Analysis of Irregular High Raised RCC Buildings by Using Tuned Mass Damping System

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Abstract*— *Tall buildings are indispensable in urban areas due to high cost of land, shortage of open spaces and scarcity of lands. The tall buildings are in general highly vulnerable to lateral forces arising out of cyclones and earthquakes. Designing the structures to withstand these occasional lateral forces is very expensive; hence it is not always desirable.

The measures to reduce the lateral forces are by way of reducing the weight of the structure and by reducing the exposed faces to thwart wind. However the architectural requirement and the utility of the building have to be honored at all times by the structural designer.

Though the technique of Tuned mass damping (TMD) is very well appreciated, the mathematical implications involved in finding the magnitude of mass, stiffness and damping of the TMD is highly intricate and suitable TMD system for a given building structure, which shall remain an integral part of the structure itself, placed on top of the building yet serves the purpose of reducing the earthquake effects on buildings.

The TMD methodology adopted for three irregular R.C. framed models having + (Plus)-shape , C-shape and T-shape in plan. This apart the device shall find its utility for all zones of seismic activity and ground/structural conditions and introduces various structural motion control methodologies with focus on tuned mass damping systems. The control properties and some aspects of TMD parameters are outlined.

ETABS software is used for dynamic analysis of various shapes of the framed buildings.

Keywords*— *Irregular High Raised RCC Buildings, Tuned Mass Damping System, Dynamic analysis.

I. INTRODUCTION

To perform better analysis of Irregular High Raised RCC Buildings the Tuned mass damper (TMD) system is applied which involves in positioning of a structure over an existing building to reduce the effects of dynamic loads. The TMD will have a certain mass, damping and stiffness. Tuning of TMD refers to suitably adjust in the values of mass, damping and stiffness to reduce the dynamic effects of given building subjected to dynamic forces/displacements. The TMD concept was first applied by Frahm in 1909 to re rolling motion of ships as well as ship hull vibrations. However not much of headway was made in possible is the field of TMD due to absence of rational theories of structural dynamics. At present with the advent of computer aided packages it is possible to apply reasonably valid dynamic theories coupled with parametric studies to assess the contribution of the TMD in reducing the effects of dynamic loads on the structure. This project presents the effectiveness of tuned mass dampers work for in reducing the seismic response of structure, duly ensuring its structural stability when subjected to earth quake loads. The concept of TMD is still not understood for real time structures, more so when damping is involved. In this context, a brief insight into the concept of TMD is presented.

Tuned mass damper (TMD) which is a passive energy absorbing device consisting of a mass, a spring and a damper. 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. There are many types of TMD systems which can be adopted for different kinds of structural systems. In this present work it is proposed to develop a TMD system which is easily constructible economically viable and easily maintainable.

II. ANALYSIS

2.1. Problem Definition

In present case study three irregular R.C. framed models with Fifteen (15) storey's were taken up and modeled using ETABS package.. The models are + (plus) -shape in plan, C-shape and the other is T-shape (from "Fig.1 to 3"). The + (Plus) - shaped building has plan dimensions of 100.0 m (25 bays of 4.0 m each) x 100.0 m (25 bays of 4.0 m each).The C-shaped building has plan dimensions of 68.0 m (17 bays of 4.0 m each) x 52.0 m (13 bays of 4.0 m each). The T-shaped building has plan dimensions of 100.0 m (25 bays of 4.0 m each) x 60.0 m (15 bays of 4.0 m each). The height of each storey is 3.5 m. The tuned

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mass damping device was placed at the centre of the grid in plan. The effect of TMD was evaluated by performing response spectrum analysis of all the models. 5% damping was considered. SRSS was used for adding the modal responses. The TMD was first analyzed separately and its natural frequency was obtained. Keeping the TMD so designed on top of the building, the structure was once again analyzed using dynamic analysis and the time period, displacements at the corresponding locations was compared with the results obtained without TMD to illustrate the utility of the study.

