Effectiveness of multi tuned liquid dampers with slat screens for reducing dynamic responses of structures

T P Nguyen[1*], D T Pham[2] and K T Ngo[1]

[1] Ho Chi Minh City Open University, 97 Vo Van Tan St., Ho Chi Minh City, Vietnam
[2] Mientrung University of Civil Engineering, 24 Nguyen Du St., Tuy Hoa City, Vietnam

[*] Corresponding author, Email: phuoc.nguyen@ou.edu.vn

Abstract. Reducing vibration in structures under lateral load always attracts many researchers in during pastime, hence the mainly purpose of paper analyzes effectiveness of multiple-tuned liquid dampers for reducing dynamic responses of structures under ground acceleration of earthquakes. In this study, the multi-tuned liquid damper with slat screens (M-TLDWSS) is considered in detail for analyzing dynamic response of multi-degrees of freedom structure due to earthquake, which is more different previous studies. Then, the general equation of motion of the structure and M-TLDWSS under ground acceleration of earthquake is established based on dynamic balance of principle and solved by numerical method in the time domain. The effects of characteristic parameters of M-TLDWSS on dynamic response of the structure are investigated. The results obtained in this study demonstrate that the M-TLDWSS has significantly effectiveness for reducing dynamic response of the structure.

1. Introduction

Tuned liquid damper (TLD) has been used as passive control devices for controlling vibrations of structures under different dynamic loading conditions, such as wind, earthquake or other dynamics loads. A TLD is rigid tank, rigidly connected to the structure, with partially filled fluid that can be water or another fluid. The vibration motion of the structure due to the external excitation causes the sloshing motion of fluid inside the tank. By means of tuning the fundamental sloshing frequency of the TLD to the natural frequency of the structure, the inertia forces created would be approximately anti-phase to the external dynamic force, thereby reducing the dynamic response of coupling a structure with a TLD, which is similar to in a way increasing its effective damping [1-3].

The TLD has been attracted significant attention for mitigating vibration in many applications due to its many advantages over other conventional damping devices such as: require low maintenance and operating cost, easy to install in existing building structures, applicable for temporary use, non-restriction uni-directional excitations, and effectiveness even for small amplitude vibrations [4-8]. However, when studying TLD-structure system, there are a number of important design parameters that have to be considered such as: the mass ratio defined as the ratio of the mass of sloshing fluid to the generalized mass of the structure corresponding to the mode to be damped, the natural frequency of the liquid sloshing motion and the damping ratio defined as the ratio of the inherent damping of the TLD to the critical damping.

Expressions to determine the optimum inherent damping value depended on the value of the mass ratio as the optimum damping of a linear tuned mass damper (TMD), it can be adopted by replacing the solid mass of the TMD with the mass of sloshing fluid of the TLD. With a TLD without additional energy dissipating devices, the main source of inherent damping arises from viscous dissipation in the boundary layers at the walls and bottom of the tank and from free surface contamination. Hence, it is usually significantly less than the optimum inherent damping value, resulting in a less effective vibration absorber. To increase the energy dissipated by the sloshing fluid, several approaches have been implemented such as: roughness elements, surface contaminants, wave breaking in shallow water TLD, and nets or screens [9-15].

Recently, the addition of slat screens in TLD has been applied to increase the energy dissipated by the sloshing fluid. The damping devices consists of horizontal slats uniformly spaced apart in order to form screens. The use of this particular screen arrangement allows the space between the slats to be varied until the targeted amount of damping is achieved. Hence, the multi-tuned liquid damper with slat screens (M-TLDWSS) is used for reducing dynamic response of multi-degree of freedom structure due to earthquake, which is more different previous works. In sections 2 and 3 is formulated problem of the TLD with screens and coupling a structure with the M-TLDWSS such as the general equation of motion of the structure and M-TLDWSS under earthquake is established based on dynamic balance of principle and solved by numerical method in the time domain, respectively. In section 4 is presented the numerical investigation based on the formulation in the above sections, the effects of characteristic parameters of M-TLDWS on dynamic response of the structure are investigated. Finally, the main conclusions are derived concerning the efficiency of M-TLDWSS for reducing dynamic response of the structure based on the results obtained in this study.

2. Formulation

2.1. The TLDWSS model

Consider the rectangular tuned liquid damper with slat screens, having a length L, a quiescent fluid depth h, and a tank width b, is shown in figure 1. It is assumed that the fluid response amplitude is small compared to the fluid depth and the slat screens located at or near the centre of the tank do not significantly alter the overall flow of the sloshing liquid. The assumptions of inviscid, incompressible, irrotational flow and negligible surface tension are also made in this model [7, 10].

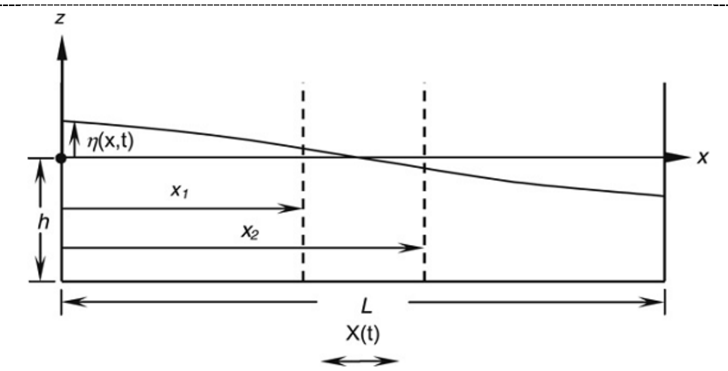

Figure 1. Definition sketch for liquid sloshing in TLD with slat screen.

The vibration motion of the structure due to the external excitation causes the sloshing motion of fluid inside the tank. Then, the energy of a system of standing waves of the simple harmonic type can be expressed in terms of the gravitational and kinematic potential as

$$V=\frac{1}{2}\rho bg\int_0^L \eta^2\left(x,t\right)dx;\qquad T=\frac{1}{2}\rho b\int_{-h}^{0}\int_0^L\left[\left(\dot{X}+\frac{\partial\Phi}{\partial x}\right)^2+\left(\frac{\partial\Phi}{\partial z}\right)^2\right]dxdz \tag{1}$$

where $\dot{X}$ is the horizontal velocity of the tank, $\Phi\left(x,z,t\right)$ is gradient of the velocity potential function.

