Experimental and numerical study on tuned liquid dampers for controlling earthquake response of jacket offshore platform

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Abstract

Earthquake loading has to be considered when the offshore platform is constructed in active fault zone. Tuned liquid dampers (TLD) have been proposed to control the dynamic response of structures. Liquid sloshing experiments on cylinder tank show the sloshing happens more seriously when the frequency of external excitation is close to the fundamental sloshing frequency of liquid. Lumped mass method is employed to numerically analyze the controlling earthquake effect on TLD. Based on TLDs the feasibility to control earthquake response of jacket platform is studied and applied to CB32A oil tank platform. Using extra TLDs in CB32A to control the seismic response of the platform is researched by the model test and numerical simulation. Lumped mass method can simulate the behavior of TLD during earthquake very well and gives close numerical results compared with those from model experiments. It has been found that the ratio of the fundamental sloshing frequency of liquid to the natural frequency of platform is the key factor to control earthquake response. The larger ratio of water-mass to platform-mass is also useful to reduce vibration as well.

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Keywords: Jacket platform; Tuned liquid dampers; Sloshing; Earthquake response; Vibration control; Model test; Numerical simulation

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1. Introduction

The offshore platforms located in hostile environment are subjected to more crucial environmental loading such as wind, wave, ice and earthquake. Controlling the dynamic response of platform is an important issue for the development of offshore hydrocarbon. Tuned liquid dampers (TLD) are energy-absorbing devices that have been proposed to control the dynamic response of structures. Tuning the fundamental sloshing frequency of the TLD to the structure’s natural frequency results in large amount of sloshing and wave breaking at the resonant frequencies of the combined TLD-structure system that dissipates a significant amount of energy. Most of the research on TLD is focused on controlling response of structures under the wind loads [1]. Less attention has been put on controlling earthquake response. Using TLD as an earthquake response controlling device has been studied since 1990s by Vancliver et al. [2], Sun et al. [3], Banerji et al. [4] and Reed et al. [5]. Kareem et al. [6] simulated ground motions as stationary stochastic process and non-stationary stochastic process and carried out analysis on random earthquake response for the combined water tank and structure system. The results showed the TLD was effective for controlling earthquake response. The main advantages of TLD are cost-effective and convenient of fabrication, installation, and minimal maintenance after installation. Chen et al. [7] found that TLD is also effective for controlling earthquake response of jacket platform. A recently study has been done for a tuned liquid column damper (TLCD), which is a variant of the TLD that dissipates energy by water flow between two water columns [8].

The objective of this paper is to investigate the effective way of controlling the earthquake response of jacket platform with cylinder TLDs.

2. Liquid sloshing experiments for cylinder container

2.1. Experimental set-up

In order to investigate the possibility of using cylinder tank as TLDs, the characteristics of the liquid sloshing has been tested for different wave height and hydrodynamic pressure under harmonic excitation in a cylinder container. Fig. 1 shows the experimental set-up. The cylinder container with the inner diameter of \( D = 580 \text{ mm} \) and the height of \( h = 700 \text{ mm} \) was made of organic glass. Four three-degree-of-freedom load cells with a measurable range of 200 N installed under the bottom of container were utilized to measure the base shear in the two horizontal directions as well as to support the tank on the shaking-table surface. A wave gauge fixed on the wall of the tank was employed to measure wave height. Seven hydraulic pressure gauges with a measurable pressure range of 50 kPa and frequency range of 1000 Hz were mounted on the other side of the wall at interval of 5 cm to monitor the impact pressures due to the liquid sloshing. The experiments were performed in the shaking table at State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, China.

Based on linear wave theory, the fundamental sloshing frequency of water simulated tuned liquid in the cylinder container is given

\[
\omega_f = \sqrt{\frac{g \sigma_1}{R} \tanh \left( \frac{\sigma_1 h_0}{R} \right)},
\]
where $\omega_f$ is the fundamental sloshing circular frequency of water; $\sigma_1$ is the coefficient of Bessel function, equal to 1.84 here; $R$ is the inner radius of cylinder container; $h_0$ is the water depth; $g$ is the gravity acceleration.