2.2. Dimensions of the structural elements

Size of beams = 0.30 m x 0.50 m
Size of column = 0.30 m x 0.75 m
Thickness of slab = 0.125m
Thickness of outer walls = 0.23 m
Thickness of inner walls = 0.115 m
Number of water tanks = 3

2.3. Material Properties and Loads

Grade of concrete ,fck = M30
Grade of reinforcement, fy = Fe415
Specific weight of RCC = 25 KN/m3
Specific weight of brick = 20 KN/m3
Young's Modulus of Concrete = 5000√fck = 27386 x 103 KN/m2
Seismic zone = IV (Table2, IS1893(part1) :2002)
Type of soil = Medium
Response spectra = 3 as per IS 1893(Part1):2002
Imposed load = 3 KN/m (assumed to act uniformly on all floors)

2.4. Stiffness calculations

Moment of inertia of column (I) = 0.010546 m4
Stiffness of each column (K) = 12EI/L3 = (12 x 27386 x 103x 0.010546)/(3.53)
= 80833.90 KN/m
Total Stiffness = no. of columns x stiffness of each column = 126 x 80833.90
= 10185071.40 KN/m
Stiffness of columns of water tank = 5/100 x 10185071.40 = 509253.57 KN/m
Stiffness of each column of water tank = 1 /12 x 509253.57 = 42437.80 KN/m

2.5. Calculation of depth of column of water tank

Let d_1, b_1 be the depth and width of water tank
Stiffness of each column of water tank = $12EI_1/ L^3$ = 42437.80 ; I_1 = 5.5366 x 10-3 m^4
Assuming width of column of water tank (b_1) = 0.30 m
$I_1 = b_1 x(d_1)^3/12$ = 5.5366 x 10-3 m^4 ; d_1 = 0.60 m
Size of each column of water tank = 0.30 m x 0.60 m
Total weight calculation at each floor:
Weight of slab = thickness of slab in m x area of slab x unit wt. of concrete = [(60 x 20) + (20 x 20)] x 0.125 x 25 = 5000 KN
Weight of Beams = c/s area of beam x total length x unit wt. of concrete = [(60 x 6) + (20 x 27)] x 0.3 x 0.50 x 25 x 15 = 50625 KN
Weight of Columns = c/s area of column x height x no of columns x unit wt. of concrete = 0.30 x 0.75 x 3.5 x 126 x 25 = 2480.625 KN
Weight of outer walls = [(60 x 1) + (20 x3)+(40 x 2)] x 0.23 x 3.5 x 20 = 3220 KN
Weight of inner walls = [(60 x 4) + (20 x 20)] x 0.115 x 3.5 x 20 x 15 = 77280 KN
Imposed load = 3 x 20 x 20 x 4 = 4800 KN
Total weight at each floor = weight of (slab + beams + columns + outer walls + inner walls + imposed load) = 143405.625 KN
Weight of 3 water tanks with columns = 5/100 x 143405.625 = 7170.28 KN
Weight of each water tanks with columns = 7170.28 / 3 = 2390.10 KN
Weight of 4 columns of water tank = 4 x 0.30 x 0.6 x 3.5 x 25 = 63 KN
Weight of water tank = 2390.10 – 63 = 2327.10 KN

III. RESULTS AND DISCUSSION

3.1. For the 15 storey building + (Plus)-shape in plan

The natural time period of the building without TMD was found to be 2.6827 sec. The natural time period of the building with TMD placed on top of the building was found to be 1.5043 sec. The natural time period of the building got reduced by 43.92% and When shear walls were placed along with TMD the natural time period of the building was found to be 0.4905 sec. The time period got reduced further by 33.91% (from Table 1). The building was subjected response spectrum of IS 1893:2002. The base shear of the building without and with TMD was 5675.00 KN and 2945.00 KN respectively. The base shear of the building got reduced by 51.89% when the TMD was placed on top of the building. The base shear of the building when shear walls were provided along with TMD was found to be 2315.00 KN. The base shear got reduced further by 26.71%. The roof displacements for the response spectrum case for the building without TMD, with TMD and shear walls were found to be 47 mm, 10 mm and 0.13 mm respectively (from "Fig" 4 to 8). The building was subjected to time history of random ground acceleration. The response of the structure was plotted with respect to time (from "Fig" 9 to 10).

3.2. For the 15 storey building C-shape in plan

The natural time period of the building without TMD was found to be 2.58 sec. The natural time period of the building with TMD placed on top of the building was found to be 1.49 sec. The natural time period of the building got reduced by 43.92% and When shear walls

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were placed along with TMD the natural time period of the building was found to be 0.594 sec. The time period got reduced further by 33.90% (from Table 2). The building was subjected response spectrum of IS 1893:2002. The base shear of the building without and with TMD was 5980.00 KN and 2975 KN respectively. The base shear of the building got reduced by 49.75% when the TMD was placed on top of the building. The base shear of the building when shear walls were provided along with TMD was found to be 2245.00 KN. The base shear got reduced further by 25.72%. The roof displacements for the response spectrum case for the building without TMD, with TMD and shear walls were found to be 54 mm, 12 mm and 0.12 mm respectively (from "Fig" 11 to 15).The building was subjected to time history of random ground acceleration. The response of the structure was plotted with respect to time (from "Fig" 16 to 17).

