International Research Journal of Engineering and Technology (IRJET) **e-ISSN: 2395-0056**
Volume: 06 Issue: 04 | Apr 2019 **www.irjet.net** **p-ISSN: 2395-0072**

Effective Control of Response of a Building Under Wind Vibration using Tuned Liquid Dampers

Nimya T Varkichan[1], Sandeep T.N[2]

[1]*M Tech. Structural Engineering, SCMS Ernakulam*
[2]*Asst. Professor, Dept. of Civil Engineering, SCMS Ernakulam*

***

Abstract – *An analytical evaluation on the potency of tuned liquid damper to suppress the wind induced structural vibrations on a multi storied building is analyzed in this paper. Modeling of the structure was done in FEAST and validated by NASTRAN and multiple analysis and comparisons were carried out with varying mass ratio. An optimal mass ratio for TLD is recorded with regard to the results and observations. The optimum mass ratio obtained was 1.5 % and corresponding reduction in acceleration was found to be 58.52%. Based on the optimum mass ratio obtained, a TLD tank, its dimensions and required water depth for the structure to control the vibrations was proposed.*

Key Words: **Tuned Liquid Dampers, energy dissipation, mass ratio, sloshing, wind.**

1. INTRODUCTION

The response of tall buildings to wind forces is a critical design criterion and it requires both conventional force based designs as well as performance based solutions, which led to the advancement of the controlled devices in the recent past .The analysis of strong unsteady wind over tall high aspect-ratio buildings are important because this induces vibrating forces which may coincide with natural frequency of buildings. This could intensify the movement of structure and leads to destruction of building.

Researchers and engineers were concerned about controlling the effects of wind over skyscrapers; there are many factors in controlling vibration of building which includes the improvements of rigidity, mass, damping, shape etc. The optimum selection of vibration control device is influenced by many factors which comprises efficiency, compactness and weight, capital cost, operating cost, maintenance requirement and safety. Damping is found to be one of the effective methods in controlling the oscillations of building. The controlling devices are classified as active, semi-active and passive control.

It is found that Tuned liquid damper proposed by Bauer [1] in 1980 is one of the effective passive controlling methods for tall structures. Tuned liquid dampers are mainly classified into Tuned Sloshing Dampers (TSD's), Tuned Liquid Column Dampers (TLCD's) and controllable TLD's. Basically Tuned Sloshing dampers are partially filled tank in rectangular or circular in shape. The major advantages include low installation, running, maintenance and operation cost, fewer mechanical problems etc. In addition to that these tanks can be used as swimming pools, for storing water for fire storage and can be placed in existing buildings. When a structural motion occurs due to wind the tank get excited. It offers inertial forces to the structures, which is not in phase with structural motion, results in the reduction of movement of structure.

The skyscrapers are undergoing different types of problems due to wind vibrations. This demands the increased concern for building owners and engineers alike. There will be a substantial increase in the forces exerted by winds on buildings with increase in building heights. Static wind effect increases as the square of the structures height. The velocity of wind increases with height and wind pressure increases as the square of velocity of wind. Thus height of the building is a determining factor for wind effects.

The main aim of this paper is the reduction of the structural response of the building by installing a TSD unit to a building which is subjected to wind vibration and to analyse the effects of mass ratio to the structural response.

2. DESCRIPTION OF TESTED BUILDING

In this study an irregular concrete reinforced building with 25-storey and 78 meter total height was considered. Building frame analysis and modeling was done using FEAST.

Table- 1: Material properties of various elements in the Model

Material	Density (kg/m^3)	Modulus of elasticity (N/m^2)	Poisson's ratio
Reinforced concrete	3880	3.31E +10	0.15

