Study of Combined Action of Coupled Tuned Liquid and Mass Damper on Earthquake Response of Buildings

Nikhil V Jacob[1], Minsu Mariyam Varkey[2], Jesmi Michael[3], Nithin M Reji[4], Er. Vivek Philip[5]

Er. Ancy Mathew[6]

[1,2,3,4]B.Tech Civil Engineering Student, Dept of Civil Engineering, Saintgits College of Engineering , Kottayam, Kerala, India
[5,6]Assistant Professor, Dept of Civil Engineering, Saintgits College of Engineering, Kottayam, Kerala, India.

Abstract - *The need to build flexible and slender buildings that have relatively low damping properties has attracted engineers attention to look for efficient and economical techniques to control the vibration response of structures. Recently dampers have become more popular for vibration control of structures, because of their safe, effective and economical design. Combination of Tuned Liquid Damper and Tuned Mass damper, as a unit, is a passive damping device that consists of movable tanks filled with liquid to suppress the horizontal vibration of structures. The tank is designed so that the liquid surface wave has frequency tuned to the fundamental frequency of the building. The structure was first modelled and then its fundamental natural frequency was found out by carrying out free vibration analysis. This unit is then modelled into the structure and changes in natural frequencies were monitored. The structure was subjected to an earthquake loading and its frequency response was compared without this unit and with it. 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. Increasing the mass ratio of the damper can improve the damping effects; under the condition of tuning frequency, the damping effects are remarkable. However, the more the deviation from the tuned frequency, the less controlling effects can be obtained.*

***Keywords**: Tuned Liquid Dampers; Eigen Value Analysis; Response Spectrum Analysis; Fluid Structure Interaction*

1. INTRODUCTION

Earthquake is one of the major natural disasters which occur due to the shaking of the ground caused by movement of the tectonic plates relative to each other. A large population lives in regions of seismic hazards, at risk from earthquakes of varying severity and frequency of occurrence. Geographical data of India shows that almost 54% of the land is susceptible to earthquakes. This natural calamity can take millions of life and can cause significant damage to structures. Hence the concept of earthquake resistant design of structures has been largely discussed over the past few decades. Several seismic construction designs and technologies have been developed over the years in efforts to reduce the effect of earthquakes on structures. Tuned mass damper and tuned liquid damper are relatively new and growing technology of this kind.

In this research we study the combined action of tuned liquid and mass damper. In the present scenario it is very important to have high rise building due to increase in population. The past experience in earthquake shows that the building without damper is more prone to earthquake. This can be reduced by the installation of damper unit in the structure.

1.1 NEED FOR PRESENT STUDY

The following observations were made from literature survey:

i. Several studies have focused on evaluating the response of high rise building with and without dampers. However there is a lack of understanding of the seismic response of structures with combined dampers. Therefore evaluation of the effect of buildings is greatly needed.

ii. Most of the research studies were conducted for tank which requires larger length for sloshing action. So study for reducing this length without affecting its damping action is necessary

1.2 OBJECTIVES

The prime requirements of earthquake resistant multi-storied structural buildings are to have safety and minimum damage level to the structure. In order to meet these requirements, the structure should have adequate lateral strength, stiffness and ductility. The main objectives of the current work are as follows:

- To experimentally investigate the effectiveness of combined TLD-TMD damping action by free vibration analysis of simple building model.
- To evaluate the effectiveness of damper on a multi-storied building equipped with TLD-TMD unit.

2. EXPERIMENTAL STUDIES

A series of experiments were conducted to study the dynamic behaviour of a structure when subjected to free vibration with TLD-TMD unit placed by connecting accelerometers. Vibration is the movement or mechanical oscillation about an equilibrium position of a machine or component. An object can vibrate in two ways: free vibration and forced vibration.

Free vibration occurs when an object or structure is displaced or impacted and then allowed to oscillate naturally. For example, when you strike a tuning fork, it rings and eventually dies down. Natural frequency often refers to the frequency at which a structure "wants" to oscillate after an impact or displacement. Resonance is the tendency for a system to oscillate more violently at some frequencies than others. Forced vibration at or near an object's natural frequency causes energy inside the structure to build. Over time the vibration can become quite large even though the input forced vibration is very small. If a structure has natural frequencies that match normal environmental vibration, then the structure vibrates more violently and prematurely fails.

The study of the structure with TLD-TMD unit will provide an understanding of the behaviour of the damper on structure system. Experimental Free Vibration of building model with and without damper unit is conducted by connecting accelerometer and time-acceleration plot was obtained using LabVIEW Interface. Natural frequency of the structure was then determined by the Fast Fourier Transform of time acceleration plot.

