CONTROL OF WIND INDUCED VIBRATION OF TALL BUILDING BY A TLCMD

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SUMMARY

The effectiveness of a tuned liquid column/mass damper in reducing wind induced vibrations of a tall building is investigated. A simplified geometric non-linear finite element system which has 3n degrees of freedom (n stories and each storey with two lateral and one torsional degrees of freedom) is used to describe the response of a torsionally coupled multistorey building under wind excitation. The numerical analysis is carried out in a time domain and Newmark's direct integration method is adopted. The wind excitation is simplified as harmonic forces acting on every floor. A numerical examples is given to explain the effect of a tuned liquid column/mass damper in controlling the wind induced vibrations.

INTRODUCTION

The growing use of high-strength materials and modern construction techniques results modern building becoming higher and relatively light, flexible and light damped. The structural vibrations caused by wind or earthquakes are consequently much more serious than those of earlier structures, so that structural failures, equipment malfunction and occupants discomfort may result. Consequently, various structural vibration control schemes capable of reducing these vibrations have received increasing attention in recent years.

Inclusion of mechanical dampers is one effective mean to control structural vibration. Tuned mass dampers (TMD), both passive and active, have found their practical application in civil engineering problems [1]. New types of dampers that depend on liquid motion to absorb and dissipate vibration energy, such as tuned liquid dampers (TLD), tuned liquid column dampers (TLCD) and liquid column vibration absorber systems (LCVA) have been proposed for suppressing structural vibrations [2,3]. These liquid dampers have definite advantages over other damping devices, including lower cost, easier handling and few maintenance requirements. Furthermore, a liquid damper does not impart a cost of weight penalty when a water tank which is normally used for water supply and fire fighting is incorporated into the design of a liquid damper.

Xu, Samali and Kwok combined mass damper and liquid column damper into a tuned liquid column/mass damper (TLCMD) for suppressing one lateral direction vibration of a tall structure [2]. It was found that this combination can be slightly more effective than either a tuned mass damper or a tuned liquid column damper with the same mass. This paper investigates the effectiveness of the combination of TMD and TLCD in two perpendicular axes for suppressing the wind induced vibrations along those two axes. This combination has particular practical significance as wind may come from any direction and real structural response to the wind is complex.

DESCRIPTION OF TLCMD-STRUCTURE SYSTEM

A tuned liquid column/mass damper is a combination of tuned mass damper and liquid column damper. In a TLCMD-structure system, a liquid column tube with liquid of mass m_d is connected to the structure through a spring and a dashpot. When the tube has a relative motion to the structure, it acts like a tuned mass damper. While the liquid moving in the tube, it acts like a tuned liquid column damper. If the tube relative motion is perpendicular to the liquid relative motion, this simple system will act like two dampers to control vibration in two directions.

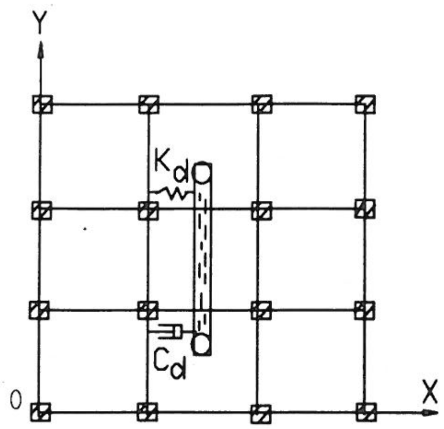

Fig.1 Plan view of a TLCMD-structural system

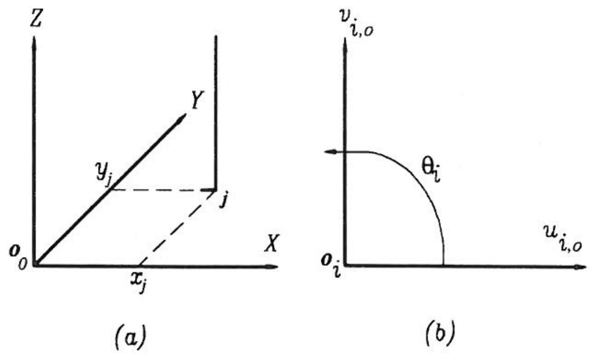

Fig.2 (a)The jth column in the global coordinate system. (b)The degrees of freedom of the ith floor.

