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Application of Tuned Liquid Damper to Control the Structural Vibration: Review Paper

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Abstract – Response controls of structures with different forms of dampers have been a core area of study which was adopted to mitigate various natural hazards like earthquake and wind. Active, passive and hybrid dampers of different forms are generally used in structures to make structures more flexible. Tuned liquid damper or TLD has been common form of damper as a response controller and has undergone different modifications in its functionality and installation to decrease the structural vibration during an earthquake. Till now several successful applications validate with the numerical, experimental and analytical investigation has been presented on TLD. For the experimental study shake table is used to find out the response of the structure. This paper presents a detailed study carried out to investigate the advances in tuned liquid dampers and its applicability in the structure. Also gives the report on various aspects of the tuned liquid damper.

Keywords-Dampers, TLD, response control, shake table

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I. INTRODUCTION

Now a day, there is an increasing trend to construct high rise buildings to minimise the space problems in the urban areas. These structures are light and more flexible with low damping. However they subjected to structural vibrations caused by the dynamic loads, they undergo vital vibrations which can become unacceptable from the perspective of serviceability and safety. So to avoid such critical damages, some kind of structural protecting (damping) systems could be implemented. This system mainly classified into two categories i.e. Active Damping techniques and Passive Damping Techniques. Active dampers require external power source to create an additional force between damper and the structure. Passive systems dissipate some part of the structural seismic input energy through its motion by introducing extra force to the structure without any need for external power source. Tuned liquid damper is the best example of passive damping system.

The use of Tuned Liquid Dampers as a method of vibration controlling technique was studied in this work. TLD's are basically liquid tanks (usually water) partially filled with the liquid, and is typically located at the top floor of the structure or immediately below it. (Karth & Ritzy, 2015). When the tank is exited through vibration, the liquid in the tank begins to slosh against the wall, imparting inertial forces into the structure, out of phase with the structural motion, thereby reducing the movement. (Karth & Ritzy, 2015). TLD's can be classified into Tuned Sloshing Dampers (TSD's), Tuned Liquid Column Dampers (TLCD's) and controllable TLD's. TSD's are generally rectangular and circular tanks. TLCD's reduces structural vibration due to the motion of liquid in the tube as a result of gravity action and by the loss of hydraulic pressure due to the orifice installed inside the container. Controllable TLD's are used to increase the effectiveness of the damper when the forces acts on the building are spread over a band of frequencies. This is done by active and semi active control devices by controlling the angle of baffle provided in the tanks or by using propellers powered by motor.

2. LITERATURE REVIEW

Ersin Aydin (2017) has carried out shaking table tests which are applied on G+3 reduced shear frame models with TLD's subjected to harmonic loadings are presented. Free vibration experiments are conducted on the structure and 1st free vibration frequency of the structure is resolved. The G+3 structure is shaken under harmonic loading at a frequency equal to 1st frequency of the structure which provides the resonance condition. Displacements and accelerations are estimated at storey levels of the structure. A container in a rectangular prism shape is manufactured as a TLD model. Liquid (water) is poured in the container and the same experiments are repeated at different liquid heights. The effect of TLD application on the structural models considering displacement and acceleration of the structure are examined. In addition the effect of TLD application and its allocation at various storey levels are calculated experimentally. As a result of this experiment, most convenient TLD models considering both displacement and acceleration behaviour are determined. It is observed that all the damping models cause significant levels of reduction in seismic behaviour of the structure under harmonic loading.

Riju Kuriakose (2016) has proposed a TLD tanks for a 40 storeyed building in Kerala. The structure was first modelled and then its fundamental natural frequency was found out by carrying out free vibration analysis on a Ansys Workbench. TLD is then modelled into the 40 storey structure and changes in natural frequencies were monitored. The building was subjected to an earthquake loading (El-Centro Earthquake) and its frequency response was compared without TLD’s and with TLD’s. The optimum mass ratio was obtained at 0.8 % and corresponding reduction in displacement was found to be 28.73 %. Based on the optimum mass ratio obtained, number of TLD tanks, its dimensions and required water depth for the structure to control vibrations was proposed.