Consider a number of screens is placed at discrete locations, x_j , shown in Figure 1. It is also assumed that constant C_m , C_d and C_l values denote inertia, drag, and loss coefficients, respectively. Then, it does contribute to the overall kinetic energy of the sloshing liquid, can be expressed as [7]

$$T = \frac{1}{2}\rho A_{cs} C_m \sum_{j=1}^{ns} \sin\left(\frac{n\pi x_j}{L}\right)^2 \int_{-h}^{0} \left[\frac{\cosh\left[\frac{n\pi(z+h)}{L}\right]}{\sinh\left(\frac{n\pi h}{L}\right)}\right]^2 dz\dot{q}_n^2 \tag{2}$$

Using the corresponding Lagrange's equations with Q_n the non-conservative forces, given by

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_n}\right) - \frac{\partial T}{\partial q_n} + \frac{\partial V}{\partial q_n} = Q_n, \qquad n = 1, 2, 3, \ldots \tag{3}$$

The resulting equations of motion is expressed as

$$m_n^* \ddot{q}_n(t) + c_n^* \dot{q}_n(t) + m_n^* \omega_n^2 q_n(t) = \gamma_n^* \ddot{X}(t) \tag{4}$$

where m_n^* is the generalized mass and ω_n is the natural frequency for the n^{th} sloshing mode as

$$m_n^* = \frac{1}{2}\frac{\rho b L^2}{n\pi \tanh\left(\frac{n\pi h}{L}\right)}; \quad \omega_n^2 = \frac{n\pi g}{L}\tanh\left(\frac{n\pi h}{L}\right) \tag{5}$$

and the generalized stiffness is also given as

$$k_n^* = m_n^* \omega_n^2 = \frac{\rho b L g}{2} \tag{6}$$

and the equation for the excitation factor can be expressed as

$$\gamma_n = \frac{\rho b L^2}{(n\pi)^2}\left[1 - \cos(n\pi)\right] \tag{7}$$

Based on the linearization of damping term for the fundamental sloshing mode ($n = 1$), the generalized damping coefficient in equation (4) is given by

$$c_n^* \equiv c_n^{eq*} = C_l \frac{4\rho b L}{3\pi^2} \Delta_n \Xi_n q_n \omega \tag{8}$$

and the corresponding generalized damping ratio can be expressed as

$$\zeta_n^{eq*} = C_l \frac{4}{3\pi}\tanh\left(\frac{\pi h}{L}\right)\Delta_n \Xi_n \frac{q_n}{L} \tag{9}$$

and the parameter Δ_n and Ξ_n are given by, respectively

$$\Delta_n = \frac{1}{3} + \frac{1}{\sinh^2\left(\frac{n\pi h}{L}\right)}; \qquad \Xi_n = \sum_{j=1}^{ns} \sin\left(\frac{n\pi x_j}{L}\right)^3 \tag{10}$$

where ns is total of slat screens and ρ is mass density of fluid.

2.2. Formulation of the structure-TLDWSS interaction

Consider the TLDWSS as the TMD model attached to the structure modeled as a generalized single degree of freedom system representing the mode of vibration being suppressed, is shown in figure 2.

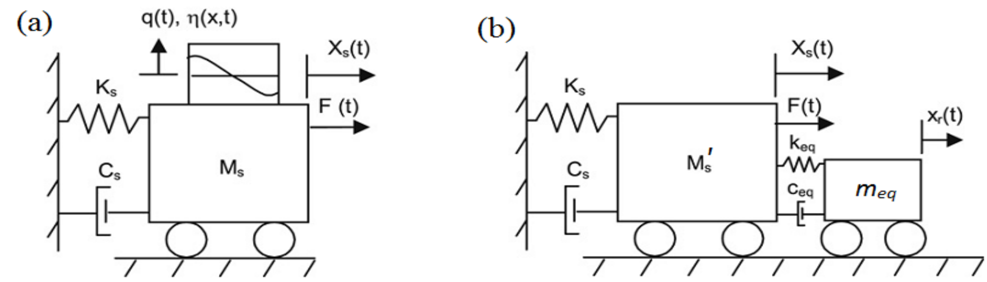

Figure 2. The model of the structure-TLDWSS interaction: (a) Structure-TLDWSS system, (b) Equivalent mechanical linearized structure-TLDWSS system.

As the TLDWSS tank moves with the structure due to the external excitation the contained fluid will exhibit a sloshing response motion. The equations of motion for a coupling the structure with TLDWSS as two degree of freedom system can be expressed as

$$\begin{bmatrix} M_s' & 0 \\ 0 & m_{eq} \end{bmatrix} \begin{Bmatrix} \ddot{X}_s \\ \ddot{x}_r \end{Bmatrix} + \begin{bmatrix} C_s + c_{eq} & -c_{eq} \\ -c_{eq} & c_{eq} \end{bmatrix} \begin{Bmatrix} \dot{X}_s \\ \dot{x}_r \end{Bmatrix} + \begin{bmatrix} K_s + k_{eq} & -k_{eq} \\ -k_{eq} & k_{eq} \end{bmatrix} \begin{Bmatrix} X_s \\ x_r \end{Bmatrix} = \begin{Bmatrix} F(t) \\ 0 \end{Bmatrix} \tag{11}$$

where $M_s^{'}$, C_s, and K_s are the total vibration mass to account for the non-participating component of the liquid corresponding with the fundamental sloshing mode, damping and stiffness of the structure, respectively, given by

$$M_s^{'} = M_s + m^{non} \tag{12}$$

where m^{non} is the mass of non-participating component of the liquid, can be expressed as

$$m^{non} = \rho bhL - m_{eq} \tag{13}$$

The equivalent mass, damping and stiffness of the TLDWSS, corresponding to the fundamental sloshing mode, which develops dynamic forces equal to the forces exerted by the sloshing fluid in the rectangular tank, are used to represent an equivalent mechanical system, given by [7]

$$\begin{aligned} m_{eq} &= \frac{8\rho bL^2}{\pi^3}\tanh\left(\frac{\pi h}{L}\right); \qquad k_{eq} = \frac{8\rho bLg}{\pi^2}\tanh^2\left(\frac{\pi h}{L}\right) \\ \omega_{eq} &= \left[\frac{\pi g}{L}\tanh\left(\frac{\pi h}{L}\right)\right]^{1/2}; \qquad c_{eq} = C_l\,\frac{256\rho bL}{3\pi^5}\tanh^3\left(\frac{\pi h}{L}\right)\Delta\Xi\,\omega x_r \end{aligned} \tag{14}$$

and the damping ratio can be also expressed as

$$\zeta_{eq} = C_l\,\frac{16}{3\pi^2}\tanh^2\left(\frac{\pi h}{L}\right)\Delta\Xi\,\frac{x_r}{L} \tag{15}$$

The aim of designing M-TLDWSS is to tune damper parameters to the modal parameters of selected modes of vibration. It means that the natural damper frequency (or a group of dampers) must be close to the natural frequency of a selected vibration mode of structure. Hence, the tuning ratio, Ω , is important parameter that strongly influence the performance of the M-TLDWSS which is defined as the ratio of the sloshing frequency to the structural frequency in the mode that the dynamic motions are to be suppressed

$$\Omega = \frac{\omega_{eq}}{\omega_s} \tag{16}$$

The optimal parameters of such a damper (or group of dampers) can be determined based on utilizing linear TMD theory, then the optimal frequency ratio and damping coefficient are given by

$$\Omega^{\text{opt}} = \frac{1}{1+\mu}(1+0.5\mu)^{1/2}; \qquad \zeta^{\text{opt}} = \left(\frac{\mu+0.75\mu^2}{4+6\mu+2\mu^2}\right)^{1/2} \tag{17}$$

where the mass ratio μ is the ratio of the generalized participating fluid mass to the structural generalized mass expressed as

$$\mu = \frac{m_{eq}}{M_s^{'}} \tag{18}$$

Assuming that the mass ratio μ is known, the characteristic parameters of the M-TLDWSS can be obtained from the above formulae. And then, the equivalent system in the coupling structure with M-TLDWSS allows direct application of design tools. In order to achieve the optimal damping ratio for a given target response amplitude and corresponding relative response motion, the required screen properties and placement can be estimated.