As shown in Fig.1, a TLCMD is to be installed on nth floor at the position of (Xd, Yd). Here, the TLCMD is composed of a second type tuned liquid column damper (TLCD-II) proposed by Gao, Kwok and Samali [3] and a spring K_d and a dashport C_d. The tube relative motion measured by z is in X direction and liquid relative motion measured by w in Y direction. The structure is modelled as a geommetrical non-linear plate-beam shear building which has 3n degrees of freedom (n storey, each storey with two lateral and one torsional degrees of freedom). The coordinate system of the structure is shown in Fig.2.

Without damper, equation of motion of the structure is:

$$M\ddot{\delta} + C\dot{\delta} + K\delta = P \quad (1)$$

Where 3n x 3n matrices M, C and K are structural mass matrix, damping matrix and stiffness matrix respectively whose development can be found in reference [4].

Structural displacement vector:

$$\delta = \begin{pmatrix} u_1 & v_1 & \theta_1 & \cdots\cdots & u_n & v_n & \theta_n \end{pmatrix}^T$$

Wind load vector:

$$P = \begin{pmatrix} U_1 & V_1 & T_1 & \cdots\cdots & U_n & V_n & T_n \end{pmatrix}^T$$

After the TLCMD is installed, equation of motion of the TLCMD-strucutre system is:

$$M^*\ddot{\delta}^* + C^*\dot{\delta}^* + K^*\delta^* = P^* \quad (2)$$

Where M^*, C^* and K^* are (3n+2) x (3n+2) matrices whose development can be found in reference[5].

Displacement vector:

$$\delta^* = (u_1 \quad v_1 \quad \theta_1 \quad \cdots\cdots \quad u_n \quad v_n \quad \theta_n \quad w \quad z)^T$$

Wind load vector:

$$P^* = (U_1 \quad V_1 \quad T_1 \quad \cdots\cdots \quad U_n \quad V_n \quad T_n \quad 0 \quad 0)^T$$

NUMERICAL EXAMPLE

A symmetrical tall building (equivalent hight is about 300m) with dual circular frequencies of 1.107 rad/s which correspond to the first modal in X direction and the first modal in Y direction is examined. The buildings modal damping ratio is 0.05. The wind load is simplified as a harmonic pressure with a resonant circular frequency of 1.107 rad/s and amplitude of $4a$(KPa). Where, a is a force factor to be 0.643 in X direction and 0.766 in Y direction. Torsion load was not considered in this study. The TLCMD with a mass of 5% general structural mass is installed at mass centre of the top floor. Optimum tuning ratio for mass damper is 94%, and for liquid column damper is 1 (correspond to a liquid column length L = 8m). Damping ratio of the dashpot is 15%, and coefficient of head loss of liquid column is 1.43 [3,6].

