Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 4; April-June, 2015 pp. 377-382

http://www.krishisanskriti.org/jceet.html

Study on Behaviour of Wrinkled Walled Tuned Liquid Column Damper on a Composite Frame

Intifa Parween[1] and Ashim Kanti Dey[2]

[1]M.tech Student NIT Silchar Silchar Assam
[2]Civil Department NIT Silchar Silchar Assam
E-mail: [1]intifaparween@yahoo.com, [2]ashim_kanti@yahoo.co.in

Abstract—*A tuned liquid column damper (TLCD) is a passive control device which is used for vibration suppression of a structure during earthquakes. A wrinkled wall TLCD is fabricated with a wrinkled walled pipe bent in a U-shape to which an orifice has been fitted at the middle of the horizontal portion of the pipe. In this paper, the behaviour of the wrinkled wall TLCD is studied and is compared to that of a normal U-shaped TLCD made of Perspex sheet fitted with an orifice at the middle. Both the TLCD's are tested on a single storied composite frame. The composite frame used under this study consists of a relatively rigid rectangular steel slab supported at the corners on three aluminum and one steel columns. The dimensions of the frame are 500 mm height, 150 mm width and 300 mm length. A forced harmonic vibration test via shake table are performed by placing two accelerometers at the midpoint of the width and length of the slab in order to obtain the experimental results for a certain blocking ratio of orifice of 0.75 and to compare the results. Moreover, another comparison has been made between the coefficients of head loss of TLCD obtained analytically using a standard formula to that of the coefficients of head loss obtained experimentally using the shake table. The test results conclude that for 0.75 blocking ratio the wrinkled walled TLCD is found to be more effective as it gives more acceleration and less displacement compared to that of normal U-shaped TLCD..*

1. INTRODUCTION

Mitigation of seismic impact on building structures has been a major concern amongst engineers. Various vibrational control devices namely active or passive systems have been applied to prevent excessive vibrations. Active control device is a device which requires external power supply to resist a vibratory motion whereas a passive control device do not require an external power requirement. In this paper we have used a passive control device named as tuned liquid column damper (TLCD).

The idea of TLCD was developed by Sakai and his co-authors in the year 1989 for the purpose of structural vibration [1] and various studies [2-5] were conducted by many successors to verify its control effectiveness. Tuned liquid column dampers are energy dissipating substructures which can be used to improve the dynamics of the structures. The basic operating principle of this damper is the energy transfer from the vibration host structure to TLCD. TLCD is a special type of dampers that relies on the motion of liquid column in U- shape tube to counteract the action of external forces acting on the structure. A TLCD mainly consists of a rigid piping system which is integrated in a structure and is partially filled with liquid preferably water. The main aim of using a TLCD is its easy and cheap installation, simple modification of natural frequency and damping properties. For instance its natural frequency is simply determined by the length of the liquid column and its damping is generated by the flow passing through the orifice in the horizontal column.

Previous work has been done with an aim of deriving optimum parameters for TLCD's. Chang and Hsu [6] studied the control performance of liquid column vibration absorbers. Balendra Wang and Rakesh[4-5] studied the vibration control of various types of buildings using TLCD. Gao. et.al(1997) studied numerically the optimisation of TLCD's for sinusoidal excitation Abe. et. al(1996) derived the optimum parameters using peterbuation technique. Jhong Cheng Wu[8] (2005) proposed a standard formula to predict the coefficient of head loss coefficients of TLCD.

In this paper a wrinkled walled TLCD has been used and the behavior has been compared to that of a normal U-shaped TLCD, both were tested on a composite frame. Moreover, a graph has been plotted between non dimensional amplitude vs. non dimensional frequency in order to compare the co-efficient of head loss obtained numerically and experimentally.

2. LITERATURE REVIEW

Chang and Hsu (1997) Studied the performance of liquid column vibration absorber of a non uniform c/s and numerically analyzed and compared to that of TLCD and TMD. They found that when the vertical cross sectional areais greater than horizontal c/s area for a fixed horizontal width the LVCA performs better than TLCD but is slightly inferior to TMD The control performance of LVCA detoriates as the loading intensity decreases because of the non uniform c/s of the column.

