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Improvement Analysis of Response Between Jacket Platforms and Sea Waves using the Vibration Dampers

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Abstract: Offshore fixed metal platforms have unique characteristics in specific location such as shallow waters, and oil platform may be physically connected to seabed. Offshore platforms in the sea are affected by complex and destructive forces caused by wind, waves, marine currents, earthquakes and even large displacement vortex forces. The purpose of refurbishing metal fixed platforms is to somehow equalize the capacity of the structure with its seismic requirements. In some cases, they increase the capacity of the structure to meet seismic requirements. In this research, dynamic vibration absorbers or dampers, such as passive dampers, fluid system adjusted for damping vibrations and reduced structural response against wave and earthquake hydrodynamic loads will be used as an efficient control method. The purpose of this research is to improve the performance of the liquid platform vibration damping of the metal platform. The results show that equipping offshore platforms with liquid damping systems has a good performance on the safety and dynamic behaviour of the platforms and has a significant effect on the displacement response and acceleration of the platform under study at its highest deck level. Also, as the water depth in the tank increases, the damping value for the rectangular and cylindrical tanks decreases and the rectangular tank creates more control and damping force than the cylindrical tank.

Keywords: Eulerian, Fluid Solution Field, Initial Conditions, Inertial Forces, Liquid Damper with Rectangular Tank, Navier-Stokes Equations