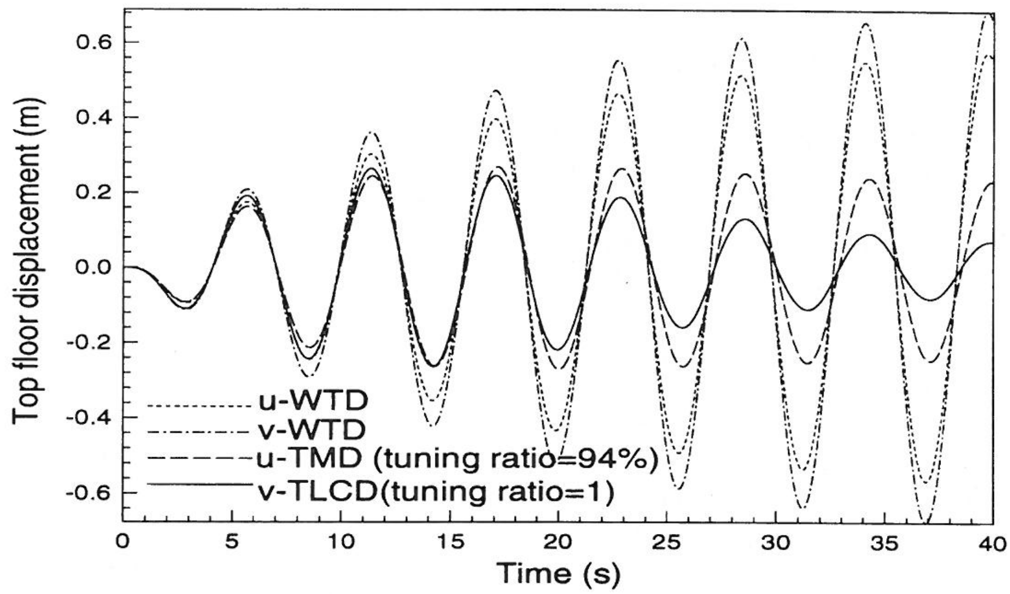

Fig.3 Displacement time histories of top floor reference point

Displacement time histories of top floor reference point (with and without damper) are compared in Fig.3. After the TLCMD was installed, the maximum displacement was reduced by about 55 percent in X direction with a maximum tube relative displacement of 0.85m, and more than 60 percent in Y direction with a maximum liquid relative displacement of 1.76m. This is consistent with the results of former work [3,6] which suggested that an optimised TLCD is more efficient than an optimised TMD in reducing the maximum response.

Fig.4 gives the envelope values of maximum displacements. Before a TLCMD is installed, Y direction has greater envelope values due to the larger excitation force. Because of the difference in efficiency of Y direction (TLCD) and X direction (TMD), after the TLCMD is installed, the envelope values in the two directions were reduced to the same level.

CONCLUSION

Results of numerical simulation show that a tuned liquid column/mass damper can effectively control wind induced structural vibrations of a tall building in two perpendicular directions. A tuned liquid column/mass damper works like two dampers at one damper's weight.

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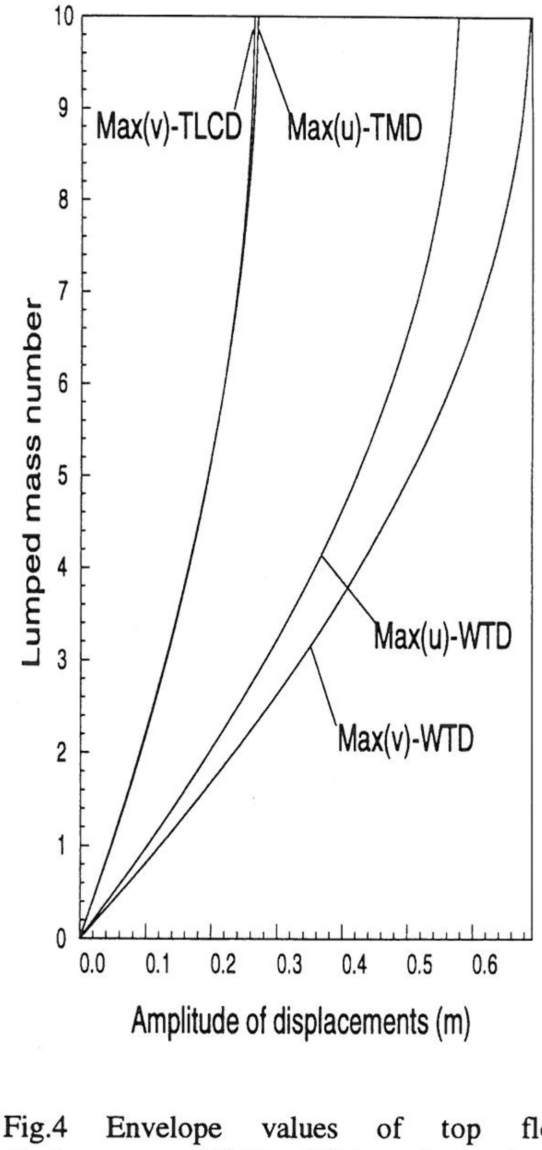

Fig.4 Envelope values of top floor displacements. (WTD---Without damper)