Gao and. Kwok (2006) made the parametric study of all the parameters affecting a TLCD structure system is presented through a nonlinear numerical procedure in the time domain. Watkins tested a variational tuned liquid column damper, the liquid column vibration absorber (LCVA) whose horizontal cross sectional area is different from vertical ones. Later, Watkins and Hitchcock la modified the unidirectional LCVA into a square-shaped LCVA for suppressing bidirectional vibrations. Watkins ,simulated his results by an equivalent Den Hartog's mass damper formula in which both mass and damping of the equivalent mass damper are quite different when compared with the mass and damping of the LCVA, with no relationship given between the two masses and the two damping. From the experimental analysis made by for TLCD results were made comparing structural displacement-frequency response curve of two systems in which both mass ratio and structural damping ratio are different (for system one: mass ratio was 26% and structural damping ratio was 0.002; for system two: mass ratio was 2.6% and structural damping ratio was 0.0004). They also investigated the effectiveness of V shaped TLCD and found that the V -shaped TLCD has a higher capacity for suppressing stronger vibrations than the corresponding U- shaped damper with a similar efficiency. The optimum parameters were determined for both U-shaped and V-shaped TLCD and results showed that the mass ratio and the structural damping ratio influence all the optimum parameters. Because of the nonlinearity of the liquid damping, the optimum coefficient of head loss also depends on the intensity of the excitation. Finally in this paper they failed to obtain the effectiveness of TLCD in a non-stationary random excitation situation.

Samali, et.al, (1992) studied both analytically and experimentally the effectiveness in suppressing vibration of SDOF structure when equipped with TLCD system, they also included a parametric study of TLCD system. The TLCD system results in the loss of hydraulic pressure due to orifice installed inside the container. An analysis is carried out using the equation of motion for TLCD system given by Sakai,et al[1] by random vibration analysis. The damping term in fundamental equation of TLD is non linear and is treated by equivalent linearization technique shown by Xu,et.al[6]. The effectiveness was found by placing the TLCD on a 40 storey building with first natural frequency and at a certain percentage of water and the required water column length for tuning was found as well as the c/s area. They further performed a free vibration test for SDOF structure in order to identify the parameters which affects its performance possessing a natural period of vibration and the effect of orifice opening ratio and mass ratio. the damping ratio is then tabulated for 100% tuning for different mass ratio and orifice opening ratio and a graph was plotted. Finally they concluded the system is most efficient with 40% orifice opening ratio i.e. the effectiveness increases with increase in mass ratio but there is a practical limitation to it.

Shatong Ye, 1997 tested three upgrades namely water shearing pyramid tube, simple piston tube and wrinkled wall tube and determined the performance of improved damper. Among the three, wrinkled walled tube was the best upgrade for TLCD as it significantly lowers the maximum acceleration of the structure during resonance because of the disturbance of the water motion travelling along the whole journey

Jong- Cheng Wu, 2005 calibrated the basic properties of TLCD i.e. frequency and coefficient of head loss, and calibrate the results experimentally using free vibration and forced harmonic vibration test. And to propose an empirical formula to predict head loss coefficient for TLCD as a quick reference. The comparison indicate that the analytical formula for natural frequencies is practically valid. The experimental investigation also confirms that the size of liquid mass and different ratio of horizontal column length to vertical length have no effect on natural frequency and head loss as well.

3. COMPARSION BETWEEN THE TLCD’S

In this paper, a composite frame is taken whose dimensions are shown in Fig. 1 below. The composite frame used under this study consists of a relatively rigid rectangular steel slab supported at the corners on three aluminum and one steel columns. In order to obtain the behavior of different types of TLCD’s used in this study two accelerometers A1 and A2 are attached on the midpoint of the width and length in order to record the behavior both in X and Y direction respectively (fig. 2).