Water depths were selected as 58, 116, 174, 232, 290 and 348 mm, respectively. Amplitudes $A_e$ of harmonic excitation were 2.5, 5, 15 and 30 mm, corresponding to the values of $A_e/R$ as 0.0086, 0.0172, 0.0517 and 0.1034, respectively. The exciting frequency ratio $\gamma_f$ of harmonic exciting frequency $\omega_e$ to fundamental sloshing frequency of water $\omega_f$ was limited in the range between 0.8 and 1.2.

2.2. Experimental results

Fig. 2 shows the results of maximum sloshing force versus exciting frequency ratio for different water depths. The ordinate is dimensionless sloshing force, $F'_b$, defined as

$$F'_b = \frac{F_b}{m\omega_e^2 A_e},$$

where $F_b$ is the sloshing force which can be obtained by subtracting the inertial force of the empty tank from the total shear force; $m$ is the liquid mass; $\omega_e$ is the harmonic exciting circular frequency; $A_e$ is the exciting amplitude.

Fig. 3 shows the sample time histories of the sloshing force when $A_e$ is 1.5 and 30 mm.

Fig. 4 shows the results of maximum hydrodynamic pressure measured on the bottom of container versus exciting frequency. The ordinate is dimensionless hydraulic pressure, $p'$. 

Fig. 1. Shaking table experimental set-up: (a) schematic of the experimental set-up and (b) actual view of the set-up.
defined as
\[ p' = \frac{p}{\gamma w h_0}, \]  
where \( p \) is the hydrodynamic pressure; \( \gamma w \) is the unit weight of water.

Fig. 5 shows the results of maximum wave height versus exciting frequency in different water depth. The ordinate is dimensionless water height, \( \eta' \), defined as
\[ \eta' = \frac{\eta}{h_0}, \]  
where \( \eta \) is the wave height.

Based on the experimental results indicated from Figs. 3 to 5, the properties of the sloshing water in the cylinder container can be concluded as follows:

(1) When exciting frequency ratio \( \gamma f \) approximately equals to unity, namely, harmonic exciting frequency is close to the fundamental sloshing frequency of water, sloshing force reaches to maximum as well as wave height and hydraulic pressure.
(2) The dimensionless parameters \( F'_{h} \), \( p' \) and \( \eta' \) increase with the increasing of exciting amplitude.
(3) The dimensionless parameters $F_b$, $p'$ and $\eta'$ decrease with the increasing of water depth.

(4) When exciting amplitudes equal to 2.5 and 5 mm, corresponding to the value of $A_e/R$ as 0.0086 and 0.0172, sloshing force as well as wave height and hydraulic pressure reduces remarkably while exciting frequency is far away from fundamental sloshing frequency of water. When exciting amplitudes equal to 15 and 30 mm, corresponding to the value of $A_e/R$ as 0.0517 and 0.1034, sloshing force as well as wave height and
hydraulic pressure reduces unremarkably while exciting frequency is not much far away from fundamental sloshing frequency of water. This illustrates a wider band of exciting frequency ratio close to unity may also cause water sloshing response.

(5) When exciting amplitudes equal to 2.5 and 5 mm, wave surface did not break even though resonant condition took place, namely, $\gamma_f = 1.0$. While exciting amplitudes equal to 15 and 30 mm, larger breaking formed in the wave surface.

3. Numerical analysis method on TLD

3.1. Lumped mass method by Housner

Simplified methods were proposed to simulate the behavior of TLD in finite element model, including lumped mass method and linear wave theory. The lumped mass method used in the paper has been suggested by Housner [9].

The wall of container is assumed as rigid tank for lumped mass method by Housner. Hydrodynamic pressure caused by liquid sloshing due to dynamic loadings is considered as impulse pressure and sloshing pressure separately. The impulse pressure is proportional to tank acceleration, but the direction is opposite. The sloshing pressure is related to wave...
height and frequency of liquid sloshing. Thereby, both types of hydraulic pressures can be simulated by two equivalent masses linked to tank with different directions. Fig. 6 shows the schematic of lumped mass method, in which $M_1$ is the impulse mass fixed to tank, $M_2$ is the sloshing mass elastically linked to tank. For cylinder tank the formulations of $M_1$ and $M_2$ are given by Housner:

$$M_1 = m \frac{h_0}{\sqrt{3R}} \tanh \left( \sqrt{3} \frac{R}{h_0} \right),$$

$$M_2 = m \frac{0.385R}{h_0} \tanh \left( \frac{1.837h_0}{R} \right).$$

Fig. 5. Maximum wave height versus exciting frequency ratio: water depth at (a) 116 mm; (b) 232 mm.
The stiffness $k$ and height $h_1$ and $h_2$ are defined as

$$k = 5.4 \frac{M_2^2 g h_0}{m R^2},$$  \hfill (7)$$

$$h_1 = \frac{3}{8} h_0 \left\{ 1 + 2 \left[ \frac{m}{M_2} \left( \frac{R}{h_0} \right)^2 - 1 \right] \right\},$$  \hfill (8)$$

$$h_2 = h_0 \left[ 1 - 0.185 \left( \frac{m}{M_1} \right) \left( \frac{R}{h_0} \right)^2 - 0.56 \beta \frac{R}{h_0} \sqrt{\left( \frac{m R}{3 M_1 h_0} \right)^2 - 1} \right],$$  \hfill (9)$$

where $m$ is the total mass of contained liquid; $\beta$ equals to 2.0 for cylinder tank; $h_0$ is the depth of liquid; $R$ is the radius of the tank.

### 3.2. Finite element method (FEM)

The equation of motion for multi-degree-of-freedom structure with a TLD attached is

$$[M][\ddot{X}] + [C][\dot{X}] + [K][X] = -[M][E]\ddot{X}_g,$$  \hfill (10)$$

where $\{X\}$ is the relative displacement vector; $\{E\}$ is the unit vector; $\ddot{X}_g$ is the ground acceleration motion; $[C]$ is the damping matrix, assumed as Rayleigh dampness; $[M]$ and $[K]$ is the total mass matrix and stiffness matrix comprised of structure and TLD as follows:

$$[M] = \begin{bmatrix} M_0 + M_1 & 0 \\ 0 & M_2 \end{bmatrix},$$  \hfill (11)$$

$$[K] = \begin{bmatrix} K_0 + k & -k \\ -k & k \end{bmatrix},$$  \hfill (12)$$

where $M_0$ is the mass matrix of structure; $[K_0]$ is the stiffness matrix of structure.
4. Study on controlling earthquake response based on CB32A platform

4.1. CB32A offshore jacket platform

CB32A is a four-leg jacket platform to store oil in a cylinder tank located on the top of deck which diameter is 15 m and volume 2000 m$^3$. It is installed in Bo Sea, China with the maximum horizontal ground design acceleration of 0.2–0.25g as shown in Fig. 7. The seabed elevation is $-18.2$ m and top deck elevation $+12.5$ m.

4.2. Using oil tank as TLD to control earthquake response

The mechanism of controlling vibration with TLD is to dissipate the input energy by liquid sloshing and wave breaking. The fundamental sloshing frequency of liquid is required to be close to natural frequency of structure in order to make TLD work effectively. It is of necessity to analyze the possibility of using existing oil tank on the top of CB32A platform as TLD. Dynamic loads cause the interaction between platform and liquid in the oil tank. Model of fluid–solid interaction is a better way to study dynamic characteristics of platform and contained liquid, and to validate the feasibility of Housner simplified method. By assuming inviscid, compressible and small disturbed liquid, small amplitude on the free surface of liquid, linear elastic solid, formulation of FEM based on Galerkin’s method is given

$$
\begin{bmatrix}
M_f & 0 \\
-Q & M_f
\end{bmatrix}
\begin{bmatrix}
\ddot{\mathbf{a}} \\
\ddot{\mathbf{p}}
\end{bmatrix}
+
\begin{bmatrix}
K_f & \frac{1}{\rho_f}Q \\
0 & K_f
\end{bmatrix}
\begin{bmatrix}
\mathbf{a} \\
\mathbf{p}
\end{bmatrix}
= 
\begin{bmatrix}
\mathbf{F}_f \\
0
\end{bmatrix}.
$$

(13)
where \( \mathbf{p} \) is the pressure vector at liquid nodes; \( \mathbf{a} \) is the displacement vector at solid nodes; \( \mathbf{Q} \) is the matrix of liquid–solid interaction; \( \mathbf{M}_f \) and \( \mathbf{K}_f \) are mass matrix and stiffness matrix of liquid, respectively; \( \mathbf{M}_s \) and \( \mathbf{K}_s \) are the mass matrix and stiffness matrix of solid, respectively; \( \mathbf{F}_s \) is the external force vector loading on the solid.