2.1EXPERIMENTAL SETUP

Accelerometer

- Data acquisition system (DAQ)
- LabVIEW virtual software
- Test structure(three storied framed building model)
- TLD-TMD Unit

2.2 TEST STRUCTURE (THREE STORIED FRAMED BUILDING MODEL)

The test structure consists of a three storied framed building model with mass at floors made of polycarbide sheet and wood and the columns separating each floor made of mild steel. The properties of the building model are summarised as follows:

- Height of each floor: 0.5m
- Plan dimension of each storey block: 0.5x0.5 m
- Floor thickness: 0.13 m
- Floor weight: 2.3kg
- Width of steel section: 4 mm
- Depth of steel section: 12 mm
- Grade of steel: Rebar HYSD 500

(a) (b)

Fig -1: Experimental Setup

The figure1 (a) shows the building model without damper unit and the figure1 (b) shows the building model with damper unit. Accelerometer is attached to the structure at the top floor. The building is then subjected to free vibration analysis and the signals were acquired through DAQ and inputted. The acceleration FFT peak was generated in LabVIEW.

Table -1: Experimental Natural Frequencies

Experiment Setup	Natural Frequency
Without damper	3.25Hz.
With damper	1.65Hz

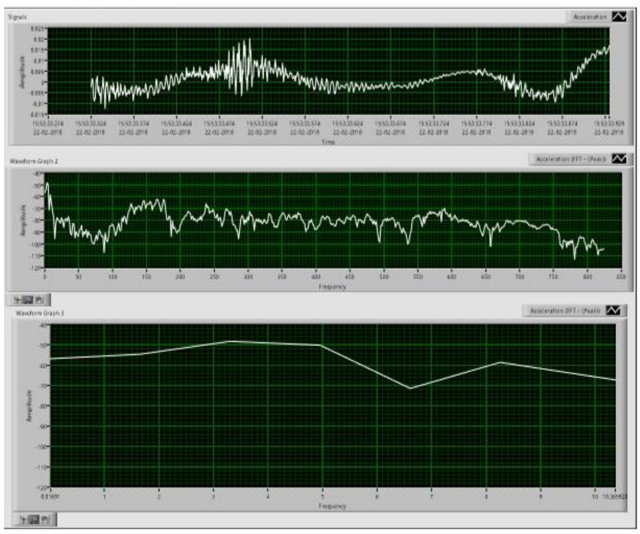

Fig - 2 : LabVIEW Results Without Damper

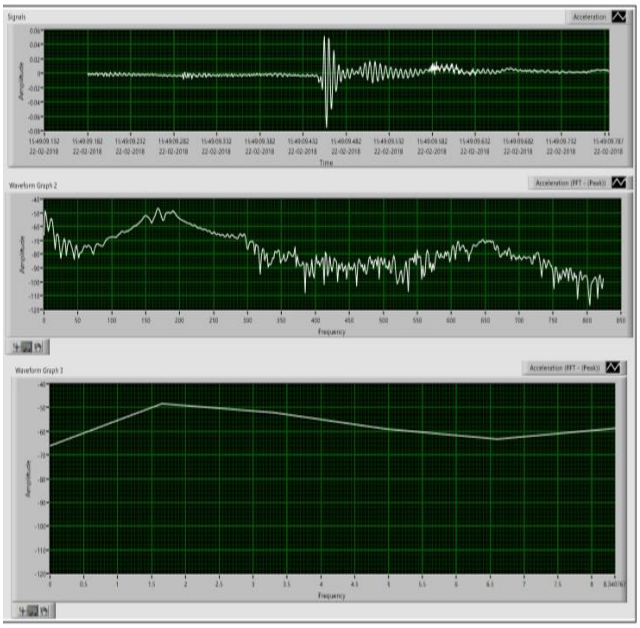

Fig - 3: LabVIEW Results with Damper

3. SOFTWARE STUDY AND PROBLEM VALIDATION

The present work is a dynamic analysis of three-storied building. This can be studied by modelling and analysing the same using software. This chapter contains brief description of the software SAP2000 which is used for analysing the structure. A detailed study about the software is carried out validating the problem.

3.1 VALIDATION OF ANALYTICAL MODEL USING SAP2000

Validation is accomplished for SAP2000 is done by comparing the results of the created structural model with the experimental model. An experimental model is prepared with the same dimensions for the above.

