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Seismic Resistance Using Water Tank and Roof Top Frame As Passive Control System

Dony Paulose[1], Annu Ann Jacob[2], Hemalatha G[3]

[1,2]PG Student, [3]Head of Department,

Department of Civil Engineering,

Karunya University, Coimbatore,

India ***E-mail:*** *donypaulose24@gmail.com[1]*

Abstract

This project is based on the analytical investigation carried out to study the feasibility of implementing water tank and roof top frame as passive Tuned Mass Damper (TMD) using SAP2000 and ANSYS. The idea of seismic response control of the structures by using TMD's is considered for this study. A tuned mass damper (TMD) is a device consisting of a mass, a spring, and a damper that is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the damper is tuned to a particular structural frequency so that when that frequency is excited, the damper will resonate out of phase with the structural motion. Energy is dissipated by the damper inertia force acting on the structure. Water tanks are integral part of all buildings and they impart large dead load on the structure. This additional mass can be utilized as TMD to absorb the extra energy imparted on the structure during earthquakes. The main objective of this project is to find the response reduction of structures subjected to various earthquake data's using different mass ratios. Response of the structure was studied using the Newmark method. Multi-storey concrete structures were taken for the study. The water tank and roof top frame was placed at the top. The mass and frequency of both were tuned to the optimized values. The behavior of the tank and roof frame subjected to earthquake data, namely, El Centro was studied. The results show that if the same is tuned properly, it can reduce the peak response of structures subjected to seismic forces and a great reduction in the displacement is observed.

Keywords: *TMD, Passive Control Systems, El Centro, Inter-storey Drift, Newmark method*

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INTRODUCTION

An earthquake is a natural phenomenon. Depending upon the intensity, it may cause damage to life and property. Earthquakes create vibrations on the ground that are translated into dynamic loads which cause the ground and anything attached to it to vibrate in a complex manner and cause damage to buildings and other structures. Civil engineering is continuously improving ways to cope with this inherent phenomenon. Conventional strategies of strengthening the system consume more materials and energy. Moreover, higher masses lead to higher seismic forces. A state-of-art review of using control systems for seismic resistance of structures is reported in literatures [1], [2].

Passive Seismic control systems

Dynamic load produces vibration in the structure which causes the damage or collapse of the structure. A large amount of energy is imparted into structure during these vibrations. To reduce these vibrations it becomes important for the structures to absorb or dissipate energy. A widely considered strategy consists of incorporating external elements to the structure to control its dynamic response. The function of seismic passive energy dissipation system is to reduce structural response due to earthquake, wind and other dynamic loads. Passive control system develops control forces at the point of attachment of the system. The power needed to generate these forces is provided by the motion of the points of attachment during dynamic excitation. Intensively used including base isolation, friction dampers, passive bracing systems, tuned-mass dampers, viscous-elastic dampers, etc. The advantage lies in their ability to absorb vibrational energy without the requirement of power or sensing, and their reliability and robustness (unconditionally stable system). Vibration control effectiveness of passive TMD is reported in literatures [3], [4].

RESPONSE OF THE STRUCTURE

The response of the structure is found using Newmark method. The Newmark method is a method of numerical integration used to solve differential equations. It is widely used in numerical evaluation of the dynamic response of structures and solids such as in fem to model dynamic systems. Since, the linear acceleration method is more accurate than the average acceleration method, $\gamma=1/2$ and $\beta=1/6$ is taken.

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A. Response of the structure

The response of the structure at different floors is obtained using the Newmark's method.

Table 1 Response of the structure

Floor Level	**Displacement in m**
U1	0.000357
U2	0.00269
U3	0.035
U4	0.048

B. Response of the structure when roof top frame is placed on top

Table 2 Response of the structure when roof top frame is placed on top

Floor Level	**Displacement in m**
U1	0.000135
U2	0.0015
U3	0.0085
U4	0.0178
U5	0.239

i. Graph comparing inter-storey drift vs storey height

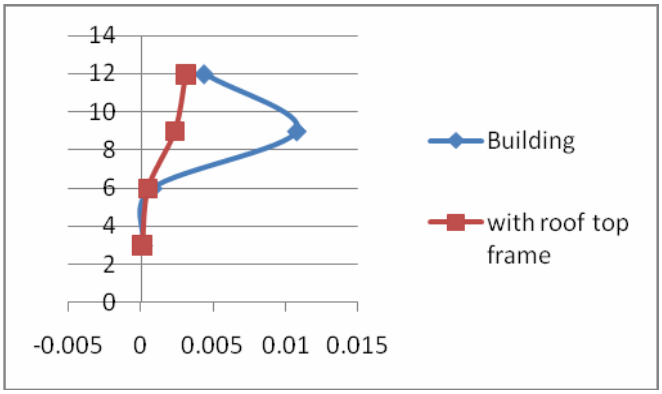


Fig.1 Graph comparing the interstorey drift vs. storey height of the structure without roof top frame and with roof top frame