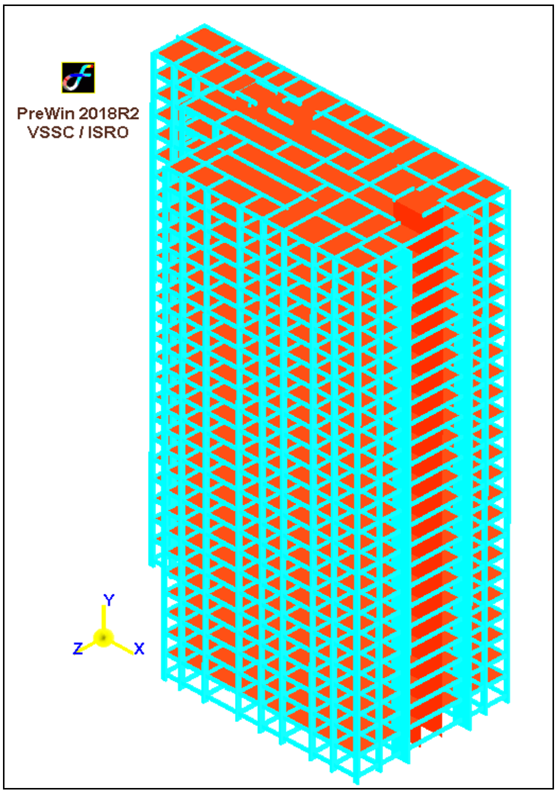

Fig - 1: 3-D model of the building studied

3. FREE VIBRATION ANALYSIS OF THE STRUCTURE

The mode shapes of a structure and natural frequency of a structure was estimated by free vibration analysis. The input details for the design of effective damping system were obtained from the free vibration analysis.

The initial Frequencies (Table 2) and mode shapes (Fig- 2 to 4) obtained from the free vibration analysis are as shown below.

Table -2: Natural Frequencies of various Modes

Mode	1	2	3	4	5
Frequency (Hz)	0.345	0.384	0.447	1.09	1.23

Mode	6	7	8	9	10
Frequency (Hz)	1.47	1.96	2.34	2.85	2.89

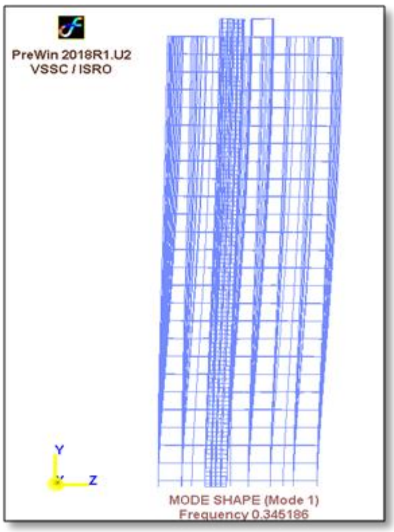

Fig - 2: Mode 1 (bending in Z direction)

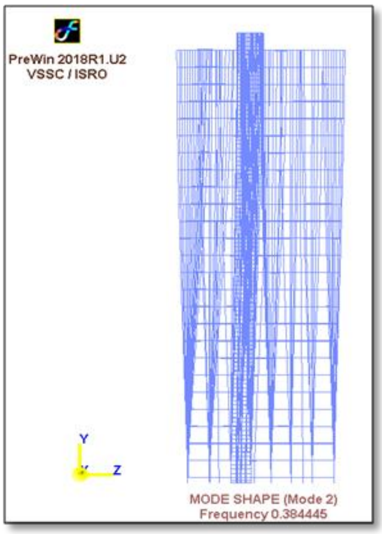

Fig - 3: Mode 2 (torsion)

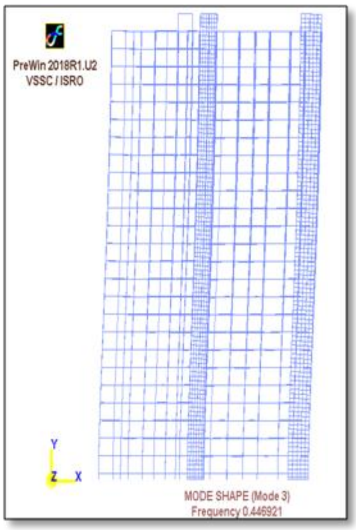

Fig - 4: Mode 3 (bending in X direction)

As mentioned earlier, between the different modes of frequencies obtained on a structure, that frequency which dominates all other frequencies is considered as dominant frequency for the whole structure. The maximum deflection of a structure on comparing with other frequencies is produced by the dominant frequency. The fundamental frequency from normal mode analysis is obtained as 0.345 Hz.

