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Efficiency of TLDs with bottom-mounted baffles in suppression of structural responses when subjected to harmonic excitations

Hossein Shad[1a], Azlan Adnan[1b], Hamid Pesaran Behbahani[1c] and Mohammadreza Vafaei[*2]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Johor, Malaysia
[2]Center for Forensic Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Johor, Malaysia

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Abstract. Tuned Liquid Dampers (TLDs) provide low damping when it comes to deep water condition, and that not all water depth is mobilized in energy dissipation. This research focussed on a method to improve the efficiency of TLDs with deep water condition. Several bottom-mounted baffles were installed inside a TLD and the dynamic characteristics of modified TLDs together with their effect on the vibration control of a SDOF structure were studied experimentally. A series of free vibration and harmonic forced vibration tests were carried out. The controlling parameter in the conducted tests was the Vertical Blocking Ratio (VBR) of baffles. Results indicated that increase in VBR decreases the natural frequency of TLD and increases its damping ratio. It was found that the VBR range of 10% to 30% reduced response of the structure significantly. The modified TLD with the VBR of 30% showed the best performance when reduction in structural responses under harmonic excitations were compared.

Keywords: tuned liquid damper; bottom baffles; deep water; vibration control of structures; harmonic excitation

1. Introduction

Vibration control of structures due to service and extreme loads have been the topic of research during past decades. Many methods have been suggested to mitigate undesired vibration of the structures (e.g., tuned mass dampers, friction dampers, viscoelastic dampers, etc.). These techniques have been categorized into active, passive and semi-active.

Among vibration control devices, Tuned Liquid Dampers (TLDs) has gained attention of researchers due to their easy installation, low-cost maintenance and multipurpose usage (e.g., as a water tank for firefighting) (Chen *et al.* 1999, Soong and Argush 1997). The dynamic response of TLD-structure systems have been studied experimentally using different types of excitations like

∗Corresponding author, Senior Lecturer, E-mail: vafaei@utm.my
[a]Ph.D., E-mail: shossein2@live.utm.my
[b]Ph.D., E-mail: azlanadnan@utm.my
[c]Ph.D., E-mail: hamidbehbahani@gmail.com

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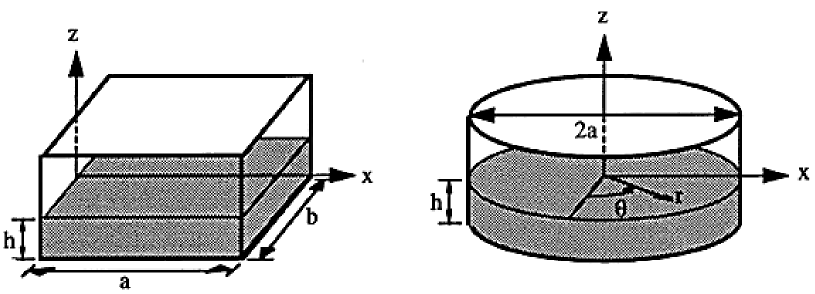


Fig. 1 Schematic of a rectangular and a circular tank TLD

conventional shaking table tests in laboratory scale (Sun *et al.* 1989, Zahraei *et al.* 2012), real-time hybrid shaking table tests (Lee *et al.* 2007, Wang *et al.* 2016) and wind-induced excitations (Tamura *et al.* 1996). The Yokohama Marine tower in Japan (Hamelin 2007), Rincon Hill Tower in San Francisco (Kareem and Kijewski 1999) and King West Building in Toronto (Hamelin 2007) are examples of application of TLD in high-rise buildings to mitigate structural vibration. Fig. 1 shows a schematic view of a rectangular and circular TLD.

TLDs utilize the liquid sloshing, liquid boundary layer friction, wave breakage and free surface contamination to dampen vibration of structures and dissipate the excitation energy (Ali Ashasi-Sorkhabi *et al.* 2014). TLDs also have the ability to control two structural sway modes if the tank has the proper dimension (Tait *et al.* 2007, Min *et al.* 2013). They are classified as shallow or deep water TLDs, depending on the depth of water in the tank. A TLD is termed “shallow tank” when the depth ratio (water height/tank length) is less than 0.15 (Banerji *et al.* 2000), otherwise, it is “deep tank” (Noji *et al.* 1988). When the water is shallow, large damping which is good for small excitation amplitude is achieved (Fediw 1992). However, when the amplitude of excitation is high, the liquid behaves nonlinearly and becomes very difficult to analyze. In deep water, the sloshing exhibits linear behavior for large amplitude excitation (Kim *et al.* 2006).

Apart from advantages of the deep water TLDs, there are two main drawbacks attributed to the deep water condition which reduce the efficiency of TLDs. One of the deep water issues is the lower damping level in comparison with the control force generated by a TMD. The other problem of TLD with deep water is that not all water depth cooperates in dissipation of energy. To tackle the problems, researchers installed internal screens (Tait 2008, Hamelin *et al.* 2013) and baffles (Tait *et al.* 2007) inside the water tanks, or adding floating particles to the fluid (Xin *et al.* 2009, Ding *et al.* 2009). Installation of baffles in TLDs have following advantages: (i) Easy and economical usability (ii) Effective reduction in acceleration and displacement responses of structure (iii) Improved nonlinear behaviour of sloshing water (iv) Possibility of adjusting for the frequency of TLD. Researcher also have studied the effect of various liquid viscosities and different geometry of tanks on the performance and dynamic characteristics of TLDs (Deng and Tait 2009, Xin *et al.* 2009).

The main aim of this research is to increase the damping ratio of deep water TLDs by installing internal vertical baffles. In addition to study on the damping ratio and natural frequency of TLDs with internal baffles, a series of free and force vibration tests were implemented. A detailed evaluate was performed on the efficiency of vertical baffles in reducing structural responses of a single-degree-of-freedom (SDOF) steel structure.

