2.2. Elements mesh details

To determine the best mesh density (i.e., number of elements), selecting a suitable mesh size is a significant step in FEM. Structure models were subjected to a convergence analysis to obtain an appropriate mesh size by dividing Structure models into an appropriate number of elements. When the reduction in mesh size (increment in the elements' number) has no effect on the finding, the findings have reached a suitable convergence.

To identify the appropriate mesh size for each modeled component, a sensitivity analysis was conducted. This involved altering the mesh size in various sections of the system and obtaining the findings of the frequency analysis. By performing this sensitivity analysis, the optimal mesh size for each component could be determined, ensuring accurate and reliable frequency analysis findings as illustrated in Figure 5.

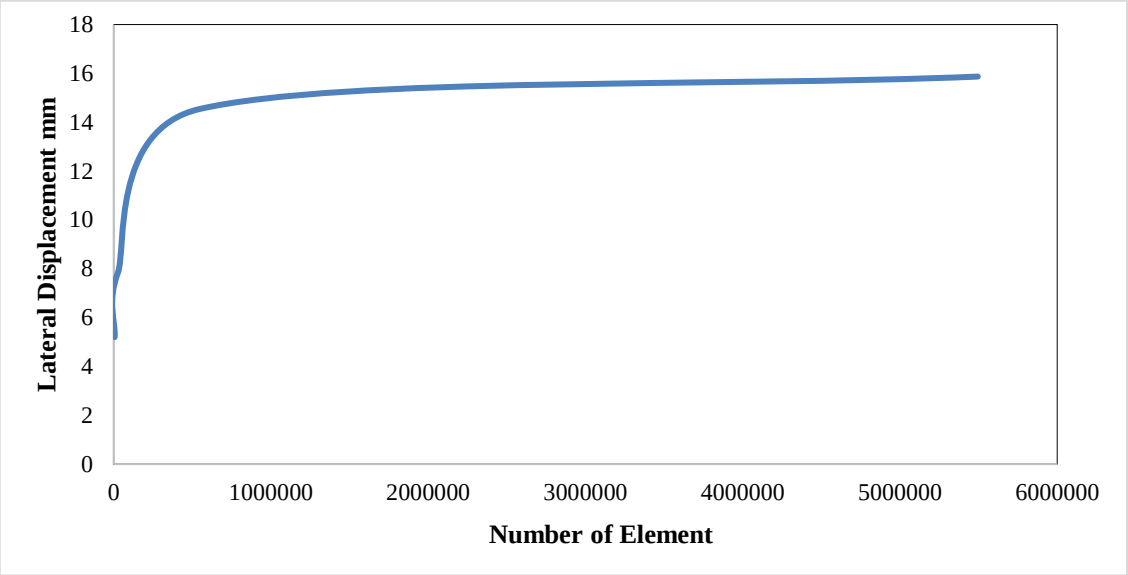


Figure 5. the mesh accuracy based on the lateral loading.

2.3. Assigning Boundary Condition

The jacket offshore steel structures analyzed in this study are designed and reinforced in accordance with internationally recognized standards and guidelines commonly adopted for offshore platforms, particularly within the oil and gas sector. **API RP 2A-WSD (American Petroleum Institute),** which recommended practice governs the planning, design, and construction of fixed offshore platforms, offering comprehensive guidelines on structural integrity, safety factors, and the consideration of environmental loads such as wind, wave, and seismic forces. And **ISO 19902 (International Organization for Standardization)**, which addresses the requirements for offshore steel jacket structures, including design, construction, and maintenance. It covers loads, materials, structural components, and fatigue analysis. Numerous elements for simulating the behavior of steel structure were applied. These components are commonly utilized in ABAQUS. The details of the elements and their descriptions are shown in the table below.

Table 2. The element type and description.

No.	Name of materials	Type of Element	Symbol	Descriptions
1	Steel	beam	B31	2-node beam element with linear interpolation formulations in three-dimensional space
2	Steel plate	Shell	S4R	4-node double curved thin of thick shell, reduced integration, hourglass control, finite membrane strain
3	Soil and waster	Deformable solid	C3D8R	8-node brick element

The boundary situations have an essential role in accurately forecasting the behavior of the model. In this thesis nine strengthen type had been made for each of the four model as can be seen in the attached excel file, the types of strengthen are describes below:

2.3.1. Case 1

In this Case two parallel steel plates that has placed at the 10 m away of the edge with 72 circular hole (with radius 0.5m) the distance between holes is (3 m horizontally and 2.5m vertically) as illustrated in Figure 5 and 6.

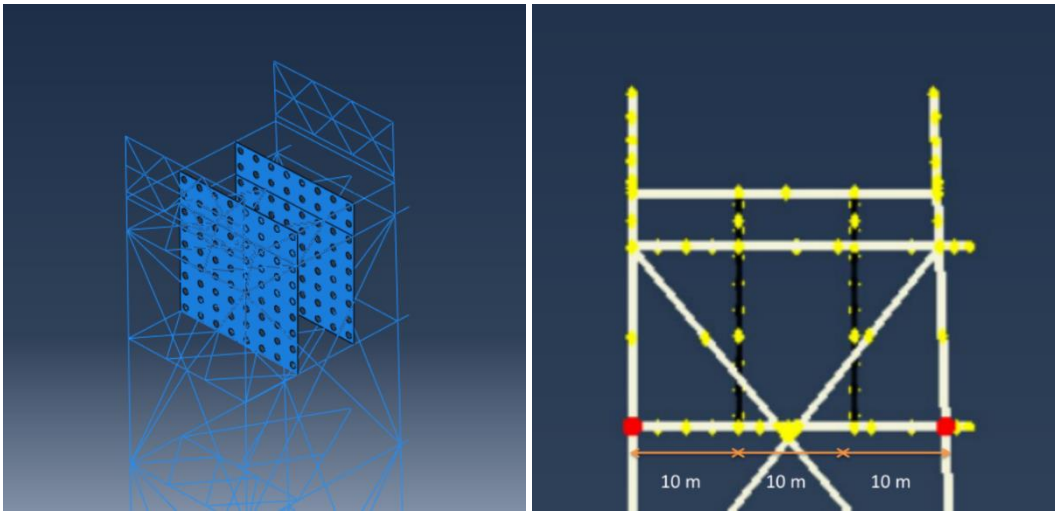


Figure 6. Front view of first strengthening case.

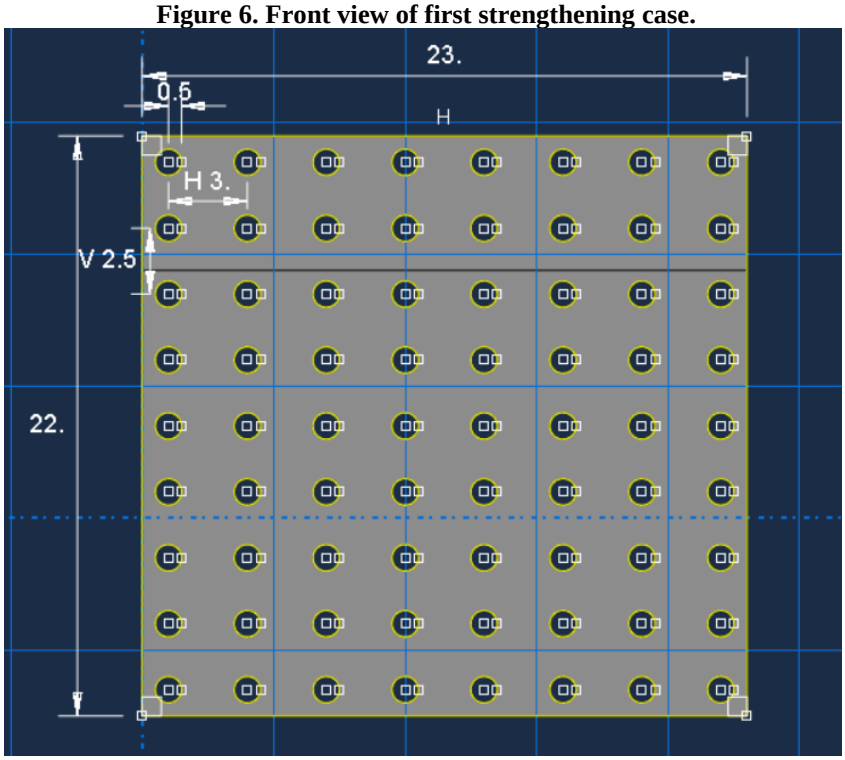


Figure 7. First strengthening case dimensions details.

