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Analysis of Vibration Control Systems using Water Tank as a Liquid Damper in High Rise Buildings

Ravi S Shiranal[1] Dr. M.B. Patil[2]
[1]M.Tech. Student [2]Professor
[1,2]Department of Civil Engineering
[1,2]Govt. S.K.S.J.T Institute under VTU, Bengaluru, India

Abstract— Current trends in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value. This increases failure possibilities and also problems from serviceability point of view. Now-a-days several techniques are available to minimize the vibration of the structure, out of the several techniques available for vibration control, concept of using TLD is a newer one. In the present work, the structure without and with tuned liquid damper buildings of G+10, G+20, and G+30 storey height structural models are considered. The vulnerability of without and with tuned liquid damper structures under various load conditions are studied and for the analysis seismic region 3 with different soil types are considered. Analysis is carried out for different heights to study the seismic behavior of structure without and with tuned liquid damper building analysis is for different heights to see what changes going to take place if the height of both structural systems varies. Therefore, the characteristics of the seismic behavior of both structural systems suggests the additional measures for guiding the conception and design of these structures in seismic regions and also to improve the performance of these structural systems under seismic loading. Present work provides a good source of information on the parameters lateral displacement, storey drift, base shear, and time period. The analysis is carried out by E-Tabs software.

Key words: Vibration Control Systems, High Rise Buildings

I. INTRODUCTION

Vibration in buildings can be caused by many different external sources, including industrial, construction and transportation activities. The vibration may be continuous, impulsive or intermittent.

Vibration in buildings also occur from internal sources, such as a road development forming part of the building or mechanical vibration sources in buildings. Vibration and its associated effects are usually classified as continuous, impulsive or intermittent as follows.

Modern tall buildings have become relatively light and flexible with the plentiful application of high strength materials in civil engineering making the structure collapse early or exceed the comport limitation at the action of dynamic loads such as seismic and wind. The structure vibration control in the buildings can be a successful method of mitigating the effects of these dynamic responses.

All vibration control systems should improve the buildings function after an earthquake as well as to enhance the seismic performance or performance in day to day vibrations of structural members.

A. Types Vibration Damping Devices

The three types of damping devices that are commonly used is as mentioned below-

1) Simple Passive Dampers

Simple passive dampers, including viscous, friction and visco-elastic systems, dependent on a damper mounted between a vibrating structure and a stationary object to dissipate vibration energy as heat. As the two systems move relative to each other, the simple passive damper is stretched and compressed, reducing the vibrations of the structure by increasing its effecting damping.

2) Passive Control Devices

Work by fastening a mass block to a structural component via a spring. This system is set up so that, when the floor vibrates at a resonant frequency (which could be caused by dancing, for example), it induces analogous movement of the mass. Examples of Passive control device are Tuned Mass Dampers and Tuned Liquid Dampers etc.

3) Active Mass Damper

Active mass dampers, which are computer controlled and can also be configured to work without relying on the relative motion between the floor and a stationary object, were also considered. These systems, currently the subject of much research for controlling wind and earthquake induced vibrations, are a generally attractive solution to vibration problems because they are so effective.

Among passive control devices, tuned mass dampers and tuned liquid dampers have been widely employed for decreasing the wind and earthquake induced vibration of tall building structures.

4) Tuned Liquid Dampers

The tuned liquid is a passive mechanical damper design to suppress undesirable structural vibration through the liquid sloshing motion in a rigid tank. The vibration energy is dissipated by means of friction in the boundary layers of the fluid, contamination of the free surface and wave breaking. Water is most commonly used as a liquid for the tuned liquid damper, hence the words ‘water’ and ‘liquid’ are used interchangeably.

For analysis purposes, the water in rigid tank is classified as ‘deep’ or ‘shallow’. This specific classification is based on the ratio of the water depth to the wave length in the direction of motion. The damping mechanism in the water is developed primarily by the viscous action in the boundary layers near the bottom surface and the side walls of the tank and the sloshing motion of the free surface layer of the water. As a damper, deep water is limit in its damping capability because a large portion of the water does not participate in the damping mechanism. Shallow water maximizes the participation of the water in the damping action.

