



Analysis of Finite Elements of Using the Tuned Liquid Damper in Architectural and Structural Structure of Stencil Platforms Affected by Earthquake Waves

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Abstract

The most common types of fixed offshore structures in marine areas around native settlements that are used today are jacket or stencil platforms. Nowadays, researchers pay great attention to modern methods of absorbing earthquake, wind and other side forces in strengthening built structures. The input energy to the structure could be reduced by adding some systems in different pieces of the structure (built or being built), hence greatly reduce the structure reaction and caused damages. to achieve this, new technologies regarding dampers could be used. In this paper the effectiveness of the tuned liquid damper system (TLD 1) in controlling the dynamic responses of templated offshore platforms (jackets) in marine areas around native settlements under earthquake waves is investigated. In this paper, a stencil platform with suitable dimensions was modeled under certain earthquake with and without dampers, and then the model was analyzed with modal and time history analysis. After certifying the models, the structure behavior was compared in two with and without TLD modes, and after studying the quantitative and general results, it turned out that using tuned liquid dampers in the lower deck of the platform is much more suitable and optimized than other methods.

Keywords: Stencil platform, tuned liquid damper, earthquake force, SPD21 platform.



1- Introduction

One of the most common steel platforms is the stencil and self-lifting platform and the restrained tower [3]. The infrastructure of these platforms are spaced frames and are built from partial connection with usually hollow circular bases. The tuned liquid damper system is used in a structure as a non-active control tool to control the vibration of the structure by using the water turbulences in a tank [4]. The TLD system is consisted of one or several tanks which contain a liquid which is mostly water. These tanks are installed in the different parts of the structure and the stored water turbulences is used to control the structure vibrations [5]. This system works as such: some tanks are installed in the lower part of the structure and the turbulence of the liquids inside these tanks absorb some of the vibration energy from the side forces. [7] The hyper-beach platforms are exposed to the environmental forces such as sea waves, torrents, wind and earthquakes. Therefore, controlling the quakes of these structures could be in the center of attention to save used materials, increasing life time, and increase structure reliability while facing earthquakes [8]. The most common methods to control structures against vibration forces are using dampers and damp increasing systems and viscosity dampers which absorb the input energy to the structures [10]. The TLD system which is one of the non-active dampers is commonly used because of its fair cost and easy implementation compared to other non-active dampers, and viscosity damper is one of the comparable dampers [11]. This study analyzes the status of the TLD and its effects in reducing and moving the stencil hyper-beach platforms affected by the earthquakes. These dampers which are made of one or more tanks which have liquid (usually water or oil) in the, could be installed on the platform deck. The hydrodynamic forces which are created from the turbulences of the liquid in the tank, act as the resistant forces against the structure vibration. So, tuning the frequency of the liquid inside the tank with the natural frequency of the structure, or in other words obtaining a frequency ration range in which the structure movement domain is considerably reduced, is one of the main goals of this study.

2-Material features and the acceleration of the used mappings

The physical and chemical features of the water for modeling the TLD and steel and water features for modeling are presented in table 1 and the used maps acceleration features are shown in table 2.

Table 1. Water and steel features for modeling [1]

<i>Steel</i>
<i>7850 kg/m density</i>
<i>210Gpa elasticity module</i>
<i>0/3 Poisson's ratio</i>
<i>Water</i>
<i>1000 kg/m density</i>
<i>2/068 Gpa bulk module</i>



Table 2. Used mappings acceleration features

<i>Earthquake</i>	<i>Magnitude (M)</i>	<i>PGA (g)</i>	<i>Time step (s)</i>	<i>Duration (s)</i>
El-Centro (1940)	6.95	0.215	0.01	40
Tabas (1978)	6.9	0.503	0.01	40.95
Qeshm (2008)	6.1	0.792	0.02	28.8
Kermanshah (2017)	7.3	0.801	0.02	30