3.3. For the 15 storey building T-shape in plan

The natural time period of the building without TMD was found to be 2.657 sec. The natural time period of the building with TMD placed on top of the building was found to be 1.504 sec. The natural time period of the building got reduced by 52.48% and When shear walls were placed along with TMD the natural time period of the building was found to be 0.5626 sec. The time period got reduced further by 35.13% (from Table 3). The building was subjected response spectrum of IS 1893:2002. The base shear of the building without and with TMD was 5325.00 KN and 2845.00 KN respectively. The base shear of the building got reduced by 53.42% when the TMD was placed on top of the building. The base shear of the building when shear walls were provided along with TMD was found to be 2543.00 kN. The base shear got reduced further by 37.78%. The roof displacements for the response spectrum case for the building without TMD, with TMD and shear walls were found to be 50 mm, 15 mm and 0.15 mm respectively (from "Fig. 18 to 22 ").The building was subjected to time history of random ground acceleration. The response of the structure was plotted with respect to time (from "Fig. 23 to 24").

IV. FIGURES AND TABLES

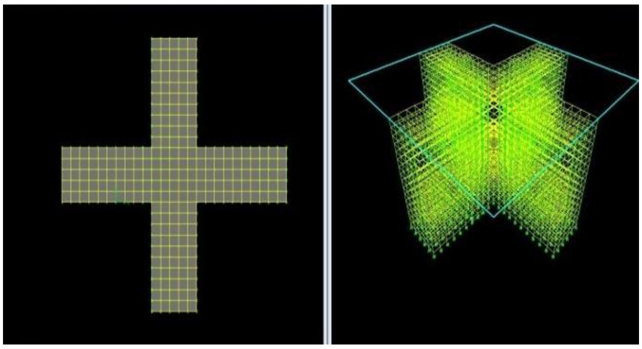

Fig. 1: Building + (Plus) - Shape in plan

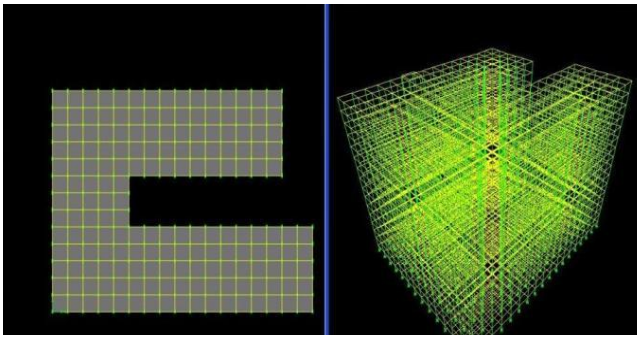

Fig.2: Building C - Shape in plan

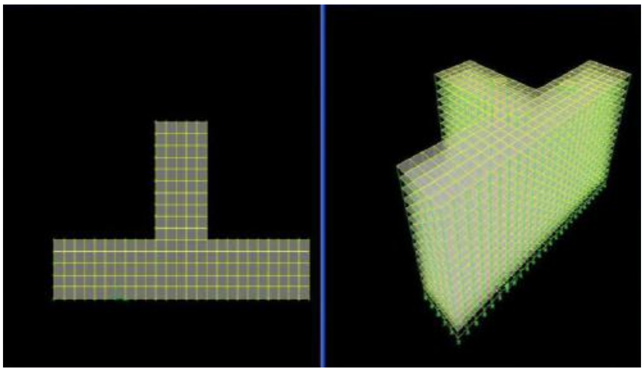

Fig. 3: Building T - Shape in plan

Table.1: Time Period for '+'(Plus)-Shape Building

Mode No.	Time period witho	Time perio d	Percentage decrease in time	Time period with shear	Percentage decrease in
1	2.683	1.50	56.08	0.44	83.63
2	2.263	1.43	63.25	0.37	83.76
3	1.897	1.35	71.54	0.39	79.44
4	0.890	1.28	69.46	0.30	66.68
5	0.620	1.20	51.49	0.33	47.51
6	0.530	1.12	47.09	0.28	47.85
7	0.378	1.04	36.24	0.36	48.97
8	0.352	0.96	36.60	0.39	75.12
9	0.224	0.87	25.56	0.40	83.45
10	0.185	0.78	23.51	0.30	84.22

% decrease in time period was calculated w.r.t. time period.