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C. Response of the structure when water tank is placed at the top

1) Empty condition

Table 3 Response of the water tank under empty filled condition

Floor level	Displacement in m
U1	0.000178
U2	0.0012
U3	0.003
U4	0.0124
U5	0.0385

i Graph comparing inter-storey drift vs storey height

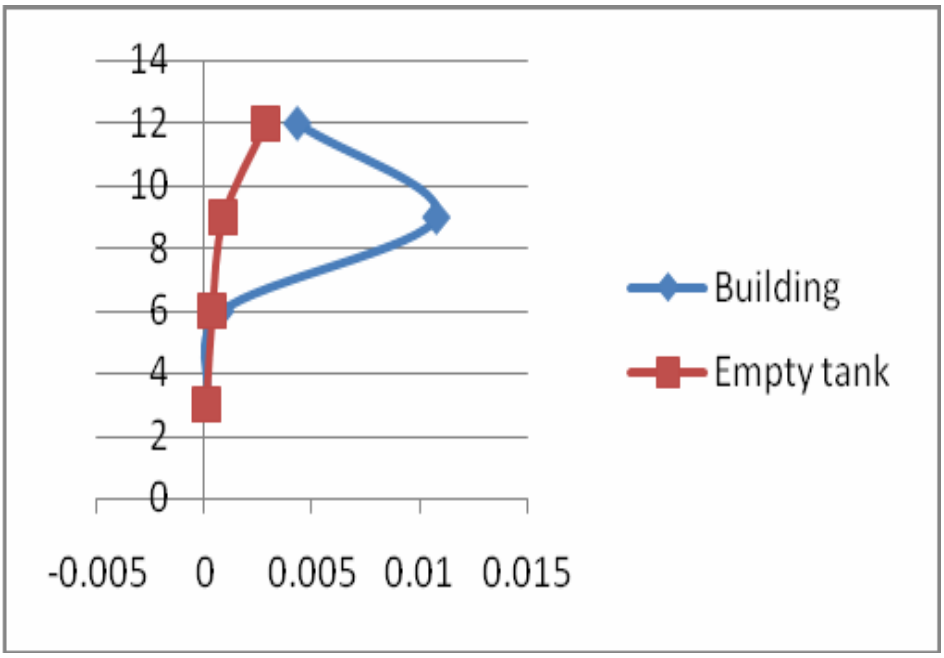


Fig.2 Graph comparing the interstorey drift vs. storey height of the structure without water tank and with water tank in empty condition

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2) *Half filled condition*

Table 4 Response of the water tank under half filled condition

Floor level	Displacement in m
U1	0.000195
U2	0.0015
U3	0.0054
U4	0.0056
U5	0.0182

ii. *Graph comparing inter-storey drift vs storey height*

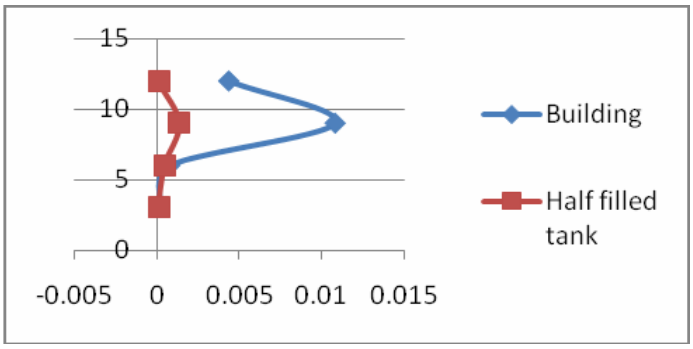


Fig. 3 Graph comparing the interstorey drift vs storey height of the structure without water tank and with water tank in half filled condition

3) *Fully filled condition*

Table 5 Response of the water tank under fully filled condition

Floor level	Displacement in m
U1	0.000179
U2	0.0012
U3	0.0037
U4	0.0119
U5	0.0364

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iii. *Graph comparing inter-storey drift vs storey height*