2. Performance parameters of TLD

Followings are the main parameters that control dynamic response of a TLD:

a) Mass ratio: which is defined as the TLD's mass to structure's mass. Often, this ratio is selected to fall within 0.5-5%. Selection of mass ratio depends on the required level for reduction in structural responses and availability of space.

$$\mu = \frac{M_w}{M_s} \tag{1}$$

b) Tuning ratio: which is referred to as the ratio of TLD's fundamental frequency to structure's natural frequency as Eq. (2).

$$\beta = \frac{f_w}{f_s} \tag{2}$$

This ratio is usually selected to be around one because when the natural frequency of a TLD is tuned close to that of a structure, the sloshing level reaches its maximum and more energy can be dissipated. For rectangular tanks, fundamental frequency of water can be estimated by applying any of the two formulas devised by Lamb (1932), Housner (1963)

$$f_w = \frac{1}{2\pi}\sqrt{\frac{\pi g}{L}\tanh\left(\frac{\pi h_0}{L}\right)} \quad \text{Lamb} \tag{3}$$

$$f_w = \frac{1}{2\pi}\sqrt{\frac{3.16g}{L}\tanh\left(\frac{3.16h_0}{L}\right)} \quad \text{Housner} \tag{4}$$

c) Damping coefficient of TLD: based on linear wave theory (Sun, 1991) the following expression is given to calculate the damping coefficient of a TLD. In Eq. (5), b, h, f_w and v_w are width of tank, water depth, and natural frequency of TLD and kinematic viscosity of water respectively.

$$\varsigma_{TLD} = \frac{1}{2\pi}\sqrt{\frac{V_w}{\pi f_w}}\left(1+\frac{h}{b}\right) \tag{5}$$

d) Sloshing force: The dimensionless sloshing force can be obtained by Eq. (6) (Shad 2015)

$$F'_w = \frac{F_w}{m_w \omega^2 A}, F_w = 0.5\rho g b(h_0^{\,2} - h_n^{\,2}) \tag{6}$$

where F_w, A, ω and m_w are the sloshing force, amplitude of excitation, circular frequency of water sloshing and mass of water, respectively. The term "$m_w\omega^2A$" represents the maximum inertia force of water mass. Also, ρ, h_n, h_0 and g are density of water, water level of two sides of the tank and acceleration due gravity, respectively.

3. Definition of SDOF model

As shown in Fig. 2, the selected structure in this research is a single-story steel frame. The

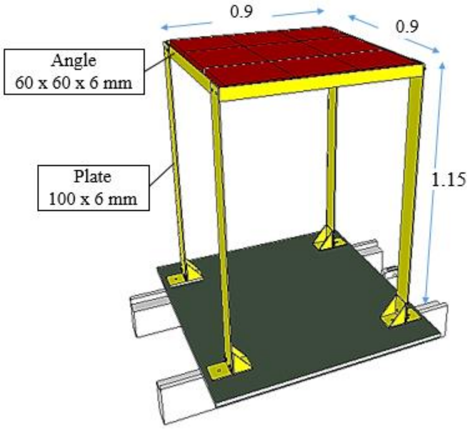


Fig. 2 Schematic and dimensions of one story steel structure (SDOF)

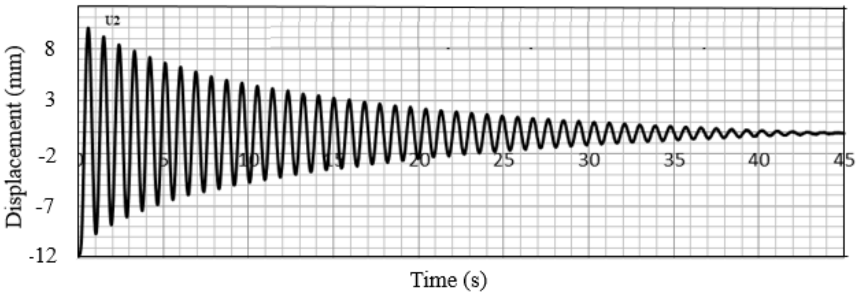


Fig. 3 The response of structure by free vibration vs. time

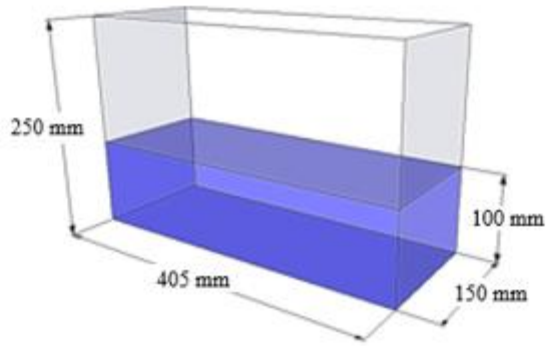
dimensions and weight of this model were selected based on the size and capacity of existing shaking table and the required dynamic characteristics form a steel structure. The selected structure is 0.9 m length, 0.9 m width and 1.15 m height. The total mass of the structure which includes members and floor is 228 kg.

Columns and beams were made of steel plates and angle sections, respectively. A steel plate was also employed at roof level to represent the floor mass. The mechanical properties of steel used in this study are as follows; (i) Density: 7800 Kg/m^3, (ii) Modulus of Elasticity: 20Gpa, (iii) Poisson ratio: 0.26 and shear modulus: 79.3 GPa.

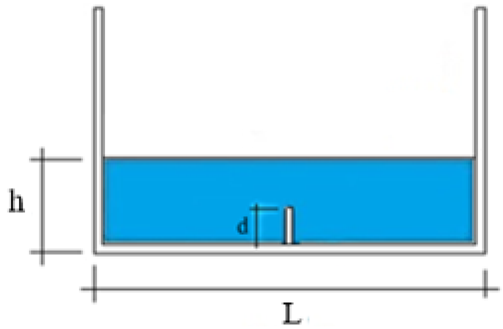
The natural frequency of the model obtained from free vibration test was 1.12 Hz. It is noteworthy that this frequency represents approximately the fundamental natural frequency of a flexible 9-story building (ASCE 2013). The damping ratio of the frame structure was determined through the logarithmic decrement technique using the displacement response of the structure shown in Fig. 3. The 1% damping ratio obtained from free vibration tests indicated that the constructed structure was a lightly damped frame.

4. Design of the employed TLD models

An ordinary deep water TLD was designed such that its natural frequency get tuned to that of



(a)



(b)

Fig. 4 (a) Dimensions of TLD (b) Modified TLD with bottom-mounted baffles

steel frame. The inner dimensions of the TLD's tank were 405×250×150 mm (length, height, and width, respectively) as shown in Fig. 4(a). The tank was fabricated using clear Perspex plates with the thickness of 6 mm. In order to achieve the tuning ratio of 1, the water height inside the tank was calculated to be 10 cm. This height of water results to a total tuned water mass of 6 kg. The mass of the tank was around 3 kg, however, since it was significantly less than structural mass (i.e., 228 kg) it was not included as a part of structural mass.