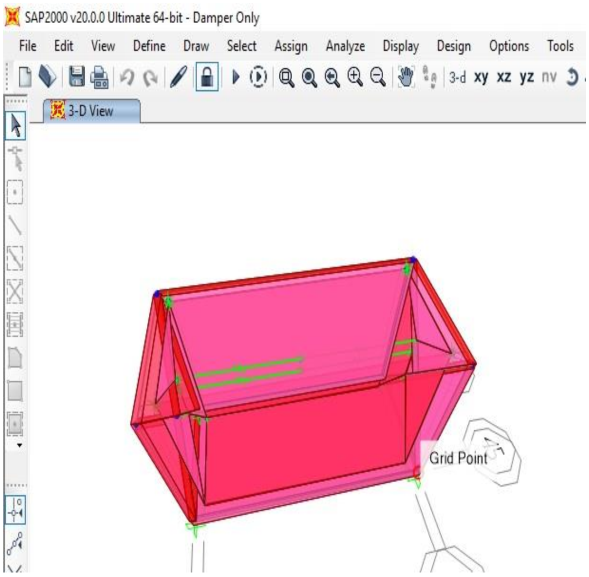

Fig - 4 : Damper Modelled Using SAP2000

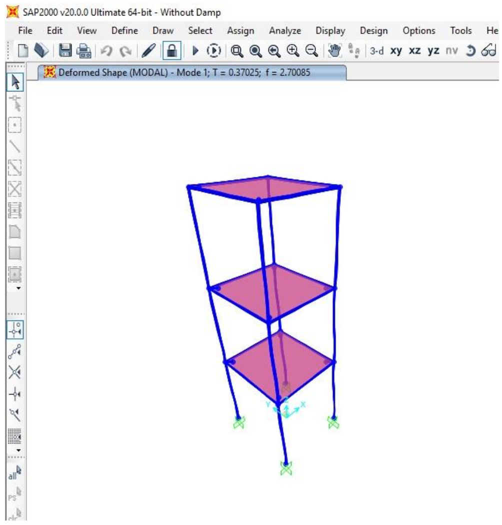

Fig - 4 : Three-Storied Building without damper modeled in SAP2000

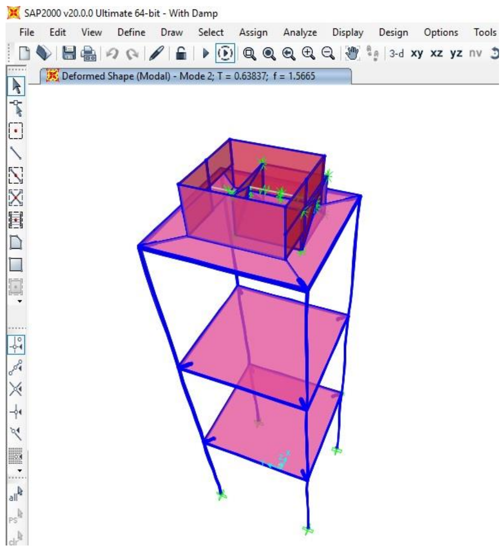

Fig - 5 : Three-Storied Building with damper modeled in SAP2000

Table -2: Numerical Model Analysis Results

Numerical Model Setup	Similar Mode Shape Frequency
Model without damper	2.70085 Hz
Model with damper	1.5665 Hz

3.2 SOFTWARE STUDY CONCLUSION

The natural frequency and mode shape of the structure in experimental investigation are found to be matching with the results obtained from the software SAP2000. Hence further analysis can be carried out to prepare finite element model of different building configuration in SAP 2000 to evaluate earthquake performance of TMD TLD Configuration by modal analysis and time history analysis using Time-Acceleration plots of any known earthquake.

4. NUMERICAL MODELLING

The building was modelled with the help of the software SAP 2000. Geometry of the building was first defined. The beam diagram was then drawn in the XY plane and the beams were replicated to form 30 storied structure. Column diagram was also drawn in the YZ plane and was replicated about the x-axis. The beams and columns are modelled using two nodded line element with six degrees of freedom at each node. The slab is modelled using shell element. The building is modeled as base frame without considering the stiffness of infill wall. After that materials were defined. The properties defined are as follows:

Grade of concrete: M30
Grade of steel: Rebar's HYSD 500
Density of concrete = 24.9926 KN/m3
Modulus of elasticity of concrete = 2.73x10^7 KN/m2
Poisson's ratio of concrete = 0.2
Density of steel = 76.9729 KN/m3
Modulus of elasticity of steel = 2x108 KN/m2

Beams and columns were created and the dimensions of beams and columns were given as specified.

Beams	300 x 500 mm
Columns (Stories 1 -10):	350 x 800 mm
Columns (Stories 10- 20):	300 x 700 mm
Columns (Stories 20- 30):	300 x 600 mm
Slabs Flooring:	150 mm

Fig 6.1 shows a model of the building in SAP 2000 software. Modal analysis was then carried out to determine the natural frequency of the building.