2.3.2. Case 2

This Case consists of two parallel steel plates with same dimensions as case one (one of the plates placed at 5 m away of the edge and the other one placed at 15 m away from the structure edge the distance between two plates is 10 m) with 72 circular hole (with radius 0.5m) the distance between holes is (3 m horizontally and 2.5m vertically) as illustrated in Figure 7.

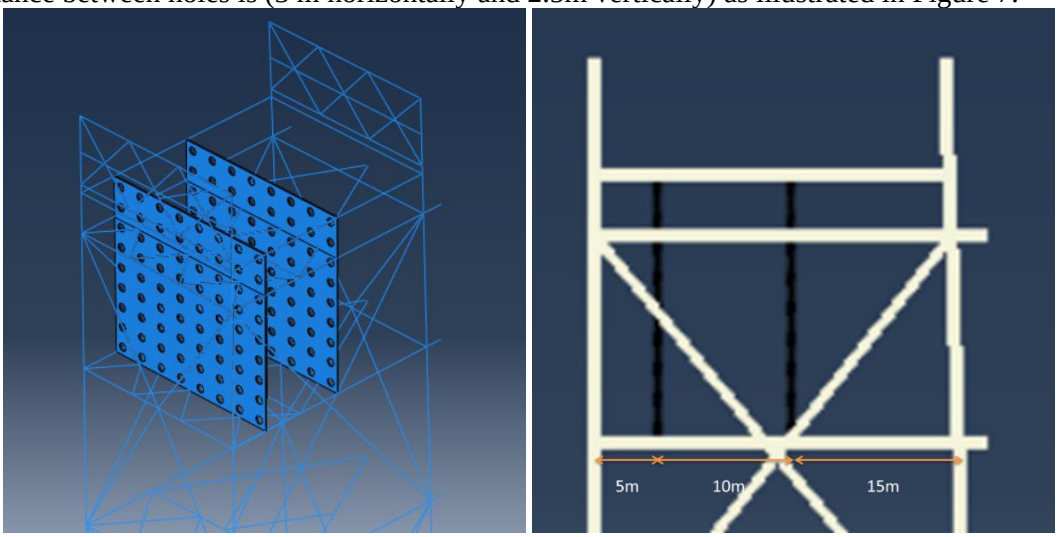


Figure 8. Front view of second strengthening case.

2.3.3. Case 3

This Case consists of two parallel steel plates with same dimensions as case one (both plates have been placed at the edge of the structure) with 72 circular hole (with radius 0.5m) the distance between holes is (3 m horizontally and 2.5m vertically) as illustrated in Figure 8.

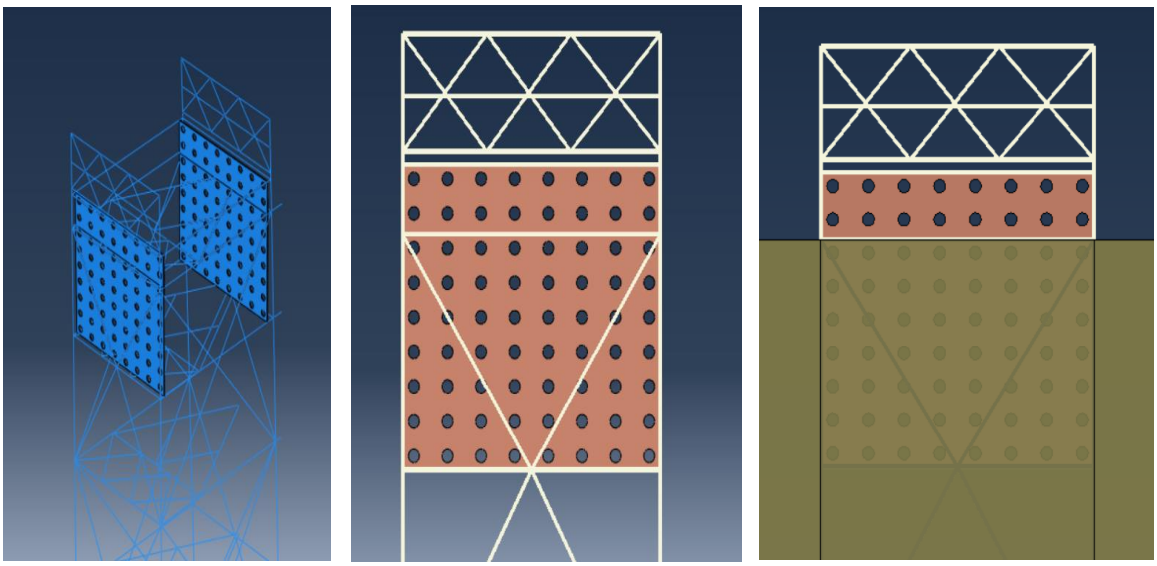


Figure 9: Front view of third strengthening case.

2.3.4. Case 4

This Case consists of four steel plates with same dimensions as case one (they placed at four structure edge one at each edge) with 72 circular hole (with radius 0.5m) the distance between holes is (3 m horizontally and 2.5m vertically) as illustrated in Figure 9.

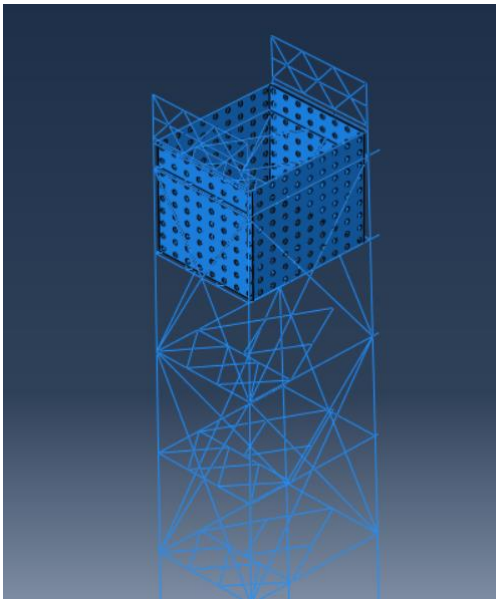


Figure 10. Front view of sixth strengthening case.

3. Results and Discussions

The obtained results from ABAQUS software program have been classified into the following sections:

3.1. Blast load and displacement

The relationship between displacement that occurred due to different blasting loads (1, 2, 5 and 10) ton and time as shown in Figures 10-13. Figure 10 shows that applying blasting load with 1 ton at 10 m distance away from the offshore steel structure was mainly affected by the transition media of load where the water increasing the impact load significantly from 0.223043 to 0.906891, which means the presence of water increase the blasting load more than 3 time its effect on air and this results are compatible with Jang et al., [50] they found that the water increase the blasting load with 2.6 time compare with air. The presence of water significantly amplifies the impact of blast loads compared to air. Water's higher density and lower compressibility facilitate more efficient transmission of blast energy, leading to increased structural displacement and deformation. The fluid nature of water also causes blast waves to expand, intensifying their effect on structures. Consequently, the same blast load results in a substantially greater impact when in water than when in air.

Figure 11 shows that applying blasting load with 2 ton at 20 m distance away from the offshore steel structure was mainly affected by the transition media of load where the water increasing the impact load significantly from 0.149723 to 1.65706, which means the presence of water increase the blasting load more than 11 time its effect on air and increasing the distance between the structure and source of explosion in air comparison with Figure 11, but in water

increasing the distance lead to expansive the wave [51] and this results are compatible with results obtained by [52] which show that the blasting wave has been expanded in water due to water fluidity. Same results have been shown in Figures 12 and 13 when applying 5 and 10 ton at 50 and 100 m distances, respectively. The amplification of blast loads in water is attributed to the medium's higher density and lower compressibility compared to air, which facilitates more efficient wave propagation. This results in greater energy transfer to the structure, intensifying the blast wave's effect. Additionally, the fluid properties of water cause the wave to disperse, further enhancing the overall impact on the structure.