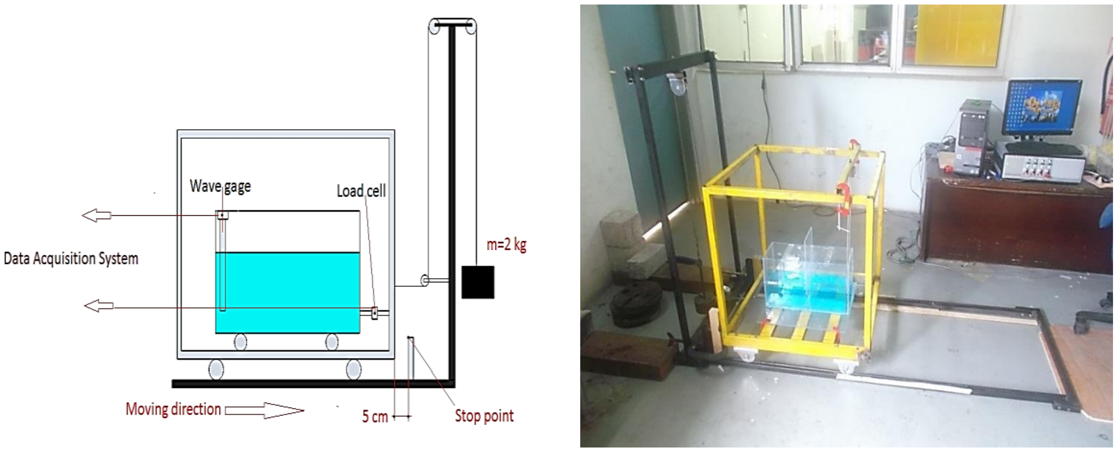
The modified TLDs were constructed using vertical baffles as shown in Fig. 4(b). The vertical baffles were mounted at the middle of tank's length rising from the bottom of the tank toward the surface of the water. The height of vertical baffles (d) was altered in order to produce a range of vertical blocking ratios (VBR). The experimental tests performed in this study considered the variation of VBR from 10% to 90%. It should be mentioned that, in this study the modified TLDs were referred to as TB which is the short form for TLD with bottom-mounted baffle.

5. Experimental tests

Free vibration and harmonic forced vibration tests were carried out in order to obtain the dynamic characterestics of the TLD and the combined structure-TLD system. The implemented method and the testing set-up for the TLDs and the structure-TLD system are explained in this section.

5.1 Free vibration tests of TLD and TB models

The test setup used for the free vibration studies are shown in Fig. 5. The water tank was seated horizontally on a box frame which was equipped with ball-bearing wheels that allowed it to move along a rail freely. For the purpose of free vibration tests, the box frame was connected to a hanging mass of 2kg through a cable. Then it was pushed back to the distances of 5 and 10 cm away from a stopper. Next, it was released and the free surface motion and the sloshing forces at locations shown in Fig. 5(a) were recorded using a wave gauge and a load cell, respectively. Four ball bearings were also embedded in the bottom of the tank in order to reduce the friction effects on the measured sloshing forces. Fig. 6 provides a closer view to the free vibration test set up.



(a) (b)

Fig. 5 (a) Schematic setup of free vibration (b) Set-up of free vibration test in laboratory

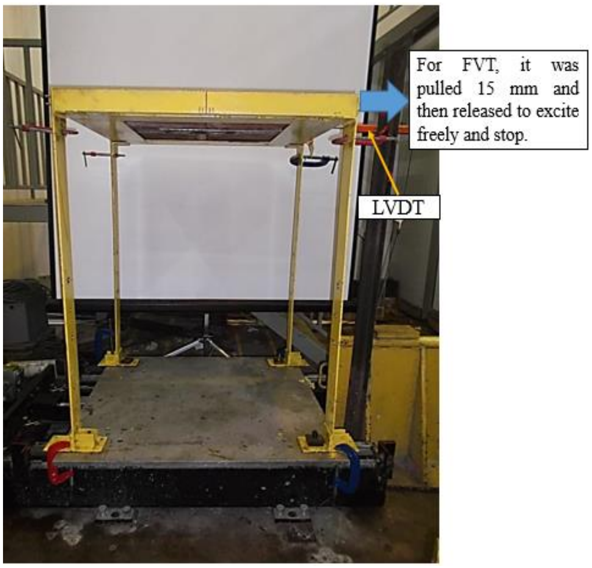
(a) (b)

Fig. 6 Components of experimental free vibration test (a) Installed wave gauge in TLD (b) Details of installed load cell

Each test was repeated five times and the average of the results were employed for further study. It should be mentioned that, the two different push back distances were employed to study the effect of excitation force on the free vibration results.

5.2 Free vibratin test of combined structure-TLD system

As Fig. 7 shows, the free vibration test of the single-story structure with and without TLD was carried out through imposing an initial displacement to the top of the frame. The supports of the structure were fixed to a solid plate during free vibration tests. The roof of the structure was pulled 1.5 cm and released after that. The structure oscillated due to the imposed displacement and its



(a)

(b)

Fig. 7 (a) The single-story steel structure installed on a rigid plate (b) Structure-TLD system

time history at the roof level was measured by an LVDT installed at the top of the structure. From the free vibration tests, dynamic characteristics of the structure with and without TLD such as natural frequency and damping ratio were calculated. The natural frequency of the system was computed by converting digitized signals from time domain to frequency domain using the Fast Fourier Transform (FFT) algorithm. The damping ratios of models were obtained from the filtered rate of decay of displacement amplitudes using the logarithmic decrement method. The free surface motion of water inside TLD was also recorded by a digital camera.