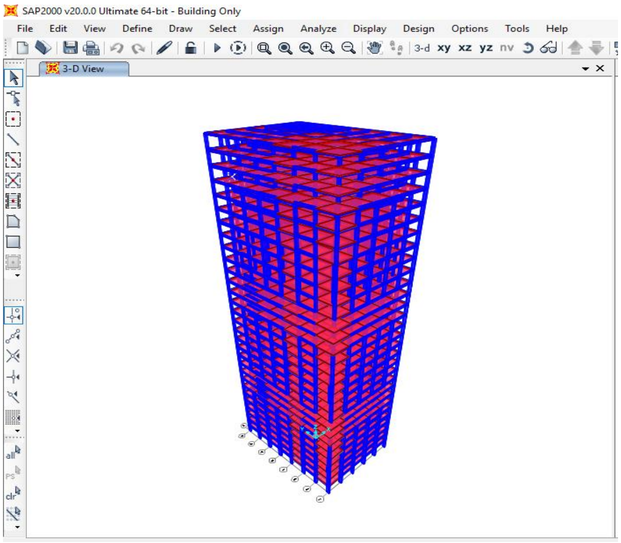

Fig – 6: 30 storied building modeled in SAP2000

4.1 MODAL ANALYSIS

Once the structure was modeled in SAP 2000, Normal Mode Analysis was carried out. The usual first step in performing a dynamic analysis is determining the natural frequencies of the structure with damping neglected. These results characterize the basic dynamic behavior of the structure and are an indication of how the structure will respond to dynamic loading.

As per IS 1893:2002, the structural damping ratio of any building can be taken as 5%. Hence the building when considered as a SDOF system has a natural frequency equal to 0.271 Hz and damping ratio equal to 5%. With the below values obtained, damper can be designed.

Modal mass for the first mode = 148881.1 KN

Damping constant = 0.05

Natural frequency = 0.27 Hz

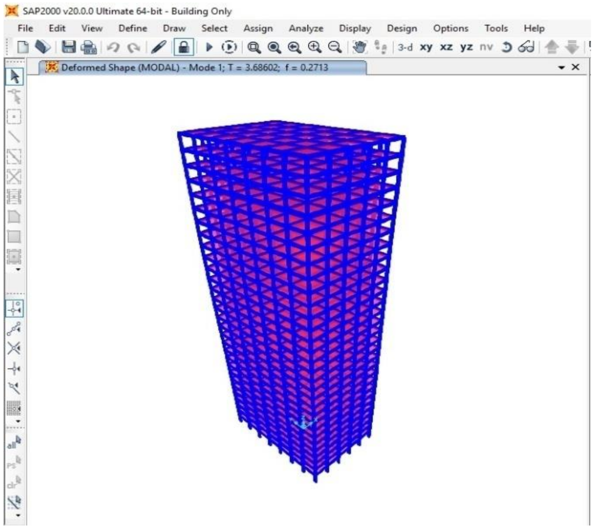

Fig – 7: 30 Storied Building Analyzed In SAP2000

4.2 MODELLING OF DAMPER

Damper unit was modeled in SAP 2000. The properties defined are as follows. Values for Fluid-Structure Interaction were obtained by using IS 1893: Criteria for Earthquake Resistant Design of Structures Part 2 Liquid Retaining Tanks.

Walls of Tank (Concrete) = 150 mm

Walls of Tank (Steel) = 6 mm

Inner Tank Dimensions = 5 m x 2 m x 3m

Outer Tank Dimensions = 5.5m x 2.25 m x 3.1 m

Mass ratio Calculation:

By conducting static dead load analysis,

Weight of building = 150384.955 KN

Weight of one tank = 564.9787 KN

Weight of 12 tank combined = 6779.7444 KN

Mass Ratio = (150384.955/6779.7444)x100

= 4.508259752%

Approximately 4.5 % mass ratio

Water tank was modeled as an external file in sap2000. The interaction planes and the grid points were defined in the respective points. Nodes were provided at respective heights and water tank was connected to springs and masses.