L. M. SUN (1995) A tuned liquid damper (TLD), which consists of rigid tanks partially filled by liquid, is a type of passive control device relying upon liquid sloshing forces or moments to change the dynamical properties and to reduce vibrational energy of a structure. An analytical non-linear model is proposed for a TLD using rectangular tanks filled with shallow water under pitching vibration, utilizing a shallow water wave theory. The model includes the linear damping of the sloshing water, which is an important parameter in the study of a TLD as it affects the efficiency of the TLD. Shaking table experiments were conducted for verification; good agreement between the analytical simulations and the experimental results was observed in a small excitation amplitude range. The simulations of TLD-structure interaction by using the proposed model show that the TLD can efficiently suppress resonant pitching vibration of a structure. It is also found that the effectiveness of a TLD for suppressing the pitching vibration depends not only on the mass of liquid (water) in the TLD but also on the configuration of the liquid (water) as well as upon the position where the TLD is located. If the configuration of the liquid (water), i.e. the liquid (water) depth and the TLD tank size, is designed suitably, the TLD can have a large suppressing moment and can be very effective even with a small mass of liquid (water).

Emili Bhattacharjee (2013) investigates the performance of unidirectional tuned liquid damper (TLD) that relies upon the motion of shallow liquid in a rigid tank for changing the dynamic characteristics of a structure and reducing its vibration energy under harmonic excitation. A series of experimental tests are conducted on a scaled model of structure tuned liquid damper systems to analyses their performance under harmonic excitation. One rectangular and one square TLD with various water depth ratios are examined over different frequency ratios, and time histories of accelerations are measured by precisely controlled shaking table tests. The behaviour of TLD is also studied by changing the orientation of the rectangular TLD subjected to the given range of harmonic excitation frequencies. From the study, it is found that for each TLD, there exists an optimum water depth that corresponds to the minimum response amplitude, and the maximum control of vibration is obtained under resonance condition with the attachment of TLD.

Pradipta Banerji (2010) performed a set of experiments to investigate the overall effectiveness of TLD’s and the specific effect of TLD parameters (depth and mass ratios) for earthquake vibration control of structures. Effects of various earthquake ground motions parameters such as amplitude, frequency content, duration of excitation etc. are also calculated. It is shown that there is good agreement between the numerical simulation and experimental results. This experimental study conclusively shows that a properly designed TLD reduces structural response to broad-band earthquake excitations. It is also observed that effectiveness of TLD increases with increase in mass ratio, depth ratio and amplitude of ground motion.

Jitadtya Mondal (2014) studied the effectiveness of a tuned liquid damper (TLD). TLD can be used in building structures to damp structural vibrations. The experimental setup models a building using PASCO beams and trusses and uses moveable base, powered by a motor, to simulate an earth quake vibrations. The sensor used in the experiment is an accelerometer that measures the acceleration at the top of the model when subjected to vibrations in the presence and absence of a TLD. A 4 storey skeletal model was constructed, with the help of PASCO members (flexible and rigid). The flexible members were oriented in the direction of the base excitation. A vernier accelerometer attached to the one of rigid members on the topmost floor, was used to measure the amplitude of the acceleration. The experiment consisted of two parts free vibration and forced vibration. The outcome of the experiment was that the TLD effectively dampened the vibrations (up to 80% reduction in vibration) when excited and the dampening effect was found to be maximum around the resonance frequency.

3. TYPES OF TLD

Various types of TLDs are proposed during last two decades for utilizing the liquid damping mechanism effectively to the structure. A schematic diagram in figure is presented to represent the different types of TLDs.

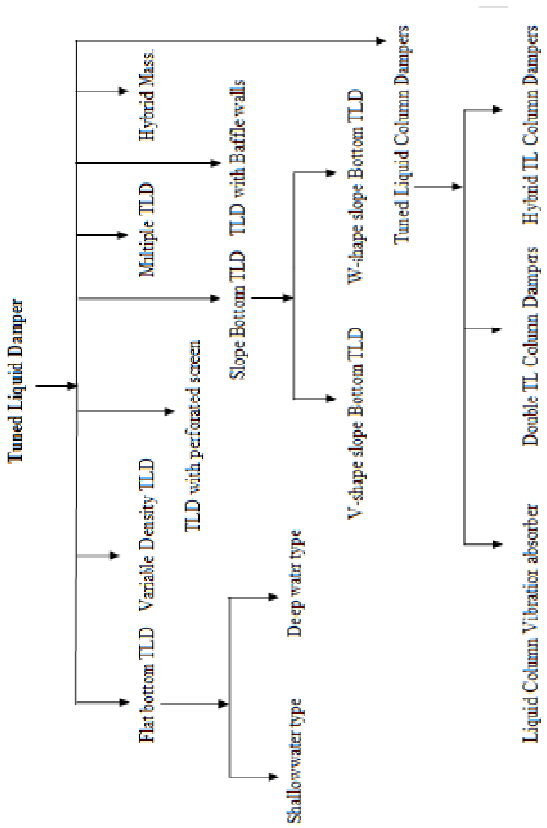

Fig: Types of TLD (Das & Chaudhury, 2014)