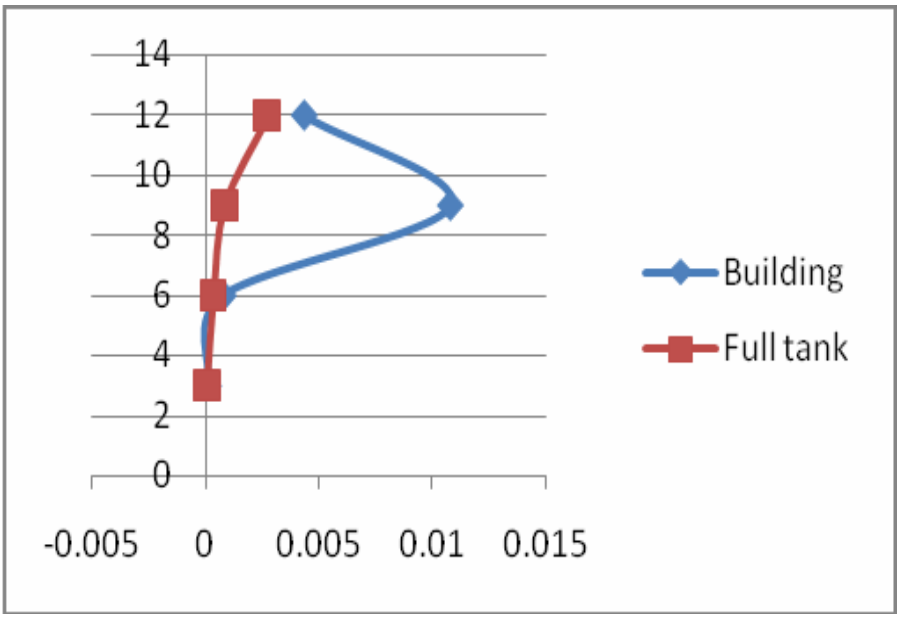


Fig. 4 Graph comparing the interstorey drift vs. storey height of the structure without water tank and with water tank in fully filled condition

ANALYTICAL INVESTIGATION

The objective of the present work is analyzing the feasibility of implementing water tank and roof top frame as passive TMD and finding the optimum design which would reduce the peak response of the structure subjected to seismic forces using SAP. [5] Carried out analysis for mitigation of structural response using water tanks as TLD (Tuned Liquid Dampers). [6] And [7] carried out analysis of roof isolation systems and their implementation.

A. Model

Analytical investigation was carried out using the routines of SAP. Two concrete models were taken for the study. The material properties used for the analysis are Young's Modulus of Concrete –0.35 kg/cm^2, Poisson's ratio –0.16 and Density of concrete – 2.5g/cc. Dimension are shown below:

Table 6- Beam dimension

No.of storey	span	Breadth	length
3	3.5m	300mm	300mm
5	3.5m	300mm	350mm

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Table 7- Column dimension

No. of storey	Column Size	No of Bars	Length
3	300 x 300	16mmΦ,6no's	6mmΦ,250mm spacing
5	350 x 350	16mmΦ,6no's	6mmΦ,250mm spacing

B. Optimization

The effectiveness of the TMD depends on the proper tuning of the characteristics of TMD to that of the structure. In the present work the mass ratio μ (Mass of TMD to Mass of the Structure) and frequency ratio α (Frequency of TMD to the frequency of the structure) are optimized and the objective function is to reduce the peak structural response subjected to seismic excitation. For optimization the structure was modeled as lumped single degree of freedom spring-mass system, with mass equal to that of the unit modal mass and stiffness adjusted to the natural frequency of the structure. The TMD was attached to the idealized system as spring mass system.

C. *Water tank as TMD*

Water tanks are integral part of all buildings and they impart large dead load on the structure. This additional mass can be utilized as TMD to absorb the extra energy imparted on the structure during earthquakes. In the present work the water tank was placed at centre so that the centre of mass of structure and that of the tank coincide. The tank had a plan dimension of 3.5 x 3.5m for the model and 1.5m height for M3 and was placed over 1.5m high columns and a tank of 3.5x3.5m for the model and 2m height for M5 and was placed over 2m high columns.

The beam-column supports for the tank were rectangular concrete sections and the walls and roof were also modeled as steel. The dimensions of the tank were taken to suit the condition that the tank half full of water condition coincides with the optimized parametric values, i) mass ratio ie, ratio of mass of water tank (water + tank + beams and column) to the mass of the structure and ii) frequency ratio ie, ratio of frequency of water tank (water + tank + beams and columns) to the frequency of the structure.

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D. Roof Top Frame as TMD

Roof top frames impart large dead load on the structure. This additional mass can be utilized as TMD to absorb the extra energy imparted on the structure during earthquakes. In the present work the roof top frame was placed at centre so that the centre of mass of structure and that of the tank coincide. The frame had a plan dimension of 3.5 x 3.5m for the model and 3m height for M3 and M5.

The beam-column supports for the roof top frame were rectangular steel sections and the slabs were also modeled as steel. The dimensions of the frame were taken to suit the condition such that ratio of frequency of roof top frame to the frequency of the structure coincides.

MODELLING OF FRAME

The space frame building is modeled in SAP 2000. The beams and columns are modelled as frame elements and the slab is modelled as a shell element. The wall load is assigned on the beams. The bottom of the frame is fixed. The diaphragm action is considered at every floor level. The beams and columns are properly connected using the end offsets provision. Figure shows the 3D model of the frame building using SAP.

