Experimental evaluation of tuned liquid column damper and tuned mass damper in a space structure model

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Abstract. Vibrations in building structure due to external force can be minimalized by absorber installation. One technique in that regard is through the dynamic absorber. Previous reports have developed double dynamic vibration absorber namely Tuned Liquid Column Damper (TLCD) and spring-mass system. However, the conduct has been applied to reduce vibrations occurred on solely one-sided movement. This study investigated the double dynamics absorber utilization of Tuned Liquid Column Damper (TLCD) and spring-mass system that was designed to be capable of vibration reduction caused by interfering forces on two-sided structures hence the implementation can be more applicable.

1. Introduction

In multiple stories building, disruptive dynamical forces such as earthquakes may cause damage to building structures. Moreover, in high level more critical breakage including on building a foundation or It has been stated that a structural failure due to dynamical loads is led by interference around the structure of natural frequencies. Thus structure endures a resonance phenomenon. Resonance phenomenon is a condition in which the structure trembles with massive vibration amplitude \cite{1}. Resonance may result in fatal effects on structures equipped with the small-scaled absorber. Therefore a dynamics absorber on a building structure is very much necessary \cite{2}. Work principle of this dynamics absorber is by transferring some of the vibration energy endured by the structure, which its natural frequencies are interfered, to another system installed on the structure. By assembling the dynamics absorber on the structure, the received vibration responses can be reduced thus the damaging effect can as well be suppressed.

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This work in particular carried out an experimental study of double dynamics absorber application of tuned liquid column damper (TLCD) and spring-mass system (TMD) that were installed on a higher
level of the structure. The structure was designed in such a way by modeling two stories building with vibration modus dominant in two directions namely x-z and y-z axis. TLCD reduction number was evaluated by varying fluids volume in TLCD, while TMD reduction number was evaluated by varying TMD mass. So that the optimum performance of the applied dynamics absorber was obtained by considering the number of vibration responses degraded by the absorber.

2. **Space structure model**

Space structure model consisting of column structures was modeled by using three dimensional (3D) frame element approach and the floor structures were modelled as plate elements. Structure model and its vibration modus are illustrated in Figure 1.

![Space structure model](image)

Figure 1. Space structure model

Figure 1 displayed the least four vibration modus of the structure. It can be denoted that the first bending modus in x-z and y-z direction in Figure 1a and 1b was the most dominant vibration modus of the structure. This vibration modus appeared due to columns cross section’s profile shape and dimension. Column cross section’s profile was rectangular in cross section size of 2mm x 2mm.

3. **Tuned Liquid Column Damper (TLCD)**

Tuned liquid column damper (TLCD) is one of dynamics absorber types in the form of U column-shaped vessel filled with fluid. Identical to other dynamics absorbers’ work principle, TLCD transfers part of vibration energy on structures to the dynamics absorber, so that the occurred vibration on the main structure can be diminished.

Aiming for achieving the system motion equation by using TLCD, the structure was modeled as a single degree of freedom vibration system with TLCD installed on top. TLCD modeling is portrayed
in Figure 2. By LaGrange energy principle, the structure motion equation and TLCD fluid motion equation could be defined. Formula 1 below described fluid movement in TLCD:

\[ AL_v y(t) + \frac{1}{2} A |y(t)| + 2Agy(t) = -Abx(t) \]  \hspace{1cm} (1)

Where \( y(t) \) is motion equation of fluid transfer in TLCD, \( x(t) \) is equation intended for structure movements as an entirety. Fluid density is \( \rho \); fluid flow loss coefficient is \( \xi \), \( A \) is the surface area of TLCD column, \( L_v \) is the vertical and horizontal length of TLCD, \( L_h \) is the total length of TLCD and \( g \) is gravity acceleration constant.

\[ \begin{align*}
  y(t) & \quad \text{motion equation of fluid transfer in TLCD} \\
  x(t) & \quad \text{equation intended for structure movements as an entirety} \\
  \rho & \quad \text{fluid density} \\
  \xi & \quad \text{fluid flow loss coefficient} \\
  A & \quad \text{surface area of TLCD column} \\
  L_v & \quad \text{vertical and horizontal length of TLCD} \\
  L_h & \quad \text{total length of TLCD} \\
  g & \quad \text{gravity acceleration constant}
\end{align*} \]

\[ F(t) \quad \text{external force} \]

\[ m_e + m_a \]

\[ k \quad \text{spring constant} \]

\[ c \quad \text{damping coefficient} \]

\[ \begin{align*}
  x(t) & \quad \text{structure displacement} \\
  y(t) & \quad \text{fluid displacement} \\
  F(t) & \quad \text{external force} \\
  m_e & \quad \text{mass of TLCD} \\
  m_a & \quad \text{mass of TMD} \\
  k & \quad \text{spring constant} \\
  c & \quad \text{damping coefficient} \\
  \end{align*} \]

\[ (m_e + m_a)x(t) + AL_h y(t) + C_v x(t) + K_v x(t) = F(t) \]  \hspace{1cm} (2)