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Table.2: Time Period for 'C'-Shape Building

Mode No.	Time period without TMD (sec)	Time period with TMD (sec)	Percentage decrease in time period (%)	Time period with shear wall and TMD(sec)	Percentage decrease in time period (%)
1	2.58	1.50	58.31	0.42	83.84
2	2.26	1.43	63.25	0.37	83.76
3	1.90	1.36	71.54	0.28	85.00
4	0.89	1.28	69.46	0.40	55.62
5	0.62	1.20	51.49	0.43	31.45
6	0.53	1.13	47.09	0.42	53.16
7	0.38	1.04	36.24	0.48	65.26
8	0.35	0.96	36.60	0.50	78.24
9	0.22	0.88	25.56	0.30	82.19
10	0.19	0.79	23.51	0.32	82.33

% decrease in time period was calculated w.r.t. time period.

Table.3: Time Period for T-Shape Building

Mode No.	Time period without TMD (sec)	Time period with TMD	Percentage decrease in time period (%)	Time period with shear wall and TMD(sec)	Percentage decrease in time period (%)
1	2.66	1.50	56.60	0.43	83.62
2	2.13	1.43	67.21	0.33	83.75
3	1.94	1.35	70.03	0.30	79.43
4	0.88	1.28	68.86	0.40	66.67
5	0.69	1.20	57.59	0.42	47.52
6	0.63	1.12	56.13	0.39	47.84
7	0.52	1.04	50.06	0.47	48.98
8	0.40	0.96	41.12	0.43	75.14
9	0.37	0.87	42.37	0.39	83.47
10	0.36	0.78	45.75	0.37	84.21

% decrease in time period was calculated w.r.t. time period.

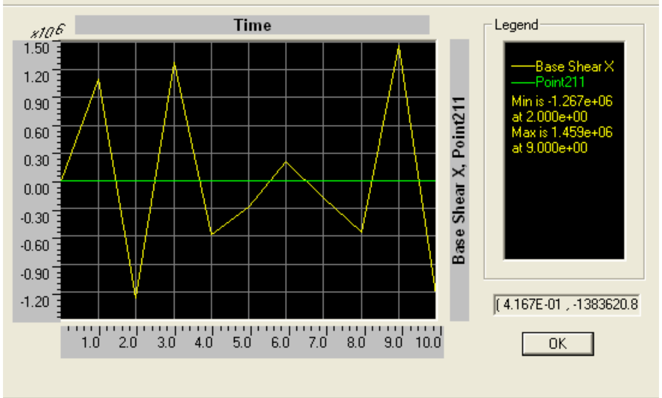

Fig.4: Displacement (m) vs Time(sec)-without TMD for Building + (Plus) - Shape in plan

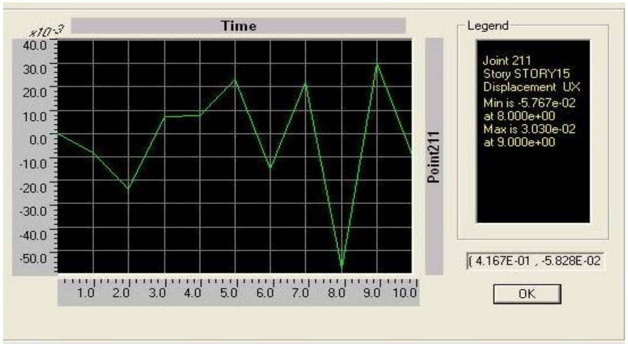

Fig.5: Displacement (m) vs Time(sec)-with TMD for Building + (Plus) - Shape in plan

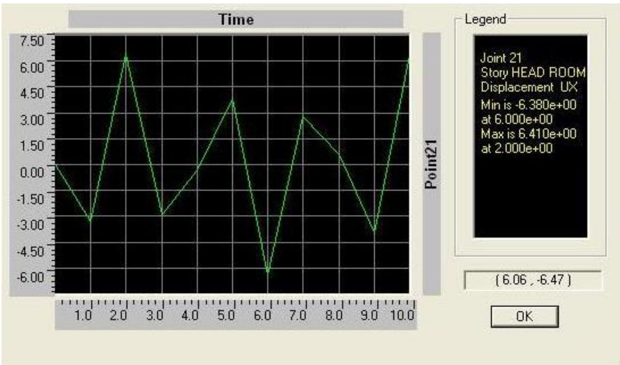

Fig.6: Displacement (m) vs Time(sec)-with TMD and shear walls for Building + (Plus) - Shape in plan