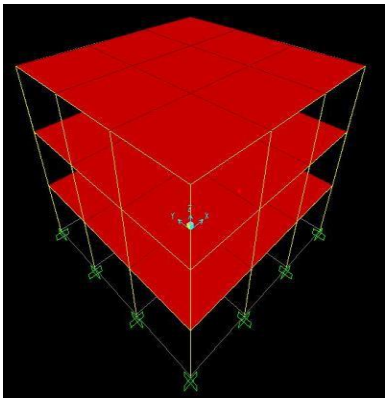


Fig 5: 3-D Model of the 3 storey building5 Storey Building

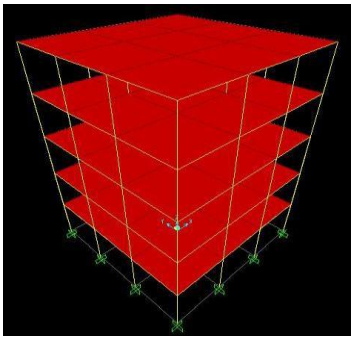


Fig 6: 3-D Model of the 5 storey building

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A. Modal Analysis Using Sap

The seismic weight is lumped at centre of mass of each floor level. Modal analysis has been carried out in SAP for both RCC frames. The mode shapes and frequencies of the frames are found out. Typical mode shapes of RCC frames are shown below. The displacement - time history data was obtained for the earthquake loading. The parameters are then optimized by considering the quantity of reduction in displacement. The optimized values were arrived at for the parameters which provide maximum reduction in displacement.

3 Storey building

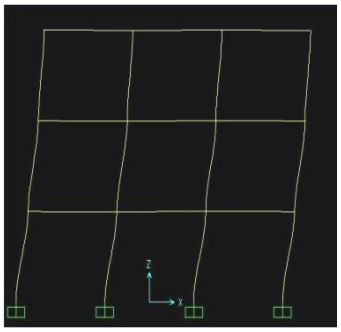


Fig 7 Mode 1 – time period = 0.266 (M3)

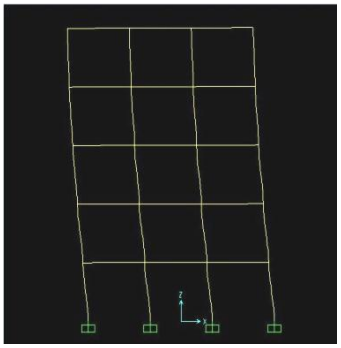


Fig 8 Mode 1 – time period = 0.603 (M5)

B. Modeling of Frame With Water Tank at the Top

The space frame building is modelled in SAP 2000. A water tank is placed at the top assuming it as filled .The tank had a plan dimension of 3.5 x 3.5m for the model and 1.5m height for M3 and was placed over 1.5m high columns and a tank of 3.5x3.5m for the model and 2m height for M5 and was placed over 2m high columns. The beam-column supports for the tank are rectangular concrete sections and the walls and roof are also modeled as steel.

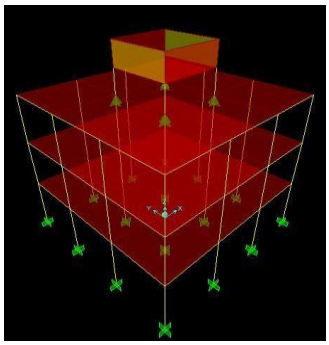


Fig 9 3D Model with water tank (M3)

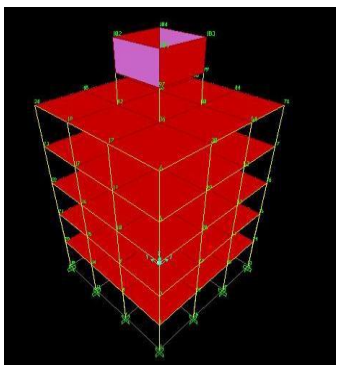


Fig 10 3-D Model with water tank (M5)

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C. Modal analysis using SAP with water tank at the top

3 Storey Building

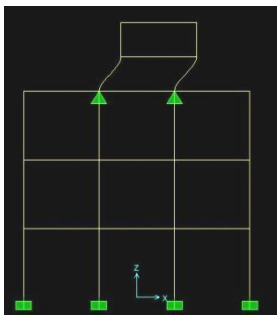


Fig 11 Mode 1 –Time Period = 0.266 (M3)

5 Storey Building

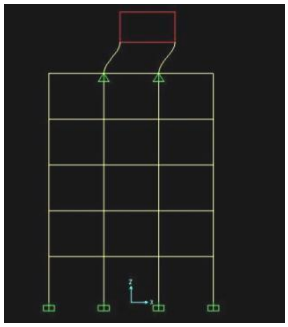


Fig12 Mode 1– time period = 0.303 (M5)

D. Modelling of frame with Roof Top Frame

The space frame building is modelled in SAP 2000. A roof top frame is placed at the top. The roof top frame had a plan dimension of 3.5 x 3.5m for the model and 3m height in M3 and M5. The beam-column supports for the roof frame are rectangular steel sections and the slabs are also modelled as steel.