ADINA software was utilized for FEM analysis of platform and contained liquid interaction. The element mesh of platform and liquid in the oil tank show in Fig. 8(a) and (b), respectively. Maximum liquid height and half of maximum liquid height in the oil tank were analyzed, respectively. Natural frequencies of platform and contained liquid are listed in Table 1. The natural frequency ratios of platform to contained liquid by numerical analysis are 7.37 and 4.83 at either of water depth, respectively, which are much larger than unity. Hence, it is unfeasible to use the oil tank as TLD. Extra TLD has to be designed for the purpose of controlling earthquake response. The error of water frequency between numerical analysis and Housner simplified method shown in Table 1 is allowable in engineering level. Considering the complexity and time-consuming of fluid–solid interaction method, lumped mass method by Housner is a rapid and accurate way to analyze practical engineering project. Thereby, Housner method is applied to the following controlling earthquake analysis.

4.3. Model tests of CB32A platform with TLD

4.3.1. Experimental set-up

The model tests of CB32A platform with TLD to control earthquake response were performed. It is impossible to find a certain kind of model material corresponding to contained liquid to fully satisfy the demand of time ratio in the design of controlling earthquake tests with TLD. Thus, the experimental model was designed based on the similarity rule that the natural frequency of model is the same as prototype one, which

![Fig. 8. (a) Meshing of platform; (b) meshing of liquid in oil tank.](image-url)
means both of frequency ratio and time ratio are unity. The scale ratio of geometry is \( \frac{1}{25} \).

A cylinder container, 380 mm in inner diameter, to simulate TLD is made of organic glass. The size of the cylinder container is decided in order that the frequency of contained water is close to the one of jacket platform. The model was fixed and excited in the shaking table at State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, as shown in Fig. 9. The measurement positions are shown in Fig. 10(a) and (b).

### 4.3.2. Definition of ground motions

Three types of ground motions are considered here: two recorded earthquake motions and one artificially generated earthquake motion. The first one shown in Fig. 11(a) is the NS component of El Centro ground motion, Imperial Valley 1940 earthquake. The second one shown in Fig. 11(b) is the Tianjing ground motion, Tangshan 1976 earthquake. The third one shown in Fig. 11(c) is an artificially generated earthquake motion based on

---

**Table 1**

<table>
<thead>
<tr>
<th>Liquid volume</th>
<th>Natural frequency of platform (Hz)</th>
<th>Natural frequency of contained water (Hz)</th>
<th>Frequency ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency ratio</td>
<td>(Deviation)(^a)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>By numerical fluid analysis</td>
<td>By Housner formula</td>
<td></td>
</tr>
<tr>
<td></td>
<td>By Eq. (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half of maximum water  height</td>
<td>1.62224</td>
<td>0.21988</td>
<td>0.1972</td>
</tr>
<tr>
<td></td>
<td>(0%)</td>
<td>(10.31%)</td>
<td>(2.69%)</td>
</tr>
<tr>
<td>Maximum water height</td>
<td>1.14718</td>
<td>0.23761</td>
<td>0.2201</td>
</tr>
<tr>
<td></td>
<td>(0%)</td>
<td>(7.37%)</td>
<td>(2.48%)</td>
</tr>
</tbody>
</table>

\(^a\)Deviation equals to ratio of absolute difference of water frequency by numerical analysis and water frequency by Housner or linear wave theory to water frequency by numerical analysis.

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**Fig. 9. Experimental model for TLD.**
API-B response spectrum. The ground motion amplitudes are 30 gal for all of the three input signals. The ground motions have different frequency content as shown in the Fourier transformation spectra given in Fig. 12.