4. Experimental data

The analyzed structure consisted of two stories building model designed with two dominant vibration modus such as first bending modus in x-z and y-z direction. Dynamics absorber was designed to eliminate vibration responses in these two directions. The analysis was conducted to obtain an optimum working condition of the double dynamics absorber - Tuned Liquid Column Damper (TLCD) and spring-mass system (TMD) application. The analysis was undertaken by evaluating the dynamics absorber parameters such as a fluid volume in TLCD and mass in TMD.

4.1. The variance of TLCD Fluid Volume in Y-Z Direction

The analysis was conducted by varying the fluid volume in TLCD in y-z direction. TMD mass, as well as the TLCD fluid volume in x-z direction, were maintained constant. The variance of TLCD fluid volume in y-z direction is enlisted in Table 1.
Table 1. The variance of TLCD fluid volume in the y-z direction

| No | Fluid volume in y-z direction (ml) | Fluid volume in x-z direction (ml) | TMD mass in y-z direction (kg) | TMD mass in x-z direction (kg) |
|----|-----------------------------------|-----------------------------------|-------------------------------|-------------------------------|
| 1  | 350                               | 350                               | 0.4                           | 0.4                           |
| 2  | 336                               | 350                               | 0.4                           | 0.4                           |
| 3  | 333                               | 350                               | 0.4                           | 0.4                           |
| 4  | 322                               | 350                               | 0.4                           | 0.4                           |
| 5  | 309                               | 350                               | 0.4                           | 0.4                           |
| 6  | 364                               | 350                               | 0.4                           | 0.4                           |
| 7  | 378                               | 350                               | 0.4                           | 0.4                           |
| 8  | 392                               | 350                               | 0.4                           | 0.4                           |
| 9  | 455                               | 350                               | 0.4                           | 0.4                           |

By an investigation using fluid volume variance in y-z direction, the absorber effectiveness can be indicated, which was shown in Figure 3 illustrating the structure responses alter prior and following the absorber installation. Optimum condition was at a fluid volume of 364 mL where the peak of the lowest structure response of 0.6931 (m/s²)/N was spotted. In the absence of dynamics absorber, vibration structures peak was at 5.2325 (m/s²)/N. Thus the decline was 4.5394 (m/s²)/N.

Figure 3. Structure responses with fluid volume variance in y-z direction

4.2. The variance of TLCD fluid volume in X-Z direction

The analysis was conducted by varying the fluid volume in TLCD in x-z direction. TMD mass, as well as the TLCD fluid volume in y-z direction, were maintained constant. The variance of TLCD fluid volume in x-z direction is enlisted in Table 2.

By an investigation using fluid volume variance in x-z direction, the absorber effectiveness can be indicated, which was shown in Figure 4 illustrating the structure responses alter prior and following the absorber installation. Optimum condition was at a fluid volume of 392 mL where the peak of the lowest structure response of 0.7212 (m/s²)/N was spotted. In the absence of dynamics absorber, vibration structures peak was at 3.622 (m/s²)/N. Thus the decline was 2.9008 (m/s²)/N.
Table 2. Variance of TLCD fluid volume in x-z direction

| No | Fluid volume in y-z direction (ml) | Fluid volume in x-z direction (ml) | TMD mass in y-z direction (kg) | TMD mass in x-z direction (kg) |
|----|----------------------------------|----------------------------------|-------------------------------|-------------------------------|
| 1  | 350                              | 350                              | 0.4                           | 0.4                           |
| 2  | 350                              | 336                              | 0.4                           | 0.4                           |
| 3  | 350                              | 333                              | 0.4                           | 0.4                           |
| 4  | 350                              | 322                              | 0.4                           | 0.4                           |
| 5  | 350                              | 309                              | 0.4                           | 0.4                           |
| 6  | 350                              | 364                              | 0.4                           | 0.4                           |
| 7  | 350                              | 378                              | 0.4                           | 0.4                           |
| 8  | 350                              | 392                              | 0.4                           | 0.4                           |
| 9  | 350                              | 455                              | 0.4                           | 0.4                           |

Figure 4. Structure responses with fluid volume variance in x-z direction

4.3. The variance of TMD Mass in Y-Z Direction

To determine the influence of TMD utilization, an analysis was conducted by varying TMD mass in y-z direction. TMD mass, as well as the TLCD fluid volume in x-z direction, were maintained constant. The variance of TLCD fluid volume in y-z direction is enlisted in Table 3.