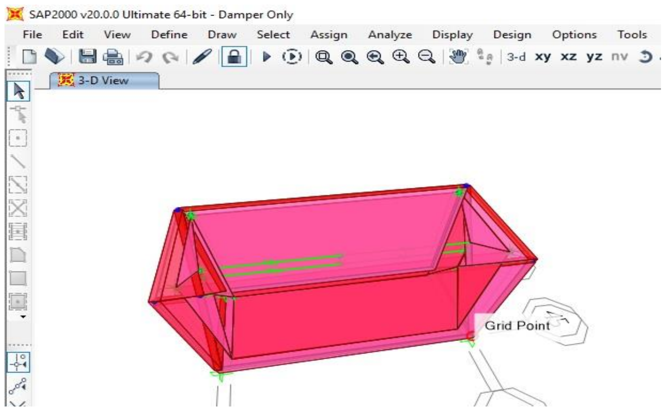

Fig –8 : Water Tank Modeled In Sap2000

4.3 FLUID STRUCTURE INTERACTION

A satisfactory spring mass analogue to characterize basic dynamics for two mass model of elevated tank was proposed by Housner (1963) after the chileane earthquake of 1960, which is more appropriate and is being commonly used in most of the international codes including GSDMA guideline. During lateral mode of shaking of the water tank, a upper part of the water moves in a long period sloshing motion, while the rest part moves rigidly with the tank wall. The former one is recognized as convective mass of water which exerts convective hydrodynamic pressure on tank wall and base, while the latter part is known as impulsive mass of water which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall. The impulsive mass of water experiences the same acceleration as the tank container and contributes predominantly to the base shear and overturning moment. In spring mass model convective mass (mc) is attached to the tank wall by the spring having stiffness (Kc), whereas impulsive mass (mi) is rigidly attached to tank wall.

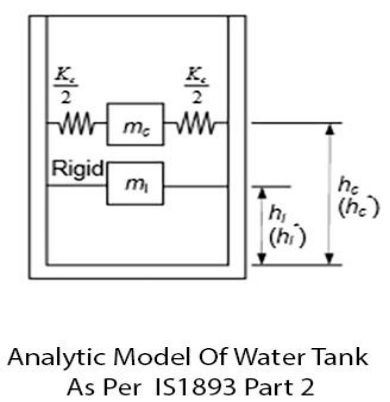

Fig: 9 Analytical Model Of Water Tank

The analytical model of the water tank is based on the following parameters:

Table -3 : FSI Parameters

mi/m	0.6196
h/L	0.6
hi/h	0.375
L/h	1.66
hi*/h	0.45
mc/m	0.4205
hc/h	0.61029
hc*/h	0.7739
Kc	735.128

The simplest method of these is the added mass approach can be investigated using some of conventional FEM software such as SAP2000, STAAD Pro and LUSAS.

The damper was already defined by providing respective nodes. Then the water tank was connected to the building with the bottom nodes. All the nodes in the internal tank were released in the direction of excitation.

Modal analysis of the building with the damper was then done by using Eigen Value Analysis to determine the natural frequency of the structure. Analysis was carried out under various stiffness ranging from 500-4500KNm. The optimum natural frequency of the structure along with damper was obtained. The stiffness configuration giving the optimum natural frequency was considered for further analysis.

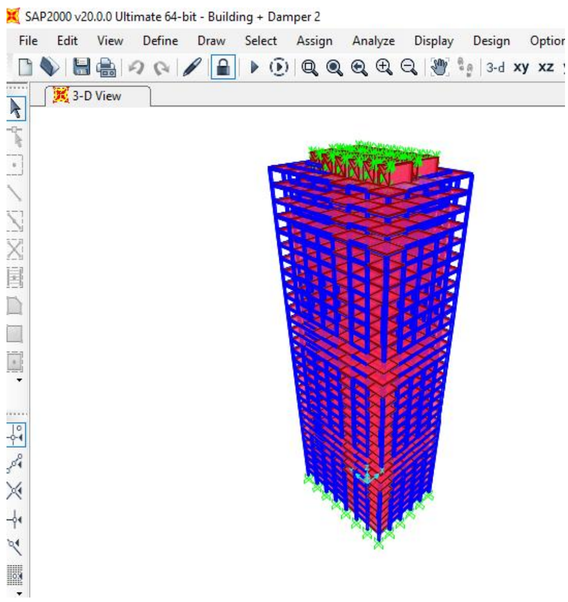

Fig: 10 Building with damper modelled in SAP2000

Table -4 : Natural frequencies at various stiffness

Stiffness	Frequency
1000	0.29435
1250	0.29564
1500	0.29635
1750	0.29764
2000	0.29814
2250	0.29925
2500	0.29898
2750	0.299
3000	0.29908
3250	0.29939
3500	0.29993
3750	0.29941
4000	0.29942
4250	0.29922