4. ROLE OF TLD ON THE RESPONSE OF BUILDING UNDER WIND VIBRATION

For a wind based design, a structure is dependent to its surroundings. Nearby buildings and the land configuration will have an effect on tall buildings. The vibrations caused by the wind action may not be visible in nature but it can be felt by the occupants in top floor. A chance for motion sickness to the occupants is high due to horizontal swings although it is not dangerous. The modern skyscrapers are more prone to wind vibrations due to the use of modern curtain walls, dry partitions and high strength materials than the early skyscrapers which had massive structural members and materials. To keep a structure stable with acceptable human tolerance is goal of the structural engineer. Hence an effective mechanism for controlling the above factors is necessary. In order to introduce such techniques, it is necessary to determine the response of the structure to the wind force.

In this study, the wind force acting on the structure was calculated as per IS 875: 1987 part 3 and applied to the nodes on each floor. The frequency response of the building to wind force with and without damper was determined.

4.1 Frequency Response Analysis

Frequency response analysis is defined as a method used to compute the structural response of steady state oscillatory excitation. Wind forces can be applied in the form of applied forces on each node at different storey level.

The differences in phase between building and damper allow the effective dissipation of energy. Also the maximum phase difference (90^0) occurs when the TLD is tuned exactly to the natural frequency of the building. From IS 1893: 2002, the damping of the structure is selected as 5%.

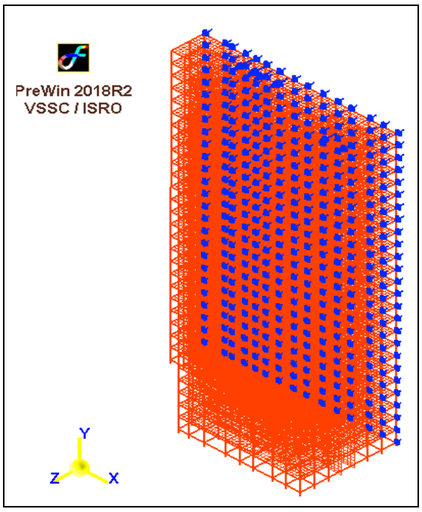

Fig - 5: Full model with wind force in FEAST

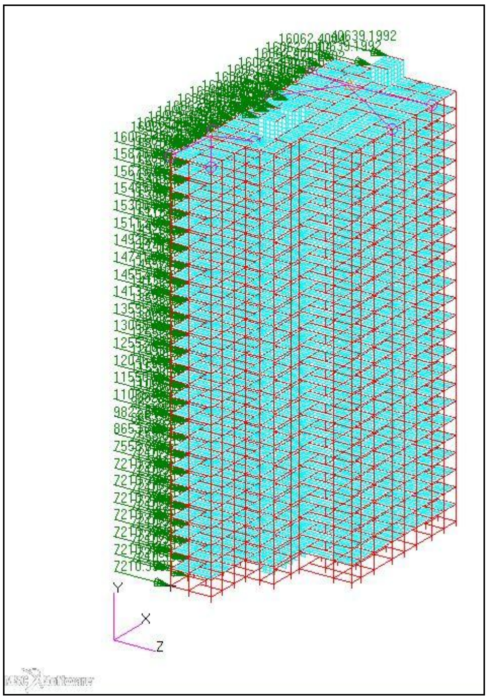

Fig - 6: Full model with wind force in NASTRAN

From frequency response analysis, the acceleration-frequency curve was obtained for a top node. The acceleration obtained was 3.93m/s^2 (Chart-1) corresponding to fundamental frequency, which is to be reduced by introducing damping system.