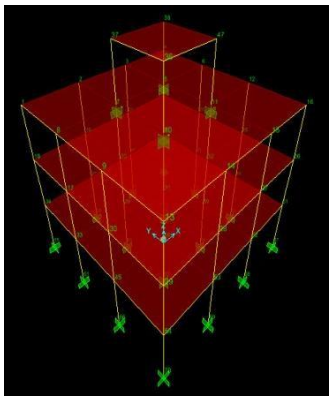


Fig 13 3-D Model with roof top frame (M3)

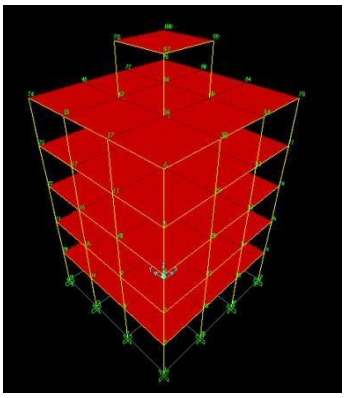


Fig 14 3-D Model with roof top frame (M5)

E. Modal analysis using SAP with roof frame at the top

3 Storey Building

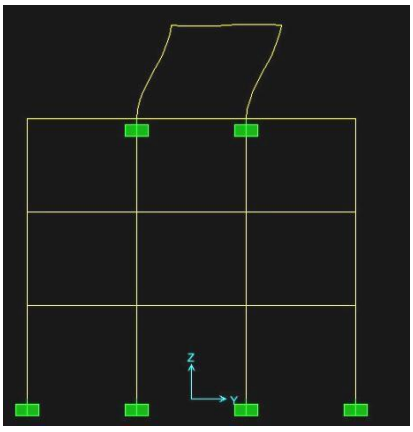


Fig 15 Mode 1–Time Period = 0.266 (M3)

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5 Storey Building

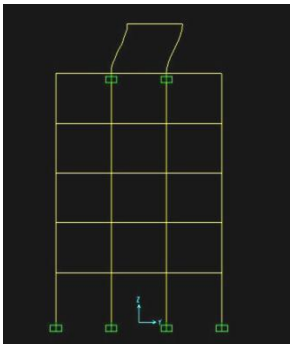


Fig 16 Mode 1-Time Period = 0.603 (M5)

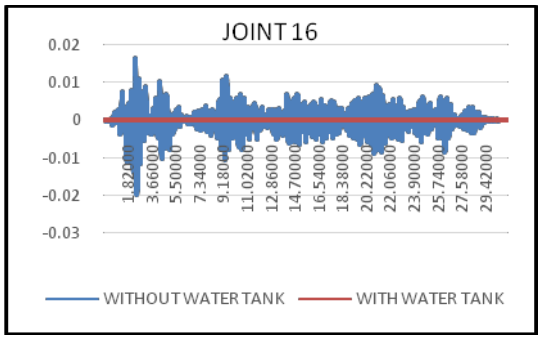
RESULTS AND DISCUSSIONS

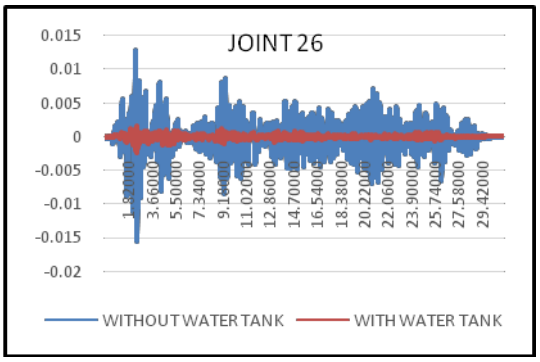
A. Graph Comparing Displacements

i. With and without water tank

The displacement at joints is noted. The displacement of joints with and without water tank is compared. The following graph shows the comparative study of the displacement caused by the frame with water tank and without water tank.

3 STOREY BUILDING





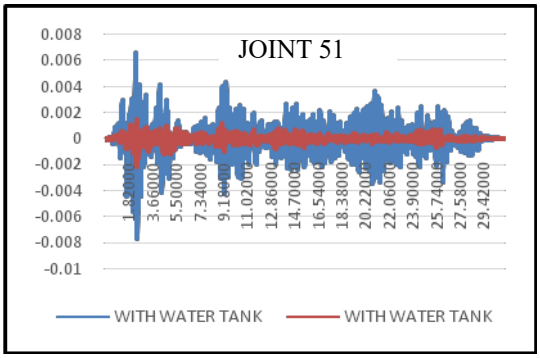
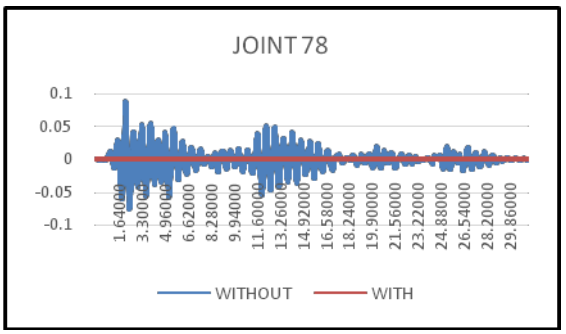
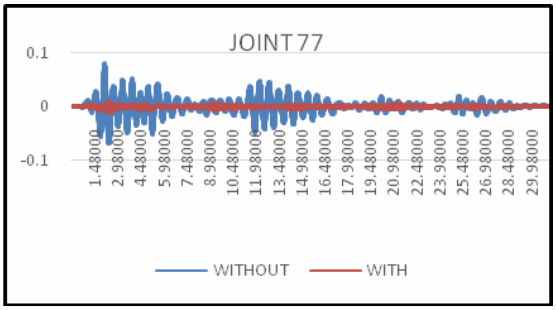