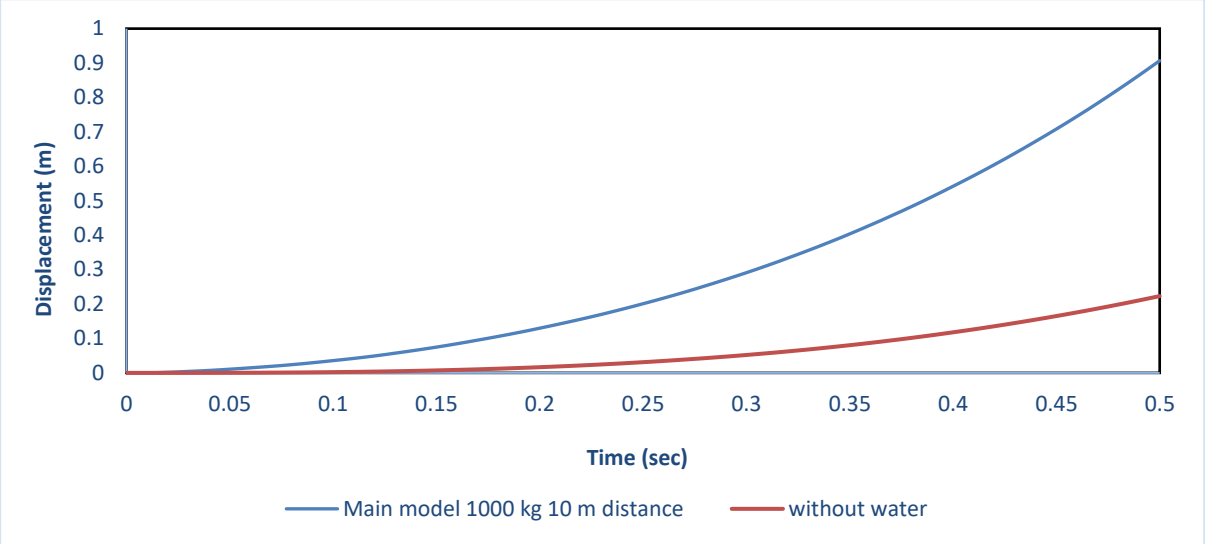


Figure 11. The relationship between displacement and time for JTOPs for blast load 1 ton at 10 m.

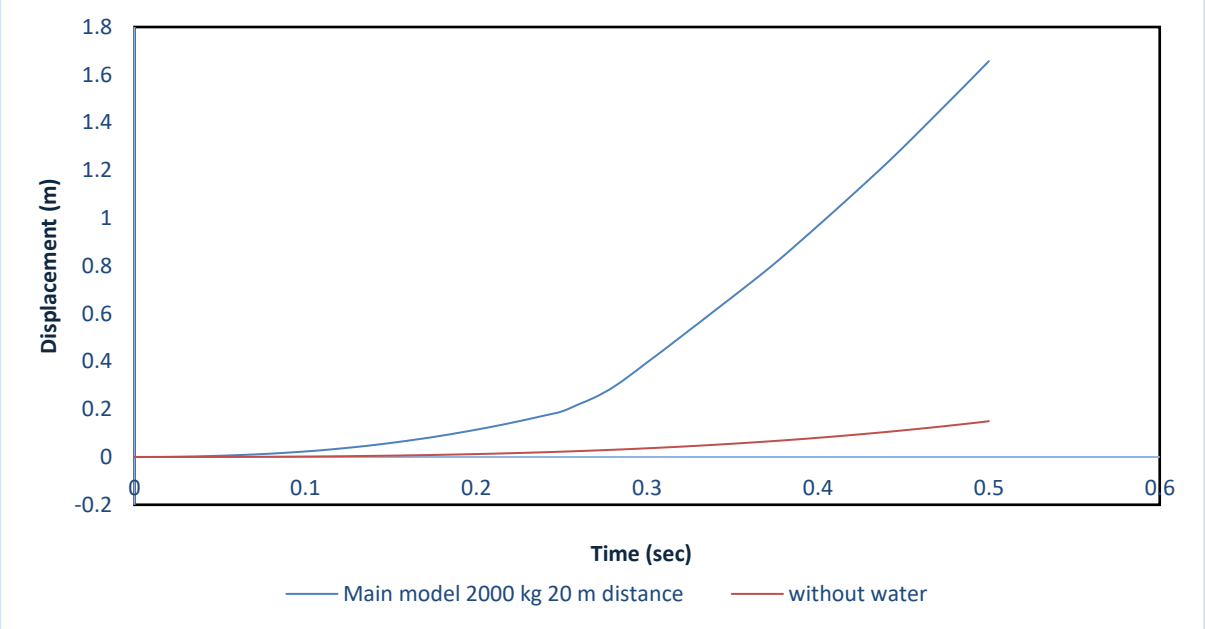


Figure 12. The relationship between displacement and time for JTOPs for blast load 2 ton at 20 m.

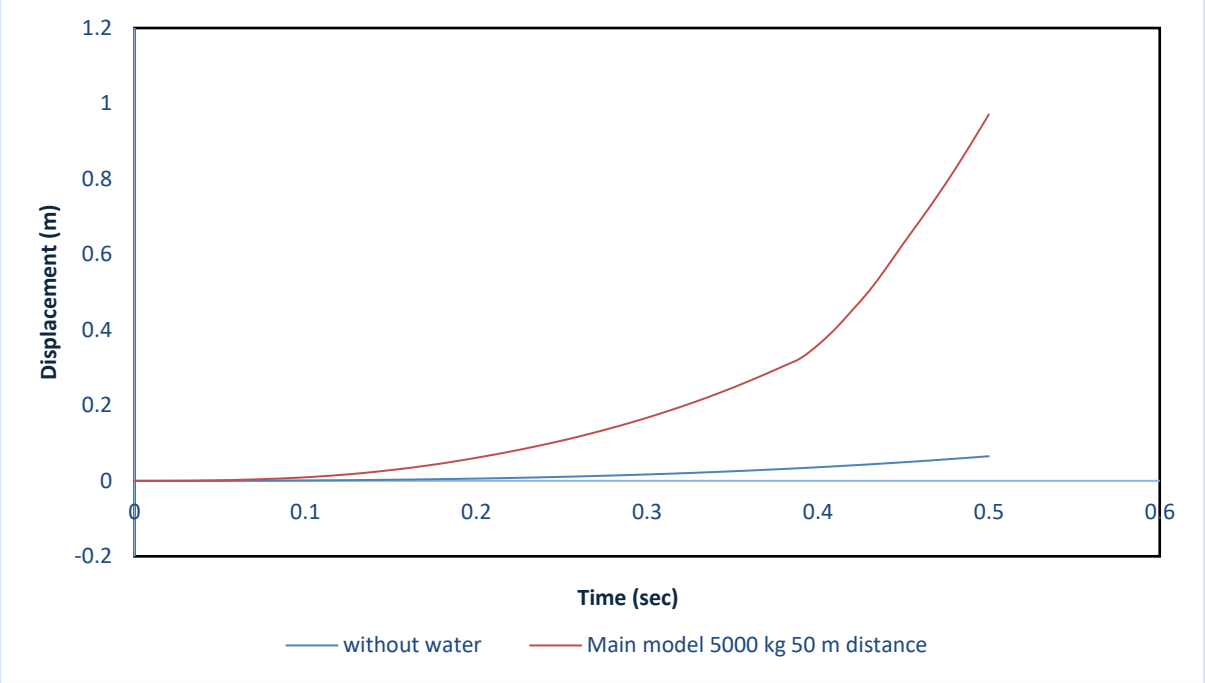


Figure 13. The relationship between displacement and time for JTOPs for blast load 5 ton at 50 m.

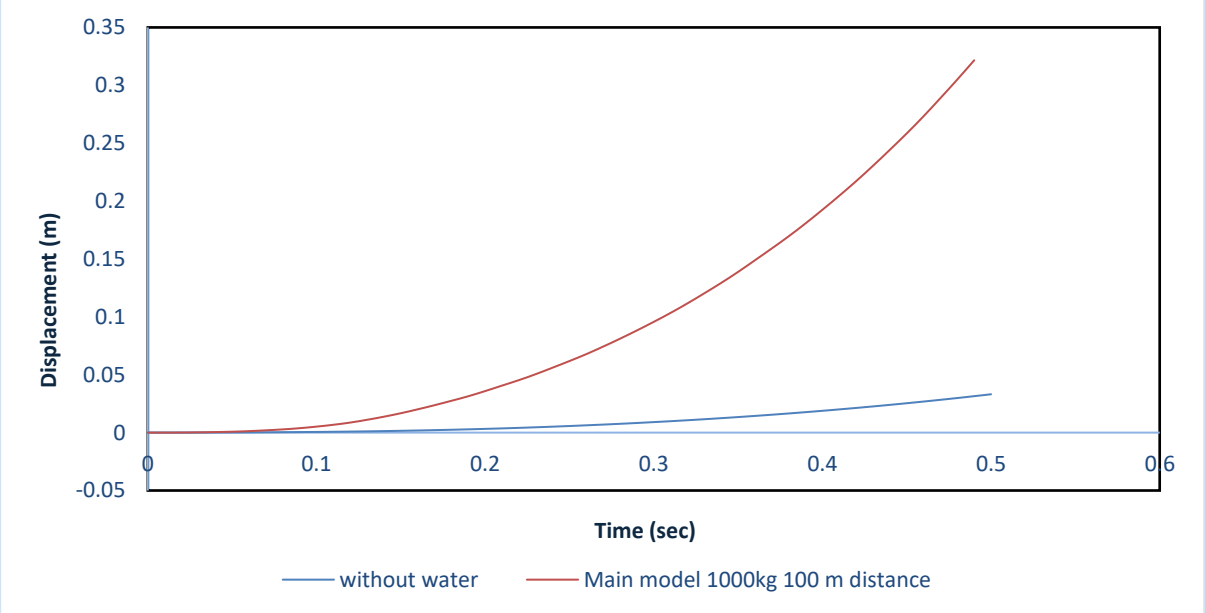


Figure 14. The relationship between displacement and time for JTOPs for blast load 10 ton at 100 m.