Table 3. The variance of TMD mass in the y-z direction

| No. | Fluid volume in y-z direction (ml) | Fluid volume in x-z direction (ml) | TMD mass in y-z direction (kg) | TMD mass in x-z direction (kg) |
|-----|----------------------------------|----------------------------------|-------------------------------|-------------------------------|
| 1   | 350                              | 350                              | 0.4                           | 0.4                           |
| 2   | 350                              | 350                              | 0.414                         | 0.4                           |
| 3   | 350                              | 350                              | 0.418                         | 0.4                           |
| 4   | 350                              | 350                              | 0.422                         | 0.4                           |
| 5   | 350                              | 350                              | 0.427                         | 0.4                           |
| 6   | 350                              | 350                              | 0.435                         | 0.4                           |
| 7   | 350                              | 350                              | 0.442                         | 0.4                           |
By an investigation using TMD mass variance in y-z direction, the absorber effectiveness can be indicated, which was shown in Figure 5 illustrating the structure responses alter prior and following the absorber installation. Optimum condition was at the mass of 0.422 kg where the peak of the lowest structure response of 0.9841 (m/s^2)/N was spotted. In the absence of dynamics absorber, vibration structures peak was at 5.2325 (m/s^2)/N. Thus the decline was 4.2483 (m/s^2)/N.

Figure 5. Structure responses with TMD mass variance in y-z direction

4.4. The variance of TMD Mass in X-Z Direction
To determine the influence of TMD utilization, an analysis was conducted by varying TMD mass in x-z-direction. TMD mass, as well as the TLCD fluid volume in y-z direction, were maintained constant. The variance of TLCD fluid volume in x-z direction is enlisted in Table 4.

| No | Fluid volume in y-z direction (ml) | Fluid volume in x-z direction (ml) | TMD mass in y-z direction (kg) | TMD mass in x-z direction (kg) |
|----|-----------------------------------|-----------------------------------|------------------------------|------------------------------|
| 1  | 350                               | 350                               | 0.4                          | 0.4                          |
| 2  | 350                               | 350                               | 0.4                          | 0.414                        |
| 3  | 350                               | 350                               | 0.4                          | 0.418                        |
| 4  | 350                               | 350                               | 0.4                          | 0.422                        |
| 5  | 350                               | 350                               | 0.4                          | 0.427                        |
| 6  | 350                               | 350                               | 0.4                          | 0.435                        |
| 7  | 350                               | 350                               | 0.4                          | 0.442                        |

By an investigation using TMD mass variance in x-z direction, the absorber effectiveness can be indicated, which was shown in Figure 6 illustrating the structure responses alter prior and following the absorber installation. Optimum condition was at the mass of 0.435 kg where the peak of the lowest structure response of 1.0835 (m/s^2)/N was spotted. In the absence of dynamics absorber, vibration structures peak was at 4.2838 (m/s^2)/N. Thus the decline was 3.2002 (m/s^2)/N.
4.5. Structure dynamical response to time
Following the optimum condition determination of variances on TLCD and TMD in y-z and x-z direction, afterward the influence of double dynamics absorber – TLCD and TMD – utilization within the obtained optimum conditions was investigated. The analysis was undertaken by observing structure response to time function in the absence and presence of dynamic absorber. Aiming for creating structural motions in both y-z and x-z directions, the structure was positioned with slope against interfering forces from the exciter. Data collection was carried out in both y-z and x-z directions. Interfering forces was given near the structure private frequency namely $f = 2$ Hz. In x-z direction, structure responses to time data were illustrated in Figure 7 and Figure 8.
Figure 8. Structure response to time on the second floor

In y-z direction, structure responses to time data in the first and second floor of the building are presented in Figure 9 and Figure 10, respectively.

Figure 9. Structure response to time on the first floor
Figure 10. Structure response to time on the second floor

Based on the attached figures above, dynamics absorbers performances can be investigated. Dynamics absorber installation was evidenced capable of reducing vibration responses received on the structure, pointed by the declining structure response peak post the dynamics absorber installation.

5. Conclusions
Dynamics absorbers functioned to reduce vibrations response on structures that endured interferences from external forces. This work has conducted double dynamics absorbers type of TLCD and TMD with spring-mass system kind which was designed to reduce structure responses occurred in two directions of y-z and x-z. In TLCD, the variance was on fluid volume and an optimum condition obtained at a volume of 364 ml in y-z direction and 392 ml in x-z direction. On the other hand, in TMD, the variance was on mass, and an optimum condition was at the mass of 0.422 kg in y-z direction and 0.435 kg in x-z direction. The performance of dynamic damper can reduce the vibration response to 57.20 % in the y-z direction and into 75.23 % in the x-z direction.

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