Figs. 3 and 4 show two different types of TLCD. The wrinkled walled TLCD is fabricated with a wrinkled walled pipe bent in a U-shape to which an orifice has been fitted at the middle of the horizontal portion of the pipe. In this paper, the behaviour of the wrinkled wall TLCD is studied and is compared to that of a normal U-shaped TLCD made of Perspex sheet fitted with an orifice at the middle. Both the TLCD are having the same dimensions given below:

Area of tube, $A=5.44cm^2$ Amplitude, D =4cm

L_h=26 cm L_v =16 cm $L=L_h+L_v$=58 cm

Blocking ratio(%) =25,50,75

Natural frequency, $\omega_d=\sqrt{(2g/L)}*2\pi$ =5.816 rad/s

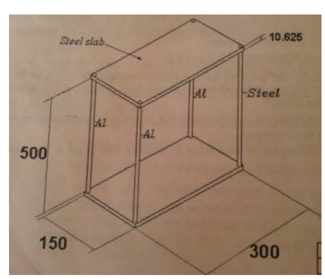


Fig. 1: Composite Frame.

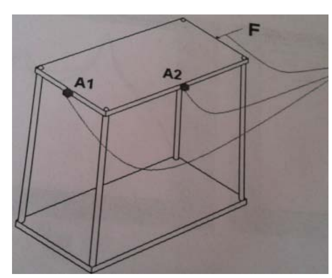


Fig. 2: Composite Frame with accelerometers.

Fig. 3: Wrinkled walled U-shaped TLCD

Fig. 4: Normal U-shaped TLCD

p=L_h/L =0.448cm

3.1. Experimental Test

The basic property of TLCD i.e. coefficient of head loss are experimentally calibrated using harmonic forced vibration test via shake table in the soil dynamics laboratory of department of Civil engineering NIT Silchar. Firstly the TLCD is placed on the top slab of the composite structure and then placed on the shake table. To calibrate the coefficient of head loss, forced harmonic vibration test are performed by driving the shake table at various frequencies and hence the liquid response is recorded accordingly by changing different blocking ratios in the orifice once at a time. Similarly, the acceleration, time, displacement and frequency is recorded through the accelerogram fitted on both the directions of the structure by driving the shake table at various frequencies.

3.2. Numerical simulation

The schematic diagram of a TLCD under excitation of forced vibration such as on shake table is shown in Fig. 5.The coefficient of head loss is numerically predicted by an empirical formula [8] is expressed as in equation(1)

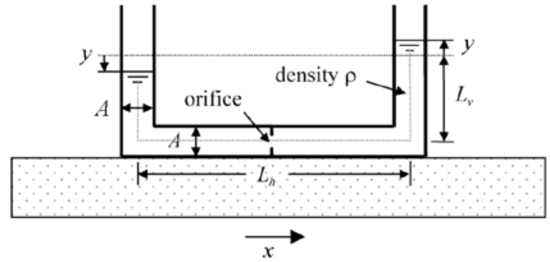


Fig. 5: TLCD under the excitation of FV

$$\eta = (-0.6\psi + 2.1\psi^{0.1})^{1.6}\,(1-\psi)^{-2} \tag{1}$$

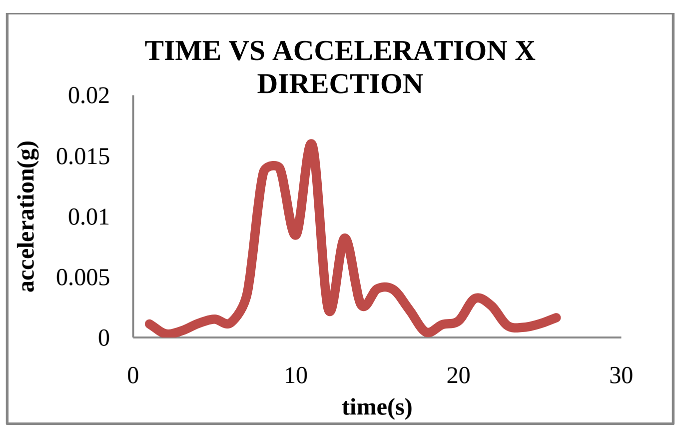
This value of η is substituted in equation(2) [8] with all other dimensions of TLCD given in(table1) in order to obtain the non dimensional amplitude φŷ from the equation as follows.