Fig 17 Displacement at different joints (M3)

5 STOREY BUILDING





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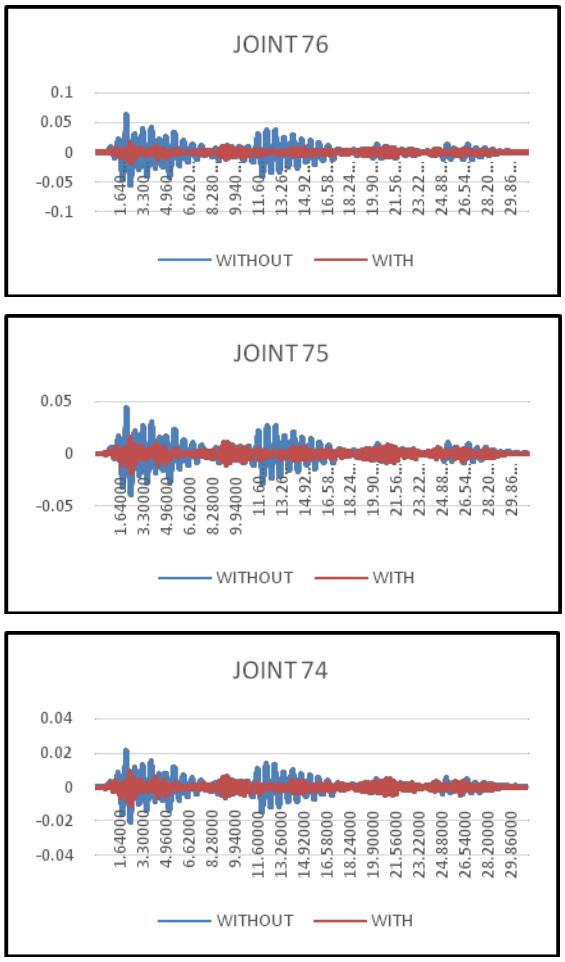


Fig 18 Displacement at different joints (M5)

ii. With and without roof top frame

The displacement at joints is noted. The displacement of joints with and without roof top frame is compared. The following graph shows the comparative study of the displacement caused by the frame with roof top frame and without roof top frame.

3 STOREY BUILDING

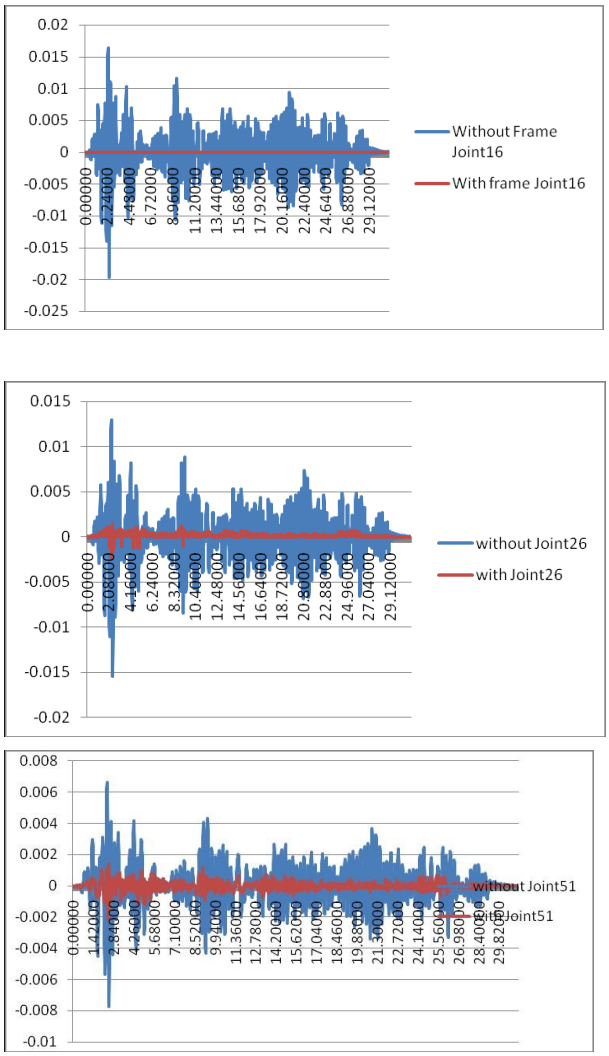
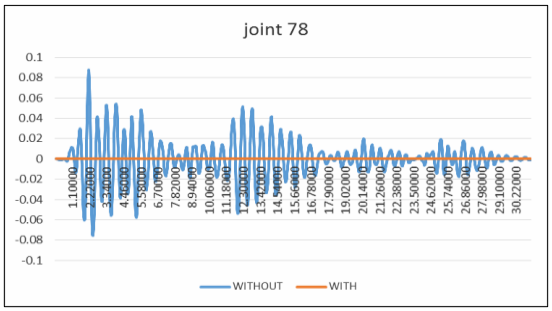