3- Case study features

SPD21 well platform used for case study in this paper is one of the south Pars phase 1 sea platforms and is the only platform installed in phase 21 in Iran. The extraction platform is designed with 4 stands and the bridge and torch platforms are designed with 3 stands. The diameter of the well platforms stands is 60 inches and includes 15, 26 inches raisers to connect to the well. The 2700 tons platform in south Pars phase 21, which is designed to extract 1 billion square foot gas from this gas field, was initialized in 1395 (2016), and structure's magnificent changes due to excessive wind and wave and earthquake forces justifies the need to add and model the controlling damper systems. The service place of this platform is installed at 79 meters deep, is located at N"54 36 and E"29 11. SPD21 platform consists of three main parts: jacket, candles and deck. This platform's deck's dimensions are 30*18 meters and includes 3 levels: lower deck with the height of 14 meters from the water surface, Mezzanine deck with the height of 18 meters and top deck with the height of 20 meters from the water surface. This deck is on a 6-stand jacket which is connected to the sea floor by 6 candles which are installed from the inside of the stands. The platform plan dimensions in the sea floor level are 39*25 meters. The maximum diameter of platform stands is 8.1 meters and the whole mass of it is 4400 tons. The equations of the project are as shown in relation (1). In relation 1, h_0 is the height of the liquid inside the tank, g is the gravity acceleration, w is the angular frequency in rad/s and f is the frequency in Hz. The value of a equals the tank length for rectangle tanks and tank diameter for cylinder tanks.

$$\omega_0 = \sqrt{\frac{\pi g}{a} \tanh\left(\frac{\pi h_0}{a}\right)} \quad (1)$$

$$f_w = \frac{1}{2\pi} \sqrt{\frac{\pi g}{a} \tanh\left(\frac{\pi h_0}{a}\right)}$$

4- Modeling and analysis of the limited parts

To model the jacket parts, the used elements should be able to consider hydrodynamic forces effects and also the added weight. The candle modeling method in this study is one



of the simplified methods called equivalent length method. This method uses a candle with equivalent length instead of modeling candle's whole length and soil around it. This candle is considered to be clipping at its endpoint. Such that the hardness specifications of the candle in the sea floor matches the real candle specifications. 8D to 12D is proposed as the clipping equivalent length for platforms in places which their soil is made of weak clay layers. In this study, the candle length is 3.1 meters and the candle length inserted in the soil is 12D which equals 8.20 meters. PIPE16 element is used for modeling the candles. The candles are modeled inside the stands and all the knots are coupled horizontally with the knots of platform stands. Therefore, candles and stand have the same movement horizontally. The PIPE16 element is used to model the deck stands and SHELL63 and PIPE16 elements were used to model the platform deck. The weight of the equipment on the platform deck is applied using SHELL63 element. Figure (1) shows a view of the geometrical model of the whole platform and a close up of its deck.

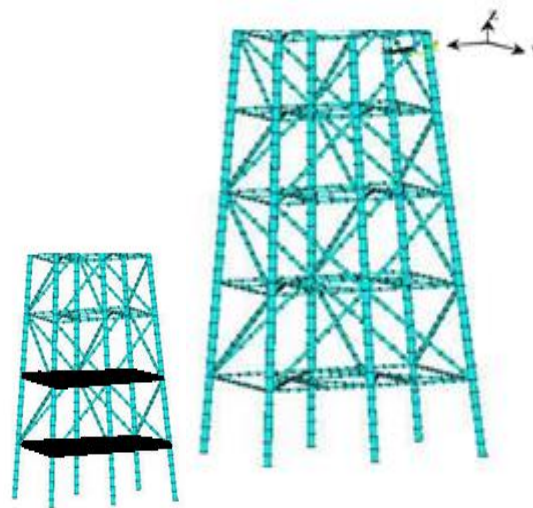


Figure (1). A view of the produced geometrical model and the lower deck for the SPD21 platform