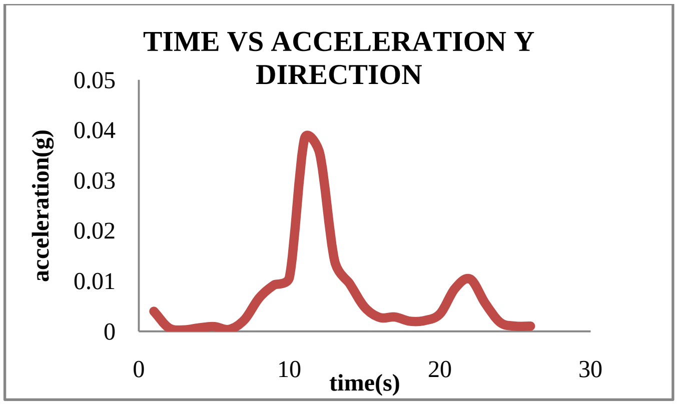
$$\varphi_{\hat{y}} = \frac{\sqrt{-2\pi^2(1-k^2)^2+(4\pi^4(1-k^2)^4+k^8(8/3\eta\rho)^2 4\pi^2\gamma^2)^{1/2}}}{k^2(8/3\eta\rho)} \tag{2}$$

From (equation2) it is noted that the amplitude φŷ is not linearly dependent on excitation amplitude D. This is due to non linearity caused by the damping term.

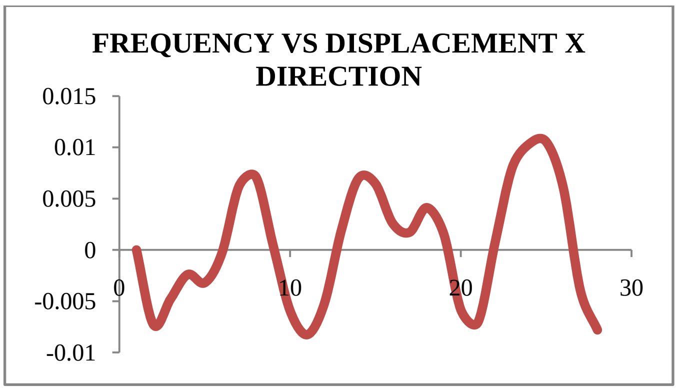
4. RESULTS AND DISCUSSION

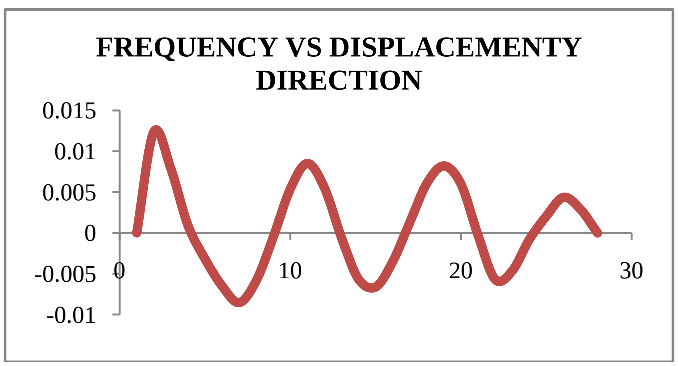
The Fig. 6(a-c) shows the experimental behaviour of wrinkled walled U-shaped TLCD for the blocking ratio of 0.75.The Fig. 7(a-c) shows the behaviour of normal U-shaped TLCD for the blocking ratio of 0.75. Comparing the time vs. acceleration curves for both U shaped and Wrinkled walled TLCD it is found that the acceleration is greater in case of wrinkled walled TLCD. The value of g in X direction increased by 0.01002g and in Y direction by 0.02789g in case of wrinkled walled TLCD. This is because of the wrinkled wall which affects the water motion travelling throughout the journey in the pipe, whereas for normal U shaped TLCD, the disturbance of water motion is restricted to surface areas. Comparing the frequency vs displacement curves it is found that the displacement in case of wrinkled walled TLCD is less than that of the U shaped TLCD. Moreover the graph for U shaped TLCD in X direction showed linear behaviour.