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Research paper

1 INTRODUCTION

Offshore structures are fundamentally different from structures built on land. Fixed template platforms are exposed to environmental loads such as wind, waves, currents, earthquakes, etc.; While the structures built on land are only under gravity, earthquake and wind loads. Also, the template platforms are affected by the interaction with the water around the structure, and in many cases these effects should be considered in the design of the structure. On the other hand, the foundations of template platforms are generally piles that pass through the foundations of the platform and are driven at the level of the seabed to a certain depth. These piles, in turn, interact with the soil around them. Fixed offshore platforms of template type are widely used in areas with water depth of less than 100 meters due to relatively easy design, transportation and installation compared to other types of platforms. Of course, these types of platforms are also installed in areas with a depth of more than 300 meters. When the lateral force is applied to the metal platform, a specific displacement occurs in the structure. If this load is under the influence of a non-uniform force or an earthquake in a dynamic way, the structure starts to vibrate in different vibration modes. In the reliable design of an offshore structure, the accurate calculation of the dynamic response is important and is of great importance in increasing the safety and service life of such structures. Therefore, the problem of dynamic movements and vibration in fixed template platforms is a fundamental problem in their analysis and design. (Investigating the performance of the dynamic response and vibrations of the template fixed metal platform is also one of the goals of this research). Therefore, using a control system in order to increase the fatigue life of these platforms is more important than controlling vibrations just to limit the displacement range. In general, different methods are used to design structures against dynamic forces. A structure with a combination of hardness, formability, and energy consumption shows resistance. Normally, the amount of damping in structures is very low and the consumed energy is very small within the range of elastic behavior of the structure. But when strong dynamic forces are introduced to the structure, large changes in places are created in the structure. In this case, the structure remains stable only because of the ability to change the inelastic place created in it. Such a change of places causes the local plastic joint to occur in the points of the structure, which itself increases the formability and also increases the energy consumption. In this case, a large amount of energy is consumed due to local damage in the lateral resistance system of the structure. The safety of a structure can be reduced by reducing the weight, replacing the weak members or increasing the stiffness of the structure, so that the natural frequency of the structure's vibration is far from the frequency of amplification. These methods are often associated with high costs or may not be possible at all. Among the methods that have been noticed in recent years for the strengthening of structures is the use of energy absorbing systems, which provides a reduction in the displacement of the structure to an optimal level. The studies conducted in the discussion area of this research have a great diversity. Extensive studies have been conducted on the issue of seismic control of template platforms against various loadings such as waves, wind, earthquakes and ice, and in this way, various control systems have been used by researchers. Dynamic loads not only affect the operation process of the platform, such as drilling and production, but also affect the safety and serviceability of the structure, and it is reasonable that the values of the dynamic responses of these structures decrease against dynamic loads. Generally, reducing the range of dynamic stresses of a marine platform by 15% can increase the service life of the platform by two times, and this issue can lead to a reduction in maintenance and inspection costs [1]. In order to control the seismicity of template platforms, different methods can be used. One of the most appropriate and up-to-date methods for seismic control of structures is the use of active and passive systems for controlling the structure. By using the mentioned control systems, instead of increasing the capacity according to the usual methods, we reduce the demand. Today, these systems are developing rapidly and a large number of structures have been equipped with these systems. The main reason for the development of this new technology is the oil industry and its need for offshore platforms to exploit the significant hydrocarbon resources in the offshore environment. Modern methods and materials have made it possible for engineers to build very tall, lightweight and flexible structures. Although these structures are economical, they are sensitive to different loads. Excessively conventional movements of the structure can cause damage to non-structural elements and equipment on it (2012, Love, Tait). Therefore, it is necessary to research and investigate practical and effective equipment that can reduce these vibrations and displacements and depreciate the incoming energy. In parallel with the use of these systems, research has also been done in this field in the field of marine structures. Kevanu and Venkatheramana [2] investigated the responses of offshore platforms with active weighted mass damper and found that this system is quite effective in reducing the structural response against hydrodynamic loads of waves and earthquakes. Abdul Rahman [3] conducted a study on the application of active and passive control mechanisms to reduce the dynamic response of steel template platforms against the wave load. Using stochastic analysis, Lee [4] described the effect of viscoelastic cases used in templated platform footings. Soneja and Datta [5] described the effect of active control system in minimizing the responses of articulated foundation platforms against wave load. Wang [6] investigated the effect of magnetic rheology dampers in reducing the response of offshore platforms against wave load. Mahdik and Jainjid [7] studied the response of template platforms armed with measured mass damper against wave load. Vandiver and Mittum [8] used storage tankers on the platform as metered liquid dampers (TLD) to reduce responses under wave loads. Vincenzo and Roger [9] used the adaptive control technique (active mass damper) to reduce the response of the platform against the tornado load. Also, Avo et al. [10] and Ding [11] conducted numerical and laboratory studies. Padil and Jainjid [12] applied three types of viscoelastic, viscous and frictional dampers on the platform to study its behaviour under wave load. Also, Avo et al. [10] evaluated the behaviour of a platform equipped with a deck isolator under ice and earthquake loads. Today, seismic control systems are the most common tools for reducing the vibrations of structures, and engineers are looking to reduce the dynamic responses of structures by designing Mir if systems. Nevertheless, the works carried out in the field of controlling offshore structures have been mostly experimental and theoretical, and in practice, less platforms have been equipped with these systems. In this research, a dynamic vibration absorber (DVA) with passive dampers, a regulated liquid system (TLD) was used in order to depreciate and control vibrations and reduce the response of the structure against the hydrodynamic loads of waves and earthquakes (in order to limit the range of displacement of the deck)[2], which is one of the effective control methods. In order to maintain the safety and increase the efficiency of the platform, by using a liquid damping tank on the platform deck, which is a simple and cheap system, it can effectively reduce the dynamic responses of the structure by using the mechanism of increasing the natural period of the structure and inducing damping to the structure waves and earthquakes in critical loads.[1]