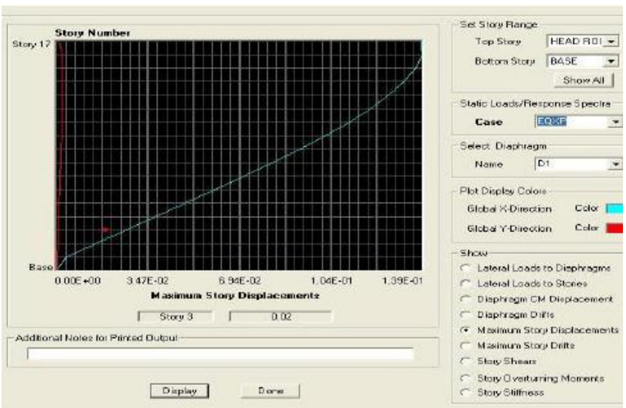

Fig.7: Storey number Vs storey displacement (m) -without TMD for Building + (Plus) - Shape in plan

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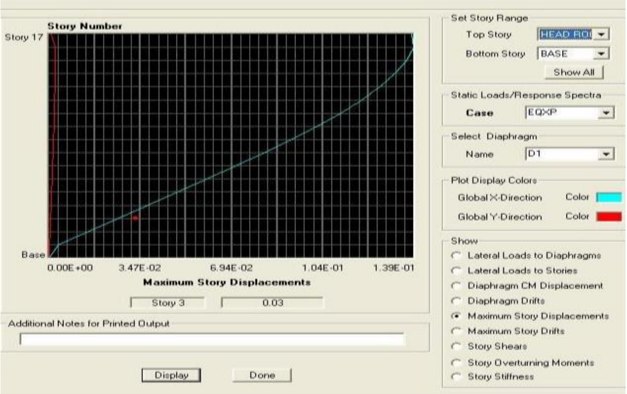

Fig.8: Storey number Vs storey displacement (m) -with TMD for Building + (Plus) - Shape in plan

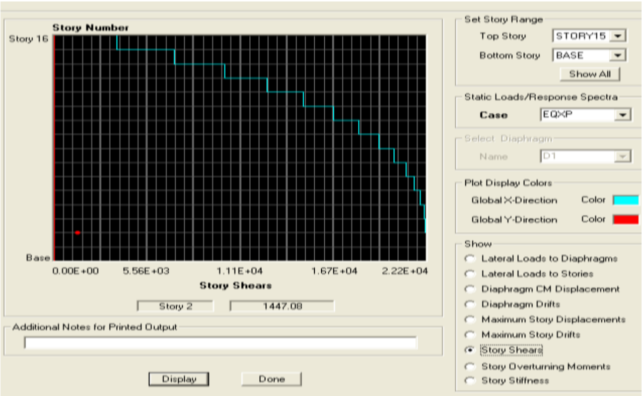

Fig.9: Storey number vs. story shear (KN) –without TMD for Building + (Plus) - Shape in plan

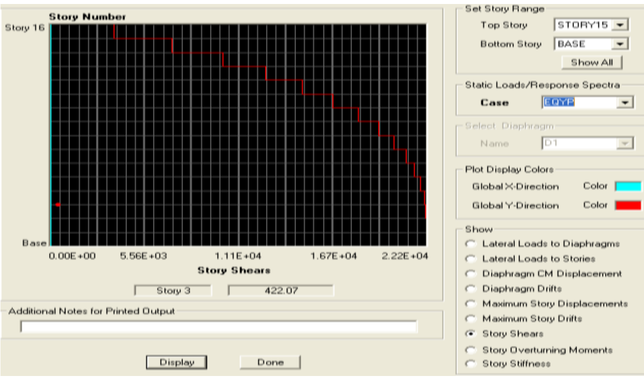

Fig.10: Storey number vs. story shear (KN) –with TMD for Building + (Plus) - Shape in plan