3. Governing equation of motion

Consider a building structure with N stories as multi-degrees of freedom system and the M-TLDWSS installed at the top floor due to earthquake, shown in figure 3a and the equivalent mechanical model of coupling the structure with M-TLDWSS due to earthquake is described in figure 4. It is assumed that the building structure is treated as a discrete and linear elastic system, the mass is concentrated at the level of building floors and the beams of the frame are infinitely stiff, shown in figure 3b.
The system equation of motion of the coupling structure with M-TLDWSS due to ground acceleration of earthquakes $\ddot{\boldsymbol{u}}_g(t)$ at time t can be expressed as

$$\mathbf{M}\ddot{\boldsymbol{u}} + \mathbf{C}\dot{\boldsymbol{u}} + \mathbf{K}\boldsymbol{u} = -\mathbf{Mr}\ddot{\boldsymbol{u}}_g(t) \tag{19}$$

where $\mathbf{M}$, $\mathbf{C}$ and $\mathbf{K}$ are the overall matrix of mass, damping and stiffness, respectively; $\boldsymbol{u}$ and $\boldsymbol{P}(t)$ are the overall vector of displacement and force, respectively. The mass matrix $\mathbf{M}$ of the system is in the following form [16]

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_s & \mathbf{0} \\ \mathbf{0} & \mathbf{M}_{TLD} \end{bmatrix} \tag{20}$$

where $\mathbf{M}_s$ and $\mathbf{M}_{TLD}$ are the mass matrix of the structure and M-TLDWSS, respectively, given by

$$\begin{aligned} \mathbf{M}_s &= diag\left(m_1, m_2, ..., m_{N-1}, m_N^{'}\right) \\ \mathbf{M}_{TLD} &= diag\left(m_1^{eq}, m_2^{eq}, ..., m_{n-1}^{eq}, m_n^{eq}\right) \end{aligned} \tag{21}$$

where $m_N^{'}$ is total mass of the top floor and non-participating component of the liquid expressed as

$$m_N^{'} = m_N + \sum_{j=1}^{n} m_j^{non} \tag{22}$$

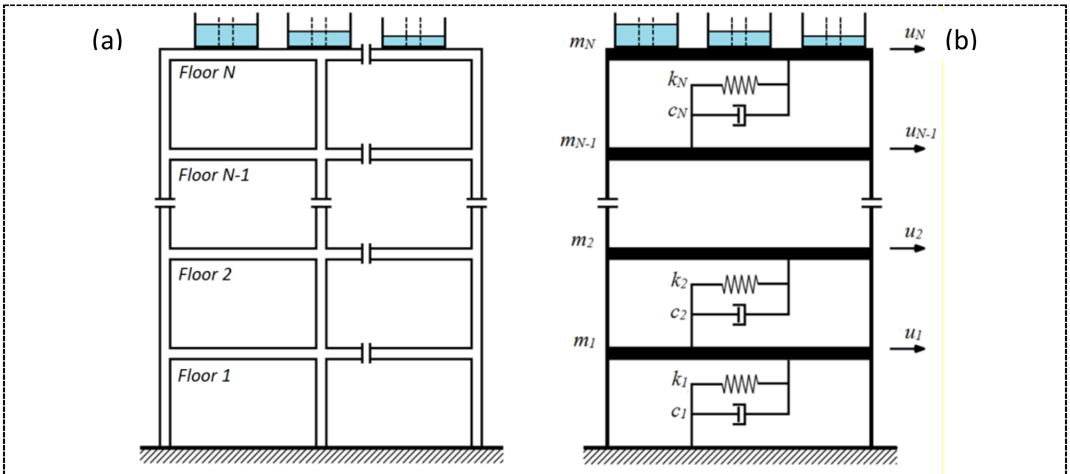

Figure 3. The coupling the structure with M-TLDWSS model under earthquake: (a) The real structure model, (b) The structure system model.

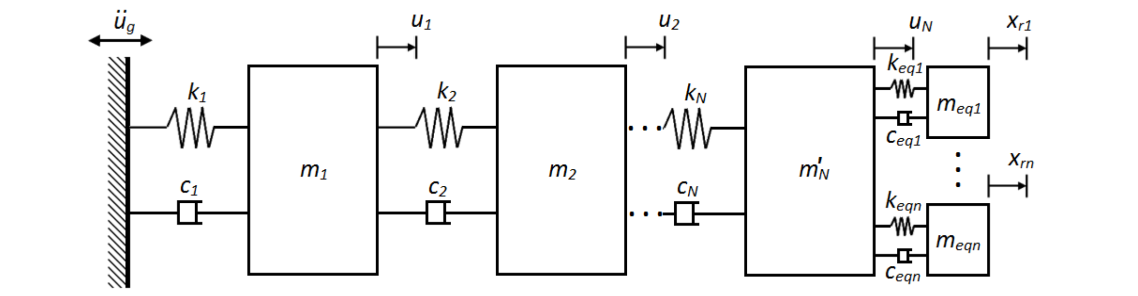

Figure 4. The equivalent mechanical model of coupling the structure with M-TLDWSS due to ground acceleration of earthquakes.