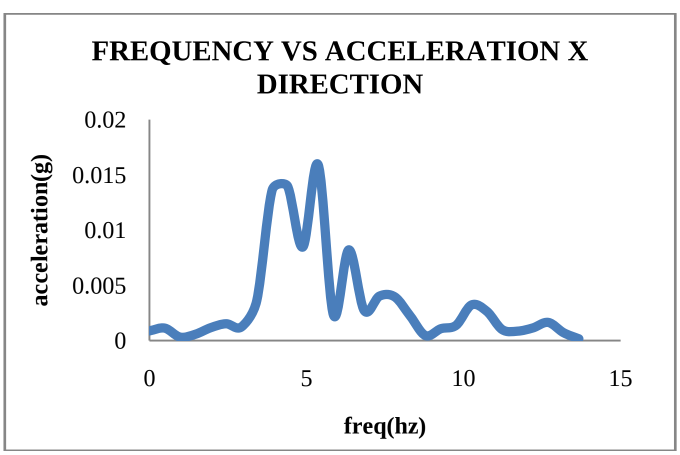


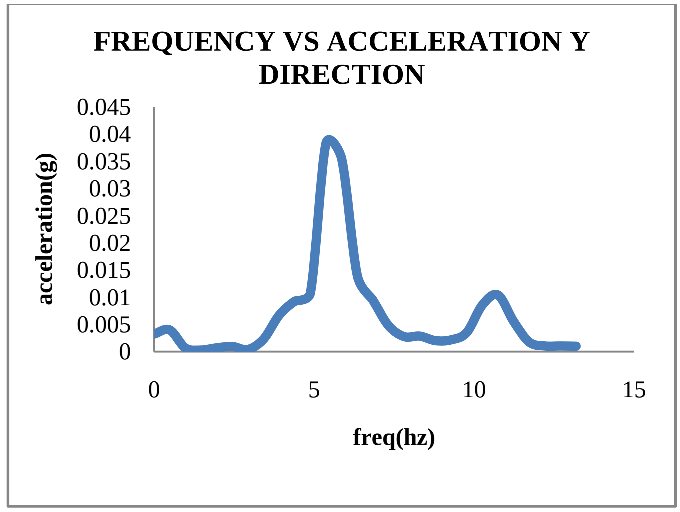
6 (a)





6(b)