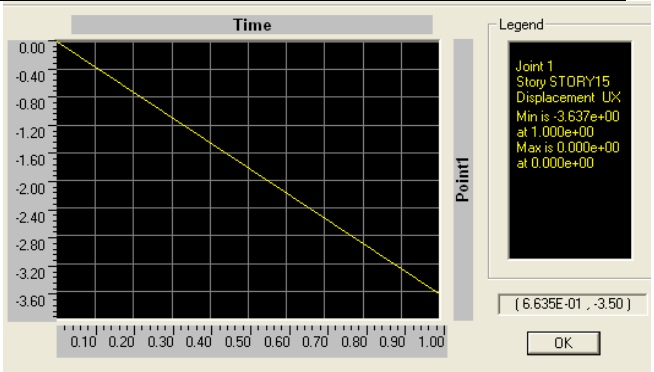

Fig.11: Displacement (m) vs Time(sec)-without TMD for Building C-Shape - Shape in plan

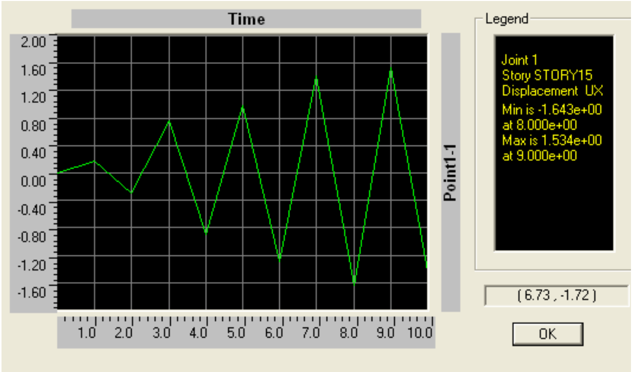

Fig.12: Displacement (m) vs Time(sec)-with TMD for Building C-Shape - Shape in plan

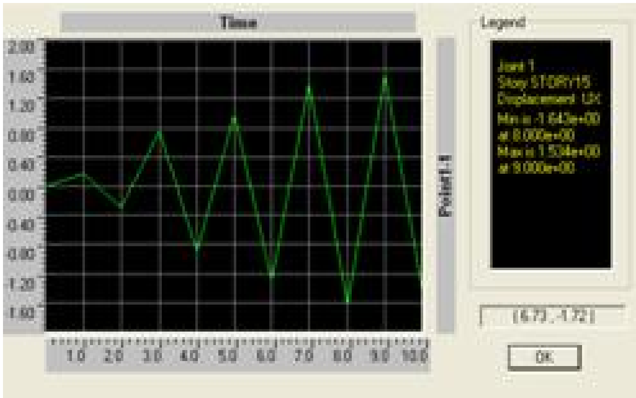

Fig.13: Displacement (m) vs. Time(sec) –with TMD and Shear wall for Building C-Shape - Shape in plan

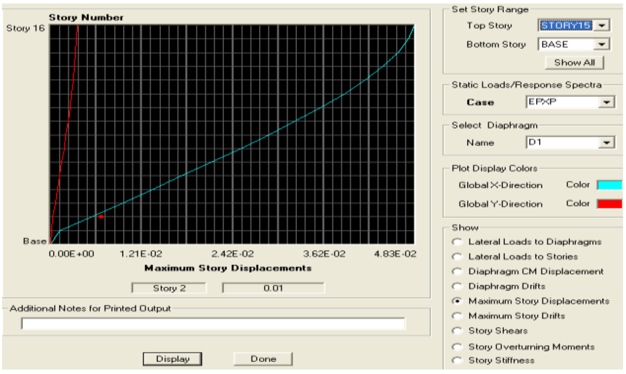

Fig.14: Storey number Vs storey displacement (m) -without TMD for Building C-Shape - Shape in plan

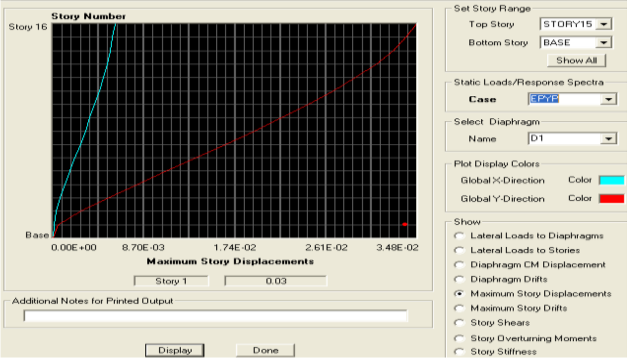

Fig. 15: Storey number Vs storey displacement (m) -with TMD for Building C-Shape - Shape in plan