2 METHOD OF RESEARCH

Quays and offshore platforms in the sea are affected by complicated and destructive forces of wind, waves, ocean currents, earthquake, and even forces resulted from vortices. These forces cause large displacements in platforms or quays, imposing negative effect on safety and serviceability of marine structures, in terms of exploitation. In the research and in order for marine and structure parameters to be analyzed; hydrodynamic ANSYS Aqwa software and ANSYS Transient Structural Analysis have been used for simulation, considering platform dynamic interaction with hydrodynamic forces. Using hydrodynamic ANSYS Aqwa software, equations governing fluid flow including continuity and momentum equations have been discretisized and simulated through “boundary element method”, considering fluid incompressibility. The approach concerns analyzing sea hydrodynamic parameters in two frequency and time domains; considering the point that rocking motions may cause overturn of gravity structure. The motion with one degree of freedom has to be considered as an important part of structural design and analysis, through modeling soil mechanics and hydrodynamic properties of the problem. In this respect, effects of seabed on damping of structural rocking motion, and also hydrodynamics of structure have to be computed through diffraction theory and Morrison’s formula. In the research, tuned liquid damper efficiency in controlling and reduction of offshore jacket platform’s vibrations under hydrodynamic forces will be discussed. Tuned liquid damper system has been rarely used in offshore structures. These types of dampers formed by one or more fluid (usually water or oil) tanks may be installed on platform’s deck. Hydrodynamic forces stemmed from fluid turbulence within tank(s) act as resistant force against structural vibration. When structure is stimulated by external forces, fluid inside tank moves in opposite side of structure’s movement. This results in oscillation of a part of fluid in form of waves; while, the other part being closer to bottom of the tank moves rigidly and impacts tank’s wall. In order for fluid motion inside tank to be capable of considerable reduction of structure’s displacement, fluid oscillation frequency have to be close to natural structural movement frequency, which may be specified through Modal analysis. The research is mainly aiming at adjusting frequency of fluid oscillation inside tank according to the natural frequency of structure, i.e., obtaining the range of frequency ratio against which structural range of movement decreases considerably. In the research, a template platform with dimensions suitable for Persian Gulf waters i.e., SPD platform has been reviewed as a case study. In this study, numerical approaches will be used (finite element elasto-plastic solids and finite volume Eulerian fluid modeling for liquid damping) Restricted components are used. Also in this research, finally, the analysis of the improved vibrational behaviour of the wave interaction and structure of the fixed metal platforms and the geometrical effect of the damping tank, the damping with the rectangular and cylindrical cube tank were used and compared.

2.1. Governing Equations

Design forces imposed on offshore platforms are stemmed from wind, ocean currents and waves, from among which waves impose huge force on submerged structure of offshore platforms. Such force imposed on body of an object stems from velocity and acceleration of fluid particles, caused by waves. When dimensions of object are bigger than wavelength, wave shape completely differs after collision with the object. In such case, Laplace equation is obtained while discussing wave hydrodynamics has to be considered as the governing equation; adding lack of flow towards inside the object, as a provision to it. The provision results in creation of diffracted waves which impose forces to the object, just like main waves. Overall force imposed on the object is equivalent to resultant of these forces and forces imposed on the object from main wave.

In general, to study diffraction phenomenon, total potential of the field Φ_t will be considered as sum of incident wave's potential Φ_i and scatter wave's potential Φ_s [7].

$$\Phi_t = \Phi_i + \Phi_s \tag{1}$$

Lumped mass and damping coefficients are created due to gravity platform's motion. These coefficients are highly effective on performance of gravity platform; so, method of calculating these coefficients via software has been referenced to.

Potential function affected by platform displacement includes two imaginary and real parts as mentioned below:

$$\emptyset_j = \emptyset_j^{Re} + \emptyset_j^{Im} \tag{2}$$

Lumped mass coefficient:

$$A = \frac{\rho}{\omega} \int_S \emptyset_j^{Im} \, n_i dS \tag{3}$$

Damping hydrodynamic coefficient:

$$B = \rho \int_S \emptyset_j^{Re} \, n_i dS \tag{4}$$

Were,

φ_j: Potential stemmed from oscillatory motion of object in still water;

n_i: Vector perpendicular to surface; and,

S: Wetted perimeter of the object in equilibrium.