A. Flat Bottom TLD:

Flat bottom TLD is the box type TLD. These types of TLD are generally of rectangular, square and circular type. This can be classified as shallow water type or deep water. If this ratio height of water in the tank to the length of tank in the direction of excitation is less than 0.15 it can be classified as shallow water type and for more than 0.15 it's called as deep water type.

B**.** Variable Density:

The main function of TLD with variable density is to increase the density of liquid by adding additional substances like sand particle.

C. Slat screen TLD:

A perforated slat screen is used in TLD tank for minimizing the off tuning effect & to make suitable for wide range of excitation frequency. A slat screen is made of a number of slats, height of slats and total solid area of the screen is S_s=n.D_s. The solidity ratio of the screen S= S_s/h.

D. Slope Bottom TLD:

Slope bottom TLD is used for mitigating the drawbacks associated with box type TLD. Slope bottom concept is originated from the sea shore phenomenon. It is well known that a sloping beach is an effective energy dissipater. The majority of ocean waves are dissipated along the shores, especially due to wave breaking. This can be divided into V-shape slope bottom and W-shape slope bottom.

E. Multiple TLD: s

Multiple TLD is another type of TLD in which number of TLD is attached together and filled with the same depth of water whose natural frequency are distributed over a certain range around the fundamental natural frequency of the structure.

F. Baffle Wall TLD:

TLD with baffles are used to compensate the effect of probable mistuning of the TLD and to make the TLD tank more controllable.

G. Hybrid Mass TLD:

To dissipate more energy TLD is subjected to more sloshing of water, which happens when the TLD tank base is subjected to a large amplitude motion for utilizing this characteristic the TLD is connected to a secondary mass that is attached to the primary structure through an appropriately designed spring system. This is called hybrid mass TLD since there are both a secondary mass and a liquid damper.

H. Tuned Liquid Column Dampers (TLCD):

Tuned Liquid Column Dampers dissipates building vibration by combined action involving the motion of the liquid mass in the tube, where the restoring force is due to the gravity action upon the liquid and the damping effect as a result of loss of hydraulic pressure due to the orifices installed inside the container.

4. PROPORTIONING OF TLD-

The TLD will be designed by tuning the natural frequency of a structure and the sloshing frequency of the liquid tank. The liquid depth in the tank is adjusted to the tuning ratio as unity or very close to unity. Tuning ratio is defined as the ratio of sloshing frequency of the liquid tank to the natural frequency of the structure.

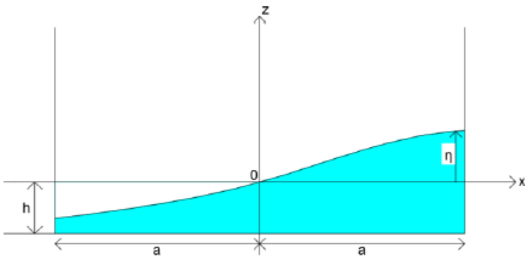

Fig: Rectangular section of liquid tank. (Aydin & Ozturk, 2017).

According to the linear shallo water theory, the fundamental sloshing frequency of liquid is givn by

$$f_w = \frac{1}{2\pi}\sqrt{\frac{\pi g}{2a} tanh\left(\frac{\pi h}{2a}\right)}$$

Where, h and g are the height of liquid and gravity acceleration.

Second parameter is the depth ratio which is defined as the ratio of depth of the liquid in the tank to the tank length in the direction of shaking. Tuning ratio for the water depths required for the short period structure with frequencies more than 2 Hz and tuning ratio of unity is adopted as 0.3. (Sharma, et. al., 2012).

CONCLUSION

As observed from the study of tuned liquid dampers from its inception, it is clearly noted that TLD has been an effective form of damper which has been successfully implemented as a technique of response control in numerical by numerical and experimental studies. It is also reported that, TLDs are less expensive and do not require any external power to operate (passive damper), rather they can be used for additional purposes like swimming pool and fire fighting. But, the TLDs that were investigated had several shortcomings and need to be investigated to be more practically applicable in buildings.

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