The stiffness matrix $\mathbf{K}$ of the considered system can also be shown [16]

$$\mathbf{K} = \begin{bmatrix} \mathbf{K}_s + \mathbf{k}_{TLD} & \mathbf{K}^* \\ \mathbf{K}^{*T} & \mathbf{K}_{TLD} \end{bmatrix} \tag{23}$$

where $\mathbf{K}_s$ is the stiffness matrix of the structure, given by

$$\mathbf{K}_s = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2 + k_3 & -k_3 & 0 \\ 0 & -k_3 & \ldots & -k_N \\ 0 & 0 & -k_N & k_N \end{bmatrix} \tag{24}$$

and the matrix $\mathbf{k}_{TLD}$ can be expressed as

$$\mathbf{k}_{TLD} = diag\left(0,\, 0,\, \ldots,\, k_1^{eq} + k_2^{eq} + \ldots + k_n^{eq}\right) \tag{25}$$

The matrices $\mathbf{K}_{TLD}$ and $\mathbf{K}^*$ are in the following form

$$\mathbf{K}_{TLD} = diag\left(k_1^{eq}, k_2^{eq}, ..., k_{n-1}^{eq}, k_n^{eq}\right)$$
$$\mathbf{K}^* = \begin{bmatrix} 0 & 0 & ... & 0 \\ 0 & 0 & ... & 0 \\ ... & ... & ... & ... \\ -k_1^{eq} & -k_2^{eq} & ... & -k_n^{eq} \end{bmatrix} \tag{26}$$

The damping matrix of the system $\mathbf{C}$ is in a form similar to the stiffness matrix $\mathbf{K}$, defined as

$$\mathbf{C} = \begin{bmatrix} \mathbf{C}_s + \mathbf{c}_{TLD} & \mathbf{C}^* \\ \mathbf{C}^{*T} & \mathbf{C}_{TLD} \end{bmatrix}$$
$$\mathbf{C}_{TLD} = diag\left(0, 0, ..., c_1^{eq} + c_2^{eq} + ... + c_n^{eq}\right)$$
$$\mathbf{C}_{TLD} = diag\left(c_1^{eq}, c_2^{eq}, ..., c_{n-1}^{eq}, c_n^{eq}\right) \tag{27}$$
$$\mathbf{C}^* = \begin{bmatrix} 0 & 0 & ... & 0 \\ 0 & 0 & ... & 0 \\ ... & ... & ... & ... \\ -c_1^{eq} & -c_2^{eq} & ... & -c_n^{eq} \end{bmatrix}$$

and the damping matrix of the structure $\mathbf{C}_s$ is determined based on Rayleigh damping as

$$\mathbf{C}_s = \alpha \mathbf{M}_s + \kappa \mathbf{K}_s \tag{28}$$

and $\boldsymbol{r} = (1, 1, ..., 1)^T$ is unit vector.

The equation (19) is used to analyze effects of the characteristic parameters of M-TLDWSS on dynamic response of the structure due to ground acceleration of earthquake. The flowchart of numerical procedure for analyzing this above problem is developed based on the Newmark's method.

4. Numerical investigation

In this section, considering real building parameters are given in Table 1 [16] and the damping ratio for first two modes of this building is taken 2%. The 1940 El-Centro earthquake is chosen to excite the building as shown in figure 5. The M-TLDWSS consists of 8 TLDWSS, each TLDWSS equipped with two damping screens located at $0.4L$ and $0.6L$, respectively, having a length $L = 6$ m, width $b = 6$ m, loss coefficient $C_l = 2.16$. To properly tune the M-TLDWSS to the structure, the tank considered as normal tank for living in the building was partially filled with water to a depth, h.

Table 1. The main parameters of the structure.

Story	Mass [kg]	Stiffness [N/m]
1	2.83×10^5	3.31×10^8
2-4	2.76×10^5	1.06×10^9
5-7	2.76×10^5	6.79×10^8
8-10	2.76×10^5	6.79×10^8
11-13	2.76×10^5	5.84×10^8
14-16	2.76×10^5	3.86×10^8
17-19	2.76×10^5	3.47×10^8
20	2.92×10^5	2.29×10^8

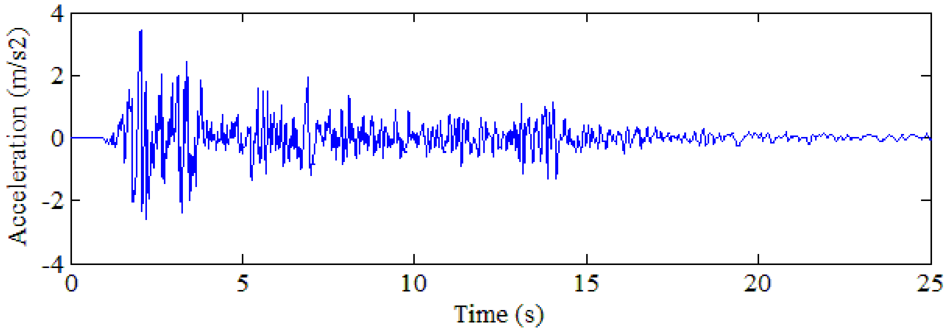

Figure 5. Ground acceleration for 1940 El-Centro earthquake.

It can be seen that the characteristic parameters of the M-TLDWSS depend on the tank length, L, width, b, water height, h, number, ns, and placement, x_j, of the slat screens. Those are important parameters for the tuning ratio and mass ratio that affect strongly on the performance of the M-TLDWSS. Hence, the effects of these parameters on reducing dynamic response of the structure due to earthquake will be investigated in detail in this section.

4.1. Effect of the ratio of depth per length $\frac{h}{L}$

From equations (14) to (15) show that this ratio effects directly on dynamic characters of the TLDWSS. Hence, this ratio is the most important parameter of the M-TLDWSS effecting strongly on reducing dynamic response of the structure. Figure 6a shows that with an increase of the ratio increase significantly the tuning ratio. It can be seen that an increase of tuning ratio is quite clear in the range of value of the ratio less than 1. With an increase of the ratio will tune the sloshing frequency to the structural frequency in the mode, then the effectiveness of M-TLDWSS for reducing dynamic response of the structure will be more significant than others.

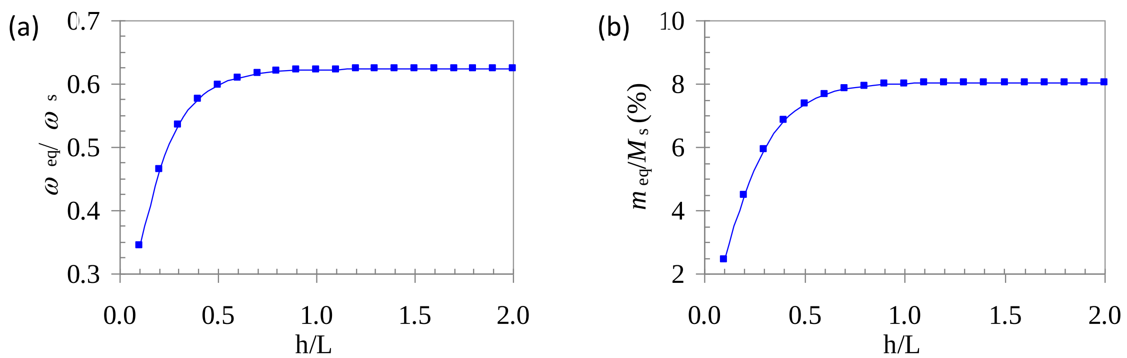

Figure 6. The effects of the ratios on: (a) the tuning ratio, (b) the mass ratio.