3.2. Structure Deformation

The structure deformation for all selected blasting loads (1, 2, 5 and 10) tons has been shown in figures 14-17. Based on Figure below increasing the distance between applying load and the source of applying lead to reduce the deformation of structure in air and increasing the deformation in water.

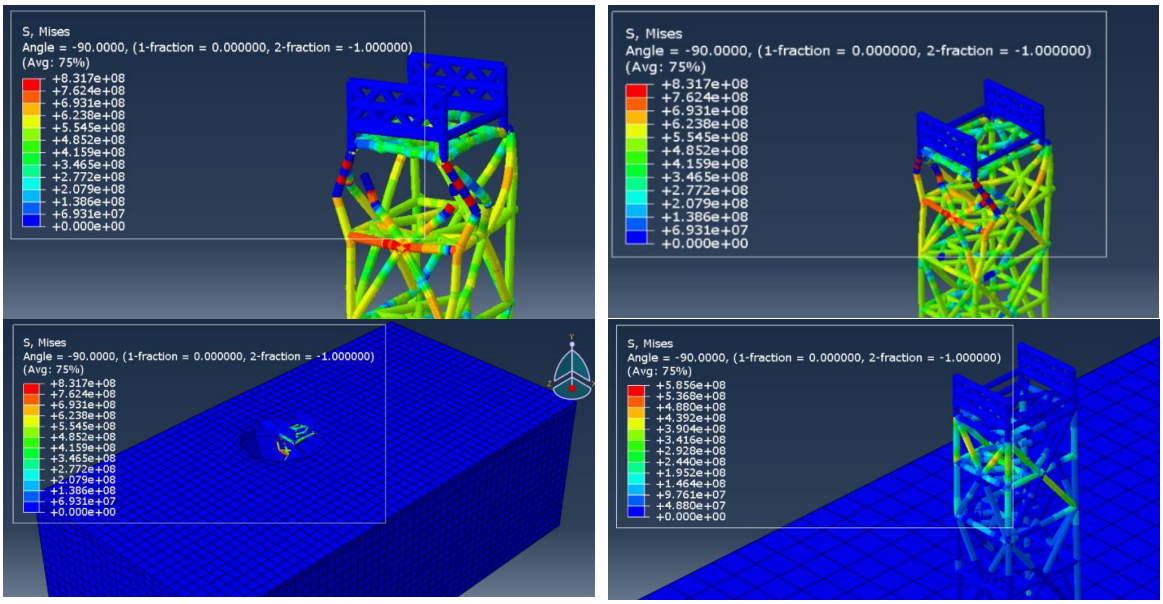


Figure 15. The deformation of JTOPs for blast load 1 ton at 10 m.

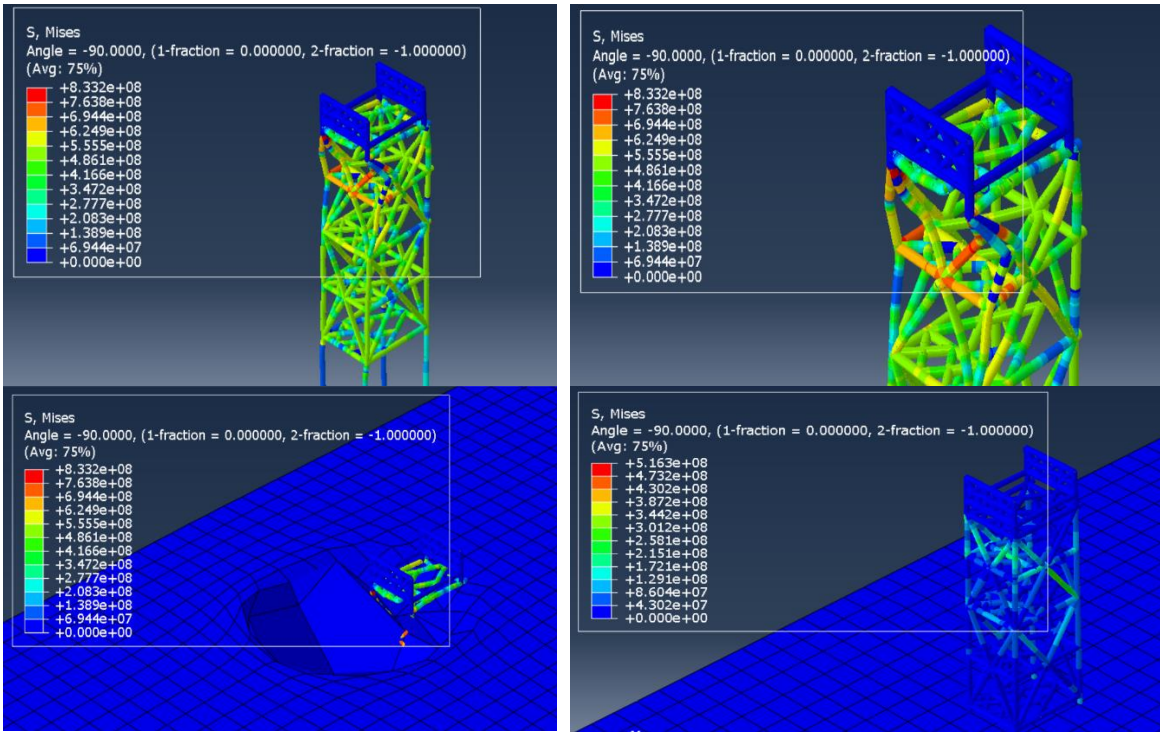


Figure 16. The deformation of JTOPs for blast load 2 ton at 20 m.

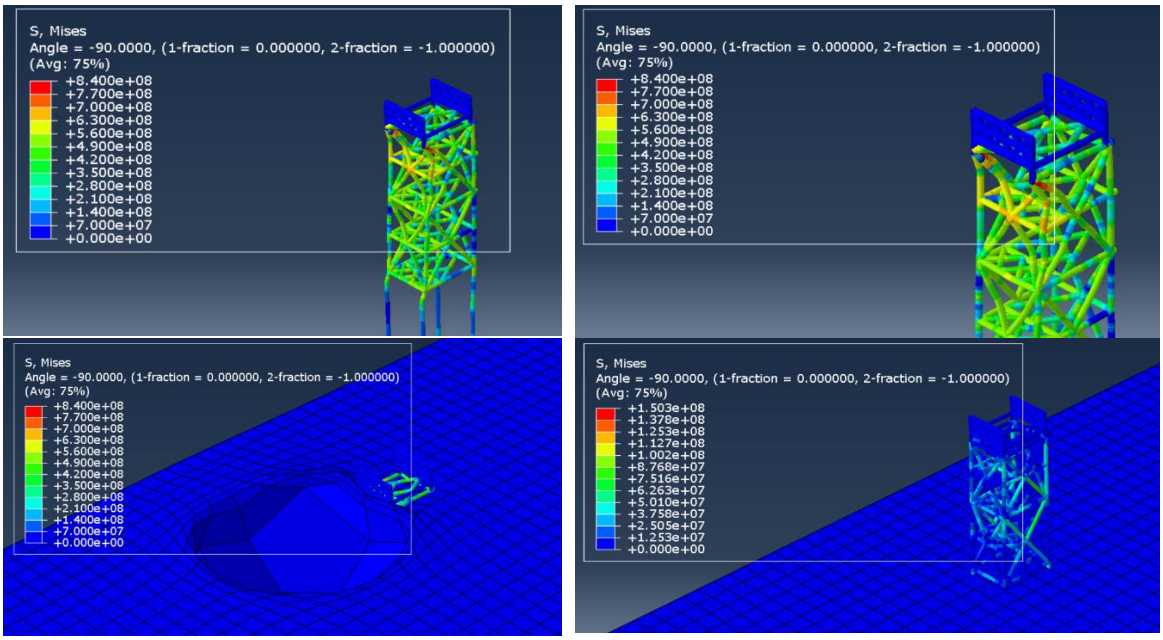


Figure 17. The deformation of JTOPs for blast load 5 ton at 50 m.