The damper is made of four cubic steel tanks with 3*3*5.2 dimensions which is filled with water to the height of 5.1 meters and is located at the lower deck of the platform. SHELL63 element was used to model the tank. This element is 2 dimensional and has four knots, and each knot has 3 degrees of translational freedom and 3 degrees of rotational freedom. FLUID80 element was used to model the liquid inside of the tank. This three-dimensional element has 8 knots and each knot has 3 degrees of rotational freedom. The FLUID80 element has the ability to consider the interactive effects of the liquid and solid by calculating the hydrostatic and hydrodynamic pressures. This element considers the liquid homogeneous, non-viscous, non-compatible and non-rotational. The elasticity module considered in this element equals to the water module. The complex behavior of the free surface of the liquid is modeled using the non-linear waves theory in the FLUID80 element and a weight spring is considered on each knot of the liquid surface to maintain the continuity of it



To increase the TLD effect in reducing the structure vibration, the tank liquid's swing first mode frequency should be equal to the main frequency of the structure vibration. This study, first conducted the modal analysis on the SPD21 platform to design the TLD and achieve the effective parameter, and the obtained structure vibration first mode frequency was 488.0 Hz. The liquid containing tank was modally analyzed by applying the interaction of the liquid and the solid by coupling the knots of the liquid and the solid which intersect and also choosing the main freedom degrees for the liquid. The first swing mode of the liquid inside of the tank was 0.487. These freedom degrees are chosen on the liquid surface and the tank walls. Using the main freedom degrees causes the hardness matrix to be exact and the mass matrix to be an approximation. The main freedom degrees are only chosen in a vertical axis for the liquid surface and for the tank walls, the main freedom degrees are chosen in the structure vibration axis. The number of chosen main freedom degrees must at least be twice the number of the considered modes in the modal analysis.

5- The acceleration of the chosen mappings and equalizing their bases

The mapping accelerations are chosen such that they match the environmental features of the platform's installation location regarding frequency content, earthquake duration, and construction site soil. The used mapping accelerations in this study are related to the America's El-Centro (1940), Iran's Tabas (1978), Iran's Qeshm (2008) and Iran's Kermanshah (2017) earthquakes. The variation of the answers is limited and the results will be more compatible by equalizing the bases of the mapping accelerations. In this study, all the records are in the same base with the maximum acceleration of the platform's shaping surface which is 0.35g.

6- Modal analysis

The modal analysis was conducted to determine the shape modes and the natural frequencies of the platform's free vibration on the limited parts model of the SPD21 without TLD tanks. The obtained frequencies were used to validate the limited parts model, optimal design of the damper system and also define the Rayleigh damping in the time history analysis. After comparing the first 10 frequencies of the produced model of the SPD21 platform frequencies, which is extracted from the Bargi and colleagues (2011) paper [9], it turned out that the limited parts model has enough precision. The modal analysis results and its comparison with the real structure frequencies is presented in table (3). To validate the produced model for the TLD, the modal analysis was conducted on the liquid containing tank by the reduced method after obtaining the tank dimension and also the water height. The first swing mode frequency was 427.0 which has a very good compatibility with the frequency obtained from relation (1)



Table (3)- platform's modal analysis results

<i>Mode number</i>	<i>Limited parts model frequency (Hz)</i>	<i>SP2 platform frequency</i>	<i>Difference (%)</i>
1	0.439	0.425	0.1
2	0.538	0.528	0.5
3	0.802	0.790	0.3
4	1.46	1.41	0.05
5	1.48	1.40	0.08
6	1.88	1.65	0.23
7	2.45	2.33	0.12
8	2.92	2.56	0.36
9	2.93	2.68	0.25
10	3.2	3.1	0.1

7- Time History Analysis

The chosen mappings' accelerations records were adjusted into a column file to be used in the time history analysis. Since the first swing mode of the used TLD in this structure is alongside the y axis, as same as the platform's first swing mode, therefore we have used the y component of the 3 chosen earthquakes. For time history analysis of the platform, the said records were applied alongside the y axis of the model's coordination system, by a macro file, as an acceleration history in the clipping level of the equivalent candles as horizontal mono-components. Figure (2) displays the width component of the mapping acceleration of the Qeshm earthquake as a sample. To study the effect of the TLD on the dynamic responses of the SPD21 platform, the non-linear time history analysis seems fitter compared to other methods. In this study, the studied platform was analyzed in two with and without damper modes by non-linear time history analysis. 4 dampers were used in the platform with TLD, which were installed symmetrically in the lower deck of the platform. Figure (5) shows the SPD21 platform with the TLD. As seen in this figure, the first swing mode of the liquid inside the tank is alongside the y axis of the platform's coordination system. In figure (3), the structure tends to the left and the liquid inside the tank tends to the right. In fact, according to this figure, the liquid inside the tank always swings in the opposite direction of the platform's movement and reduces the dynamic responses of the platform.