5) Tuned Liquid Column Dampers

Tuned liquid column dampers (TLCD) combine the effect of liquid motion in a tube, which results in a restoring force using the gravity effect of the liquid, and the damping effect caused by loss of hydraulic pressure.

Some advantages of TLCD are:

1) It can have any arbitrary shape which helps it to be fitted in an existing structure;
2) Its behavior is quite well understood.
3) The TLCD damping can be controlled by adjusting the orifice opening;
4) The TLCD frequency can be modified by adjusting the liquid column in the tube. A Double Tuned Liquid Column Damper (DTLCD) is made of two TLCDs in two directions of motion. Thereby DTLCD acts in more than one direction eliminating the limitation of regular unidirectional TLDC.

6) Tuned Sloshing Damper

A tuned sloshing damper (TSD) dissipates energy through the liquid boundary layer friction, the free surface contamination, and wave breaking. A TSD can act as a shallow or deep water damper. It is considered that waves in the range of ½>h/L>1/20 to 1/25 are shallow water waves, where h is water depth and L is wave length. Recent studies show that a ratio equal to or less than 0.15 introduces more amount of damping corresponding to more energy dissipation. Under high amplitude excitations, shallow water TSDs dissipate a large amount of energy due to its nonlinear behavior corresponding to wave breaking. On another hand, a linear behavior can be observed for the deep water case even under high excitations.

The liquid frequency plays an important role in the TLD behavior. Earlier experimental studies have shown that the optimum value of the liquid frequency is a value near the excitation frequency where the liquid is in resonance with the tank motion. Therefore, tuning the TLD frequency to the natural frequency of the structure will provide significant amount of energy dissipation. Mass ratio is another significant parameter that affects the behavior of TLD-structure system. It is shown that with a relatively small mass ratio for e.g. 4%, without contributing significantly to the overall inertia of the system, effective structural response reduction can be obtained.

II. OBJECTIVES OF PRESENT STUDY

The objectives of the study are:

- The objective of the work is to study the behavior of tuned liquid damper with different Water depths.
- To study and compare structure without TLD and structure with TLD, with different structure height for different combinations of static loading.
- To study the vulnerability of with and without TLD models considering different factor such as Storey drift, lateral displacement, time period and base shear for different combinations of dynamic loading with varied building height.
- To study and compare the response of structure without TLD and structure with TLD for different soil conditions in earthquake zone 3.

III. METHOD OF ANALYSIS

The Present Study Done For the Below Mentioned Analysis.

- Equivalent static analysis Method
- Response Spectrum method.

IV. PARAMETRIC STUDY

- In the present work, the structural models of without water tank structures and with water tank structures of 10, 20 and 30 story's are considered
- To develop 3D frame models of without and with water tank models, using E-Tabs software.
- Static and dynamic analysis is adopted to analyse these structural systems.
- Evaluating the results from analysis and compared the displacements, storey drift, base shear and time period on both the systems.

V. DATA CONSIDERED FOR MODELING

Building Properties	**Type of Structure**					
	Without Tank			**With Tank**		
Building	G+10	G+20	G+30	G+10	G+20	G+30
Building height (in m)	30	60	90	30	60	90
No of stories	10	20	30	10	20	30
Story height	3	3	3	3	3	3
Grade of concrete	M30	M30	M30	M30	M30	M30
Grade of steel	Fe415	Fe415	Fe415	Fe415	Fe415	Fe415
Size of beams (In mm)	300x 600	300x 600	300x 600	300x 600	300x600	300x 600
Size of columns (in mm)	600x600	600x1000	600x1200	600x600	600x1000	600x1200
Depth of slab (In mm)	175	175	175	175	175	175
Wall thickness (in mm)	NIL	NIL	NIL	230	230	230

Plan Dimension: 25m x 25m
Spacing between columns: 5m

A. Description for Loading

The loading on the building is considered as per following calculation:

Dead Loads:

Wall load with 200 mm thickness = 12.15 KN/ m
Floor finish = 1.5 KN/m$^{2.}$
Self-weight of building considered automatically by software
Live Loads: 2.5 KN/m^2
Earthquake forces Data: Earthquake load for the building has been calculated as per IS: 1893-2002