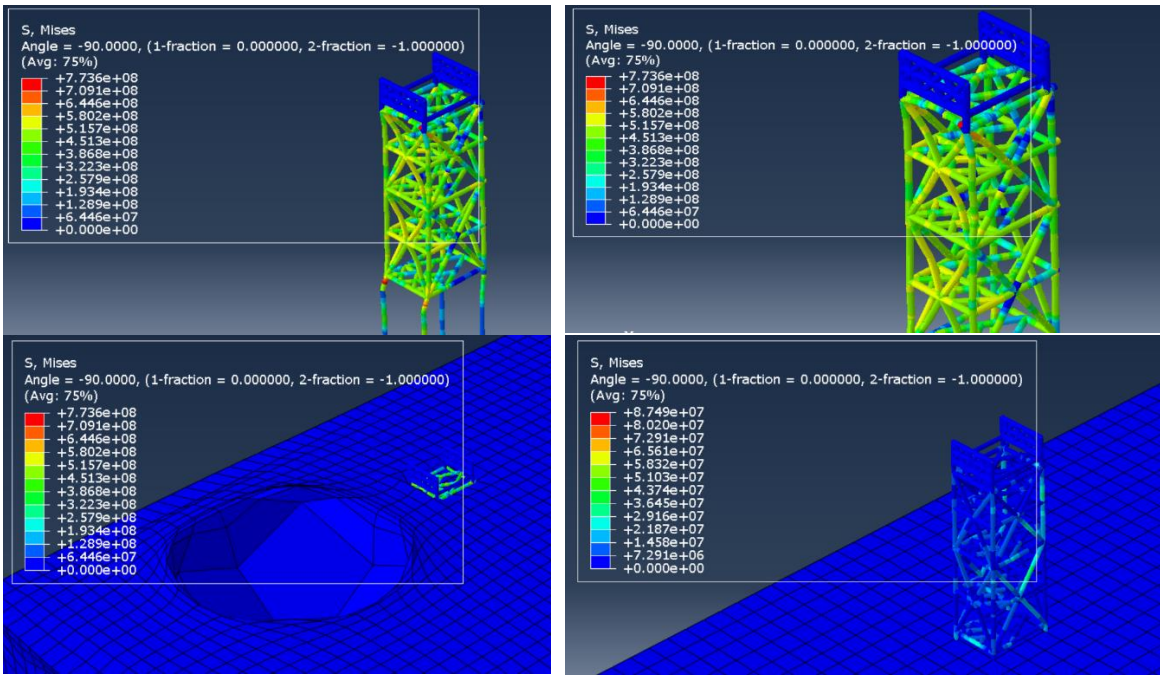


Figure 18. The deformation of JTOPs for blast load 10 ton at 100 m.

3.3. Strengthening Structure

3.3.1. Blast load and displacement

Figure 18 shows that applying blasting load with 2 ton at 20 m distance away from the offshore steel structure was changed based on the strengthening case, where case 5 with single parallel steel plate has the highest displacement, while case 8 with steel slices has been placed on four offshore structure's sides has the lowest displacement.

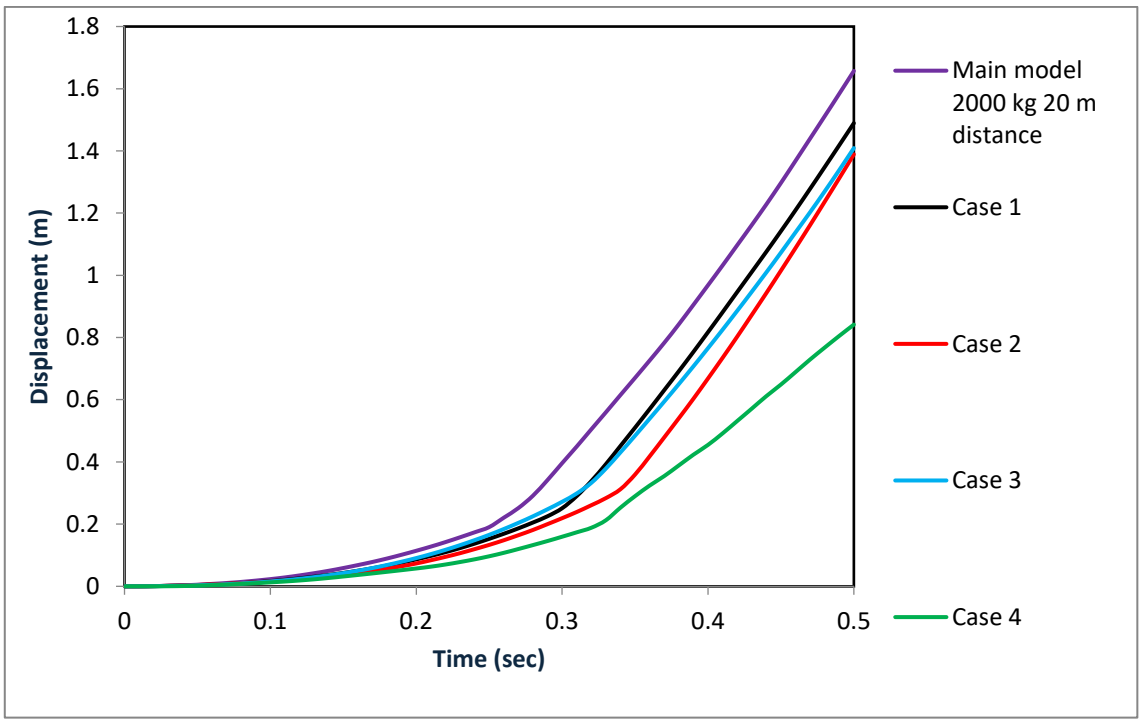


Figure 19. The relationship between displacement and time for strengthened JTOPs subject to blast load 2 ton at 20 m.

3.3.2. Structure Damaging

Figure 19 shows that applying blasting load with 2 ton at 20 m distance away from the offshore steel structure was changed based on the strengthening case, where case 5 with single parallel steel plate has the highest displacement value 2.54489m, while case 8 with steel slices has been placed on four offshore structure's sides has the lowest displacement value 0.282685m. The relationship between displacement and damage is a positive relationship, therefore Case 4 has the lowest damaging and best condition to resist the explosion, while case 1 has highest damaging and worst condition against the same explosion.

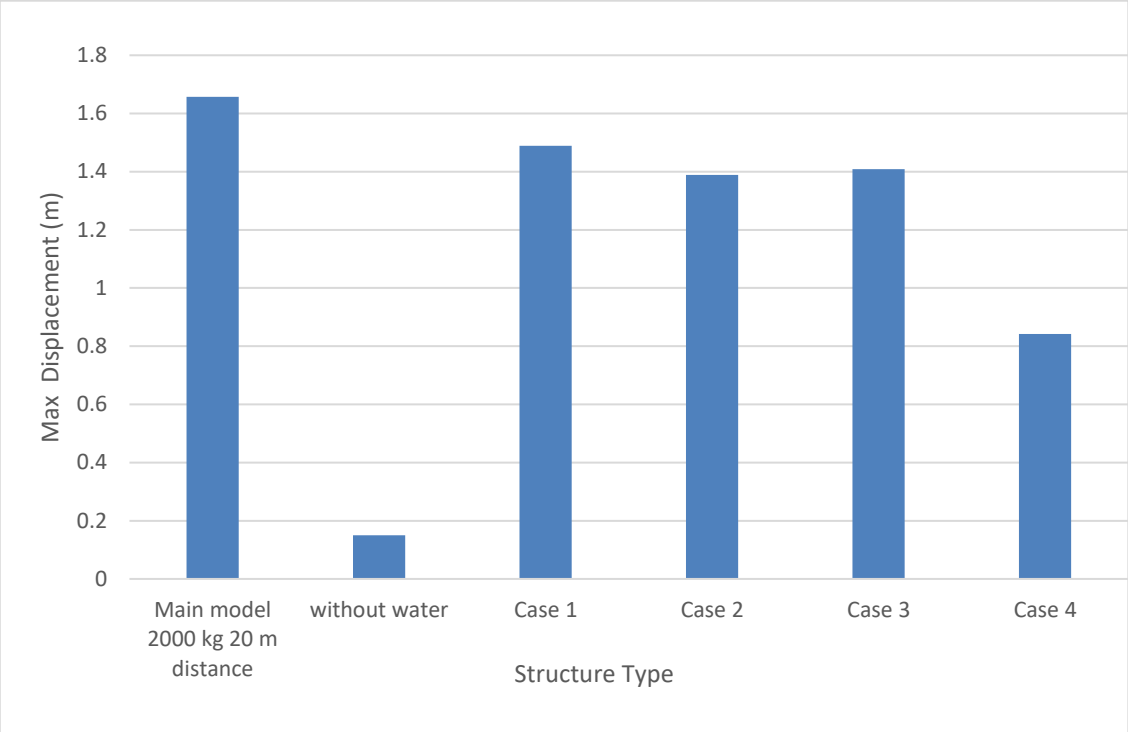


Figure 20. Max displacement value for model 2 ton and 20 m displacement with different strengthening.