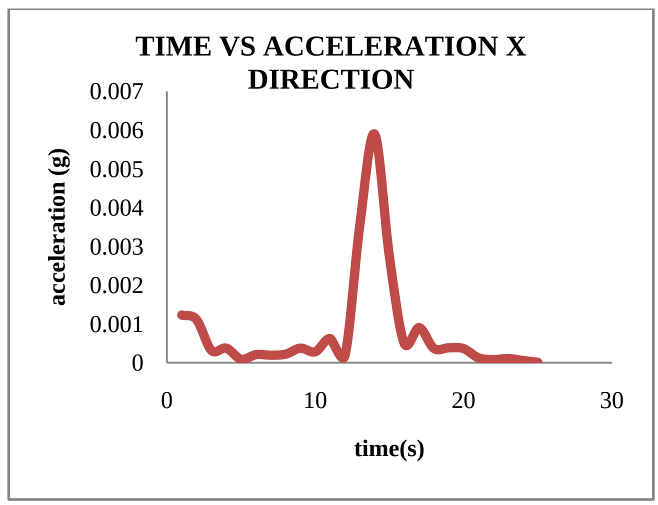


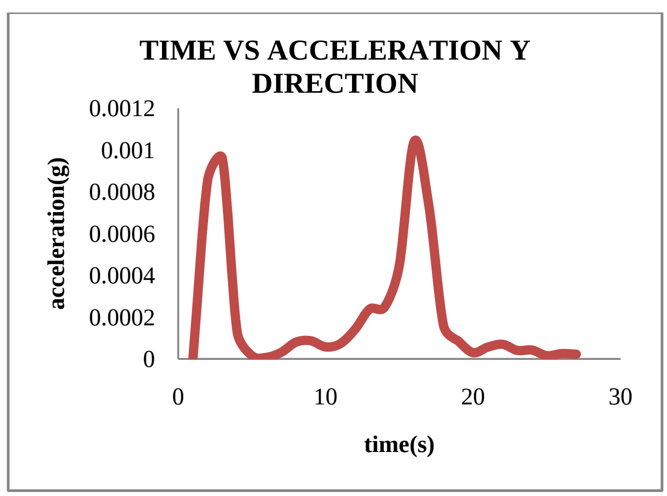


6(c)

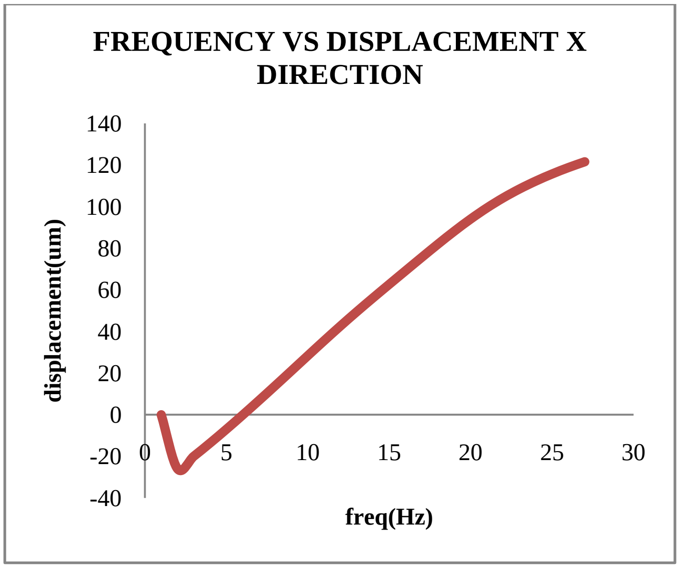
Fig. 6(a):Time vs Acceleration for X and Y direction (b) Frequency vs Displacement for X and Y direction

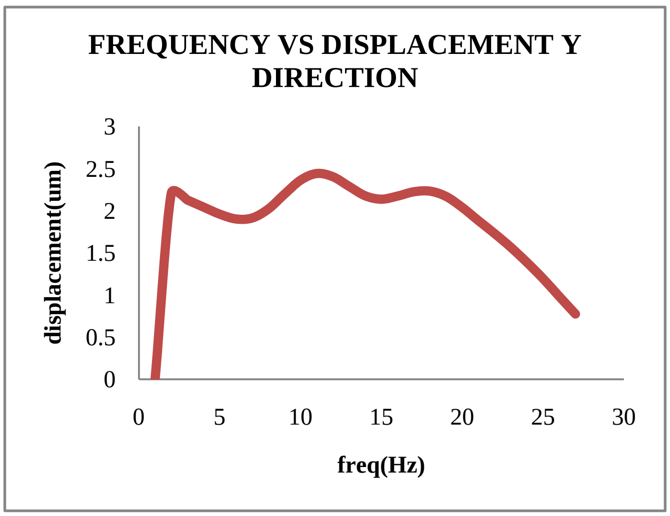
(c)Frequency vs Acceleration for X and Y direction