- Zone (Z) = lll
- Response Reduction Factor (RF) = 5
- Importance Factor (I) = 1.5
- Type of soil = hard, medium and soft
- Structure type = SMRF
- Damping Ratio (DM) = 0.05

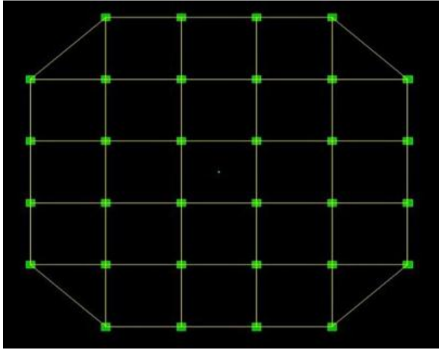

Fig. 1: Plan of the Analytical Model

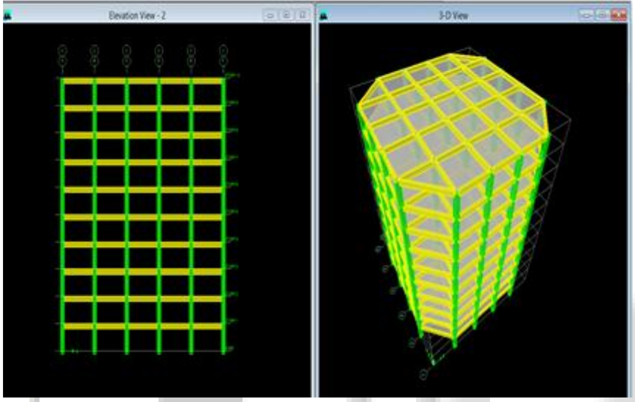

Fig. 2: Model 1: G+10 structure without tank

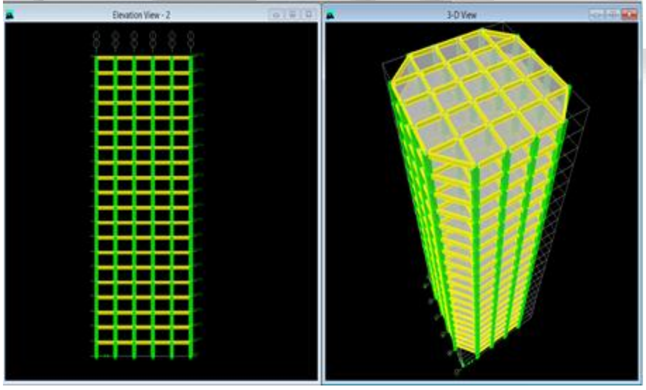

Fig. 3: Model 2: G+20 structure without tank

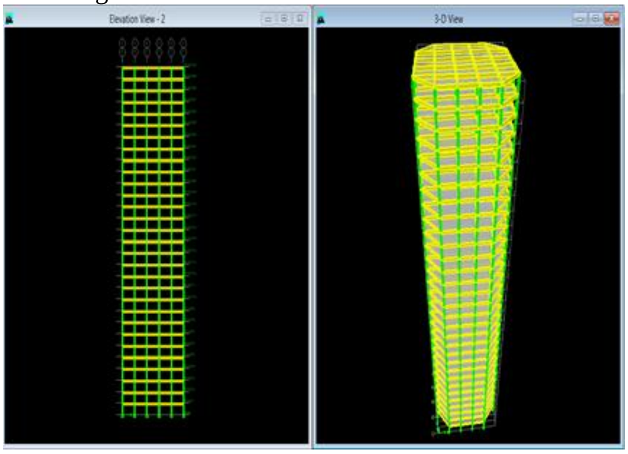

Fig. 4: Model 3: G+30 structure without tank

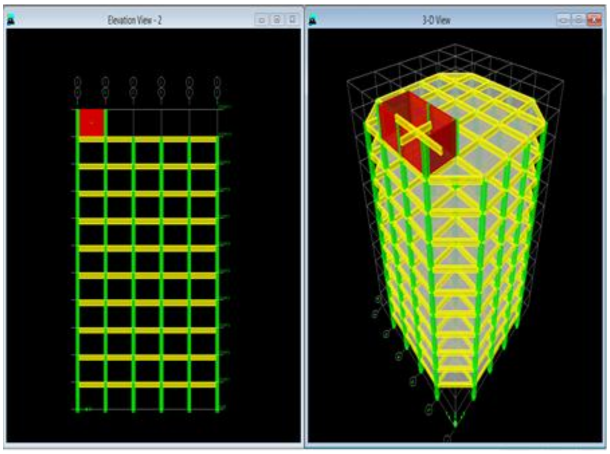

Fig 5: Model 4, 5, 6: G+10 structure with tank of water depth 1.5m, 1.8m and 2.1m

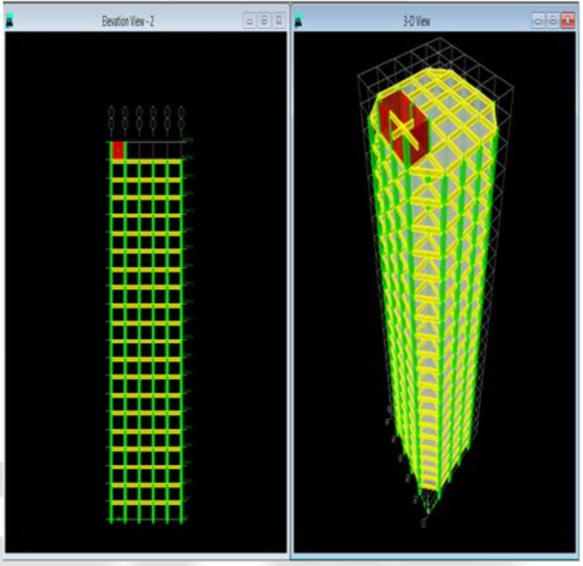

Fig 6: Model 7, 8, 9: G+20 structure with tank of water depth 1.5m, 1.8m and 2.1m