It can be also seen that with an increase of the ratio also increase the generalized participating water mass causing increase of the mass ratio, shown in figure 6 (b). With increase of the ratio in the range of value of the ratio less than 1, the mass ratio is significantly more increasing than others. When the mass ratio increases, the general vibration mass of the structure system is also increase causing increase building mass and various dynamic character of the structure system.
The influence of the ratio on damping coefficient and damping ratio are also studied, shown in figure 7. It can be seen that the ratio effects stronger on characteristic damping of the M-TLDWSS in the range

of value less than 1 than others. Additionally, with an increase of the ratio increases damping coefficient, shown in figure 7(a), but the damping ratio decreases with an increase of the ratio, shown in figure 7(b). It can be confirmed that this ratio effects strongly on dynamic characters of the M-TLDWSS such as tuning ratio, mass ratio, damping coefficient and damping ratio. Therefore, it also causes various dynamic character of the structure system. Hence, the effectiveness of the M-TLDWSS for reducing dynamic response of the structure due to earthquake is also different with various value of this ratio, shown in figure 8. In this real problem, the effectiveness of the M-TLDWSS is clear in the range of value of the ratio from 0.5 to 1 and 1.3 to 1.7. Reduction of displacement of the top floor and shear force of the first floor are more significant in this range than others. But, a comparison of increase of addition mass of the M-TLDWSS shows that the effectiveness of the M-TLDWSS is the strongest on both reducing dynamic response of the structure and addition mass in the range of value of the ratio from 0.6 to 0.8.

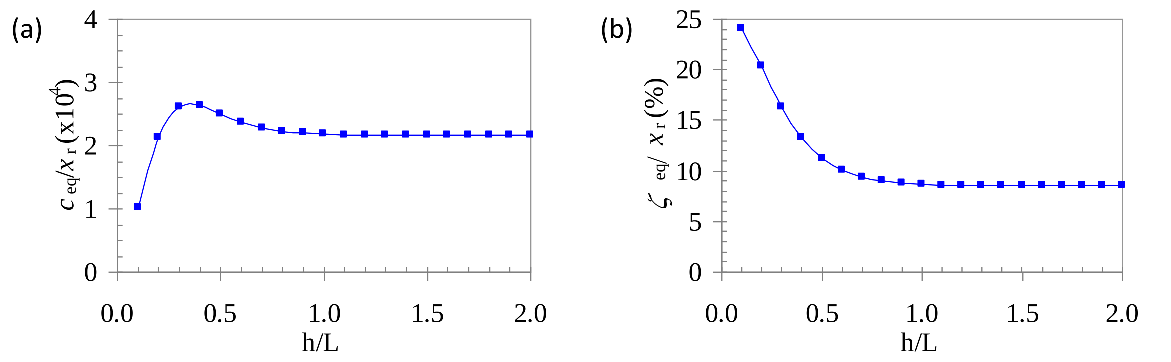

Figure 7. The effects of the $\frac{h}{L}$ ratios on: (a) the damping coefficient, (b) the damping ratio.

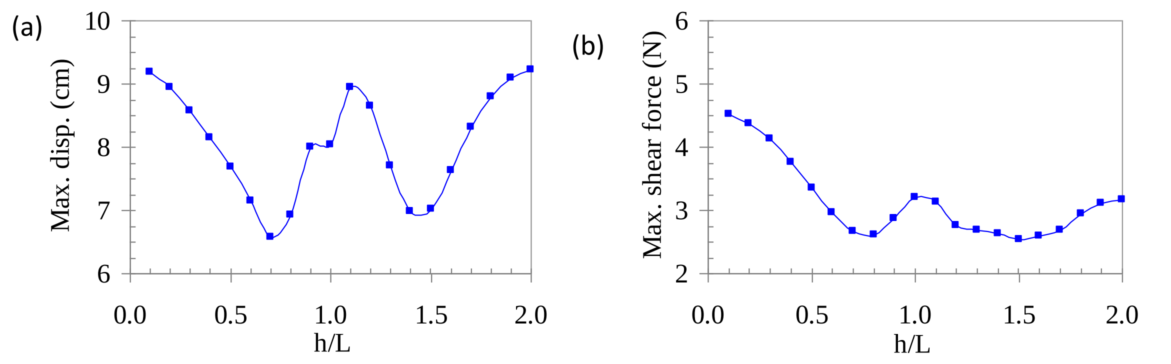

Figure 8. The effects of the $\frac{h}{L}$ ratios on: (a) the maximum displacement of the top floor, (b) the maximum shear force of the first floor (x10^6).

4.2. Effectiveness of the M-TLDWSS on reducing dynamic response

In this investigation, the value of the ratio of depth per length is chosen 0.6 and 0.7 to analyze effectiveness of the M-TLDWSS on the dynamic response, respectively. The time history of displacement at each floor and shear force of the first floor is presented in figures 9, 10, respectively. The maximum displacement and shear force of each story are shown in figure 11.