5.3 Forced vibration tests of TLD and TBs

The TLD and TBs were subjected to one-directional harmonic displacements generated by a shaking table. The excitation displacements (D) at each time intervals (t) followed a sinus wave represented by $D=A$. Sin $(2\pi.\beta.\mathrm{f.t})$.The maximum displacement amplitude (A) and frequency (f) of the wave were ±2.5 mm and 1.12 Hz, respectively. The excitation frequency ratio (β), defined as the ratio of the frequency of loading to the natural frequency of water, varied from 0.75 to 1.20 (i.e., 0.75, 0.80, 0.85, 0.90, 0.92, 0.93, 0.94, 0.96 ,0.98, 0.99 , 1.00, 1.01, 1.02, 1.04, 1.06, 1.07, 1.08, 1.10, 1.15, 1.2). The considered blocking ratio of baffles in the forced vibration tests were 10%, 20%, 30%, 40%, 50%, 60%, and 80%. A high speed camera was also used to record sloshing of water at each frequency ratio. The captured motions allowed for study on the natural frequencies and maximum water heights of TLD and TBs Furthermore, the influence of blocking ratio on the free surface response of water was also studied.

5.4 Forced vibration tests of S, S-T, and S-TB system

Forced vibration tests were also implemented for three different cases including (i) the bare steel structure (S), (ii) the steel structure equipped with ordinary TLD (S-T) and (iii) the steel structure equipped with modified TLD (S-TB). The shaking table excited these three cases by one-directional harmonic displacements with the amplitude of ±5 mm and frequency ratios ranging from 0.88 to 1.32.

Using a LVDT and two accelerometers, the displacement and acceleration responses of the structure and the shaking table were measured. In addition, the free surface motion of water was recorded by a high-speed digital camera. Typical displacement time histories of the structure with and without the TLD for different frequency ratios were plotted. The maximum acceleration and displacement responses of all systems were studied and compared with each other.

6. Results and discussions

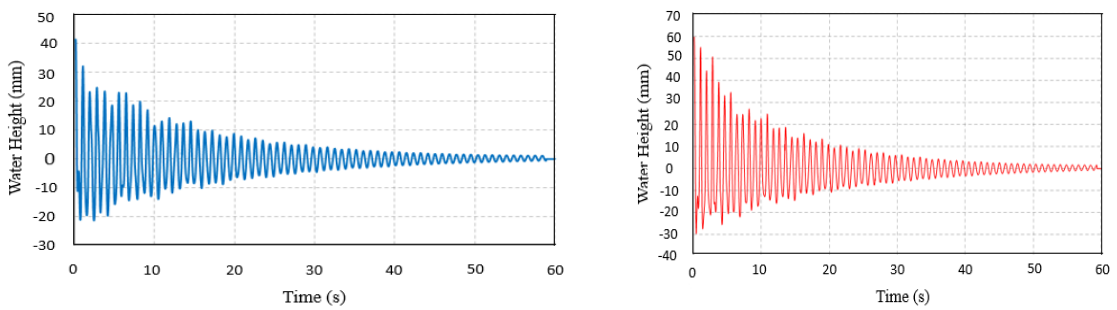
As mentioned earlier, two different series of tests were carried out in order to obtain dynamic characteristics of TLD and TBs including free vibration and forced vibration tests. At first results of free vibration tests are presented and then results of forced vibration tests are explained.

6.1 Results of free vibration tests of TLD and TB models

The setup of free vibration test of TLD and TLD with baffle was explained earlier in previous section. It was mentioned that free vibration tests were carried out with two initial displacement amplitudes of 50 and 100 mm. The obtained results included the frequency, free surface motion, maximum water height and sloshing force of models.

6.1.1 Frequency of TLD and TBs

Figs. 8 (a) and (b) show the free surface response of water with two excitation displacements (5 cm and 10 cm). Using Fast Fourier Transform (FFT), for both cases, the natural frequency of water was obtained 1.12 Hz, signifying this fact that the frequency of sloshing water was independent of excitation amplitude. It should be mentioned that the obtained natural frequency for TLD form free vibration tests was in close agreements to that of Housner's equation (Housner 1963). In addition, as it was expected, the water height graphs indicated that the excitation amplitude had a significant effect on the level of water heights. Fig. 9 shows the obtained natural frequency for TLD using the FFT method.



(a) (b)

Fig. 8 Water height time histroies of TLD for different excitaion amplitudes (a) 5 cm (b) 10 cm

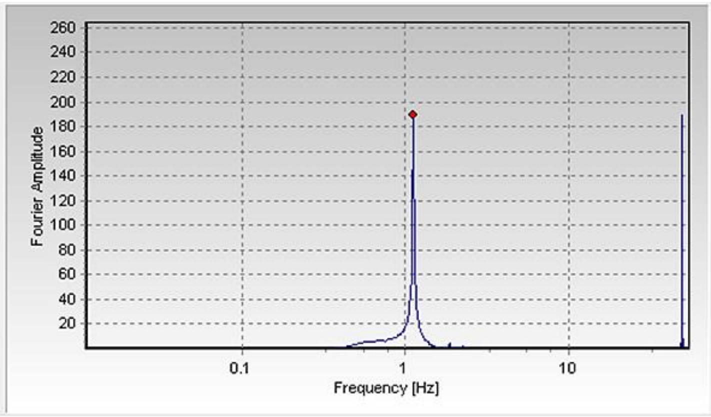


Fig. 9 Frequency content of TLD using FFT method

Table 1 Natural frequency of TBs

VBR%	10	20	30	40	50	60	70	80	90
Frequency (Hz)	1.092	1.08	1.068	1.05	1.025	0.97	0.915	0.818	0.72

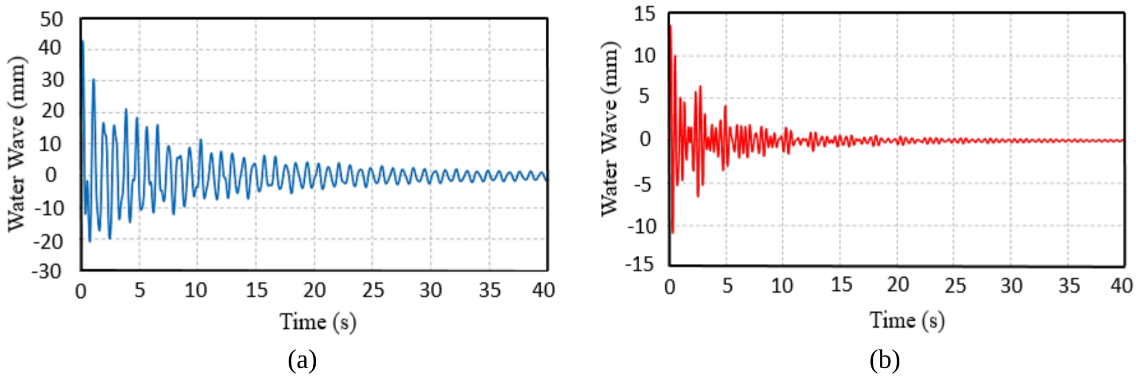


Fig. 10 (a) Water height of TBs with different blocking ratios (a) VBR=10% (b) VBR=80%