3 GEOMETRIC FEATURES AND NUMERICAL SIMULATION

In the research, rocking motion of a gravity platform under wave's torque has been formulated and modeled; then, it was solved through harmonic response of sustainable rotation angle method. The theory governing interaction of waves and platform is called diffraction theory; and, after solving platform's surroundings' velocity potential function, dynamic pressure of wave has been obtained via first and second types of Bessel functions. Another important step in designing offshore structures is inspection of soil where equipment has to be located. Soil inspection is of specific importance; because it is soil characteristics of deep sea that has to resist against forces and stimulations related to oil platform in depth of water especially under stormy condition. Seabed soil may consist of clay, sand and mud and/or a combination of them. Soil properties in each project have to be examined against load toleration under pressure and tension, and also shear stress. Displacement characteristics of axial and mass forces also have to be studied and reported to authorities. The report based on sampling of soil, and performance of specific site or laboratory tests on it provides useful information to design engineers. Considering analysis of tensions and strains resulted from forces imposed by sea and also damper's performance, ANSYS Transient Structural Analysis will be used for simulation. Among basic points in need of consideration in numerical simulations, reference could be made to imposing such boundary conditions as bearing conditions and degrees of freedom, in addition to imposed forces. ANSYS Workbench has been used in the research for analysis of marine and structural parameters, applying capability of such modules as ANSYS Transient Structural Analysis and ANSYS Aqwa. So, the research is based on following hypotheses. Should other conditions be intended, mathematical equations have to be modified. In addition to linear wave theory and harmonic regular waves, metal platform of the structure has been considered to have four rigid legs. Waves are of random and irregular nature; and, analysis of their time history is of high importance for evaluation of offshore structures. Time history of waves has two fundamental characteristics: major wave height and frequency content. These two are dependent on various factors such as field of study, sea status, and etc. Using waves' energy spectrum, and having oceanography data of the region at hand, desirable time history may be achieved. In the approach, numerical methods are used to analyze structural response to irregular waves through JONSWAP spectrum parameters; and, its response to regular waves through Stokes wave theory. Meanwhile, performance of various wave parameters on hydrodynamic forces will be evaluated, in addition to response of the riser to fixed metal platform with four legs (See "Fig. 1"). In the research, a jacket platform with dimensions appropriate for Persian Gulf waters e.g., SPD platform has been case studied, after optimum design of dampers. Considering geographical location of the platform in South Pars field, environmental conditions and specifications of the region are as follows:

$$(\rho = 1025 \, {}^{kg}/_{m^3}, \; g = 9.81 \, {}^{m}/_{s^2}, H_0 = 6.7m, \; T = 8.6 \, s, H = 67m)$$

$$\omega = \frac{2\pi}{T} = 0.730 \left(\frac{rad}{s}\right) \quad (5)$$

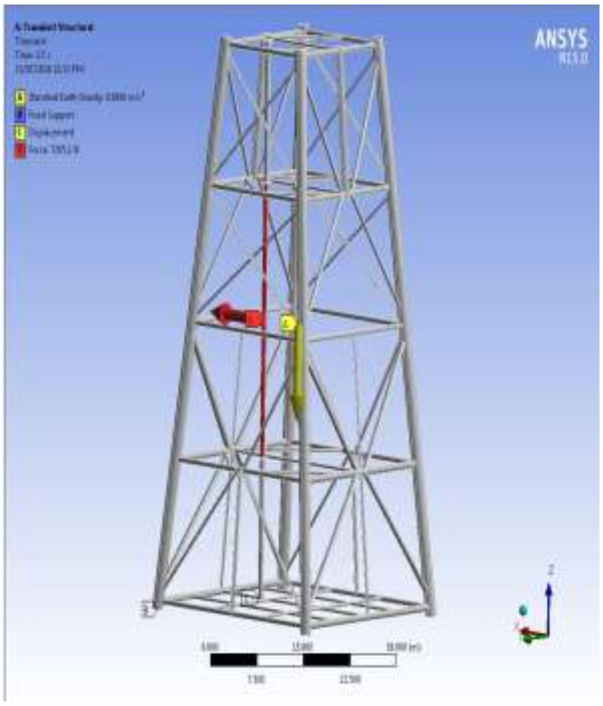


Fig. 1 A view of structural boundary conditions and riser, bearing on metal platform in model.

3.1. Tuned Liquid Damper

In tuned liquid damper system as an inactive control tool, effects of water turbulence in a tank are used to control structural vibration. Tuned liquid damper has been first used at the beginning of 20th century to control vibrations stemmed from sea waves, occurring in ocean liners. Then, in second half of 20th century, it was used for controlling free oscillations with high frequency cycle in satellites. Since the mid-eighties, tuned liquid damper has been applied to control vibrations in reconstructive structures. Usage procedure of the system is as mentioned below: a number of tanks are installed on top of structure, and fluid turbulence within these tanks damps vibrational energy imposed on the structure, during earthquake or hurricane. Such turbulence creates difference in values of free surface of fluid in lower end shells of tank; and, pressure difference stemmed from such difference in values appears as a shear force in tank floor. Control force used in the method for reduction of structural vibrations stems from dynamic pressure imposed on surface of tank wall. For optimum design of these systems i.e. to considerably reduce structural vibrations, damper's frequency has to be adjusted according to frequency of first vibration mode of the structure.