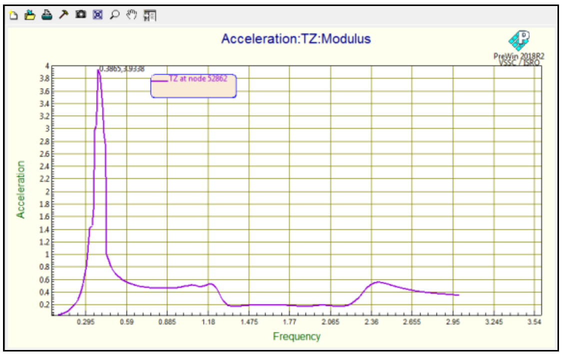

Chart - 1: Response of the building without damper during wind

4.2 Equivalent Mechanical Model Formation of TLD

The vibration due to the wind can be reduced by attaching a secondary mass through a suitably selected spring. The important feature in optimum reduction is the effective tuning of the spring and damper.

4.3 Optimization of Mass Ratio [μ]

$$\mu = \frac{Ms}{Meff} \qquad (1)$$

Where Ms is the slosh mass and M_{eff} is the effective mass of the structure

Effective mass of the building for the first mode = 14591760 kg

Thus sloshing mass can be calculated using above equation with different mass ratios. Corresponding spring constant 'k' can be calculated using the equation

$$f = \frac{1}{2\pi} \times \sqrt{\frac{k}{m}} \qquad (2)$$

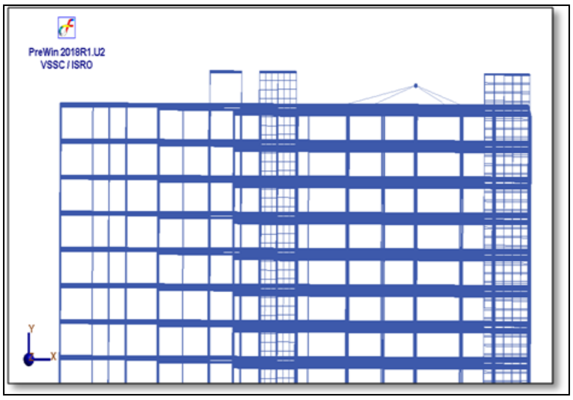

Fig - 7: Model with spring mass system

The response reduction of building at different mass ratios as shown in table below.

Table -3: Reduction of responses with varying mass ratios

Sl no.	Mass ratio	Without TLD	With TLD	Percentage reduction
1	0.50%	3.93	2.01	48.85
2	1%	3.93	1.77	54.96
3	1.50%	3.93	1.63	58.52
4	2%	3.93	1.77	54.96
5	2.50%	3.93	1.75	55.47
6	3%	3.93	1.71	56.49
7	3.50%	3.93	1.56	60.31

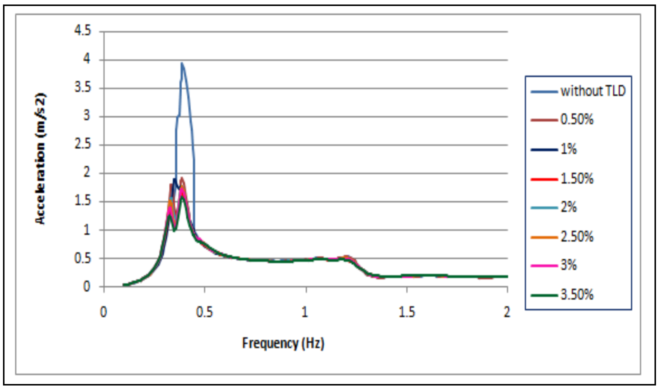

Chart - 2: Response reduction of the building at different mass ratios under wind vibration

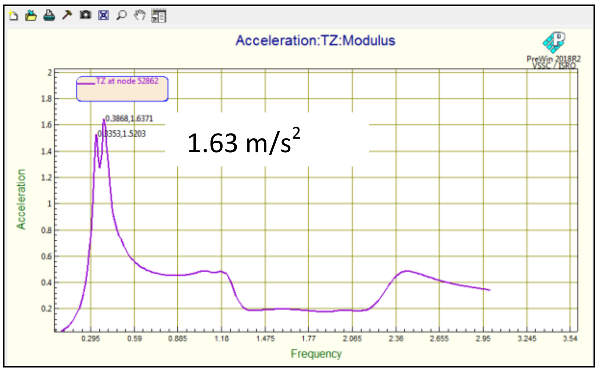

Chart - 3: Response of the building during wind at 1.5% mass ratio reduction (FEAST)