4.3.3. Experimental results

The natural frequency of prototype platform is 1.17 Hz from the FEM analysis, while the measured value of model platform is 1.20 Hz from the model test. The fundamental sloshing frequencies of three water depths from Eq. (1) are listed in Table 2. The fundamental sloshing frequencies at depth of 57 and 76 mm are closer to measured natural frequency of model platform.
The maximum displacement and acceleration response of model platform under the exciting of the ground motion are listed in Table 3. Uncontrolled displacement and acceleration in Table 3 mean the response measured that the water in container is simulated as mass block, while controlled displacement and acceleration mean TLD is effective. Some conclusions can be drawn from the TLD model experiments. (1) TLD effect of controlling earthquake response is decided by the interaction of seismic input, structure and liquid. (2) When the fundamental sloshing frequency of TLD is close to the natural frequency of structure, the effect of controlling earthquake response is apparent. (3) Although the fundamental sloshing frequency of TLD is not close to the natural frequency of model platform at the water depth of 38 mm, TLD still results in beneficial effect to platform vibration.

The tuning ratio defined as the ratio of the fundamental sloshing frequency of liquid, \( \omega_f \), which is given by Eq. (1), to the natural vibration frequency of the platform, \( \omega_s \), or \( x = \omega_f / \omega_s \), is the key to control earthquake response. The experiments show that it is reasonable to consider this tuning ratio to be close to unity.

Fig. 12. Fourier spectra of ground motions: (a) El Centro wave; (b) Tianjing wave; (c) artificial generated wave.

<table>
<thead>
<tr>
<th>Water depth (mm)</th>
<th>Fundamental sloshing frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>0.92</td>
</tr>
<tr>
<td>57</td>
<td>1.09</td>
</tr>
<tr>
<td>76</td>
<td>1.22</td>
</tr>
</tbody>
</table>
4.4. Validation of lumped mass method

FEM model shown in Fig. 13 is meshed on the base of model platform. Lumped mass method is employed to simulate TLD. The ground motions and water depth are the same as model experiments. The experimental results and numerical results listed in Table 4 are obtained from the same position on the physical model measured and FE model calculated. The numerical results are in good agreement with experimental ones.

4.5. TLD design procedures on CB32A platform

Based on the above analysis, it is effective for CB32A platform to control earthquake response using TLD. The design procedures are given as the follows [5]:

(1) Determine frequencies and generalized modal masses of the platform according to the number of modes needed to control, based on in situ measurement or numerical analysis. It is rational to only control the first order frequency of jacket platform, \( \omega_1 \), in general.
(2) Calculate the fundamental sloshing frequency of liquid, \( \omega_f \) based on linear wave theory, from Eq. (1).
(3) Consider the tuning ratio, \( \alpha \), to be unity

\[
\alpha = \frac{\omega_f}{\omega_1} = 1.0. \tag{14}
\]

(4) Choose the ratio, \( \kappa \), of water depth to radius of TLD,

\[
\kappa = \frac{h_0}{R}, \tag{15}
\]
where $h_0$ is the water depth of TLD; $R$ is the radius for cylinder TLD. Then, water depth and radius of one tank can be obtained from Eqs. (1), (14) and (15).

(5) Calculating the mass of water in one tank, $m_f$, from the expression $m_f = \rho \pi R^2 h_0$, where $\rho$ is the mass density of water. Assuming mass ratio, $\mu$, defined as the ratio of the

Table 4
Comparison between test data and calculate data under the earthquake motion