Table 1 shows the effect of VBR of baffles on the natural frequency of TBs. The results indicate that the natural frequency of models decreases dramatically with the increase in the blocking ratio of baffles. The reason lies in the fact that increase in VBR shifts the dynamic behaviour of the TLD toward a two rectangular water tanks each of which having the half length of the reference's TLD. In other words, the natural frequency of the TLD with the VBR of 90% is close to the frequency of a TLD with 200mm tank length. Fig. 10 shows that the VBRs have also great impact on the measured water height time histories. Increase in the VBRs resulted in a shorter water heights and faster decay in their amplitude. Fig. 11 shows that decrease in the maximum water height is almost linearly relates to the VBRs.

6.1.2 Maximum sloshing force of TLD and TBs

This subsection presents the maximum sloshing forces obtained from free vibration tests for TLD and TBs. The tests were carried out using two displacement amplitudes of 5 and 10 cm. The

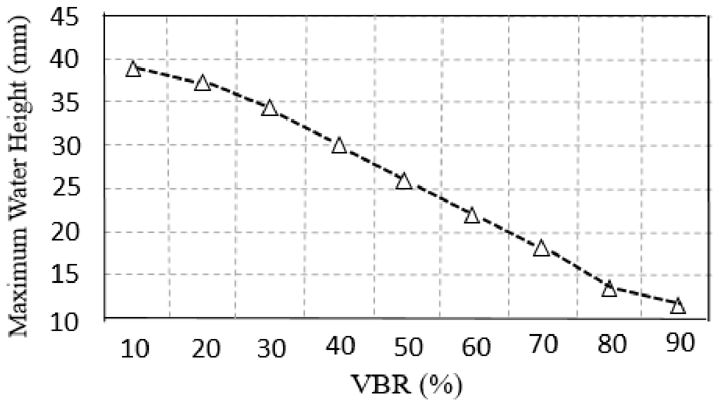


Fig. 11 Maximum water height of TBs versus theirs VBRs

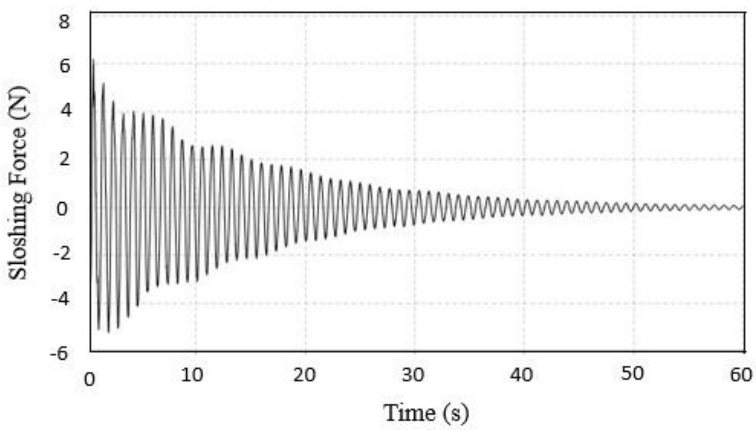


Fig. 12 Sloshing force response of TLD with excitation amplitude of 5 cm

sloshing force time history of the TLD when the excitation amplitude is 5 cm is plotted in Fig. 12. Fig. 13 shows the maximum sloshing force of TBs versus vertical blocking ratios. As can be seen, the amounts of sloshing forces are decreased as the VBRs are increased. In addition, TBs has resulted in lower amplitude of sloshing forces when compared to that of referenced TLD (i.e., 6 N, see Fig. 12). The reason was found to be due to the increase in the damping level of TBs as a result of installed baffles which is discussed in the next sections.

6.2 Results of forced vibration test of TLD and TBs

Forced vibration tests were carried out with the excitation amplitudes of ±25 mm. The excitation frequency ratio ranged from 0.89 Hz to 1.33 Hz. From the forced vibration tests, the maximum water heights and damping ratios of TLD and TBs were calculated and plotted.

6.2.1 Maximum water height of TLD and TBs

Fig. 14 shows the obtained results for water height of TBs versus different VBRs under forced harmonic excitations. As can be seen, the water height falls sharply when the VBR increases from

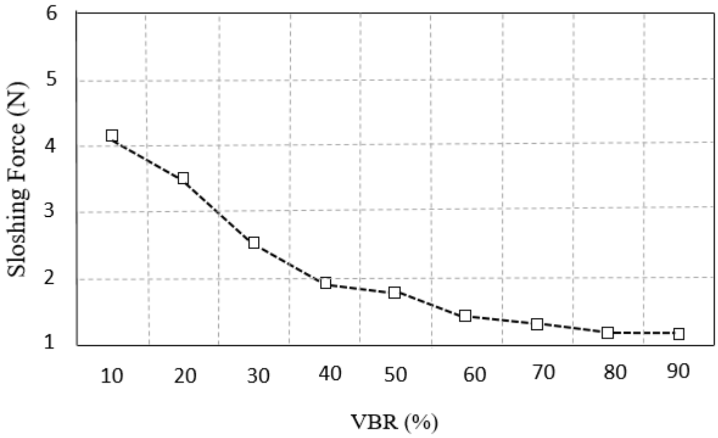


Fig. 13 Maximum sloshing force of TBs versus various VBR

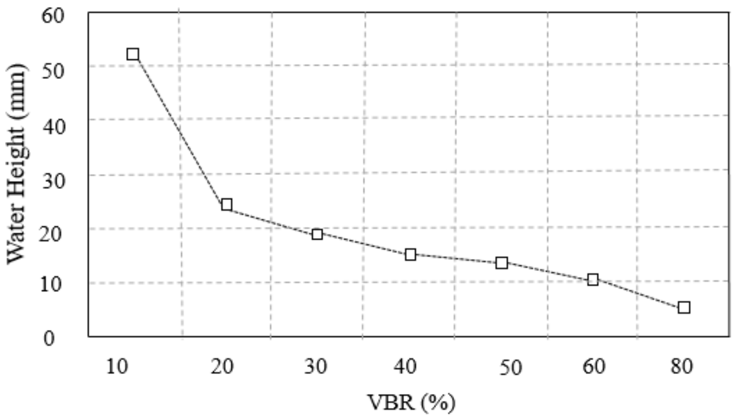


Fig. 14 Maximum water height of the TBs versus various VBRs obtained from forced vibration tests

10% to 30%. However, it experiences a gradual decrease for VBRs of more than 30%. It is noteworthy that the water height is an important controlling parameter for the design of TLDs as it can lead to a smaller size for them.