Therefore, properties of damper e.g., tank's dimension and depth of water inside it have to be determined so that frequency of fluid turbulence inside tank would become coordinated with vibration frequency of structure. To simulate tuned liquid damper behaviour in limited element methods, simplified methods have been proposed, the most important of which are lumped mass and linear wave theory methods. In lumped mass method, tank wall is supposed to be rigid; and, hydrodynamic pressure created by fluid turbulence inside the tank which is resulted from dynamic stimulation is considered in two forms of impact pressure and oscillatory pressure. Impact pressure is proportionate to fluid tank acceleration, but in its opposite direction. Oscillatory pressure is related to height of formed wave on free surface of the fluid; and, it follows frequency of fluid oscillation. Aforementioned hydrodynamic pressures could be replaced through two equivalent lumped masses connected to the tank's wall, in two opposite directions. Pressure simulation is oscillatory. In continuation, relationships related to calculation of fluid oscillation frequency inside the tank are presented.

Steel properties for jacket platform modeling as well as physical and mechanical properties of water for tuned liquid damper modeling are presented in "Table 1".

Table 1 Steel and water properties for modeling

Density	7850kg/m3
Elasticity modulus	210GPa
Poisson's Ration	0.3
Water	
Density	1000kg/m3
Bulk modulus	2.068

Best networking in terms of shape and accuracy is enhanced networking as shown in "Fig. 2".

It goes without saying that, number of created cells will be higher and problem solving will take more time. Elements under study have to meet certain conditions so that software performs better. Maximum value of used elements will be defined according to maximum frequency of the incident wave. Smallest period under study in the paper has been considered to be 2.39s. Considering 2.39s as the period, maximum frequency of incident wave would be 0.418Hz. Accordingly, next maximum that could be defined for elements under study would be 2m. Of course, numbers of created diffraction elements (below water level) have not to exceed 18000; because software is not capable of solving equations with more than 18000 elements.

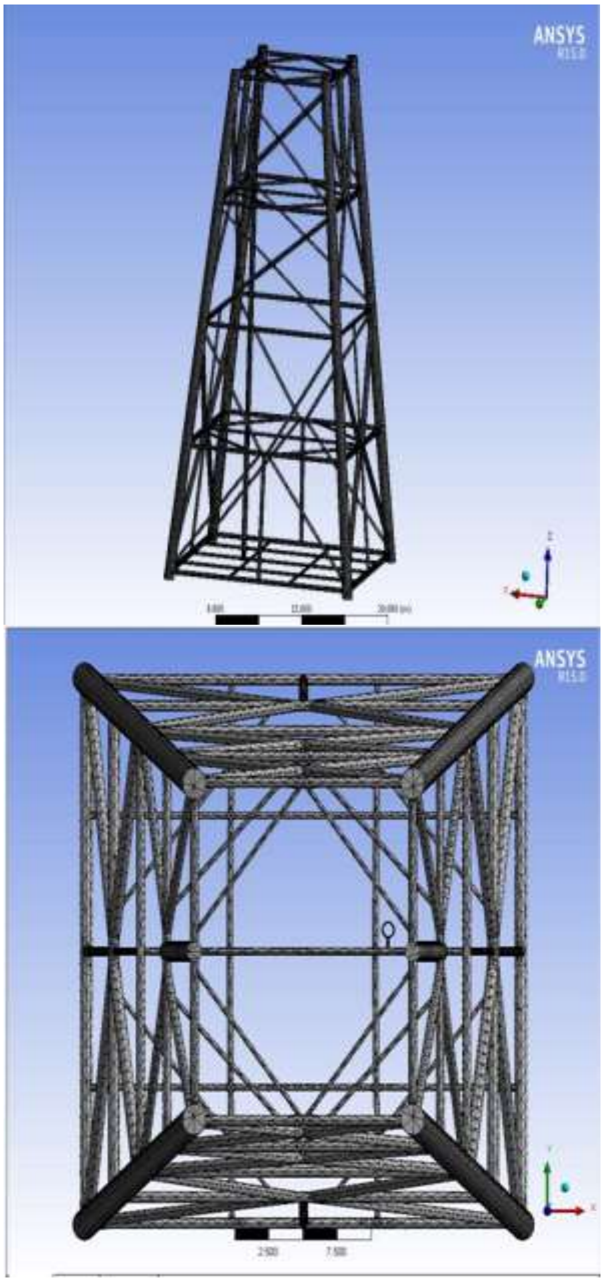


Fig. 2 A view of geometric configuration and networking.