3.3.3. Structure Deformation

Figure 20 to 22 show the offshore structure deformation simulation for different strengthen cases by ABAQUS software program using 2 ton blasting load located at 20 m away from the structure. Figure 20 shows the offshore structure deformation for case 1 that strengthening with two parallel steel plates at the middle of the structure. The structural deformation has been reduced after placing symmetrical strengthening. Figure 21 shows reduction in deformation of the structure in one side due to unsymmetrical strengthening of the offshore structure.

Figure 22 shows increment in the structural deformation after placing the steel plates at the edge of the structure, due to increasing the structural resistance against the blast load that happened when increasing the surface area of that effected by blasting load and that compatible with [53].

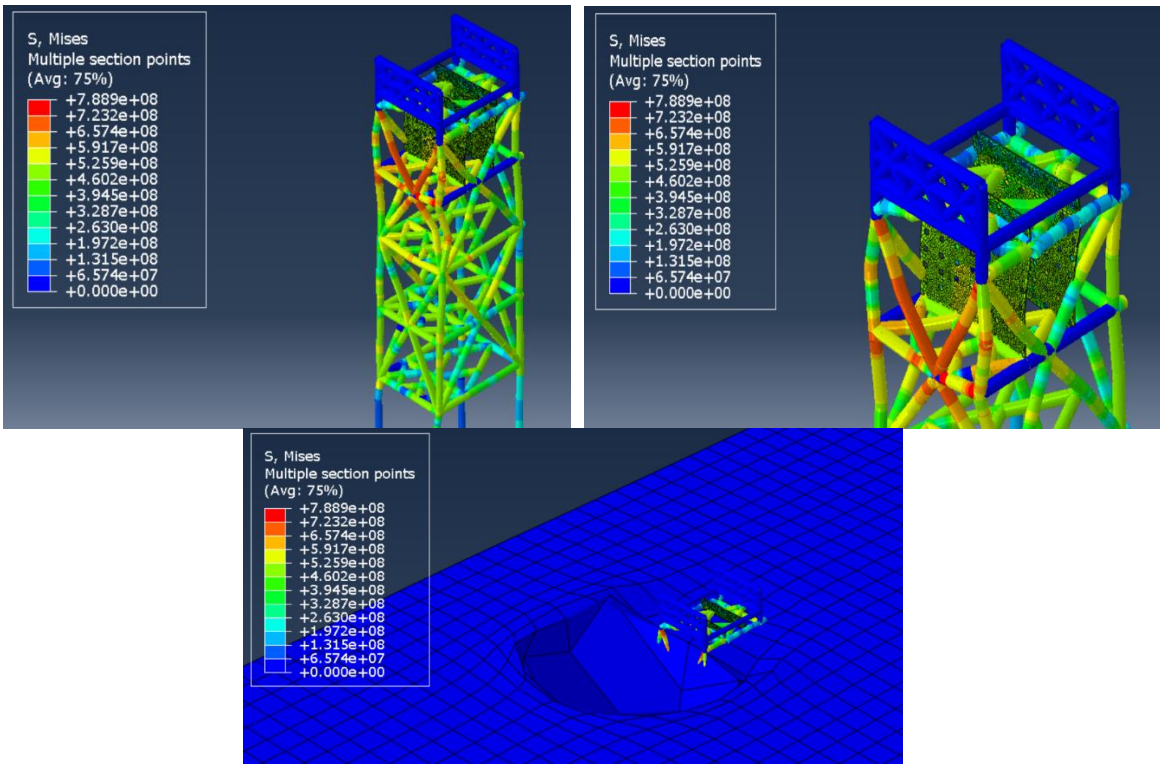


Figure 21. Strengthened offshore structure Case 1 with 2 ton loading and 20 m distance

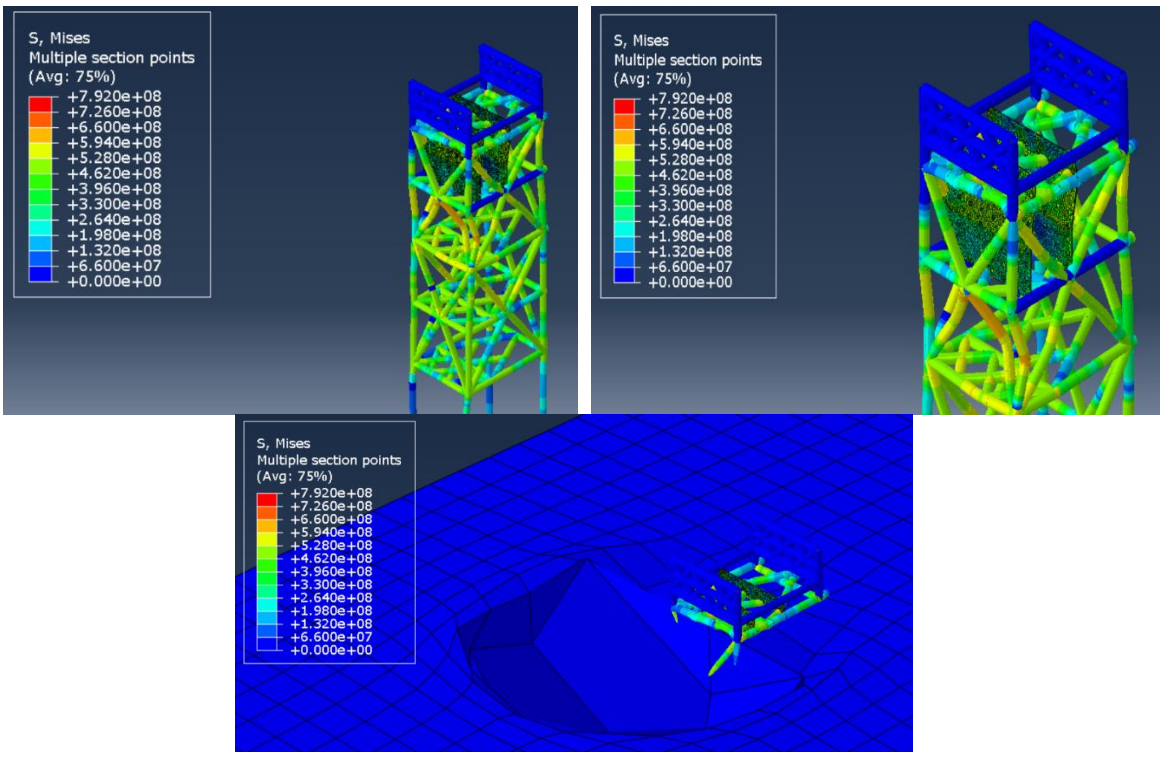


Figure 22. Strengthened offshore structure Case 2 with 2 ton loading and 20 m distance

