CHAPTER 4

DESIGN OF TUNED LIQUID DAMPER (TLD) AND MULTIPLE TUNED LIQUID DAMPERS (MTLD)

4.1 Tuned Liquid Damper

4.1.1 Mathematical model and response

Geometrical model of rectangular TLD is shown in Fig. 4.1. The advantage of TLD over TMD can be summarized as follows. (1) Maintenance cost is minimized. This is because the simple physical concepts on which the restoring force is provided in TLD, no activation mechanism is required. (2) TLD systems are at all times active, avoiding problems due to an inadequate activation system, while the mechanism activating a TMD must be selected to a certain threshold level of excitation. (3) For large amplitude of oscillation, the system is not very sensitive to the actual frequency ratio between primary and secondary system. (4) For structures with different fundamental frequencies in the two major directions, tuning may be accomplished by using rectangular thanks as shown in Fig. 4.1.

For the rectangular tank, the sloshing natural frequency in rad/s can be expressed from the application of linear wave theory as [Fujino et al. 1992]

$$\omega_R = \left(\frac{g}{a}\pi \tanh\left(\pi\frac{h}{a}\right)\right)^{0.5} \tag{4.1}$$

where h is height of water and a is length of water tank.

4.1.2 Optimal damping ratio

For the rectangular tank, damping ratio of liquid sloshing can be approximately calculated from linear theory and assuming that the shear stress outside the boundary layer is negligibly small as [Fujino et al. 1992]

$$\xi_R = \frac{1}{2h}\sqrt{\frac{\nu}{\pi f_R}}\left(1+\frac{h}{b}\right) \tag{4.2}$$

where f_R is the natural frequency of TLD in Hz and ν is the kinematic viscosity = 0.01 cm^2/sec for water at room temperature and b is the width of water tank.

This type of dynamic damper utilizes the liquid motion, which is governed by the mass of liquid due to gravity. The effective moving mass m_a can be determined as [Chang 1998]

$$m_a = \left(0.259\frac{a}{h}\tanh\left(3.14\frac{h}{a}\right)\right)m_t \tag{4.3}$$

where m_t is the total mass of the liquid. m_a, ω_R and ξ_R can be computed together passing EXCEL computer program.

Using the notation that the first mode structural force $F_s(t) = k_s f(t)$. $f(t) = e^{i\omega t}$ is assumed to calculate the complex frequency response H_{xs}. The mean square displacement response, computed by MATLAB, of the first mode structure is generated to compute the equivalent damping ratio.

The damping ratio of TLD in Eq. (4.2) is usually lower than its optimal value and can be increased by using the liquid with the higher viscosity and/or adding the slice into the tank. The size and number of TLD tank are calculated from frequency and mass ratio requirements. The tank is preferred to be large so that the total number of the tank become small (low cost) to attain the required mass ratio. However, the depth of water should be small, say $h/a \approx 0.1 - 0.3$ to avoid the dead-mass effects in liquid motion from the friction between the water and the bottom of the tank.

4.1.3 Effect of complex frequency response on equivalent damping ratio

The Complex response of the 183-m. height building ($\omega_s = 0.263$, $\xi_s = 0.015$) in along wind direction, attached with optimal TMD ($\mu = 0.01$) and optimal TLD ($\mu = 0.01$, a = 7.62 m, h = 1.955 m) is shown in Fig. 4.2. It can be expressed that the reduction of Complex frequency response of first mode structure with TMD is higher than TLD. Because of the flatter the response in the case of TMD, the higher the equivalent damping ratio.

4.1.4 EXCEL computer program for design TLD

Because two parameters have to be tuned as the mass and the natural frequency of TLD include the calculating of TLD damping ratio, so EXCEL is very helpful for design TLD. Figure of Design planning of TLD, by EXCEL computer program, is shown in Fig. 4.3. Designed parameters of TLD can be seen from Chapter VI.

4.2 Multiple Tuned Liquid Dampers (MTLD)

4.2.1 Mathematical model and response

From Fig. 4.4, each natural frequency of each TLD is optimal tuned by changing the depth of water. The equation of motion of MTLD is similar to MTMD excepted that the damping ratio of each TLD can be changed consequently from the depth of the water. Especially, total damping ratio of MTLD is higher than damping ratio of one optimal TLD. It is because the smaller the depth of water, the higher the damping ratio of TLD, for the same friction boundary layer factor (h/a). This is due to the lower the depth of water, the higher the speed of the water moving. For the rectangular tank, the sloshing natural frequency in rad/s can be expressed from the application of linear wave theory as [Fujino et al. 1993]

$$\omega_{Rk} = \left(\frac{g}{\mathrm{a}_k}\pi \tanh\left(\pi \frac{h_k}{\mathrm{a}_k}\right)\right)^{0.5}, k = 1,2,\ldots,n \tag{4.4}$$

Where h_k, a_k are the depth and the width of water of TLD_k respectively.