4 RESULTS ANALYSES

4.1. Analyzing Effect of Wave's Hydrodynamic Parameters and Structural Response

Waves are of irregular and random nature and analyzing their time history is of high importance in evaluation of offshore structures, (See "Fig. 3 to 5")

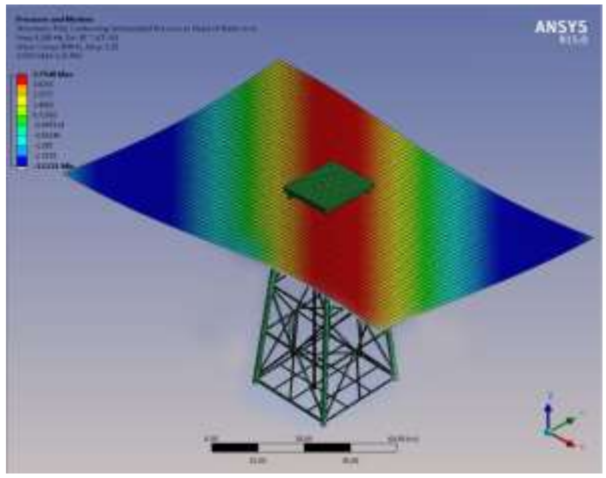


Fig. 3 A view of wave resulted from hydrodynamic pressure at an angle of incidence of period of 8.6s, and wave height of 6.7m (in one period) in frequency domain.

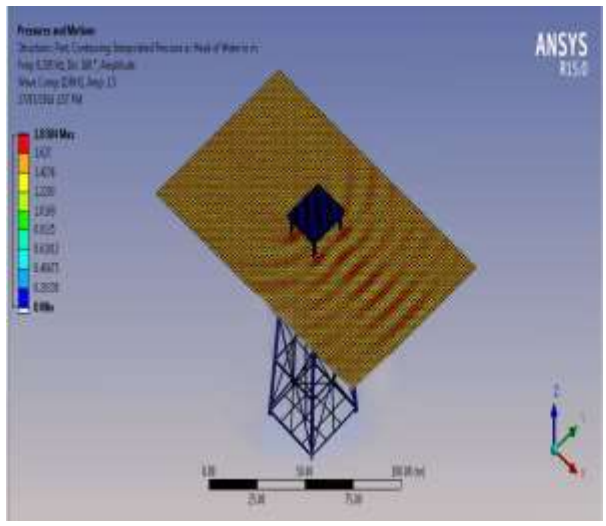


Fig. 4 A view of wave resulted from hydrodynamic pressure at an angle of incidence period of 3.38s, and wave height of 3m (amplitude) in frequency domain.