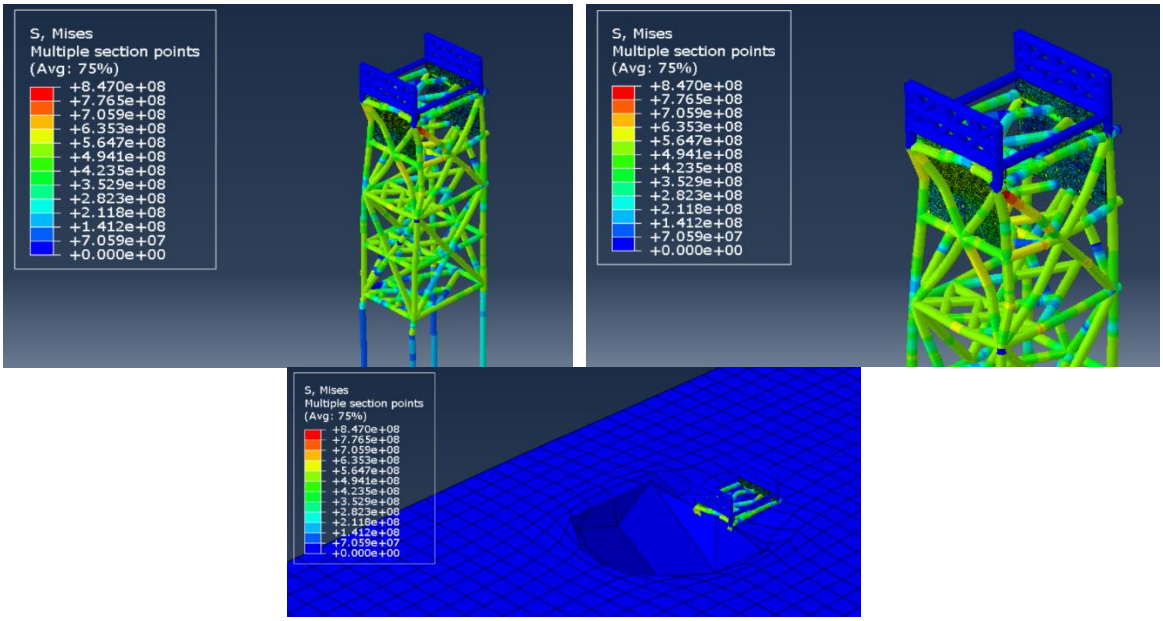


Figure 23. Strengthened offshore structure Case 3 with 2 ton loading and 20 m distance

Figure 23 shows the offshore structure deformation for case 4 that subject to 2 ton blasting at 20 m and strengthening with four parallel steel plates near to the structural edges. Figure 23 shows increment in the structural deformation after placing the four steel plates comparison with figure 22 due to increasing the structural resistance against the blast load that happened when increasing the surface area of that effected by blasting load and that compatible with [53].

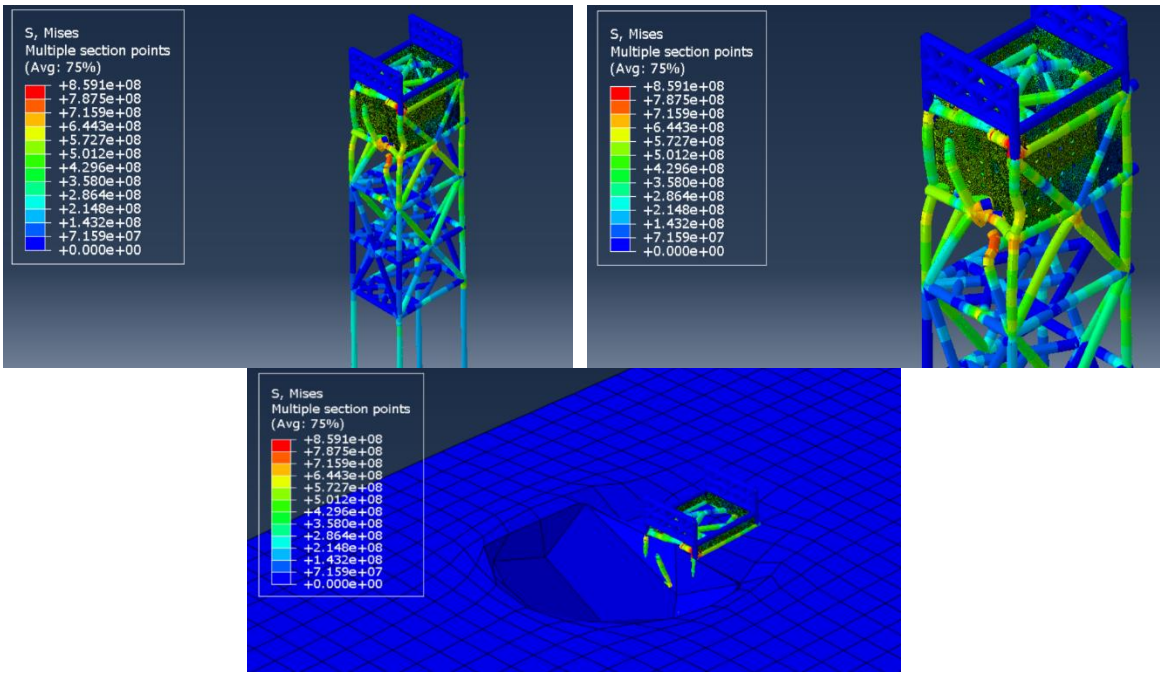


Figure 24. Strengthened offshore structure Case 4 with 2 ton loading and 20 m distance

4. Conclusion

The study concludes that the presence of water significantly amplifies structural displacement under blasting loads, with a threefold increase in displacement compared to air for a 10-ton load. Increasing the distance between the structure and the blast source reduces displacement in air but causes the opposite effect in water. Similarly, deformation increases with distance in air, while decreasing in water. Strengthening techniques generally enhance structural resistance, except for the use of steel plates, which increases the exposed surface, leading to higher displacement and deformation. These findings highlight the complex interactions between blasting loads, environmental conditions, and structural reinforcement:

- Applying 10 tons of blasting load in water leads to 3 times structure displacement when applying similar load at air.
- Increasing the distance between the offshore structure and the source of blasting leads to reduced structure displacement in absence of water, while lead to increase the structure displacement in presence of water.
- Increasing the distance between the offshore structure and the source of blasting leads to increased structure deformation in absence of water, while leads to reduce structure deformation in presence of water.
- Applying different strengthening cases lead to increase the structure resistance against blasting load incases 1, 2, 3, while using steel plate around the structure lead to increase the structural surface that exposure to blasting and then increasing the structural displacement and deformation.

For future work, it is recommended to investigate the response of different materials under similar blasting conditions, analyze the dynamic response of structures to repeated blasts, and examine the impact of water depth on displacement and deformation. Further research should focus on optimizing strengthening techniques to enhance structural resistance and evaluating the long-term effects of blasting loads, such as fatigue and material degradation.

References

1. Z. S. A.-K. Dr. Abdullah Jabar Hussain, “The Fields of Applying the Recycled and Used Oils by the Internal Combustion Engines for Purposes of Protecting the Environment against Pollutions,” J. Adv. Res. Dyn. Control Syst., vol. 12, no. 01-Special Issue, pp. 666–670, 2020, doi: DOI: 10.5373/JARDCS/V12SP1/20201119.
2. J. Hussain and Z. S. Al-Khafaji, “Reduction of environmental pollution and improving the (Mechanical, physical and chemical characteristics) of contaminated clay soil by using of recycled oil,” J. Adv. Res. Dyn. Control Syst., vol. 12, no. 4 Special Issue, pp. 1276–1286, 2020, doi: 10.5373/JARDCS/V12SP4/20201604.
3. Furlan and C. Mortarino, “Forecasting the impact of renewable energies in competition with non-renewable sources,” Renew. Sustain. Energy Rev., vol. 81, pp. 1879–1886, 2018.
4. R. M. Elavarasan, “The motivation for renewable energy and its comparison with other energy sources: A review,” Eur. J. Sustain. Dev. Res., vol. 3, no. 1, p. em0076, 2019.
5. A. L. I. SHUBBAR, Z. Al-khafaji, M. Nasr, and M. Falah, “Using non-destructive tests for evaluating flyover footbridge: case study,” Knowledge-Based Eng. Sci., vol. 1, no. 01, pp. 23–39, 2020.