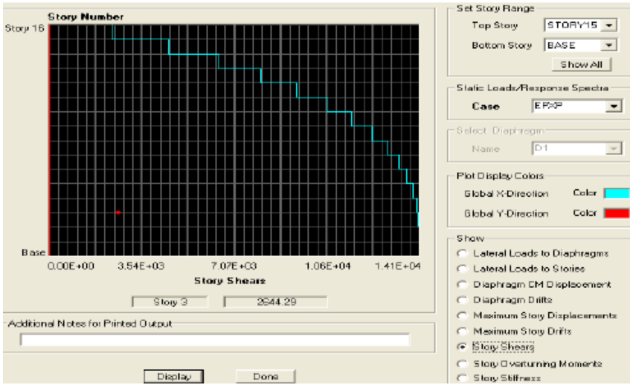

Fig. 16: Storey number vs. story shear (KN) –without TMD for Building C-Shape - Shape in plan

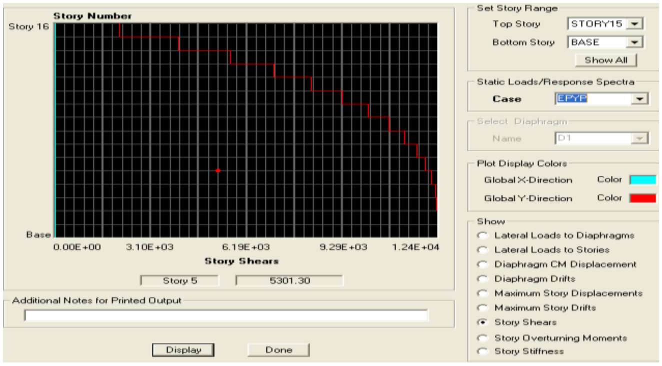

Fig.17: Storey number vs. story shear (KN) –with TMD for Building C-Shape - Shape in plan

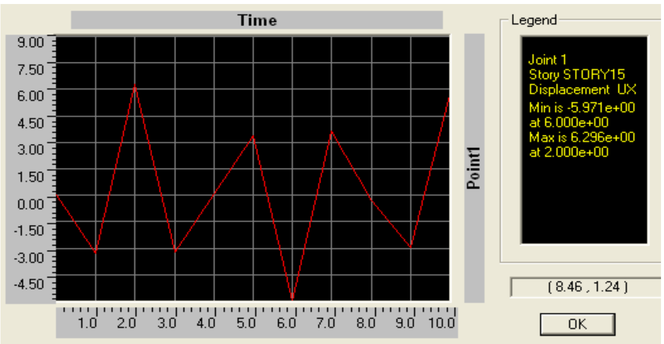

Fig. 18: Displacement (m) vs Time(sec)-without TMD for Building T-Shape - Shape in plan

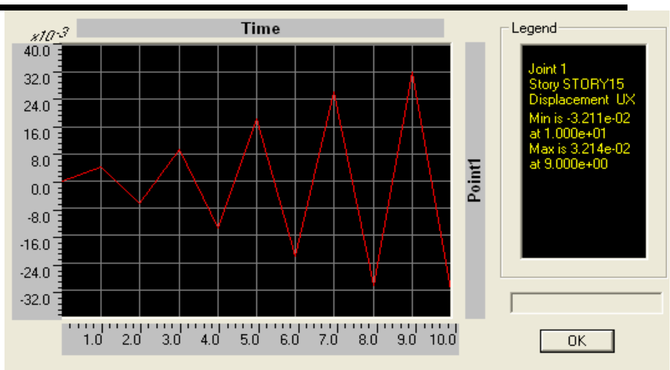

Fig. 19: Displacement (m) vs Time(sec)-with TMD for Building T-Shape - Shape in plan

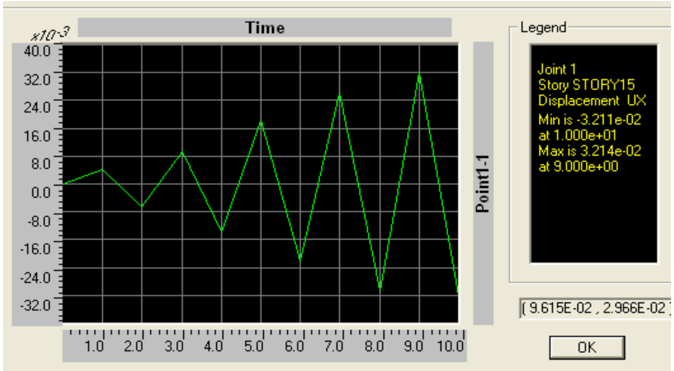

Fig. 20: Displacement (m) vs. Time(sec) –with TMD and Shear wall for Building T-Shape - Shape in plan