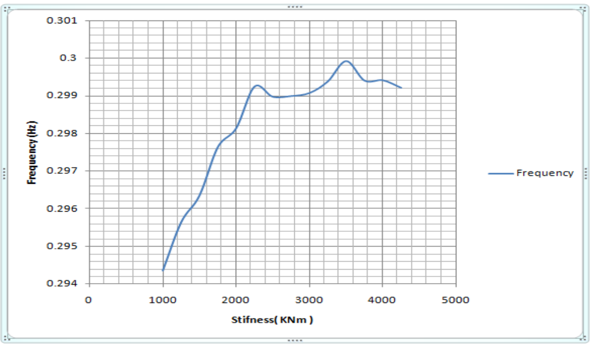

Chart -1: Natural Frequency Vs Stiffness Curve

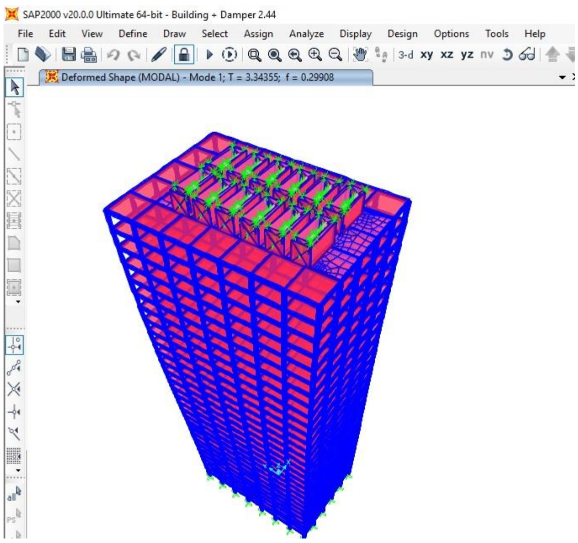

Fig: 11 Building With Damper Analysed In SAP2000

4.4 TIME HISTORY ANALYSIS OF BUILDING WITH DAMPER

Time history data of El Centro earthquake has been inputted. Analysis was done using the mode shapes obtained from the modal analysis. Building response was plotted for relative displacement of the structure and the response spectrum.