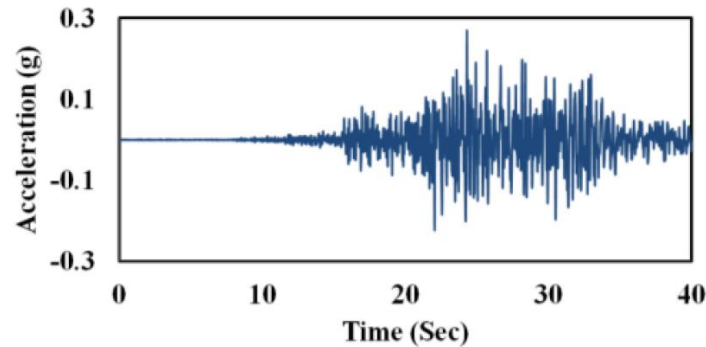


Figure (2)- mapping acceleration of the Qeshm earthquake

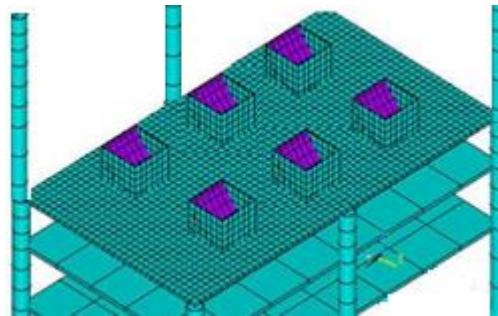


Figure (3)- SPD21 platform's vibration with TLD

8- Results and discussion

8-1- TLD effects analysis on the lower deck movement

Figure (4) presents the movement time history of the platform's lower deck affected by the mapping accelerations of the El-Centro, Geshm, Tabas and Kermanshah earthquakes, with and without TLD. Table (4) compares the maximum movement values with and without dampers. As seen in figure (4) and table (4), using tuned liquid damper system could considerably reduce the movement of platform's lower deck. Table (4) states that this reduction in SPD21 platform was from 0.15 to 0.2.