6.2.2 Damping ratio of TLD and TBs

As discussed before, damping ratio is one of the important dynamic characteristic of TLDs. This subsection presents the damping ratio of TLD and TBs. In the forced vibration studies, the damping ratios of models were obtained through half-power bandwidth method using water sloshing response curves.

Fig. 15 displays the calculated damping ratios for TBs versus various VBRs. The graph shows that, the damping ratio of TBs gradually increases as the VBR increases. This finding is in line with the observed results for water heights. It should be mentioned that the obtained damping ratio for the ordinary reference TLD (1.75%) was significantly lower than those obtained for TBs. As we discussed before, such increase in the damping ratio comes with the change in the natural frequency of TBs that can result in mistuning.

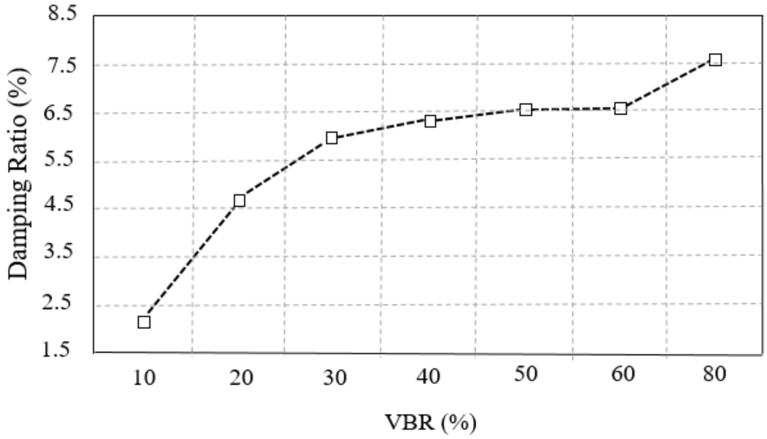


Fig. 15 Damping ratios obtained for TBs from forced vibration tests

6.3 Results of tests performed on S-T and S-TB

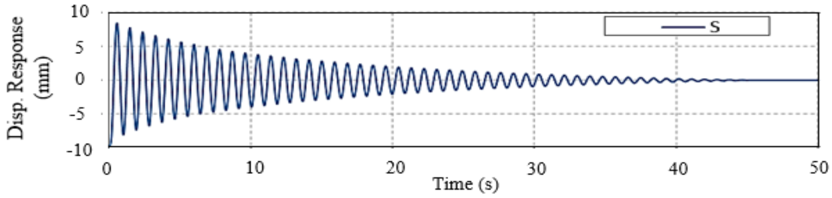
To compare the efficiency of TLD and TB models in reducing structural responses they were installed on a single-storey structure. This section presents the obtained results from free and forced vibrations tests.

6.3.1 Results obtained from free vibration tests

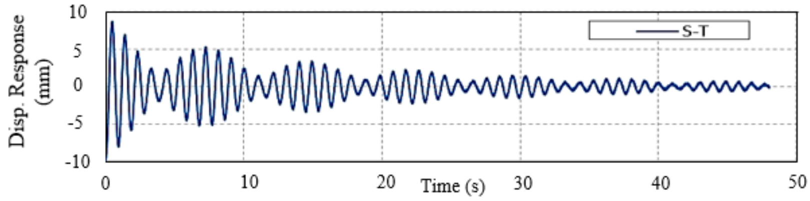
As it is shown in Fig. 7, for free vibration test on S-T and S-TB, an initial displacement of 15mm was imposed to the roof of the structure and then it was released to vibrate freely. The time histories of displacements were recorded through an LVDT which was installed at the roof level.

Fig. 16 shows obtained time histories of structural displacements with and without installation of TLD and TBs. As can be seen, the beating phenomenon is observed in free vibration response of some systems. This phenomenon commonly occurs in S-TLD systems when the frequencies of water tank and the structure are close to each other. It is also expected to see the beat phenomenon in structural system with very high damping in secondary system. Results indicated that addition of baffles inside the TLD can significantly reduce the effect of beat phenomenon. As Fig. 16 shows, the VBR of 30% is the threshold for existence of beat phenomenon in the measured displacement responses. By increasing the VBR to 40%, the behaviour of combined system approaches to that of structure alone and beat phenomenon disappears from the measured signals.

The frequency content of measured displacement signals was studied using FFT analysis. Fig. 17(a) and (b) displays the obtained Fourier amplitudes for structure alone and S-TLD. As can be seen the frequency content of the structure alone shows only a single peak while for the S-TLD system two peaks appear in the frequency domain of the decomposed signals. For S-T system the first peak has a similar frequency to that of structure alone, therefore it shows the natural frequency of the bare structure. However, the second spike which has higher frequency belongs to the second mode shape of the combined TLD-structure system. Similar graphs were plotted for TB-S systems and are shown in Fig. 17(c). For VBR of less 30% two clear spikes can be seen in the decomposed signals. However, when the VBR reaches to 40% only one peak appears in the frequency domain of signals. As can be seen from Fig. 18, the values of the first peaks are slightly less than the natural frequency of the bare structure (1.12 Hz) while the second peaks are close to



(a)



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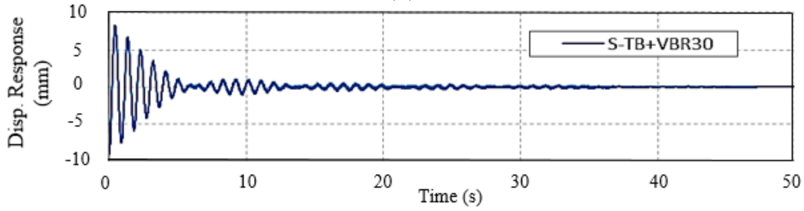