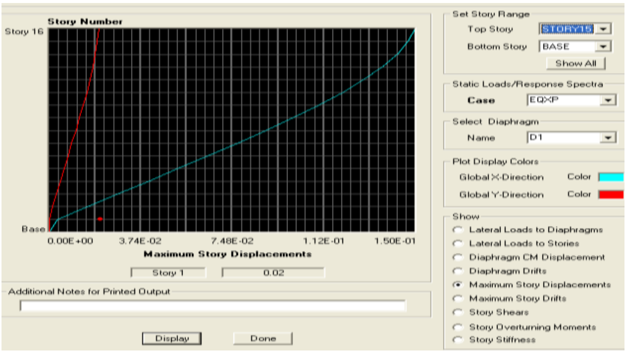

Fig. 21: Storey number Vs storey displacement (m) -without TMD for Building T-Shape - Shape in plan

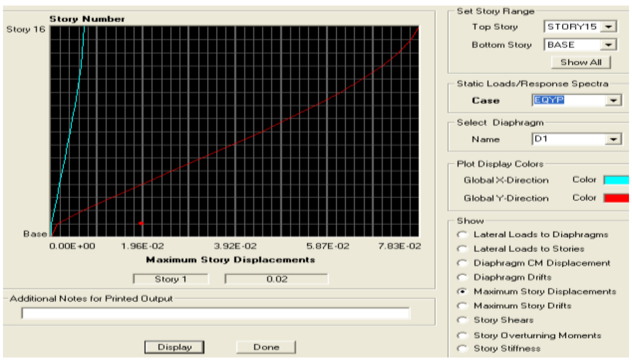

Fig.22: Storey number Vs storey displacement (m) -with TMD for Building T-Shape - Shape in plan

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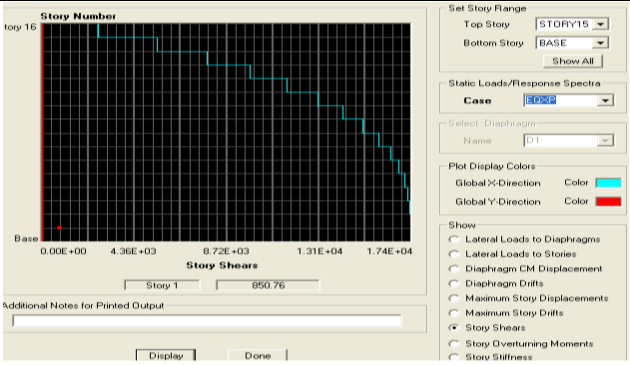

Fig.23: Storey number vs. story shear (KN) –without TMD for Building T-Shape - Shape in plan

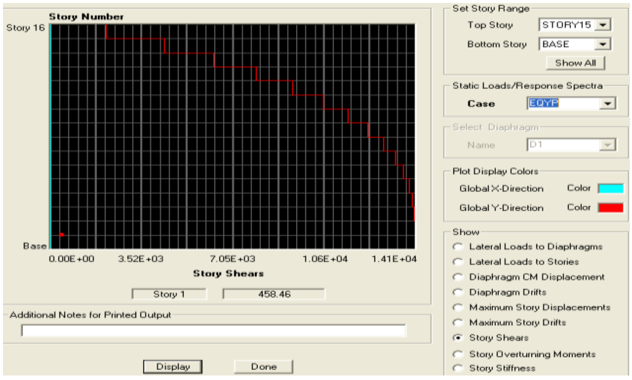

Fig.24: Storey number vs. story shear (KN) –with TMD for Building T-Shape - Shape in plan

V. CONCLUSION

- The elevated R.C. water tank placed on top of the building with hinged supports is found to be an effective TMD mechanism.
- The effectiveness of TMD (water tank) was noticed when its mass was approximately 5% of the total mass of one floor.
- The sectional dimensions- of the TMD were so proportioned that its frequency matches with the frequency of the structure.
- The introduction of shear walls did not significantly influence the functioning of the TMD's.
- The methodology adopted in the present study may be used to design a suitable TMD for each type of R.C. building structure regular or otherwise.

SCOPE FOR FUTURE WORK

- Future study may be with the effect of TMD made of steel on framed structures.
- The effect of TMD can be validated with experimental studies.

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