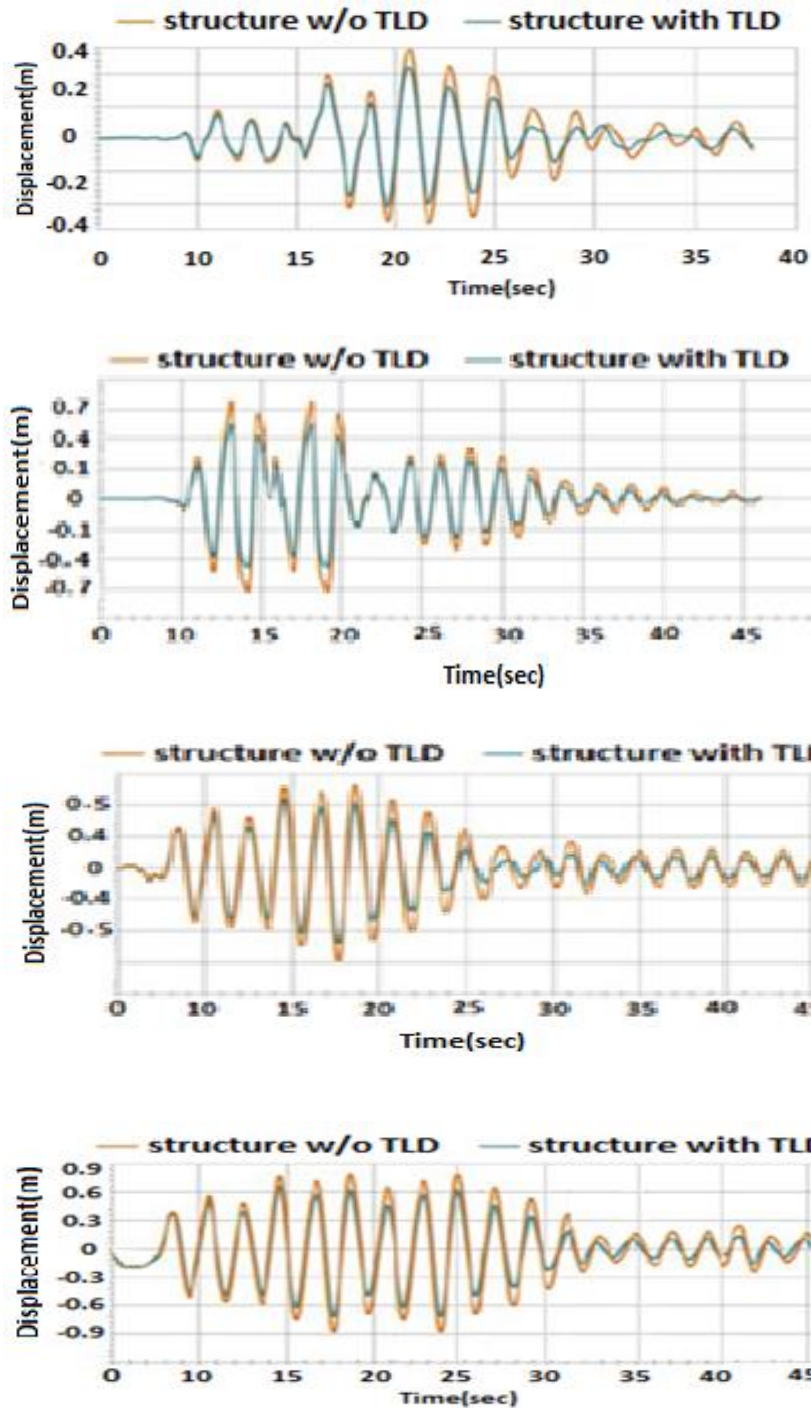


Figure (4)- movement time history of platform's lower deck with and without dampers affected by: a: Tabas b: Qeshm c: El-Centro d: Kermanshah



Table (4)- the effectiveness level of the TLD system on the platform's lower deck movement

<i>earthquake</i>	<i>Maximum movement of the lower deck (m)</i>		<i>Difference (m)</i>
	<i>Without TLD</i>	<i>With TLD</i>	
<i>Tabas</i>	<i>0.416</i>	<i>0.212</i>	<i>0.2</i>
<i>Qeshm</i>	<i>0.71</i>	<i>0.51</i>	<i>0.2</i>
<i>El Centro</i>	<i>0.564</i>	<i>0.414</i>	<i>0.15</i>
<i>Kermanshah</i>	<i>0.771</i>	<i>0.6</i>	<i>0.17</i>

8-2- Tthe TLD effect on the stand's cut

One of the effective parameters in safety and integration of the platform is the platform's stand cut. Too much cut leads to damages such as candle problems due to plastic joints and soil around the candle. The time history of the platform stand cut affected by the El Centro, Qeshm, Tabas and Kermanshah for the platform with and without TLD was extracted and compared. Figure (5). Table (5) compares the maximum stand cut with and without damper. As seen in figure (9) and table (5), using tuned liquid damper system could considerably reduce the platform's stand cut. As seen in table (5), the reduction varied between 110 to 179 kilonewton in the SPD21 platform.

8-3- TLD effects analysis on the lower deck acceleration

Too much acceleration causes damages to the non-structural parts of the deck such and equipment and different facilities. Such damages could harm the employees and also leak harmful material and cause environmental pollutions. Time history of the platform's lower deck acceleration affected by the mapping acceleration of the El Centro, Qeshm, Tabas and Kermanshah with and without damper was extracted and studies. Table (6) compares the maximum lower deck acceleration with and without damper.