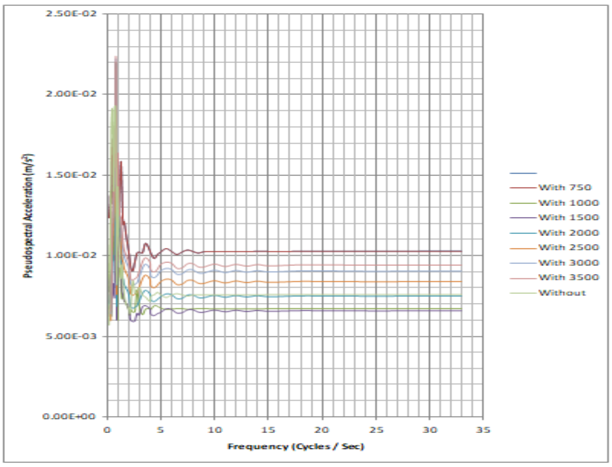

Chart -2: Response Curve at all Stiffness

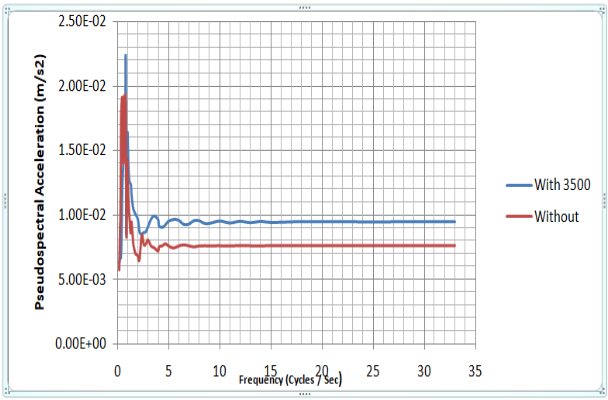

Chart -3: Response Curve at Stiffness 3500KN/m

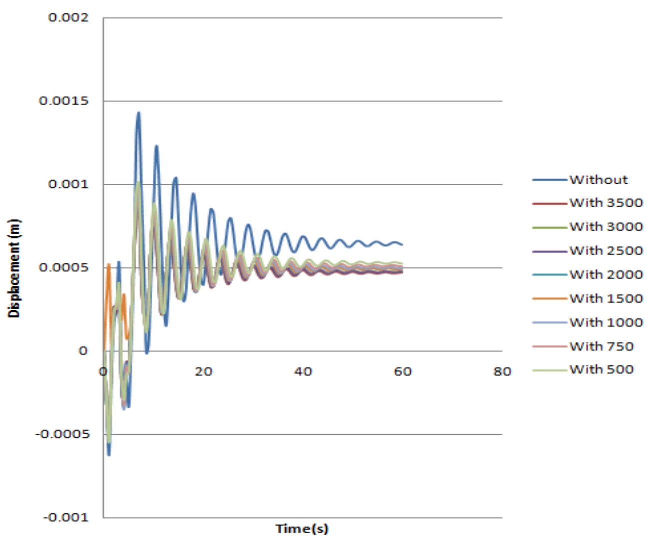

Chart -4: Displacement Curve At All Stiffness

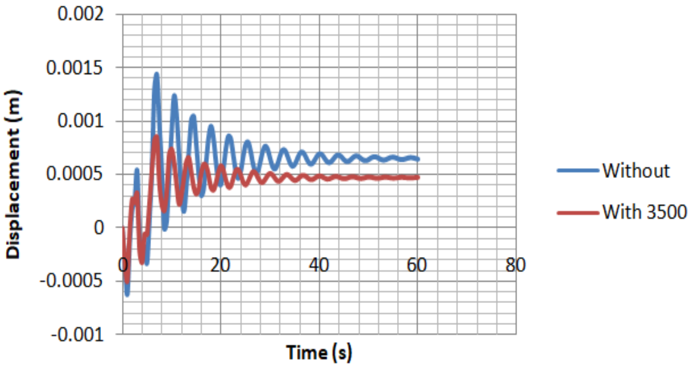

Chart -5: Displacement Curve at Stiffness 3500KN/m

5. RESULTS AND DISCUSSION

After carrying out the normal mode analysis of the structure with TMD- TLD tanks, it was found that the structural frequency increase with increasing stiffness, making it less vulnerable to exciting forces. The optimum natural frequency was obtained at a stiffness of 3500KNm.

The natural frequency of the structure without damper unit = 0.2713Hz.

The natural frequency of the structure with damper unit = 0.29908Hz.

It was found out that response can be adjusted by controlling the frequency and the stiffness. The displacement and response graphs obtained from the time history analysis shows the effectiveness of damper unit in earthquake response. There is considerable reduction in the displacement of the structure after placing the damper unit in the building and there is an increase in the response of the structure after placing the damper unit.

6. CONCLUSIONS

The effectiveness of TLD-TMD unit as a damper in controlling the structural vibrations was investigated experimentally and then analytically using Sap 2000 and effective results were obtained.

The following conclusions were made from the study:

- After conducting experimental investigations it was concluded that the damper was experimentally viable to adjust the frequency.
- In validation the experimental model was converted to finite element model which is found to be effective.
- A finite element procedure was developed to denote actual TLD-TMD damper.
- The newly suggested damper was effective in controlling response.
- Apart from other stiffness of the structure this can be adjusted to get maximum response.
- The building response was reduced. So it is a promising device.

REFERENCES

[1] Chidige Anil Kumar , E Arunakanthi, "A Seismic Study on Effect of Water Tank Modelled as TMD" International Journal of Innovative Research in Science, Engineering and Technology, Vol. 6, Issue 2, February 2017.

[2] Midhun Krishnan R , Dr. C K Prasad Varma Thampan, "A Study on Vibration Control of Framed Structures Due to Seismic Excitation Using Tuned Mass Damper" International Journal of Scientific & Engineering Research, Volume 7, Issue 10, October-2016.

[3] Namrata Yannawar, G.R.Patil, "Response Behaviour of a Three Storied Framed Structure with Tuned Liquid Damper" International Journal of Innovative Research in Science, Engineering and Technology Vol. 3, Issue 7, July 2014.

[4] Namrata Yannawar, " Analysis of Lateral Loads for a Framed Model with Tuned Liquid Damper" IOSR Journal of Mechanical and Civil Engineering January 2005.

[5] Muhammed Murad.K Lavanya.G, "Dynamic resistance of tall buildings by using tuned mass damper's (TMD'S)" International Journal of Scientific & Engineering Research, Volume 7, Issue 10, August-2016.

[6] Riju Kuriakose , Lakshmi P, "Effectiveness of Tuned Liquid Dampers on High Rise Buildings in Kerala" International Journal of Engineering Research & Technology Vol. 5 Issue 09, September-2016.

[7] Bauer H.F., "Oscillations of immiscible liquids in a rectangular container: A new damper for excited structures." Journal of Sound and Vibration, Volume 93, Issue 1, 8 March 1984

[8] Modi V.J., and Welt F., "Damping of wind induced oscillations through liquid sloshing." Journal of Wind Engineering and Industrial Aerodynamics, Volume 30, Issues 1–3, August 1988.