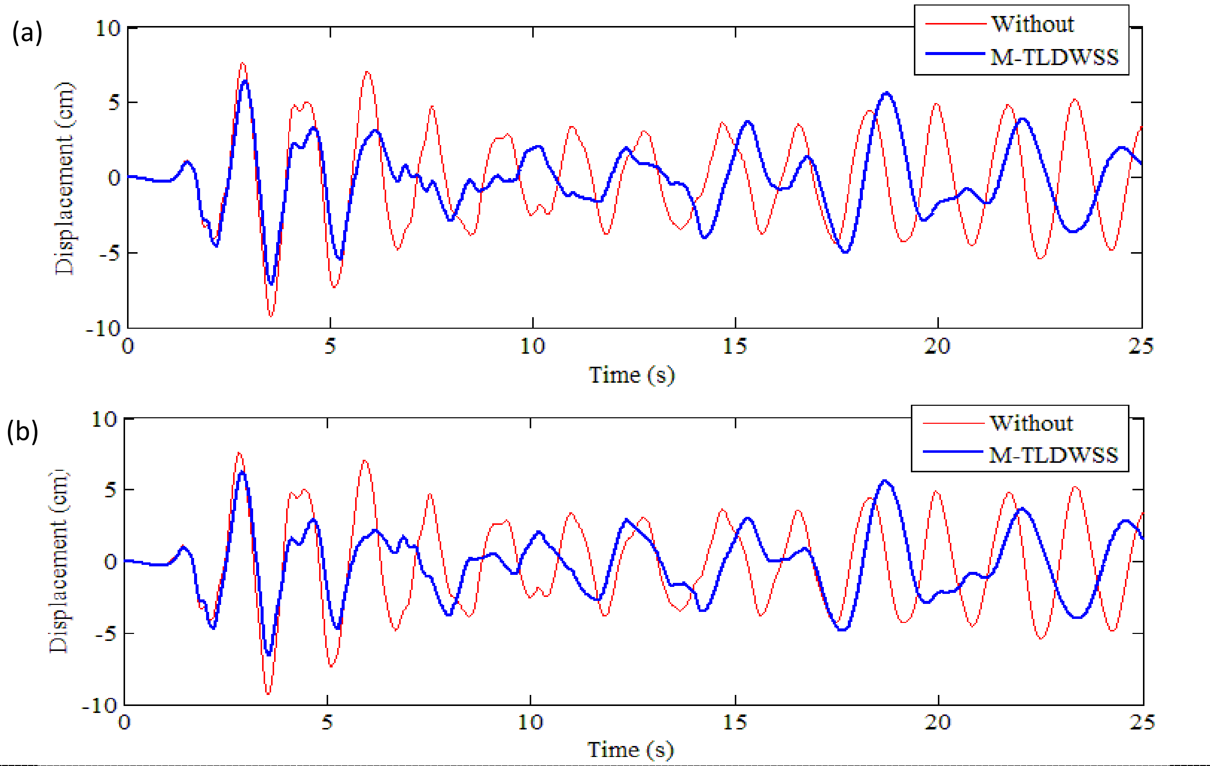

Figure 9. The time history of displacement of the top floor with: (a) $\frac{h}{L} = 0.6$, (b) $\frac{h}{L} = 0.7$

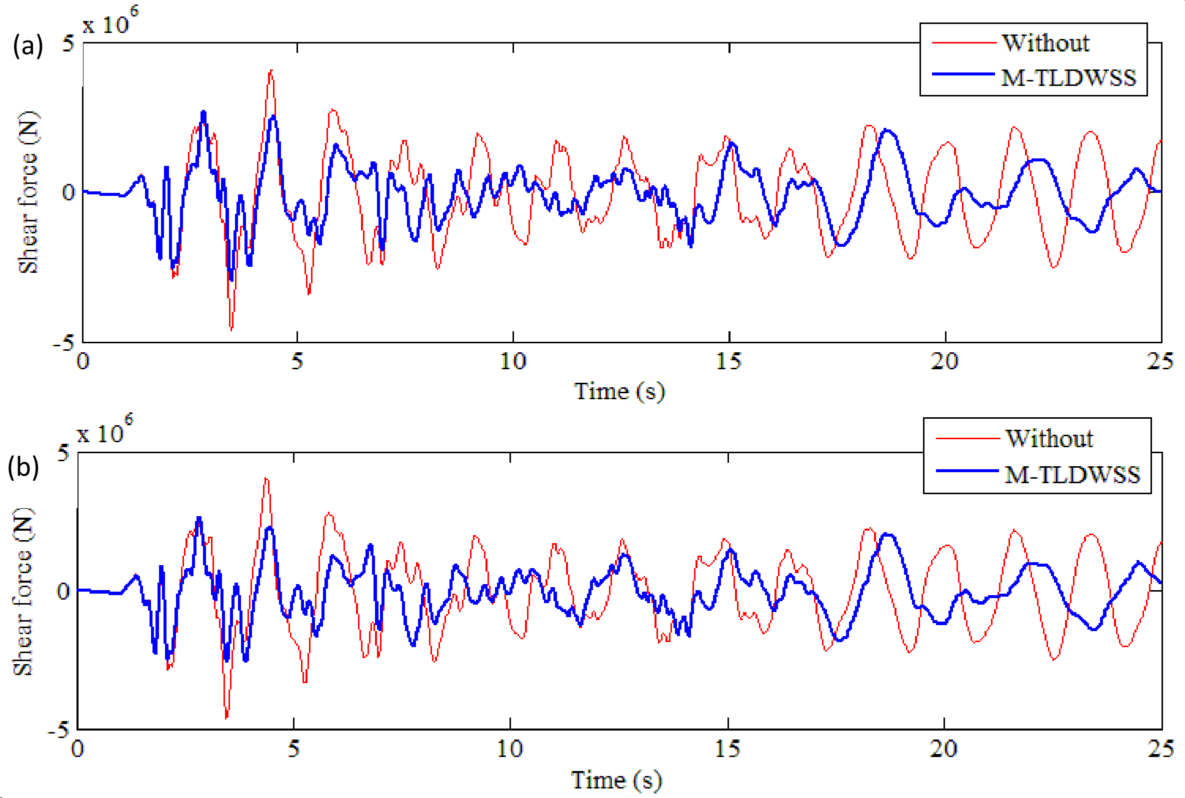

Figure 10. The time history of displacement of the top floor with: (a) $\frac{h}{L} = 0.6$, (b) $\frac{h}{L} = 0.7$

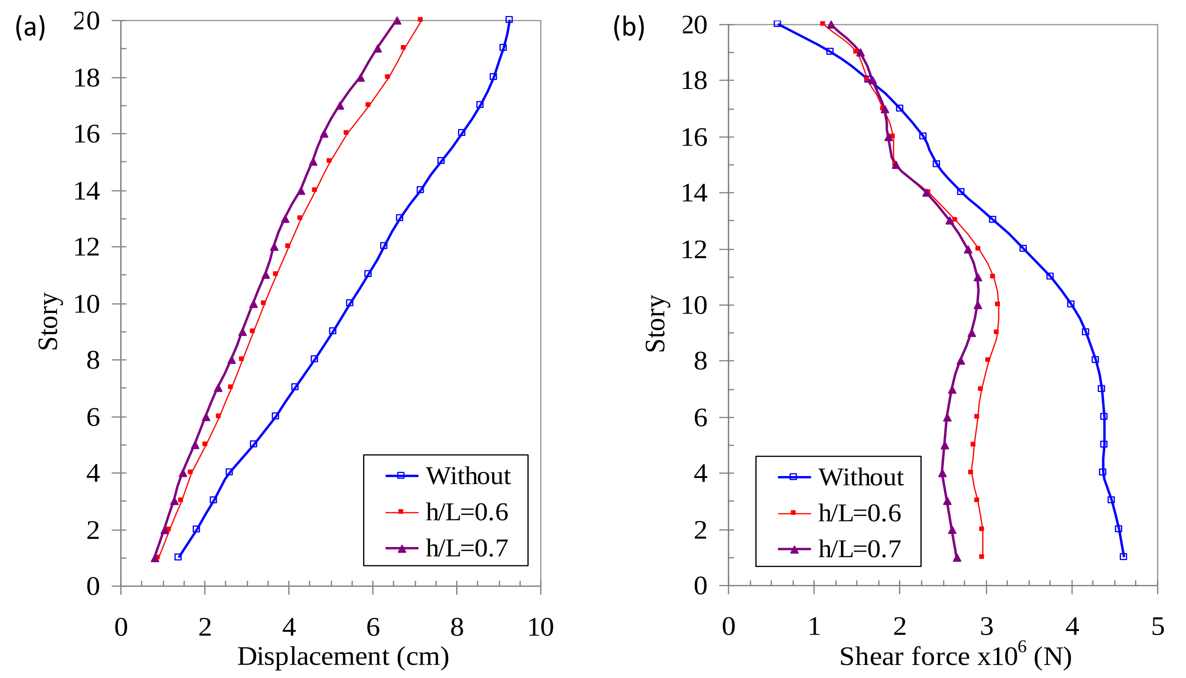

Figure 11. The effect of the $\frac{h}{L}$ ratio on the structure response**:** (a) the maximum displacement, (b) the maximum shear force.