The damping ratio of liquid sloshing in rectangular tank can be approximated as [Fujino et al. 1993]

$$\xi_{Rk} = \frac{1}{2h_k}\sqrt{\frac{v_k}{\pi f_{Rk}}}\left(1+\frac{h_k}{b_k}\right), k = 1,2,\ldots,n \tag{4.5}$$

where b_k is the width of water of TLD_k, f_{Rk} is the natural frequency of TLD_k in Hz, and v_k is the kinematic viscosity of TLD_k= 0.01 cm^2/sec for water at room temperature.

This type of dynamic damper utilizes the liquid motion, which is governed by the mass of liquid due to gravity. The effective moving mass m_{ak} of TLD_k can be determined as [Chang 1998]

$$m_{ak} = \left(0.259\frac{a_k}{h_k}\tanh\left(3.14\frac{h_k}{a_k}\right)\right)m_{tk} \tag{4.6}$$

where m_{tk} is the total mass of the liquid of TLD_k. m_{ak}, ω_{Rk} and ξ_{Rk} can be computed together passing EXCEL computer program.

Using the notation that the first mode structural force $F_s(t) = k_s f(t)$. $f(t) = e^{i\omega t}$ is assumed to calculate the complex frequency response H_{xs}. The mean square displacement response, computed by MATLAB, of the first mode structure is generated to compute the equivalent damping ratio.

4.2.2 Robustness on natural frequency error

The robustness on natural frequency error of TLD and MTLD, which almost the same total mass ratio, are investigated and compared in Fig. 4.5 for the case of 183-m. high-rise building with first modal ξ_s=0.015 and first modal ω_s=0.263 in along wind direction. The optimal TLD has μ=0.01, a = 7.62 m, h = 1.955 m. The MTLD has the central natural frequency tank (μ=0.002, a=0.833 m., h=5.22 m), and constant $\delta\gamma$=0.035.

Fig. 4.5 shows that the robustness on natural frequency error of MTLD is much better than optimal TLD. This is because: 1) small phase different among the liquid motion in each TLD of the MTLD; 2) lower depth in MTLD results in higher damping ratio for MTLD; and 3) the effect of mass unequally for each TLD on the robustness is small. It can be mentioned that, for the case of uncertainly natural frequency of the high-rise building, the MTLD is more effective than TLD.

4.2.3 Optimal equivalent damping ratio

The procedure to determine optimal MTLD is similar to the case of MTMD. In this study, the damping ratio in each TLD of the MTLD is assumed to be equal.

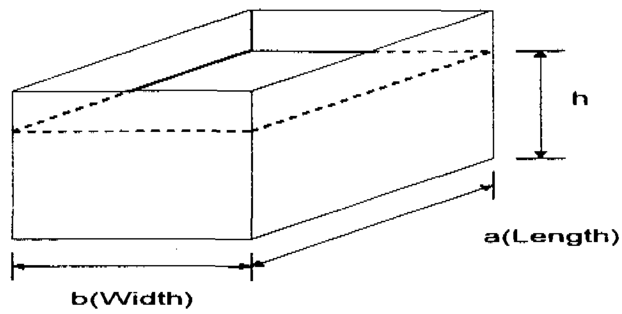


Fig. 4.1 Geometric of tuned liquid damper

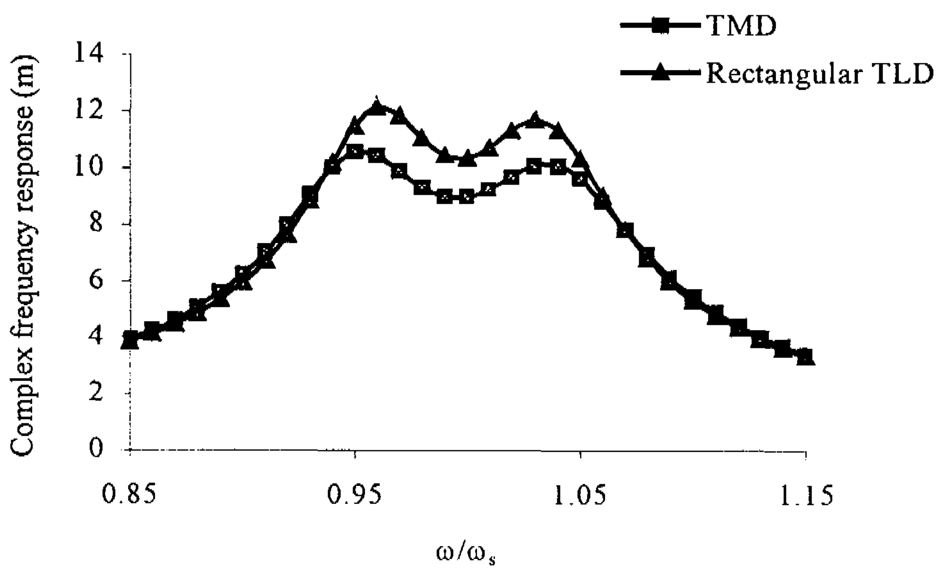


Fig. 4.2 Complex frequency response of 183-m high building with optimal TMD and optimal rectangular TLD