6. C. V. Amaechi, A. Reda, H. O. Butler, I. A. Ja'e, and C. An, "Review on fixed and floating offshore structures. Part I: Types of platforms with some applications," J. Mar. Sci. Eng., vol. 10, no. 8, p. 1074, 2022.
7. H. Baardsen, "A concept study on offshore floating hydrogen production, storage, and offloading." The University of Bergen, 2022.
8. Zhang, G. Gholipour, and A. A. Mousavi, "Blast loads induced responses of RC structural members: State-of-the-art review," Compos. Part B Eng., vol. 195, p. 108066, 2020.
9. K. Cragin, S. A. Daly, S. S. Everingham, J. Hoube, M. R. Kilburn, and C. Y. Marcum, The dynamic terrorist threat: An assessment of group motivations and capabilities in a changing world. Rand Corporation, 2004.
10. J. Revill, Improvised explosive devices: The paradigmatic weapon of new wars. Springer, 2016.
11. Kyei and A. Braimah, "Effects of transverse reinforcement spacing on the response of reinforced concrete columns subjected to blast loading," Eng. Struct., vol. 142, pp. 148–164, 2017.
12. M. E. O'Hanlon, "Forecasting change in military technology, 2020-2040," Mil. Technol., vol. 2020, p. 2040, 2018.
13. N. Brown and D. L. Borovina, "The trinity high-explosive implosion system: the Foundation for Precision Explosive Applications," Nucl. Technol., vol. 207, no. sup1, pp. S204–S221, 2021.
14. G. Liu and H. Li, Offshore platform integration and floatover technology. Springer, 2017.
15. W. Smith, Communication structures. Thomas Telford, 2007.
16. R. S. Nair, "Progressive collapse basics," Mod. steel Constr., vol. 44, no. 3, pp. 37–44, 2004.
17. H. Hao, Y. Hao, J. Li, and W. Chen, "Review of the current practices in blast-resistant analysis and design of concrete structures," Adv. Struct. Eng., vol. 19, no. 8, pp. 1193–1223, 2016.
18. Z. Koccaz, F. Sutcu, and N. Torunbalci, "Architectural and structural design for blast resistant buildings," in The 14th world conference on earthquake engineering, 2008.
19. M. S. Ayob, A. E. Kajuputra, K. Mukherjee, and B. S. Wong, "Global ultimate strength assessment of existing offshore jacket structures," in Offshore Technology Conference Asia, OTC, 2014, p. OTC-24938.
20. Z. NIZAMANI, "Environmental load factors and system strength evaluation of jacket platforms in offshore Malaysia." Universiti Teknologi PETRONAS, 2013.
21. M. A. El-Reedy, Marine structural design calculations. Butterworth-Heinemann, 2014.
22. M. Zarrin, B. Asgarian, and R. Fulad, "A review on factors affecting seismic pile response analysis: a parametric study," Numer. Methods Civ. Eng., vol. 2, no. 2, pp. 35–51, 2017.
23. J. A. Pratt, T. Priest, and C. J. Castaneda, Offshore pioneers: Brown & Root and the history of offshore oil and gas. Elsevier, 1997.
24. M. G. Stewart, M. D. Netherton, and D. V Rosowsky, "Terrorism risks and blast damage to built infrastructure," Nat. Hazards Rev., vol. 7, no. 3, pp. 114–122, 2006.

25. G. Mays and P. D. Smith, Blast effects on buildings: Design of buildings to optimize resistance to blast loading. Thomas Telford, 1995.
26. G. J. McKenzie, "Design Criteria for Blast Loadings in the Australian Environment With Special Reference to Controlled and Uncontrolled Implosions." Western Sydney University (Australia), 2018.
27. A. Neuberger, S. Peles, and D. Rittel, "Scaling the response of circular plates subjected to large and close-range spherical explosions. Part I: Air-blast loading," Int. J. Impact Eng., vol. 34, no. 5, pp. 859–873, 2007.
28. A. Neuberger, S. Peles, and D. Rittel, "Scaling the response of circular plates subjected to large and close-range spherical explosions. Part II: Buried charges," Int. J. Impact Eng., vol. 34, no. 5, pp. 874–882, 2007.
29. S. A. Tekalur, A. Shukla, and K. Shivakumar, "Blast resistance of polyurea based layered composite materials," Compos. Struct., vol. 84, no. 3, pp. 271–281, 2008.
30. S. A. Tekalur, K. Shivakumar, and A. Shukla, "Mechanical behavior and damage evolution in E-glass vinyl ester and carbon composites subjected to static and blast loads," Compos. Part B Eng., vol. 39, no. 1, pp. 57–65, 2008.
31. S. A. Tekalur, A. E. Bogdanovich, and A. Shukla, "Shock loading response of sandwich panels with 3-D woven E-glass composite skins and stitched foam core," Compos. Sci. Technol., vol. 69, no. 6, pp. 736–753, 2009.
32. M. S. Hoo Fatt and L. Palla, "Analytical modeling of composite sandwich panels under blast loads," J. Sandw. Struct. Mater., vol. 11, no. 4, pp. 357–380, 2009.
33. S. Defranco, P. O'Connor, F. Puskar, J. R. Bucknell, and K. A. Digre, "API RP 2SIM: Recommended practice for structural integrity management of fixed offshore platforms," in Offshore Technology Conference, OTC, 2010, p. OTC-20675.
34. G. Abaqus, "Abaqus 6.11," Dassault Syst. Simulia Corp. Provid. RI, USA, 2011.
35. H. Sharifian, K. Bargi, and M. Zarrin, "Ultimate strength of fixed offshore platforms subjected to near-fault earthquake ground vibration," Shock Vib., vol. 2015, pp. 1–19, 2015.
36. A. A. Golafshani, V. Bagheri, H. Ebrahimian, and T. Holmas, "Incremental wave analysis and its application to performance-based assessment of jacket platforms," J. Constr. Steel Res., vol. 67, no. 10, pp. 1649–1657, 2011.
37. M. Abyani, B. Asgarian, and M. Zarrin, "Statistical assessment of seismic fragility curves for steel jacket platforms considering global dynamic instability," Ships Offshore Struct., vol. 13, no. 4, pp. 366–374, 2018.
38. T. Elsayed, M. El-Shaib, and K. Gbr, "Reliability of fixed offshore jacket platform against earthquake collapse," Ships Offshore Struct., vol. 11, no. 2, pp. 167–181, 2016.
39. R. H. Cole, Underwater explosions. Princeton Univ. Press, 1948.
40. Y. Jen, "Coupled acoustic–structural response of optimized ring-stiffened hull for scaled down submerged vehicle subject to underwater explosion," Theor. Appl. Fract. Mech., vol. 52, no. 2, pp. 96–110, 2009.

41. A. M. Zhang, X. L. Yao, and J. Li, “The interaction of an underwater explosion bubble and an elastic–plastic structure,” Appl. Ocean Res., vol. 30, no. 3, pp. 159–171, 2008.
42. Y. S. Shin, “Ship shock modeling and simulation for far-field underwater explosion,” Comput. Struct., vol. 82, no. 23–26, pp. 2211–2219, 2004.
43. A. Forghani et al., “Modelling of damage development in blast loaded composite panels,” in the 16th International Conference on Composite Materials, Kyoto, 2007, pp. 1–8.
44. R. Kalavalapally, R. Penmetsa, and R. Grandhi, “Multidisciplinary optimization of a lightweight torpedo structure subjected to an underwater explosion,” Finite Elem. Anal. Des., vol. 43, no. 2, pp. 103–111, 2006.
45. K. Hibbitt and I. Sorensen, “AbaqusTutorial Version 6. 10 Example Problems Manual,” USA2010, 2010.
46. F. Hung, B. J. Lin, J. J. Hwang-Fuu, and P. Y. Hsu, “Dynamic response of cylindrical shell structures subjected to underwater explosion,” Ocean Eng., vol. 36, no. 8, pp. 564–577, 2009.
47. Y. S. Shin, “Naval ship shock and design analysis: course notes for underwater shock analysis,” Daejeon, Repub. Korea KAIST, 2009.
48. N. Zhang and Z. Zong, “The effect of rigid-body motions on the whipping response of a ship hull subjected to an underwater bubble,” J. Fluids Struct., vol. 27, no. 8, pp. 1326–1336, 2011.
49. C.-C. Liang and Y.-S. Tai, “Shock responses of a surface ship subjected to noncontact underwater explosions,” Ocean Eng., vol. 33, no. 5–6, pp. 748–772, 2006.
50. H. Jang, D. Handel, Y. Ko, H.-S. Yang, and J. Miedecke, “Effects of water deck on rock blasting performance,” Int. J. Rock Mech. Min. Sci., vol. 112, pp. 77–83, 2018.
51. H. X. Yu and J. Y. R. Liew, “Steel framed structures subjected to the combined effects of blast and fire-Part 1: State-of-the-art review,” Adv. Steel Constr., vol. 1, no. 1, pp. 67–84, 2005.
52. Ainalis, O. Kaufmann, J.-P. Tshibangu, O. Verlinden, and G. Kouroussis, “Modelling the source of blasting for the numerical simulation of blast-induced ground vibrations: a review,” Rock Mech. rock Eng., vol. 50, pp. 171–193, 2017.
53. J.-H. Choi, S.-J. Choi, J.-H. J. Kim, and K.-N. Hong, “Evaluation of blast resistance and failure behavior of prestressed concrete under blast loading,” Constr. Build. Mater., vol. 173, pp. 550–572, 2018.

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