It can be seen that the M-TLDWSS attached in the top floor had effectiveness for reducing dynamic response of the structure due to earthquake in this real problem. It is more decreasing significantly the time history of displacement at each story than without damper. These things are also similar to on the time history of shear force in the structure, shown in figure 9 and figure 10. When the tuning ratio increases nearly the optimal ratio, the M-TLDWSS will have strongly effects on the structure response. Hence, it is more decreasing significantly dynamic response of the structure than without damper, shown in figure 11.

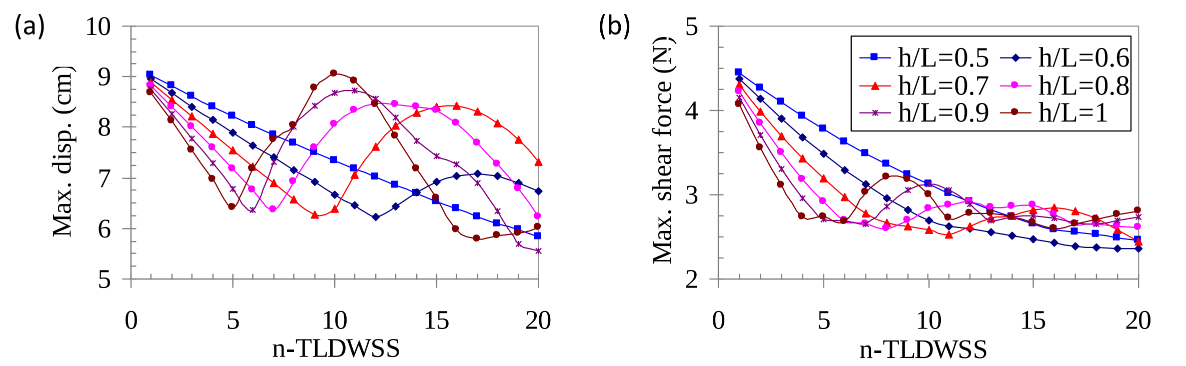

Figure 12. The effect of TLDWSS number**:** (a) the displacement, (b) the shear force (x10^6).

Continuously, the influence of number of TLDWSS on performance of the M-TLDWSS is investigated with various values of the ratio, presented in figure 12. This numerical result shows that the number of the TLDWSS has affect significantly on the structure response. The influence of the TLDWSS number is also different corresponding with each the ratio. But, a general estimate shows that the effectiveness of the M-TLDWSS does not have quite differences with various values of the ratio corresponding with various values of the TDWSS number. Therefore, it can be seen that the main performance of M-TLDWSS completely depends on both important parameters the ratio and number of the TLDWSS. Hence, in order to target for reducing dynamic response of the structure, the both above parameters must be considered to tune the tuning ratio to the optimal ratio, and then, the effectiveness of the M-TLDWSS for reducing dynamic response of the structure due to earthquake will be clear and more significant than others.

4.3. Suitability of M-TLDWSS with various earthquakes

The main purpose of this section verifies suitability of effectiveness of the M-TLDWSS for reducing dynamic response due to various random ground accelerations, shown in figure 13 and figure 14. The effectiveness of the M-TLDWSS for reducing dynamic response of the structure due to ground acceleration is studied with various values of the ratio, shown in figure 15 and figure 16, respectively. The numerical results show that the M-TLDWSS is more decreasing the maximum displacement and shear force at each story than without damper. Specially, in range of value of the ratio from 0.6 to 0.8, the performance of the M-TLDWSS for reducing dynamic response of the structure is clearer than others. Therefore, it can be confirmed that the M-TLDWSS has effectiveness for reducing dynamic response of the structure due to various ground accelerations in this real problem. It is more decreasing significantly structure response than without damper. Hence, the M-TLDWSS including many tanks as living water tanks in the building can be considered as a useful solution for designing earthquake resistance. And, one of the best important things for designing characteristic parameters of the M-TLDWSS is tune both the ratio and TLDWSS number to achieve target for reducing dynamic response.

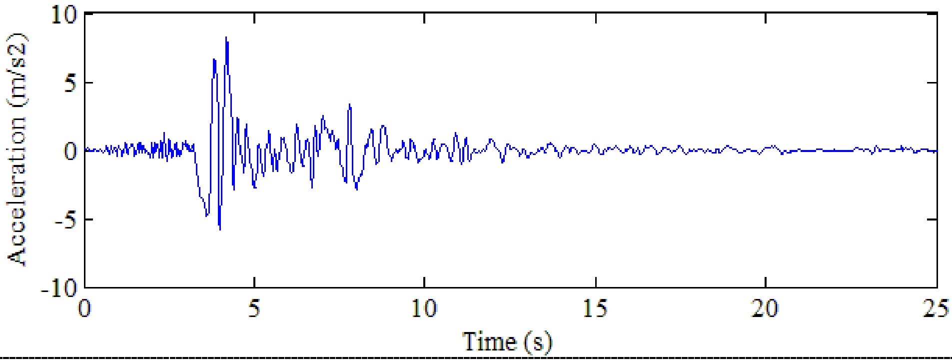

Figure 13. Ground acceleration for Northidge earthquake.

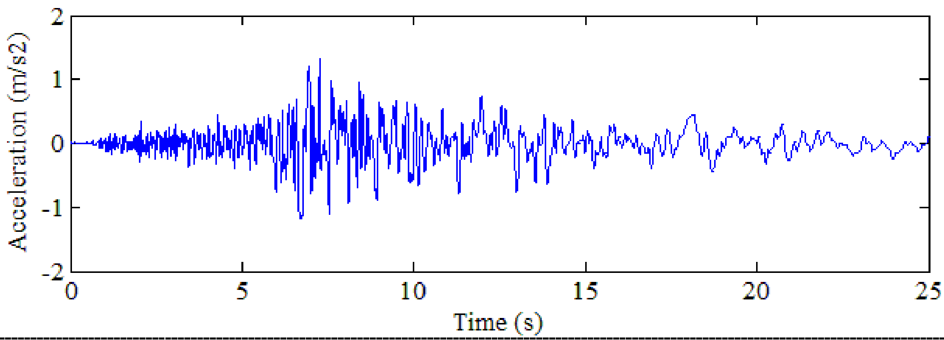

Figure 14. Ground acceleration for Superstition earthquake.