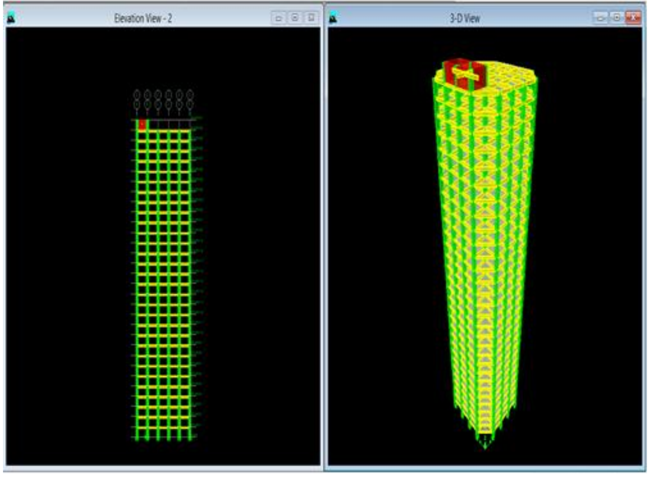

Fig 7: Model 10, 11, 12: G+30 structure with tank of water depth 1.5m, 1.8m and 2.1m

VI. RESULTS AND DISCUSSION

A. *Displacement*

ZONE	**Model Type**	**Displacement**		
ZONE 3		**Soil Type**		
		Hard	**Medium**	**Soft**
	MODEL 1	0.0184	0.025	0.027

	MODEL 2	0.0364	0.0548	0.0608
	MODEL 3	0.1125	0.1531	0.1880
	MODEL 4	0.006	0.0084	0.01
	MODEL 5	0.0073	0.0092	0.0118
	MODEL 6	0.0076	0.0116	0.0135
	MODEL 7	0.0058	0.0079	0.0098
	MODEL 8	0.0066	0.0094	0.0124
	MODEL 9	0.0077	0.0011	0.0136
	MODEL 10	0.0061	0.0084	0.0104
	MODEL 11	0.0069	0.0096	0.0123
	MODEL 12	0.008	0.0111	0.0137

Table 1: Maximum displacement for different types of models in x directions of static analysis