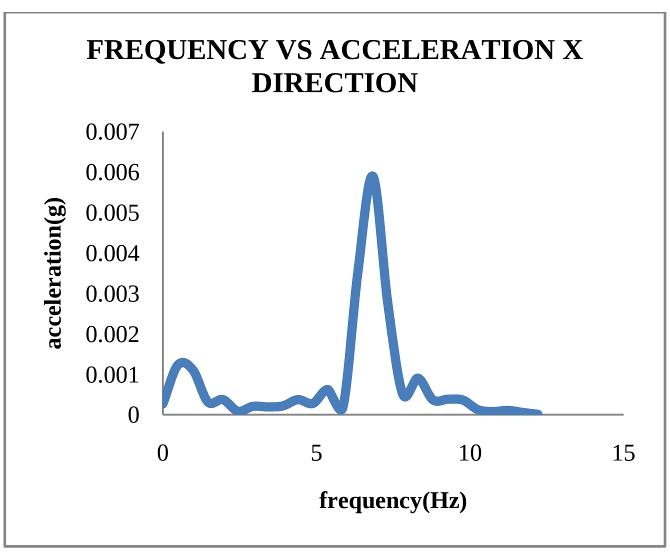


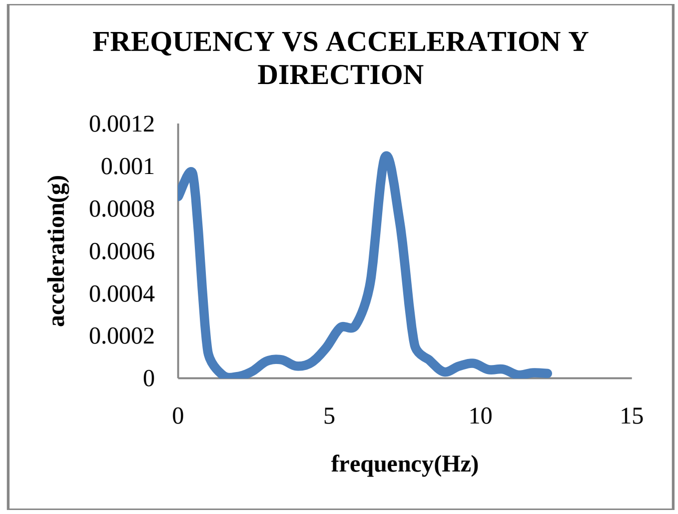
7(a)





7(b)





7(c)

Fig. 7(a): Time vs Acceleration for X and Y direction (b) Frequency vs Displacement for X and Y direction (c)Frequency vs Acceleration for X and Y direction

The Fig. 8(a) shows the comparision of amplitude of liquid displacement using different damping forms. The curve is for non dimensional frequency k=(ω/ωd) vs non dimensional amplitude φŷ for blocking ratio of 0.25,0.50 and 0.75. The curve obtained is compared to the curve obtained from the experimental test results fig. (8b).

Both the graphs shows that as the orifice blocking ratio increases the non dimensional amplitude decreases. Both the graphs showed resonance at the same non dimensional frequency. The only difference is that non dimensional amplitude difference for increases in blocking ratio for the fitting technique has larger difference in peak non dimensional amplitude than the one obtained from the experimental test.