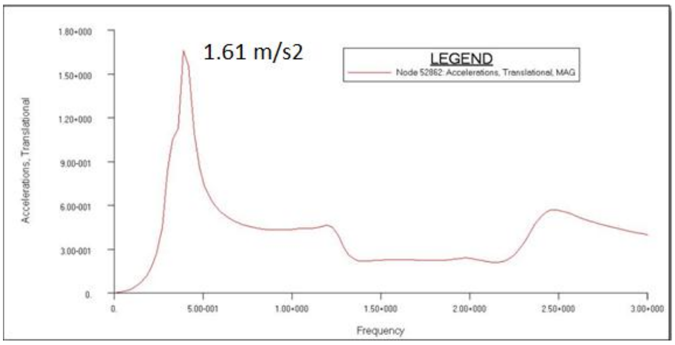

Chart -4: Response of the building during wind at 1.5% mass ratio reduction (NASTRAN)

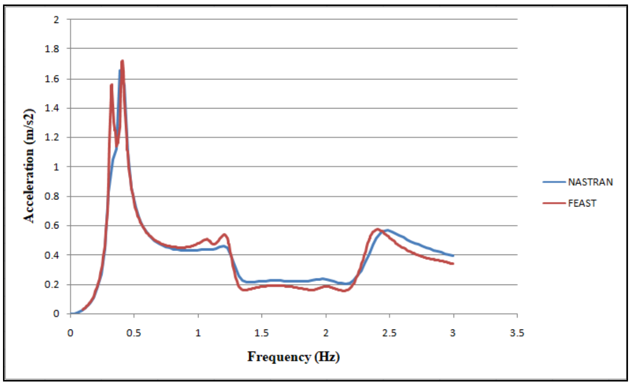

Chart - 5: Comparison of FEAST and NASTRAN results at optimized mass ratio

It was found that the maximum peak acceleration 3.93m/s^2 was reduced when the dampers were installed. There was considerable reduction in the maximum peak amplitude for mass ratios 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 %. But it was found that the reduction in response at higher mass ratios were almost same, the differences very marginal. Also, from structural perspective, it is advisable not to provide any extra mass in the building greater than 2 %. Thus 1.5 % mass ratio is taken as the most optimum case when considering the structural, damping and economy factors. The reduction in maximum amplitude achieved was 58.52 %.

5. PRACTICAL IMPLEMENTATION OF TLD

Tuned sloshing damper is a liquid containing structure; rectangular or cylindrical in shape. These are generally attached to the top most floor of the building. The height of liquid in the container is so adjusted that its fundamental natural frequency in sloshing motion is tuned to one of the natural frequency of the structure. Due to the importance of water, tank on top of a building it can be effectively used as a swimming pool or fire fighting tank and efficient vibration absorber. So Based on the optimum mass ratio obtained, following dimensions are required for the tank and water depth for the structure to control vibrations effectively.

Table -4: Practical implementation of Circular Tank

CASE	Diameter of the tank (m)	Height of water (m)	Total mass of liquid (Kg)	Slosh mass of liquid in tank (Kg)	Slosh mass required (Kg)	Remarks
Single TLD with 1.5% mass ratio	14	1.828	281398.73	218937.34	218876.4	On right top of the building

Table -5: Practical implementation of Rectangular Tank

CASE	Width of the tank (m)	Length of the tank (m)	Height of water (m)	Total mass of liquid (Kg)	Slosh mass of liquid in tank (Kg)	Slosh mass required (Kg)	Remarks
Single TLD with 1.5% mass ratio	11.5	18	1.635	338445	218968.5	218876.4	On right top of the building

6. CONCLUSIONS

For an effective control of wind vibrations over structures TLDs serve as an optimum solution. The comparative performances of TLD corresponding to different mass ratios (ranging from 0.5 to 3.5%) were analyzed and following conclusions were made from the results.