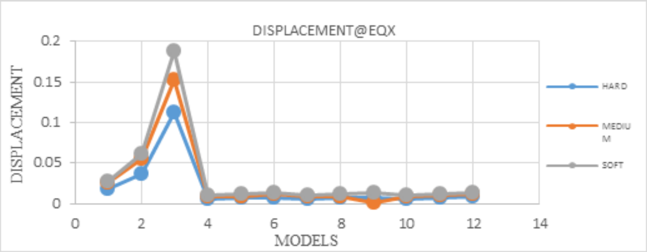

Fig. 8: Maximum displacement for different types of models in x directions of static analysis

ZONE	Model Type	Displacement		
		Soil Type		
		Hard	**Medium**	**Soft**
ZONE 3	MODEL 1	0.0184	0.025	0.027
	MODEL 2	0.0381	0.0548	0.0637
	MODEL 3	0.1864	0.2535	0.3113
	MODEL 4	0.0134	0.0182	0.0213
	MODEL 5	0.0136	0.0174	0.0213
	MODEL 6	0.0128	0.0185	0.0214
	MODEL 7	0.0225	0.0079	0.0214
	MODEL 8	0.0219	0.003	0.037
	MODEL 9	0.0219	0.0299	0.0391
	MODEL 10	0.0305	0.0417	0.0368
	MODEL 11	0.0303	0.0414	0.0511
	MODEL 12	0.0303	0.0411	0.0509

Table 2: maximum displacement for different types of models in y directions of static analysis

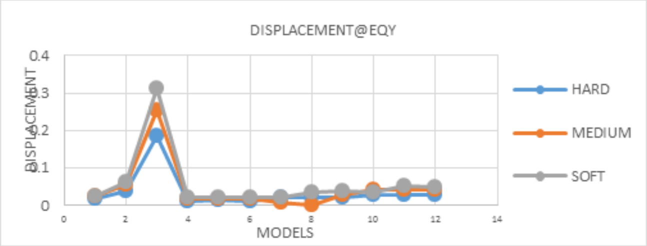

Fig 9: maximum displacement for different types of models in y directions of static analysis

ZONE	Model Type	Displacement		
		Soil Type		
		Hard	**Medium**	**Soft**
ZONE 3	MODEL 1	0.0127	0.0176	0.0189
	MODEL 2	0.0249	0.0378	0.0415
	MODEL 3	0.0754	0.1025	0.1259
	MODEL 4	0.0032	0.0045	0.0059
	MODEL 5	0.004	0.0057	0.0074
	MODEL 6	0.0048	0.0068	0.0088
	MODEL 7	0.0024	0.0033	0.0041
	MODEL 8	0.0029	0.0043	0.0056
	MODEL 9	0.0037	0.0054	0.0067
	MODEL 10	0.002	0.0028	0.0035
	MODEL 11	0.0025	0.0036	0.0045
	MODEL 12	0.0031	0.0045	0.0056

Table 3: maximum displacement for different types of models in x directions of dynamic analysis

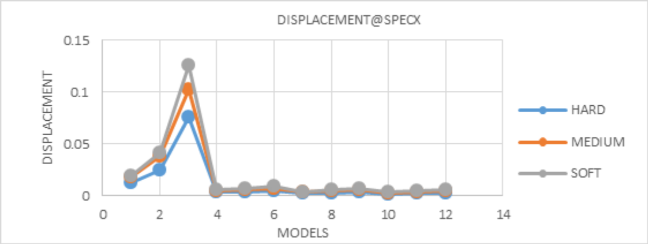

Fig 10: Maximum displacement for different types of models in x directions of dynamic analysis

ZONE	Model Type	Displacement		
		Soil Type		
		HARD	MEDIUM	SOFT
ZONE 3	MODEL 1	0.0127	0.0176	0.0189
	MODEL 2	0.0264	0.0378	0.0442
	MODEL 3	0.127	0.1728	0.2122
	MODEL 4	0.0081	0.011	0.0135
	MODEL 5	0.0083	0.0111	0.0137
	MODEL 6	0.0083	0.0112	0.0138
	MODEL 7	0.0138	0.0183	0.0225
	MODEL 8	0.0134	0.0183	0.024
	MODEL 9	0.0133	0.0183	0.0225
	MODEL 10	0.0185	0.0254	0.0312
	MODEL 11	0.0184	0.0252	0.0317
	MODEL 12	0.0184	0.0252	0.0311