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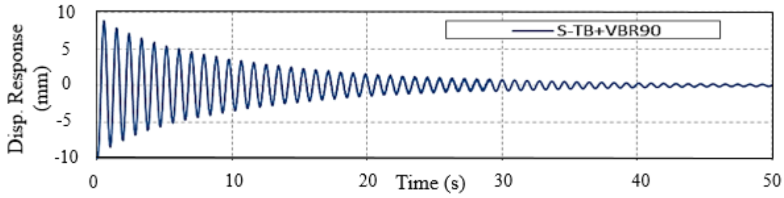
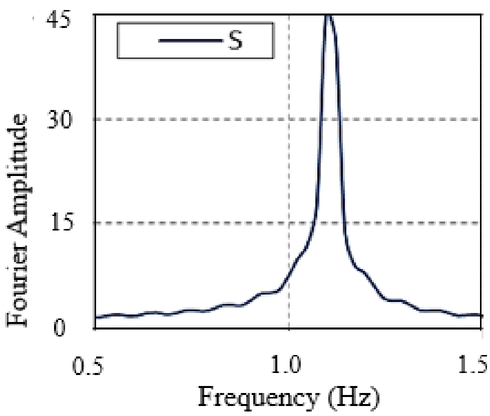
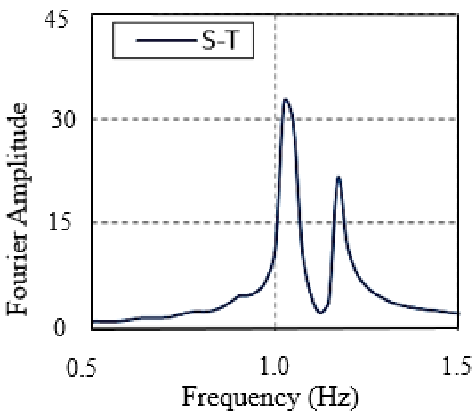


(d)

Fig. 16 Time history of displacement response (a) Structure (b) Structure-TLD (c) S-TB+VBR30% (d) S-TB+VBR90%

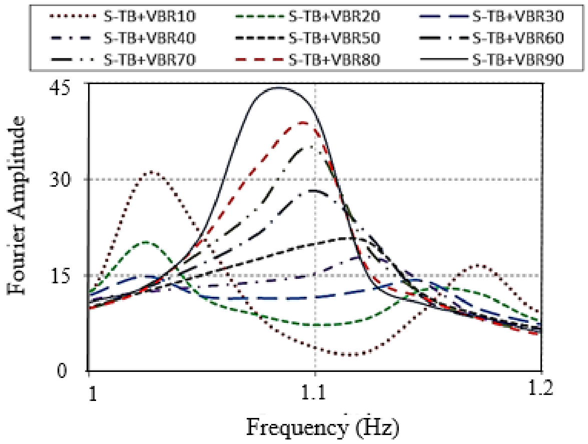


(a)



(b)

Fig. 17 Variation of transfer functions by Fourier amplitude versus frequency of system (a) Structure (b) S-TLD (c) S-TB Models



(c)

Fig. 17 Continued

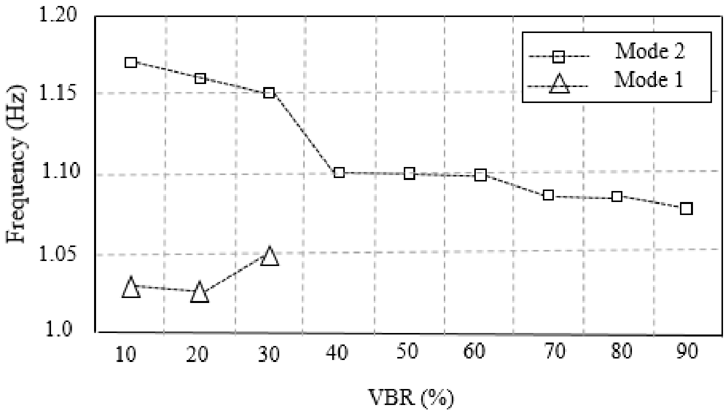


Fig. 18 Obtained frequencies for TBs versus VBRs

it. This observation indicates that, systems with the VBR of more 40% will have two resonance frequencies while for system for others only one resonance frequency is expected under external excitations. This issue is addressed more in detail in the next section.

It is worth mentioning that, due to the existence of beat phenomenon in the measured displacement responses exact calculation of damping values through free vibration tests was impossible and misleading. However, a comparative study indicated that when the blocking ratio reached to 30% the measured displacement responses were damped faster than other combined systems.

6.3.2 Results obtained from forced vibration tests

In addition to free vibration tests, a series of forced vibration tests were also conducted on S-TLD and S-TB models. All models were subjected to a harmonic displacement at their base with a frequency ratio ranging from 0.88 to 1.32 Hz. Time histories of displacement and acceleration responses were recorded at the roof level for each model and were used for comparative studies.