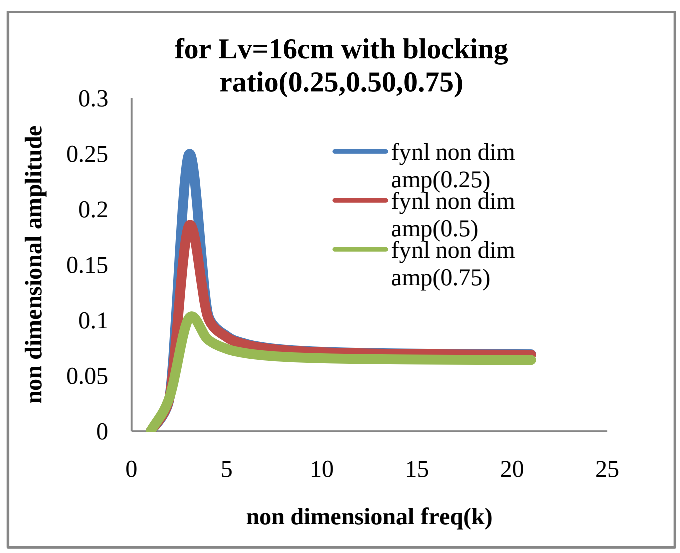


Fig. 8(a): Numerical result

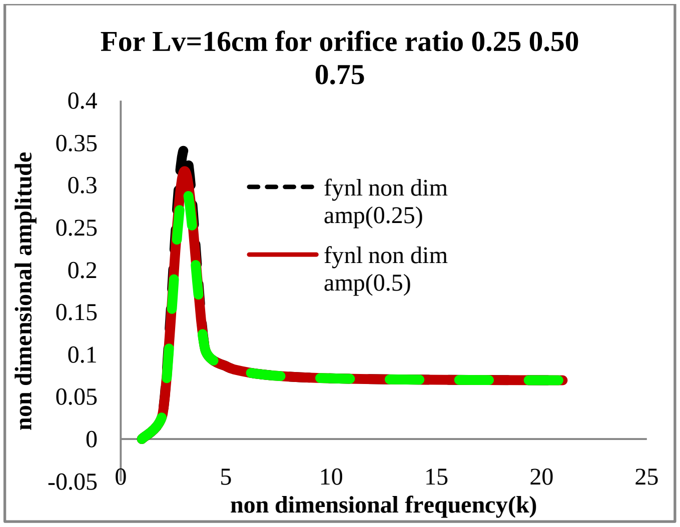


Fig. 8(b): Experimental result

5. CONCLUSION

The behaviour of the wrinkled walled U-shaped TLCD on a composite structure is studied experimentally through forced harmonic vibration test presented in this paper. This behaviour has been compared to that of normal U-shaped TLCD for a certain blocking ratio of 0.75. It is observed that the wrinkled walled TLCD gives more acceleration and less displacement compared to the other and hence the experimental investigation conclude that the wrinkled walled TLCD is more effective than the other. Moreover a comparision is made between numerical and experimental head loss coefficient for blocking ratio of 0.25,0.50 and 0.75. This comparision concluds that both the graphs shows difference for increases in blocking ratio for the fitting technique has larger difference in peak non dimensional amplitude than the one obtained from the experimental test..Resonance occurs at the same non dimensional frequency for both the graphs. The only difference is that non dimensional amplitude is greater than the one obtained from the experimental test.

REFERENCES

[1] Sakai, F., Takaeda, S. and Tamaki, T., "Tuned Liquid Column Damper-New Type Device for Suppression of BuildingVibration," Proc. International Conference on High-rise Building, Nanjing, China, pp. 926□931(1989).

[2] Xu, Y. L., Samali, B. and Kwok, K. C. S., "Control of Along-wind Response of Structures by Mass and Liquid Dampers," ASCE J. of Engineering Mechanics,Vol. 118, pp. 20□39 (1992).

[3] Gao, H., Kwok, K. C. S. and Samali, B., "Optimization of Tuned Liquid Column Dampers," Engineering Structures, Vol. 19, pp. 476□486 (1997).

[4] Balendra, T.,Wang, C. M. and Rakesh, G., "Effectiveness of TLCD on Various Structural Systems," Engineering Structures, Vol. 21, pp. 291□305 (1998).

[5] Balendra, T. and Wang and Rakesh, G., "Vibration Control of Various Types of Buildings Using TLCD," Journal of Wind Engineering and Industrial Aerodynamics,Vol. 83, pp. 197□208 (1999).

[6] Chang, C. C. and Hsu, C. T., "Control Performance of Liquid Column Vibration Absorbers," Engieering Structures, Vol. 20, pp. 580□586 (1998).

[7] Chang, C. C., "Mass Dampers and Their Optimal Designs for Building Vibration Control," EngineeringStructures, Vol. 21, pp. 454□463 (1999).

[8] Jhong-Cheng Wu., "Experimental Calibration and Head Loss Prediction of Tuned Liquid Column Damper," Tamking Journal of Science and Engineering, Vol 8, No 4,pp.319-325(2005).