Fig 19 Displacement at different joints (M3)

5 STOREY BUILDING



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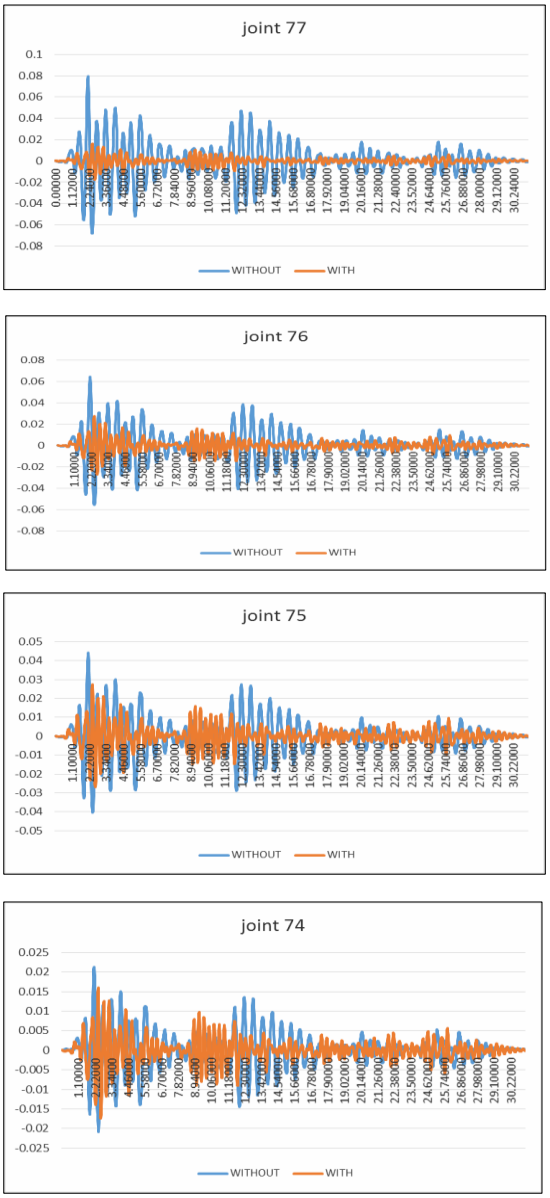


Fig 20 Displacement at different joints (M5)

B. Comparison of Inter-Storey Drift

Inter-story drift is an important indicator of structural behaviour in performance-based seismic analysis. It is the relative horizontal displacement of two adjacent floors in a building. Inter-story drift can also be expressed as a percentage of the storey height separating the two adjacent floors.

C. Graph comparing inter-storey drift vs. storey height

- With And Without Water Tank

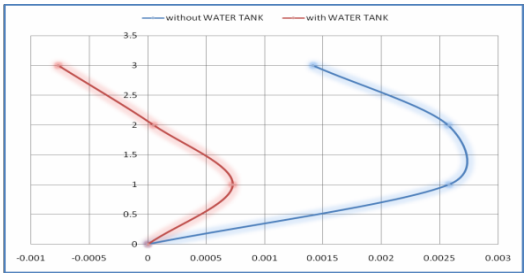


Figure 21: M3

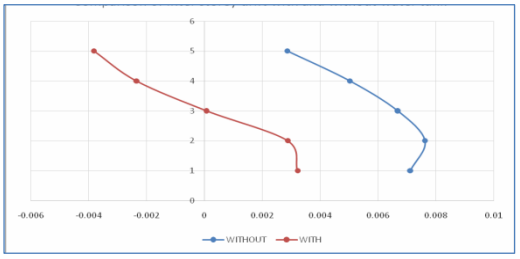


Figure 22: M5

- With And Without Roof Top Frame

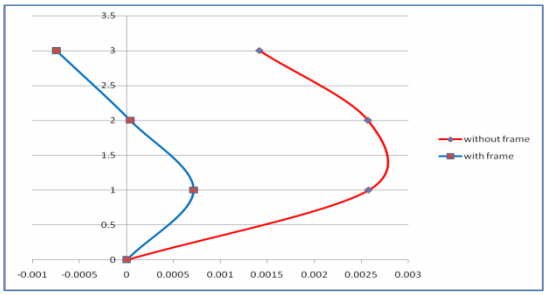


Figure 23: M3

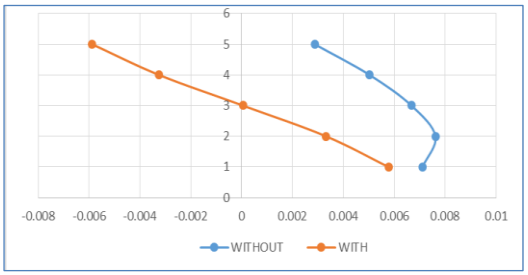


Figure 24: M5

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D. Deformation in the Structure using Ansys

The sloshing effect in the water tank is analysed using Ansys.Empty ,half filled and fully filled condition are analysed.