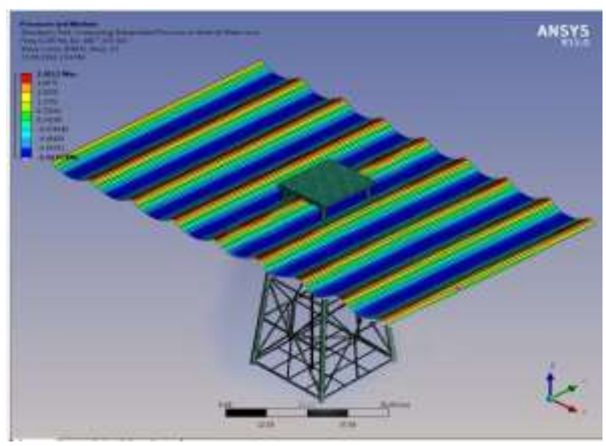
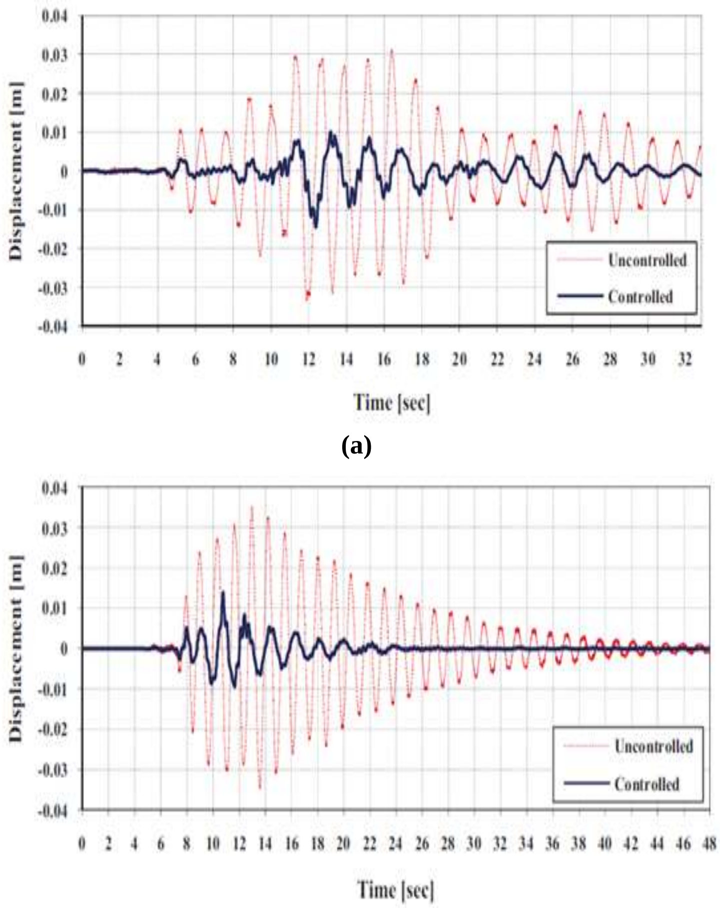


Fig. 5 A view of wave resulted from hydrodynamic pressure at an angle of incidence of period of 3.38s, and wave height of 3m (period) in frequency domain.

4.2. Comparison of the Main Acceleration and Displacement of The Highest Surface of The Platform under the Time Basin

Waves are random and irregular in nature and their time history analyses are highly important for evaluation of offshore structures. Time history of waves has two main characteristics as: major wave height, and frequency content. These two characteristics are dependent on various factors including field of study, sea status, and etc. Meanwhile, having regional oceanography data at hand and using energy spectrum of waves, desirable time history is achievable. In this research, finally, the analysis of the improved vibrational behavior of the wave interaction and structure of the fixed metal platforms and the geometrical effect of the damping tank, the damping with the rectangular and cylindrical cube tank were used and compared. Therefore, the performance of the studied platform in two cases is not equipped with TLD system and equipped with liquid damper system under Tabas earthquake record with maximum acceleration of 0.15 g. For this purpose, in addition to the maximum structural response criterion, the criterion for absorbing the mean squares of the structural response during the analysis period has also been evaluated and evaluated. The comparative results in the platform analysis under study include the highest plane displacement of the platform, base platform shear, main platform acceleration, relative displacement between two platform deck levels, the maximum equivalent stress of the platform, and the dynamic properties of the platform. To analyse the behaviour, the time history diagram of the displacement of the highest surface of the platform substructure, for the two uncontrolled and uncontrolled states, is shown below for the two geometrical forms of the damper tank, as shown in “Fig. 6” and “Table 2”. Based on this figure, it is possible to realize the superior performance of the rectangular liquid damping system in controlling the displacement of the highest surface of the platform structure.



(b)

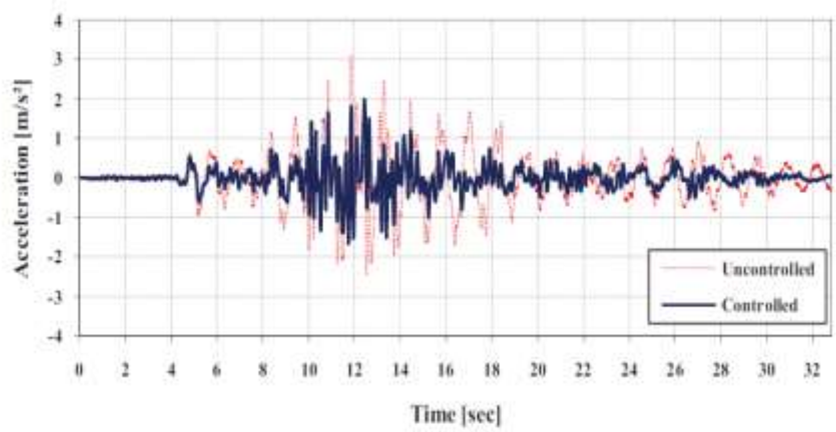
Fig. 6 Time history of displacement of the highest level of platform substructure for uncontrolled and controlled earthquake modes: (a): Cylindrical tankand (b): Rectangular Cube Tank.