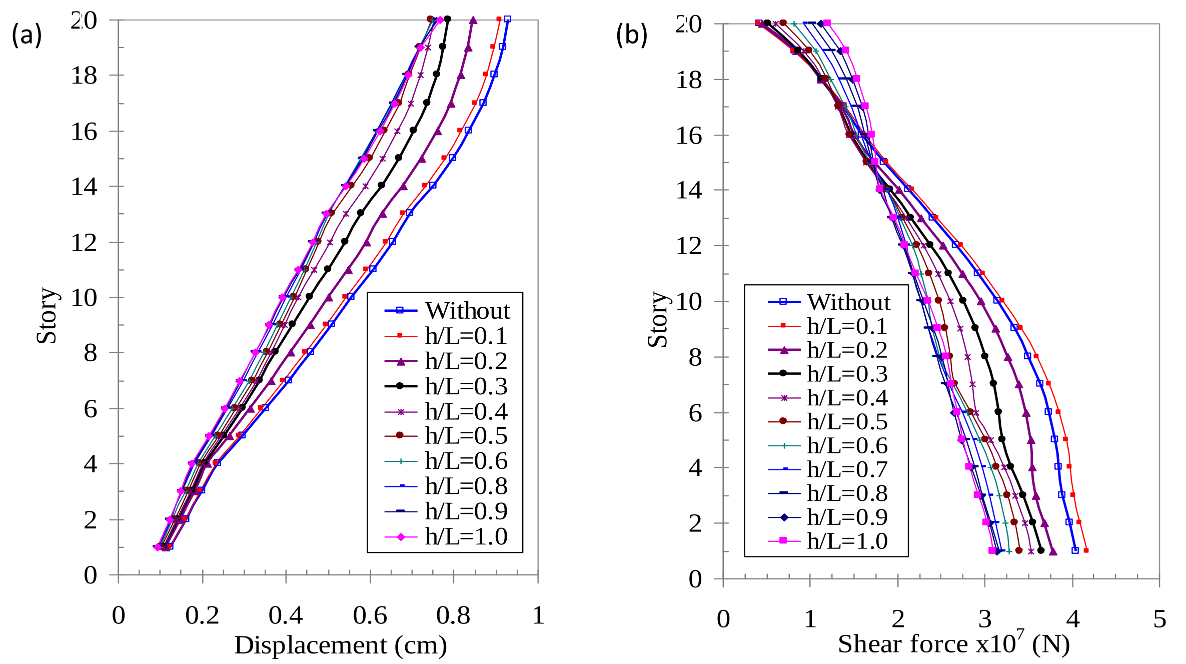

Figure 15. The effectiveness of the M-TLDWSS with Northidge earthquake: (a) the maximum displacement, (b) the maximum shear force.

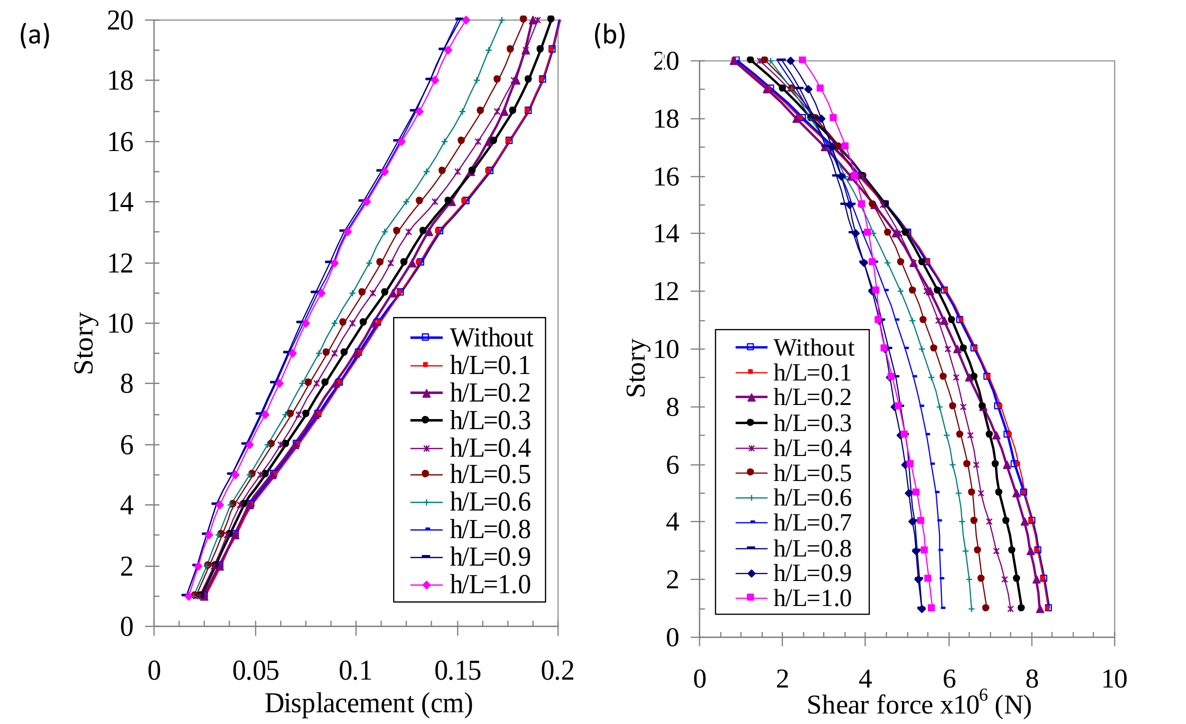

Figure 16. The effectiveness of the M-TLDWSS with Superstition earthquake: (a) the maximum displacement, (b) the maximum shear force.

5. Conclusion

The main concern of this paper is to analyse the effectiveness of the multi-tuned liquid damper with slat screens (M-TLDWSS) for reducing dynamic response of the structure. The M-TLDWSS includes many TLD which is added slat screens to increase the energy dissipated by the sloshing fluid. The character parameters of TLDWSS response depend on the response amplitude of the TLD, the water depth, tank length, damping screen location and damping screen loss coefficient. The response of the coupling structure with M-TLDWSS due to earthquake in the time domain has been analysed.

The following conclusions could be formulated from the numerical results as follows:

- The ratio of depth per length is affect strongly on dynamic character of the M-TLDWSS, it increases tuning ratio which is one of the most important parameters for performance of the M-TLDWSS on reducing dynamic response of the structure. In this real problem, the effectiveness of the M-TLDWSS for reducing structure response is more significant in the range of value of the ratio from 0.6 to 0.8 than others.
- The performance of the M-TLDWSS also depends on TLDWSS number. The influence of the TLDWSS number is also different corresponding with each the ratio. But, a general estimate shows that the effectiveness of the M-TLDWSS does not have quite differences with various values of the ratio corresponding with various values of the TDWSS number.
- The M-TLDWSS applied for reducing dynamic response of the structure can be suitable for various ground accelerations in this real problem. It is more decreasing significantly structure response than without damper.

The above parameters must be considered to tune the tuning ratio to the optimal ratio to achieve target for reducing dynamic response of the structure due to lateral loads.

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