Table 4: maximum displacement for different types of models in y directions of dynamic analysis

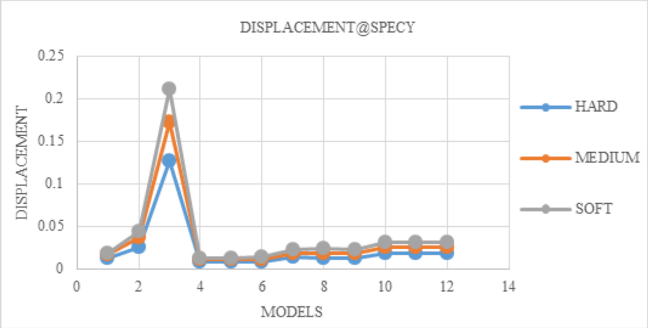

Fig 11: Maximum displacement for different types of models in y directions of dynamic analysis

B. Base Shear

ZONE	Model Type	Model	Base Shear		
			Soil Type		
			Hard	**Medium**	**Soft**
ZONE 3	MODEL 1	1	1978.62	2690.93	3243.25
	MODEL 2	2	2244.99	3052.51	3748.3
	MODEL 3	3	2158.06	2934.96	3603.95
	MODEL 4	4	1518.55	1721.25	2165.06

	MODEL 5	5	1389.71	1779.55	2242.38
	MODEL 6	6	1396.73	1977.89	2318.5
	MODEL 7	7	1479.38	1979.97	2411.62
	MODEL 8	8	1512.21	2027.57	2611.47
	MODEL 9	9	1550.91	2077.03	2525.99
	MODEL 10	10	1506.26	2009.52	2445.9
	MODEL 11	11	1544.41	2052.6	2446.66
	MODEL 12	12	1575.29	2093.67	2535.18

Table 5: Design base shear for different types of models in x directions of static analysis

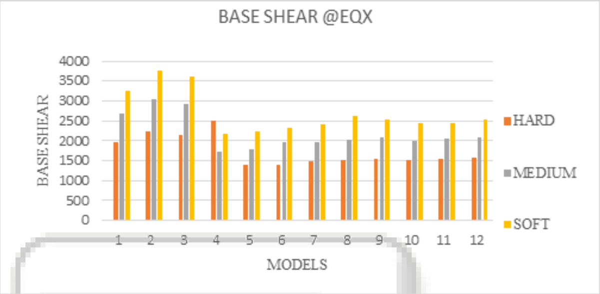

Fig 12: Design base shear for different types of models in x directions of static analysis

ZONE	Model Type	Model	Base Shear		
			Soil Type		
			Hard	Medium	Soft
ZONE 3	MODEL 1	1	1978.62	2690.93	3243.25
	MODEL 2	2	2099.43	2855.22	3506.04
	MODEL 3	3	2158.06	2934.96	3603.95
	MODEL 4	4	1798.79	2045.66	2566.63
	MODEL 5	5	1613.71	2040.88	2560.44
	MODEL 6	6	1535.15	2208.63	2561.46
	MODEL 7	7	1522.4	2062.03	2532.85
	MODEL 8	8	1520.51	2063.16	2680.46
	MODEL 9	9	1519.53	2061.10	2527.63
	MODEL 10	10	1447.72	1962.19	2403.45
	MODEL 11	11	1448.56	1961.96	2428.13
	MODEL 12	12	1450.71	1962.95	2404.58

Table 6: Design base shear for different types of models in y directions of static analysis

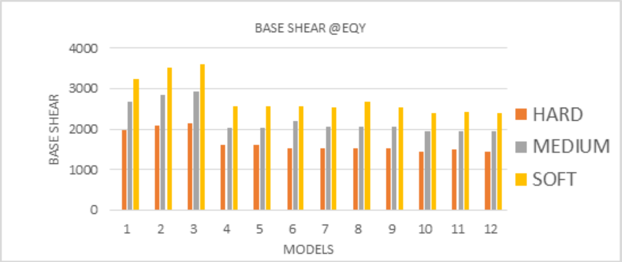

Fig 13: Design base shear for different types of models in y directions of static analysis

