Vibration Control by Tuned Liquid Dampers

Motive

Construction of tall structures in regions around the world where earthquakes and extreme-wind conditions take place have been a concern to structural engineers. Supplementary damping systems were proposed to reduce the response of a structure to such excitations. Dynamic vibration absorbers have been proven to be effective in controlling the response of a structure. Two main types of dynamic absorber include:

- Tuned Mass Damper (TMD)
- Tuned Liquid Damper (TLD)

TLD Background Information

TLD consists of a rigid tank partially filled with a fluid, typically water and is usually placed on the roof of a structure. TLD reduces the response of a structure by absorbing the kinetic energy from the base excitation, then energy is dissipated by wave breaking in the tank.

The design of the TLD is dependant on the structure parameters. There can be multiple tanks with different shapes, the most common include rectangular, cylinder, annular and conical. Recently, the TLD has become more popular due to low installation cost, easy installation into existing structure and requires very little maintenance.

To effectively reduce the resonant response of the structure, the frequency of a TLD must be tuned to the natural frequency of the structure. The natural frequency is directly proportional to
the liquid-depth ratio. Based on experimental results, the natural frequency can reach its maximum value when the liquid-depth ratio is small. Adding or removing liquid from a tank will change the natural frequency of the system.

**Mathematical Model of a Simple TLD**

The sloshing water in a tank has non-linear characteristics and therefore it is more difficult to predict the performance of TLD. The performance of TLDs can be defined in terms of their efficiency and robustness. Efficiency measures the effectiveness of the TLDs system when compared to an optimal theoretical damping system. Robustness is a measure of the insensitivity of damper effectiveness when changes in the system’s parameters take place. It can be determined by calculating the efficiency under various loading conditions, different sloshing frequency and different water depths.

The response of a structure with a dynamic vibration absorber system is a function of four parameters:

**Mass Ratio**

\[
\mu = \frac{\varphi^2 m_A}{M^*}
\]

- \( m_A = \text{absorber mass} \)
- \( M^* = \text{generalized mass} \)
- \( \varphi = \text{normalized modal deflection value} \)

**Tuning Ratio**

\[
\Omega = \frac{f_A}{f_S}
\]
• \( f_A = \text{absorber natural frequency} \)
• \( f_S = \text{structure natural frequency} \)

**Vibration Absorber Damping Ratio**

\[
\zeta_A = \frac{C_A}{4\pi m_A f_A}
\]

- \( C_A = \text{equivalent viscous damping of absorber} \)

**Structural Damping Ratio**

\[
\zeta_S = \frac{C^*}{4\pi M^* f_S}
\]

- \( C^* = \text{equivalent viscous damping of structure} \)

To find efficiency, must find optimal damping ratio of structure.

**Optimal Structural Damping Ratio**

\[
\zeta_{S-\text{optimal}} = \frac{1}{4} \sqrt{\frac{\mu + \mu^2}{1 + \frac{3\mu}{4}}}
\]

**Efficiency of TLD**

\[
\psi = \frac{\zeta_S}{\zeta_{S-\text{optimal}}} \times 100
\]

**Multiple Tuned Liquid Dampers (MTLDs)**

The multiple tuned liquid dampers system consists of TLD tanks with different natural sloshing frequencies. A TLD system’s performance will be improved once changed to MTLDs system. Based on several studies, using an MTLDs system with frequencies tuned to a range near the frequency of the structure will improve efficiency of the system.

The number of TLDS (N) affects the maximum response of the structure. The figure below shows the plot for a general structural response versus frequency ratio, where \( f \) is the frequency...
of TLD tuned to the structure and $f_s$ is the frequency of structure. At $N=1$ there are two local peaks at frequency ratio 0.95 and 1.05 with max response at approximately 0.016. For $N > 1$ the curve has one peak and the maximum response of the structure is reduced. It is noted that as $N$ increases the maximum structure response is reduced however at a certain value of $N$ the response does not decrease furthermore.

Case Study – York Place Hong Kong
In Hong Kong, wind-induced motion of a structure is common because it is located in a typhoon-active region. Land suitable for construction in urban Hong Kong is very limited which created constraint for the structural engineers. York Place is a 39-story building (152 meters) built in an urban area in Hong Kong with a tuned liquid damper system installed on the top floor of the structure. The base width is 13 meters and therefore it has a high slenderness ratio of 1:12 which is considerably low.

The plot above shows the acceleration of the structure for damped (green) versus undamped (red). The plot shows the acceleration of the damped structure to be much lower than the undamped one.