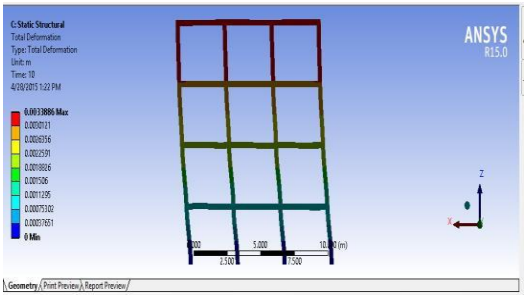


Fig. 25 Deformation in the structure without water tank on the top

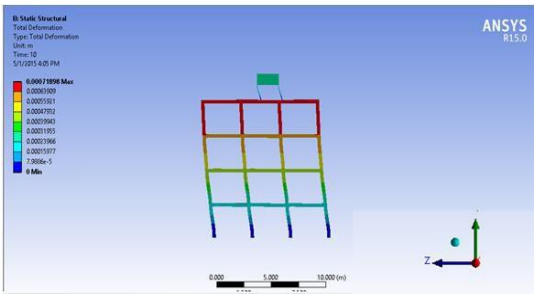


Fig. 26 Deformation in the structure with water tank(empty condition) on the top

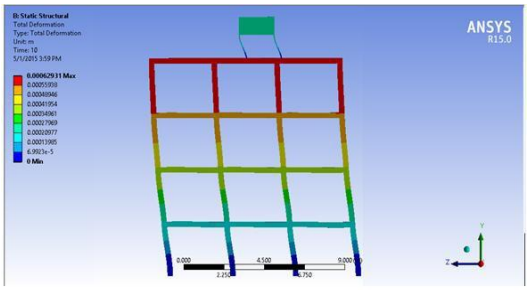


Fig. 27 Deformation in the structure with water tank(half filled condition) on the top

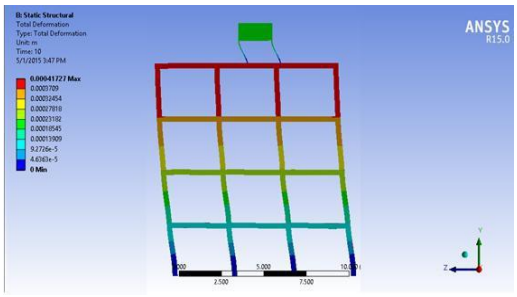


Fig. 28 Deformation in the structure with water tank(fully filled condition) on the top

CONCLUSION

The feasibility of implementing roof top frame and water tank as passive TMD was analysed and the following conclusions can be drawn from the study using SAP 2000,Ansys and the Newmark method as

1. If the roof top frame and water tank is tuned properly it can reduce the peak response of structures subjected to seismic forces.
2. Inter-storey drift reduces
    i. 83% reduction with roof top frame
    ii. 82.5% reduction with water tank
3. Displacement of the structure reduces. Percentage reduction in displacement is shown below.
    i. When roof top frame is placed on the top = 63%
    ii. When water tank is placed on the top
    - Empty condition = 74.1%

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- Half filled condition = 75.2%
- Fully filled condition = 88.3%

REFERENCES

[1] K. Krishne Gowda And K. K. Kiran (2013), "Earthquake Resistance Of Structures Using Dampers - A Review", International Journal Of Advanced Structures And Geotechnical Engineering Issn 2319-5347, Vol. 02, No. 01.

[2] Soong Tt, Constantinou Mc (1994)," Passive And Active Structural Vibration Control In Civil Engineering", Isbn 978-3-7091-3012-4, New York

[3] Chi-Chang Lin, Chih-Ming Hu, Jer-Fu Wang and Rong-Yu Hu (1994), "Passive Control Effectiveness Of Passive Tuned Mass Dampers", Journal Of Chinese Institute Of Engineers, Vol 17, No.3, Pp. 367-376.

[4] S.S.Patil,S. B.Javheri, C.G.Konapure (2012), "Effectiveness Of Multiple Tuned Mass Dampers", International Journal Of Engineering And Innovative Technology (Ijeit) Volume 1, Issue 6, 78-83.

[5] Villaverde, R (2000), "Implementation Study Of Aseismic Roof Isolation System In 13-Storey Building", Journal Of Seismology And Earthquake Engineering, Vol. 2, Pp. 17-27.

[6] Nicola Nistico, Eleftheria E, Charis J Gantes (2014), "Roof Isolation With Tuned Mass-Based Systems And Application To A Prefabricated Building", Arab J Sci Eng 40:431-442.

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