<table>
<thead>
<tr>
<th>Seismic input</th>
<th>Tianjing</th>
<th></th>
<th>El Centro</th>
<th></th>
<th>Artificially generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>Acceleration</td>
<td>Displacement</td>
<td>Acceleration</td>
<td>Displacement</td>
<td>Acceleration</td>
</tr>
<tr>
<td>(m)</td>
<td>(m/s²)</td>
<td>(m)</td>
<td>(m/s²)</td>
<td>(m)</td>
<td>(m/s²)</td>
</tr>
<tr>
<td>38 (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>0.0138</td>
<td>0.9668</td>
<td>0.0091</td>
<td>0.6871</td>
<td>0.0161</td>
</tr>
<tr>
<td>Numerical</td>
<td>0.0130</td>
<td>0.9910</td>
<td>0.0091</td>
<td>0.6301</td>
<td>0.0150</td>
</tr>
<tr>
<td>Deviation (%</td>
<td>5.8</td>
<td>2.5</td>
<td>0.0</td>
<td>8.3</td>
<td>6.8</td>
</tr>
<tr>
<td>57 (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>0.0116</td>
<td>0.9732</td>
<td>0.0074</td>
<td>0.6248</td>
<td>0.0128</td>
</tr>
<tr>
<td>Numerical</td>
<td>0.0103</td>
<td>0.8807</td>
<td>0.0085</td>
<td>0.5323</td>
<td>0.0112</td>
</tr>
<tr>
<td>Deviation (%)</td>
<td>11.2</td>
<td>9.5</td>
<td>14.9</td>
<td>14.8</td>
<td>12.5</td>
</tr>
<tr>
<td>76 (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>0.0113</td>
<td>0.8041</td>
<td>0.0084</td>
<td>0.5949</td>
<td>0.0080</td>
</tr>
<tr>
<td>Numerical</td>
<td>0.0101</td>
<td>0.7301</td>
<td>0.0078</td>
<td>0.6203</td>
<td>0.0081</td>
</tr>
<tr>
<td>Deviation (%)</td>
<td>10.6</td>
<td>9.2</td>
<td>7.1</td>
<td>4.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Deviation equals to ratio of absolute difference of experimental data and numerical data to experimental data.
mass of total TLDs to the mass of platform, compute the \( N \) number of tanks required from 
\[
N = \frac{m_s}{m_f},
\]
where \( m_s \) is the mass of the platform.

(6) Calculating earthquake response of TLD and platform system based on FEM. Return Procedure (4) to redesign if controlling earthquake response does not satisfy request.

(7) Design TLD system in terms of \( h_0 \) and \( R \).

4.6. Controlling earthquake response analysis on CB32A platform

For CB32A platform, finite element model without TLDs, but with oil tank simulated as lumped mass method, is built. The natural frequency is 1.14 Hz from modal analysis. Assuming \( k = 0.65 \), water depth and radius of one TLD can be calculated as 0.455 and 0.35 m, respectively. The finite element model of CB32A platform is remeshed considering jackets, deck, oil tank and TLDs simulated a lumped mass as well. The histories of earthquake response are computed under El Centro ground motion, Tianjing ground motion and artificially generated ground motion which amplitudes equal to 200 gal. Assuming three mass ratios, numerical results are listed in Table 5.

From Table 5, the larger the mass ratio is, the more effective the controlling earthquake response is. However, the cost will increase as well.

4.6. Controlling earthquake response analysis on CB32A platform

<table>
<thead>
<tr>
<th>Seismic input</th>
<th>( \mu = 0.5% )</th>
<th>( \mu = 1% )</th>
<th>( \mu = 3% )</th>
<th>( \mu = 0.5% )</th>
<th>( \mu = 1% )</th>
<th>( \mu = 3% )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tianjing</td>
<td>2.26</td>
<td>4.53</td>
<td>15.09</td>
<td>2.22</td>
<td>4.60</td>
<td>15.60</td>
</tr>
<tr>
<td>El Centro</td>
<td>5.18</td>
<td>10.28</td>
<td>17.6</td>
<td>3.43</td>
<td>5.11</td>
<td>11.28</td>
</tr>
<tr>
<td>Artificially generated</td>
<td>4.21</td>
<td>8.35</td>
<td>23.67</td>
<td>2.48</td>
<td>4.90</td>
<td>13.61</td>
</tr>
</tbody>
</table>

5. Conclusions

The objective in the paper is to study the effectiveness of cylinder TLD in controlling earthquake response of jacket platform. Meanwhile, TLDs are applied to CB32A oil tank platform to prove its feasibility.

It is effective for CB32A using TLDs to control the response due to ground motions based on liquid sloshing experiment, model experiment and numerical analysis. The effectiveness of TLD is determined by the interaction of seismic input, structure and liquid. Aiming to enhance the vibration reduction efficiency of the TLD system, the TLD frequency is normally adjusted to be close to the frequencies of the structure and ground motion. However, the frequency content of ground motion is abundant and complicated. Only the frequency of TLD is tuned to the frequency of structure in design, namely, tuning ratio equals to be unity.

The larger the mass ratio is, the more effective the controlling earthquake response is. However, the cost will increase as well. It is economic for cost and effective for vibration reduction that the mass ratio ranges from 1% to 5%.
References