Table 2 Influence of damping system on the displacement parameter of the highest surface of the platform substructure

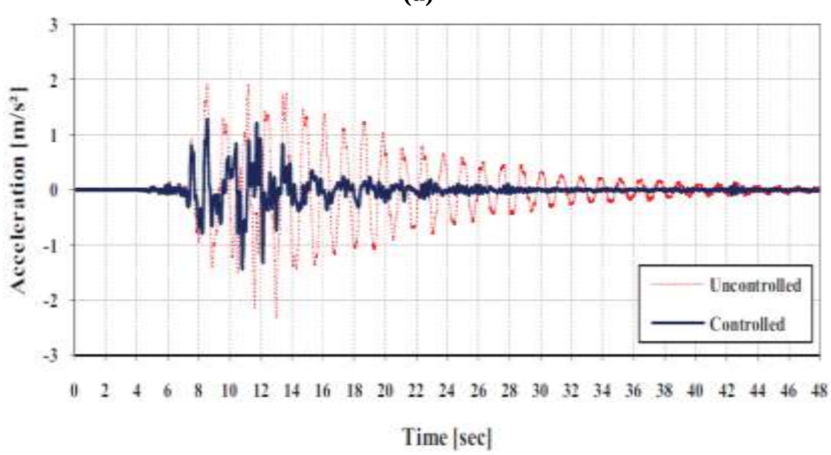
Earthquake	Maximum displacement of substructure cap (cm)		Percentage Reduction (%)	RMS displacement of substructure cap (cm)		Percentage Reduction (%)
	Uncontrolled	Controlled		Uncontrolled	Controlled	
Rectangular Cube Tank	3.34	1.44	56.89	1.17	0.30	74.36
Cylindrical Tank	3.34	1.68	49.70	1.17	0.52	55.55

Based on this figure, it is possible to realize the superior performance of the rectangular liquid damping system in controlling the displacement of the highest surface of the platform structure.

It was observed that equipping the platform structure with the rectangular cubic damper system significantly reduces the acceleration of the main deck, (See “Fig. 7 and Table 3”)



(a)



(b)

Fig. 7 Acceleration time history of the main deck for uncontrolled and controlled earthquake modes: (a): Cylindrical tank and (b): Rectangular Cube Tank.

Table 3 Influence of damping system on the main deck acceleration parameter

Earthquake	Maximum acceleration of deck(m/s^2)		Percentage Reduction (%)	RMS acceleration of deck(m/s^2))		Percentage Reduction (%)
	Uncontrolled	controlled		Uncontrolled	controlled	
Rectangular Cube Tank	3.09	1.99	35.60	0.64	0.35	45.31
Cylindrical Tank	3.09	2.35	23.94	0.64	0.44	31.25

5 CONCLUSIONS

According to results, the effect of the fluid damping system on the dynamic response of the platform under stimulation is evaluated by the hydrodynamic force and the effect of the damped fluid damping system on the dynamic response indicates that the use of the adjusted liquid damping system can lead to a significant reduction in the dynamic response of the platform. TLD liquid dampers are less effective in structures with high hardness. The more shaping the structure, the more damping it is, the better the control effects on the dynamic response and the better the damping of the structure.

Using the damper system, the earthquake input energy to the platform structure is greatly reduced and a significant portion of the reduced input energy is also wasted in the damper system, which results in major structural members such as brackets, pedestals, and so on. It is reduced and the structure can be optimized. Also, as the water depth in the tank increases, the damping value for the rectangular and cylindrical tanks decreases and the rectangular tank creates more control and damping force than the cylindrical tank.

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