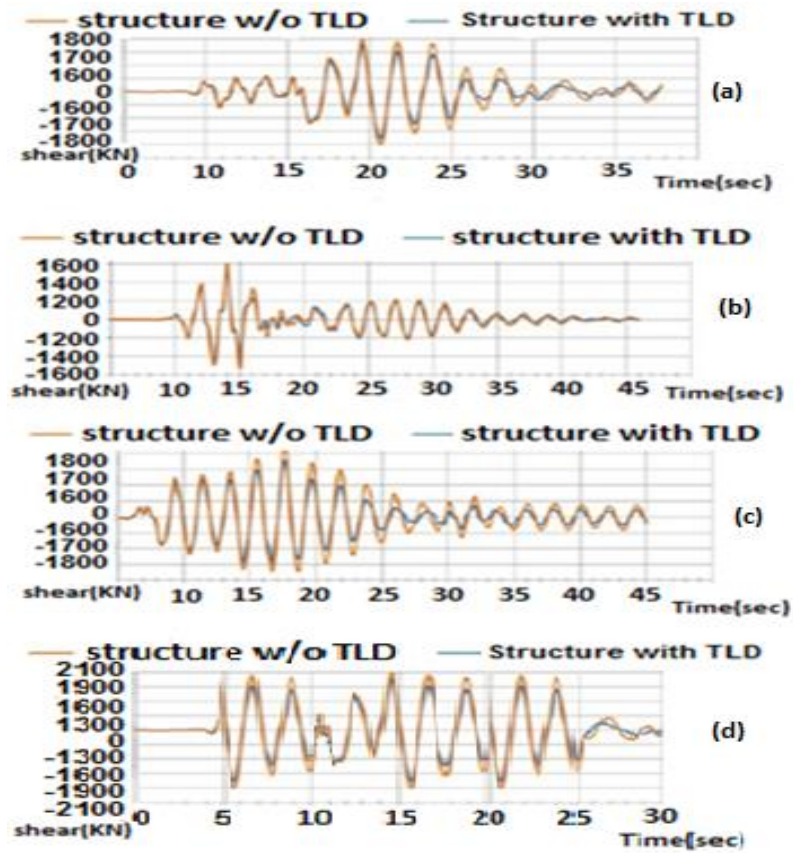


Figure (5). Movement time history of platform's lower deck with and without dampers affected by: a: Tabas b: Qeshm c: El-Centro d: Kermanshah

Table (5). The TLD effectiveness on the platform's maximum stand cut

Earthquake	Maximum stand cut (kN)		
	Without TLD	With TLD	Difference (kN)
Tabas	1810	1710	100
Qeshm	1680	1501	179
El Centro	1950	1820	130
Kermanshah	2100	1990	110

Table 6. The effectiveness level of the TLD system on the platform's lower deck's maximum acceleration

Earthquake	Maximum deck acceleration (m/s ²)		
	Without TLD	With TLD	Difference ((m)/s ²)
Tabas	4.7	3.57	1.13
Qeshm	5.1	4.21	0.89
El Centro	7.2	6.61	0.5
Kermanshah	4.4	3.55	0.85



9- Conclusion

The results of the current study indicate that using the TLD system in the platform's lower deck could considerably reduce the dynamic responses of the platform.

The reduction levels for the SPD21 platform in lower deck's maximum movement, maximum stand cut, and the maximum acceleration of the lower deck are as followed.

- ✓ The reduction level of the platform's lower deck movement is about 0.15 to 0.2 meters.
- ✓ The reduction level for the platform's stand cut is about 110 to 179 kilonewtons.
- ✓ The reduction level of the platform's lower deck acceleration is about 0.5 to 1.13 meters over second squared.

Due to the reduction of deck displacement and consequently the reduction of the platform base shear, which is due to the optimal reduction of deck acceleration, it was found that the use of TLD dampers is a new and innovative method that can be used in In stenciled platforms of marine areas around native settlements in case of relatively severe earthquakes. And energy absorption play an important role.

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