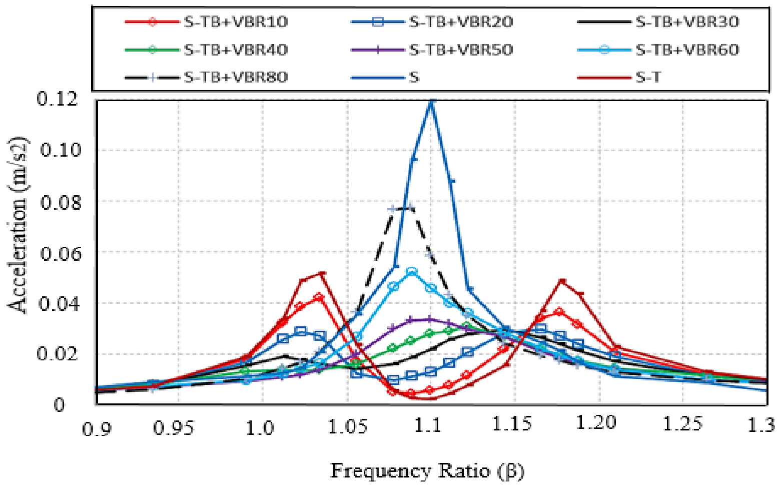


Fig. 19 Acceleration response of S-TB system against various range of frequency

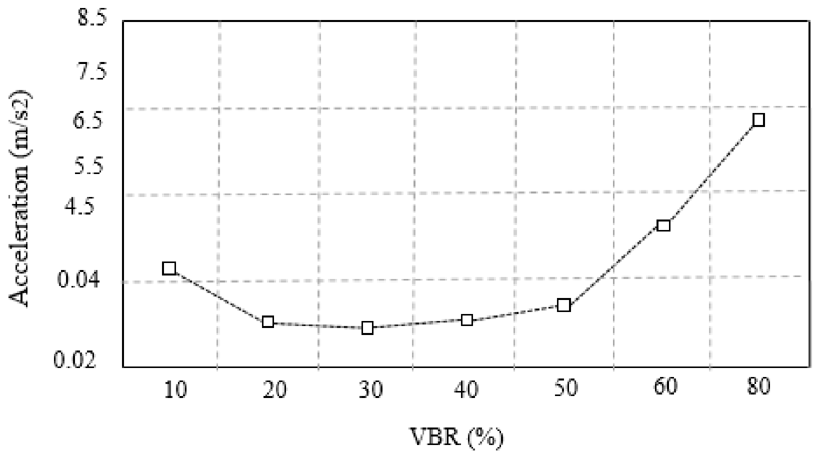
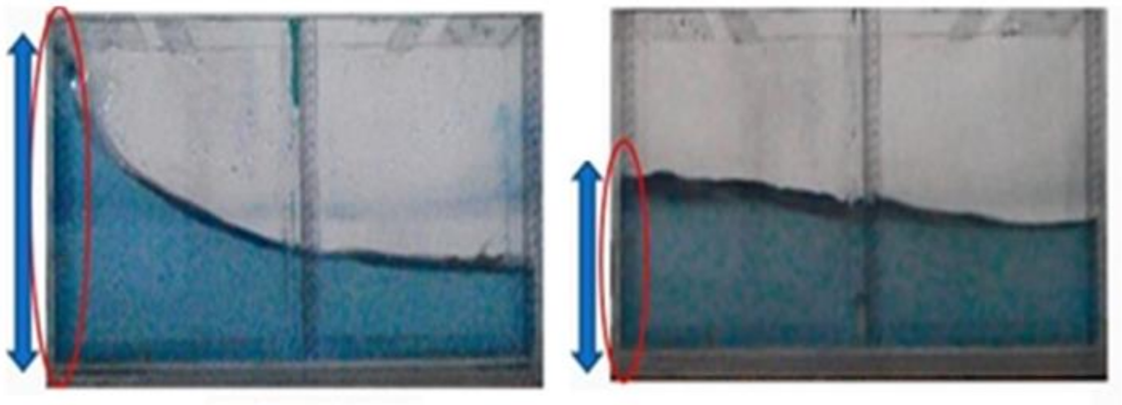


Fig. 20 Acceleration response trend of S-TB system versus VBR

Fig. 19 shows the obtained acceleration responses for S, S-T and S-TB models throughout the excitation ranges. As can be seen, the uncontrolled structure (S) has the highest response acceleration (0.12 m/s^2) among all studied models. It can be also observed that by introducing an ordinary tuned TLD to the bare structure the maximum acceleration response is reduced to 0.05 m/s^2. This clearly shows the efficiency of a tuned TLD in reducing vibration level of an uncontrolled structure. Fig. 19 also confirms the findings of free vibration tests. S-TB Models with less than 40% blocking ratio have displayed two spikes in their acceleration responses demonstrating existence of two resonance frequencies. Results also indicate that S-TB models with VBR of 20%, 30%, 40% and 50% have more stable responses throughout the excitation frequencies ratios compared to other models. This means that when structures are subjected to signals with rich frequency content application of these types of models may result in better vibration control.

Fig. 20 compares the maximum response acceleration obtained for S-TB models. It can be seen



(a) (b)

Fig. 21 Water height in resonance excitation (a) S-T (b) S-TB+VBR30

that, increase in the blocking ratio from 20% to 50% has negligible impact on the efficiency of S-TB models. However, VBR of more than 50% significantly reduces the efficiency of TB models in suppressing structural vibrations. The results also show that the blocking ratio of 30% has suppressed the structural vibration to its maximum. It is worth mentioning that, TLD with VBR of 80% has higher peak response acceleration compared to the reference TLD.

Fig. 21 shows the water height in the tank for the ordinary TLD model and TB model with 30% of blocking ratio. The measured water height at resonance frequency for the ordinary TLD was 12cm which was almost twice that of the TB model. This indicate another advantage of using bottom mounted baffles in ordinary TLDs in which the setting time of sloshing water and the size of the water tank is reduced.

7. Conclusions

In this study, free and forced vibration tests were conducted on the ordinary and modified TLDs in order to determine the dynamic characteristics of baffled TLDs and their efficiency in reducing structural responses. Baffles were installed vertically at the bottom of TLD’s water tank. Different ranges of vertical blocking ratios (VBRs) were included in the experimental tests. Results showed that baffles were influential on the natural frequency, damping ratio and water height of modified TLDs. It was observed that fundamental natural frequency of modified TLDs decreased with the increase in VBRs. Increase in the VBRs of baffles reduced the water height in the tank. Increase in VBRs also decreased the measured sloshing forces. In contrast, increase in VBRs resulted in higher damping ratios in modified TLDs.

Introducing of vertical baffles to the ordinary TLD reduced the effect of beat phenomenon in the displacement responses of structure-TLD system and leaded to faster decay in the oscillation of structure-TLD system under free vibration. In addition, frequency domain studies showed that vertical baffles with small VBRs can impose a second resonance frequency to the dynamic response of ordinary TLDs. In general, TLDs with the VBRs of less than 60% resulted in lower response accelerations compared to the ordinary TLD. The TLD with 30% blocking ratio showed the best performance among modified TLDs and reduced the acceleration responses up to 75%

while the referenced TLD reduced them around 58%.

Since only free vibration and harmonic excitation were included in this study, it would be of great interest for future studies to investigate the effectiveness of TLDs with bottom-mounted baffles when the TLD-structure system is subjected to seismic loads.

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