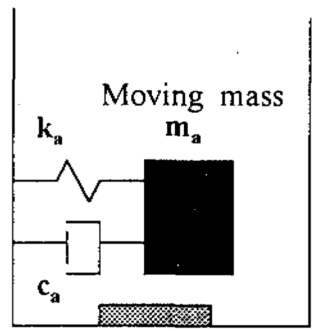
Linear analysis model

$$\omega_R = \left(\frac{g}{a} \pi \tanh \left(\pi \frac{h}{a} \right) \right)^{0.5}$$

(First modal natural frequency)

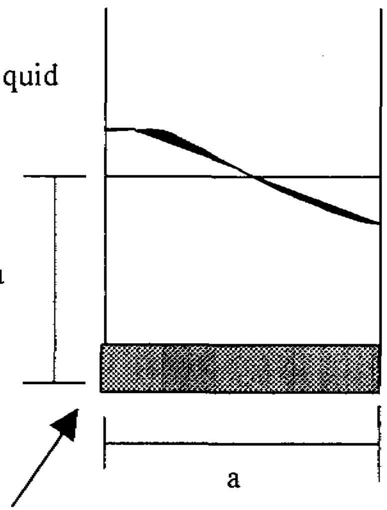
$$\xi_R = \frac{1}{2h} \sqrt{\frac{v}{\pi f_R}} \left(1 + \frac{h}{b} \right)$$

(From linear boundary layer)



m_d
Dead mass

Chang (1998)



Shear stress is high

Fig. 4.3 Design planning of TLD by EXCEL computer program

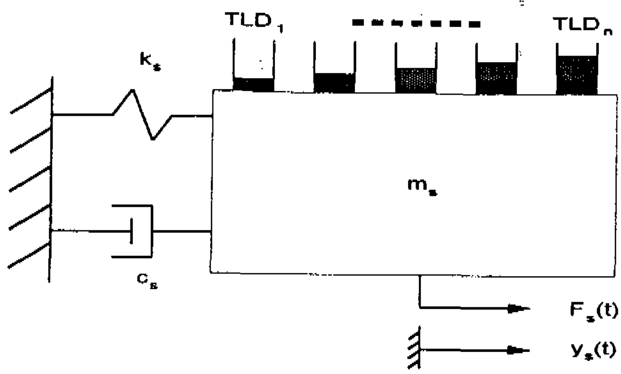


Fig. 4.4 Mathematical model of first mode structure with MTLD

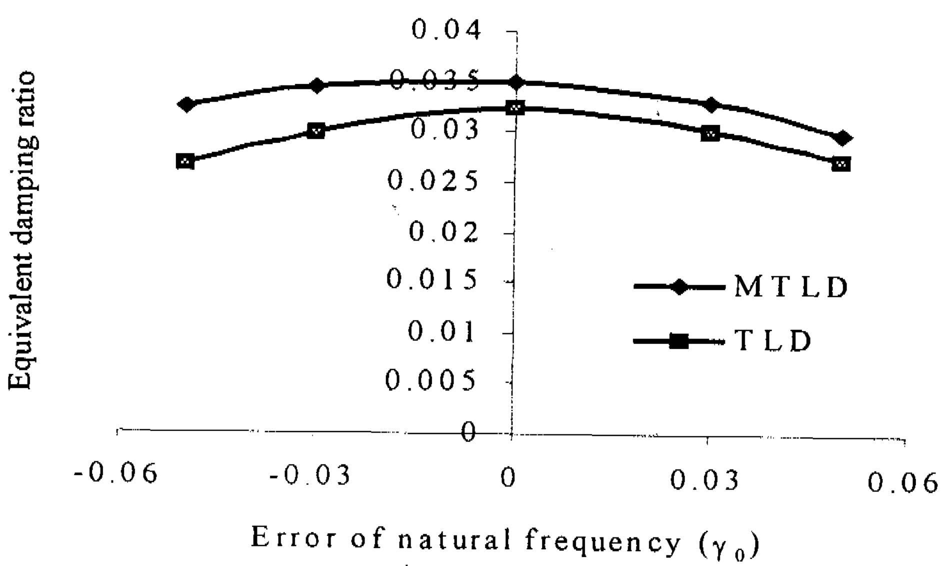


Fig. 4.5 Robustness of TLD and MTLD on natural frequency for 183-m high building