- From this study, it is found that the TLDs are successful in controlling the vibrations of a structure due to wind.
- After conducting normal mode analysis, It was found that the structural frequency increase with increasing mass ratios of a structure with TLDs, making it less vulnerable to wind forces.
- The attempts made to optimize the mass ratio of TLD's for the particular structure was found that the

most optimum mass ratio would be 1.5 % and the corresponding reduction in response was 58.52%.

- Swimming pools and Fire tanks in the building can be effectively used as vibration absorbers.

ACKNOWLEDGEMENT

The authors thank the funding supported from the SCMS School of Engineering and Technology and other members of Civil Engineering Department for their timely guidance.

REFERENCES

[1] Bauer H.F (1984), “Oscillations of immiscible liquids in a rectangular container: A new damper for excited structures”, Journal of Sound and Vibration, 93(1), pp.117-133.

[2] Kareem Ahsan (1990), “Reduction of Wind Induced Motion Utilizing a Tuned Sloshing 3. Damper.” Journal of Wind Engineering and Industrial Aerodynamics, 36, pp. 725-737.

[3] Wakahara T, Ohyama T, and Fujii K (1992), “Suppression of Wind-Induced Vibration of a Tall Building using Tuned Liquid Damper” Journal of Wind Engineering and Industrial Aerodynamics, 41-44, pp. 1895-1906.

[4] LIU Feipeng, LIU Ruyi, BI Haifeng, XIN Mingming1and XU Jiayun (2016), “Research on wind-induced torsional control with annular damper for high-risebuilding”,International Conference on Smart City and Systems Engineering.

[5] Balendra T, Wang C.M, and Yan N (2001), “Control of wind-excited towers by active tuned liquid column damper” Engineering Structures, 23, pp. 1054-1067.

[6] Shum K.M, Xu Y.L, and Guo W.H (2008), “Wind-induced vibration control of long span cable-stayed bridges using multiple pressurized tuned liquid column dampers” Journal of wind engineering and industrial aerodynamics, 96, pp. 166-192.

[7] Modi V.J. and Akinturk A (2002) “An efficient liquid sloshing damper for control of wind-induced instabilities” Journal of wind engineering and industrial aerodynamics, 90, pp. 1907-1918.

[8] Tamura Y, Fujii K, Ohtsuki T, Wakahara T, and Kohsaka R (1995), “Effectiveness of tuned liquid dampers under wind excitation” Engineering Structures, Vol. 17, No.9, (1995), pp. 609-621.

[9] Wakahara T, Ohyama T, and Fujii K (1992), “Suppression of Wind-Induced Vibration of a Tall Building using Tuned Liquid Damper” Journal of Wind Engineering and Industrial Aerodynamics, 41-44, pp. 1895-1906.

[10] Tamura Y, Fujii K, Ohtsuki T, Wakahara T, and Kohsaka R (1995), “Effectiveness of tuned liquid dampers under wind excitation” Engineering Structures, Vol. 17, No.9, (1995), pp. 609-621.

[11] Modi V.J. and Akinturk A (2002) “An efficient liquid sloshing damper for control of wind-induced instabilities” Journal of wind engineering and industrial aerodynamics, 90, pp. 1907-1918.

[12] Ueda T, Nakagaki R, and Koshida K (1992), “Supression of wind induced vibration by dynamic dampers in tower-like structures” Journal of wind engineering and industrial aerodynamics, 41-44, pp. 1907-1918.

[13] Balendra T, Wang C.M, and Yan N (2001), “Control of wind-excited towers by active tuned liquid column damper” Engineering Structures, 23, pp. 1054-1067.

[14] Dodge Franklin T (2000), "The New Dynamic Behaviour of Liquids in Moving Containers", NASA, SP–106, National Aeronautics and Space Administration, Washington, DC.

[15] IS 875:1987(Part III) Indian Standard Code of Practice for Design loads (Other than Earthquake) for buildings and structures, Bureau of Indian Standards, New Delhi.

[16] IS: 456 – 2000 Indian Standard Plain and Reinforced Concrete - Code of Practice, Bureau of Indian Standards, New Delhi.

[17] IS: 1893 – 2002 Indian Standard Criteria for Earthquake Resistant Design of Structures- Code of Practice, Bureau of Indian Standards, New Delhi.