[9] Banerji P., Murudi M, Shah A.H. & Popplewell N., "Tuned liquid dampers for controlling earthquake response of structures", Earthquake Engng Struct. Dyn, volume 29, issue 5, 2000.

[10] Roshni. V. Kartha*, Ritzy. R, "Tuned Liquid Damper to Control Earthquake Response in a Multi-Storied Building Frame"Int. Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 5, Issue 8, (Part - 4) August 2015, pp.49-56.

[11] G. Hemalatha And K.P. Jaya, "Water Tank As Passive Tmd For Seismically Excited Structures" Asian Journal Of Civil Engineering (Building And Housing) Vol. 9, No. 4 (2008) Pages 349-366.

[12] Ashasi-Sorkhabi, A., Kristie, J., and Mercan, O., "Investigations of the use of multiple tuned liquid dampers in vibration control." Proc., Structures Congress, ASCE, Reston, VA, (2014), pp.1185–1196

[13] Banerji P., Murudi M, Shah A.H. & Popplewell N., "Tuned liquid dampers for controlling earthquake response of structures", Earthquake Engineering Structural Dynamics, 29 (2000), pp. 587-602

[14] Fujii K., Tamura Y., Sato T., Wakahara T., "Wind-induced vibration of tower and practical applications of Tuned Sloshing Damper." Journal of Wind Engineering and Industrial Aerodynamics, 33, (1990), pp. 263-272.

[15] Fujino, Y., and Sun, L. M., "Vibration control by multiple tuned liquid dampers (MTLDs)." J. Struct. Eng., 10.1061/(ASCE)0733 -9445(1993)119:12(3482), (1993), pp. 3482–3502

[16] Igusa, T., and Xu, K., "Vibration control using multiple tuned mass dampers." J. Sound Vib., 175(4), (1994), pp. 491–503.

[17] IS 456 - 2000, IS 875 - Part I, II, III, IS 1893 Part I – 2002

[18] Kaneko S. and Ishikawa M, "Modelling of Tuned Liquid Damper with submerged nets", Journal of Pressure Vessel Technology, Vol. 121 (3), (1999), pp. 334-342.

[19] Kim Young-Moon, You Ki-Pyo, Cho Ji-Eun, and Hong Dong-Pyo, "The Vibration Performance Experiment of Tuned Liquid Damper and Tuned Liquid Column

[20] Damper." Journal of Mechanical Science and Technology, Vol. 20, No. 6, (2006), pp. 795-805.

[21] Koh C.G., Mahatma S., and Wang C.M., "Reduction of structural vibrations by multiple-mode liquid dampers," Engineering Structures, Vol. 17, No. 2, (1995), pp. 122-128

[22] Love J. S. and Tait M. J., "Multiple Tuned Liquid Dampers for Efficient and Robust Structural Control", Journal of Structural Engineering, 10.1061/(ASCE)ST. 1943-541X.0001290, (2015), pp. 04015045-1 - 04015045-6

[23] Modi V.J, Seto M.L, "Suppression of flow-induced oscillations using sloshing liquid dampers: analysis and experiments", Journal of Wind Engineering and Industrial Aerodynamics 67&68, (1997), pp. 611-625.

[24] Sun L.M., Fujino Y., Pacheco B.M., and Chaiseri P., "Modeling of Tuned Liquid Damper (TLD)." Journal of Wind Engineering and Industrial Aerodynamics, 41- 44, (1992), pp. 1883-1894.

[25] Tait M.J., Damatty A.A. El, Isyumov N., and Siddique M.R., "Numerical flow models to simulate tuned liquid dampers (TLD) with slat screens," Journal of Fluids and Structures, 20, (2005), pp. 1007-1023.

[26] Tait M.J., "Modeling and preliminary design of a structure-TLD system," Engineering Structures, 30, (2008), pp. 2644-2655

[27] Tait M.J., Isyumov N. and Damatty A.A.El., "Effectiveness of a 2D TLD and Its Numerical Modeling", Journal of Structural Engineering, Vol. 133, No. 2, (2007), pp. 251-263.

[28] S. R. Damodarasamy, S. Kavitha "Structural Dynamics and Aseismic Design" PHI Learning Private Limited, New Delhi, India, 2009, pp. 16-73.

[29] Bangale S Taranath, "Structural Analysis and Design of Tall Buildings", McGraw Hill Book Company, New York, (1979), pp. 643-700.

[30] Sun Limin, "Semi-Analytical Modelling of Tuned Liquid Damper (TLD) with Emphasis on Damping of Liquid Sloshing", Ph.D. Thesis, University of Tokyo, Bunkyo, Tokyo, Japan, 1991