ZONE	Model Type	Model	Base Shear		
			Soil Type		
			Hard	Medium	Soft
	MODEL 1	1	1748.95	2301.99	2724.68
	MODEL 2	2	2003.95	2677.72	3253.04
	MODEL 3	3	1813.01	2465.69	3027.72
ZONE 3	MODEL 4	4	1561.82	1823.92	2526.68
	MODEL 5	5	1456.2	1922.05	2463.15
	MODEL 6	6	1512.59	1995.81	2421.4
	MODEL 7	7	1396.13	1998.95	2502.15
	MODEL 8	8	1362.34	2023.51	2531.53
	MODEL 9	9	1396.13	2023.86	2568.71
	MODEL 10	10	1380.81	2102.06	2591.83
	MODEL 11	11	1394.23	2105.63	2581.33
	MODEL 12	12	1396.28	2106.96	2596.05

Table 7: Design base shear for different types of models in x directions of dynamic analysis

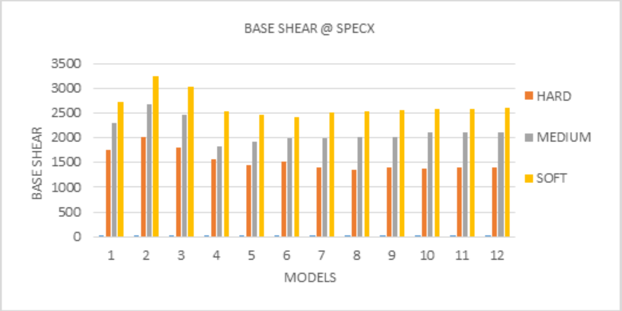

Fig 14: Design base shear for different types of models in x directions of dynamic analysis

ZONE	Model Type	Model	Base Shear		
			Soil Type		
			Hard	Medium	Soft
ZONE 3	MODEL 1	1	1748.95	2301.99	2724.68
	MODEL 2	2	1882.86	2535.61	3081.83
	MODEL	3	1794.4	2440.57	2996

	3		2		.56
	MODEL 4	4	1560.94	1715.95	2102.06
	MODEL 5	5	1343.63	1733.87	2122.18
	MODEL 6	6	1374.12	1755.27	2140.18
	MODEL 7	7	1396.93	1855.81	2234.79
	MODEL 8	8	1368.95	1856.08	2374.99
	MODEL 9	9	1398.54	1856.41	2233.01
	MODEL 10	10	1390.56	1845.89	2291.93
	MODEL 11	11	1394.23	1886.89	2281.33
	MODEL 12	12	1395.97	1889.48	2296.88

Table 8: Design base shear for different types of models in y directions of dynamic analysis

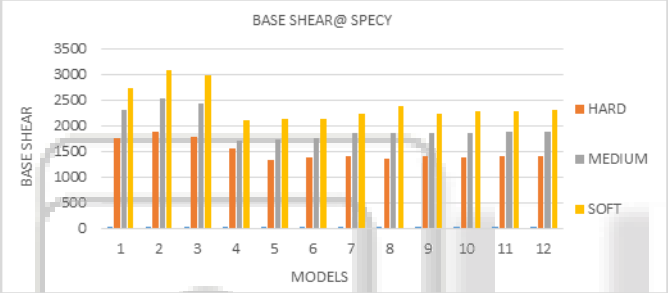

Fig 15: Design base shear for different types of models in y directions of dynamic analysis

C. *Time Period*

Model Type	Time Period (Sec)
MODEL 1	1.3924
MODEL 2	2.7905
MODEL 3	7.2774
MODEL 4	1.5712
MODEL 5	1.7748
MODEL 6	1.8667
MODEL 7	2.4809
MODEL 8	2.4821
MODEL 9	2.4835
MODEL 10	3.7572
MODEL 11	3.7582
MODEL 12	3.7592

Table 9: Fundamental natural time period for different types of models

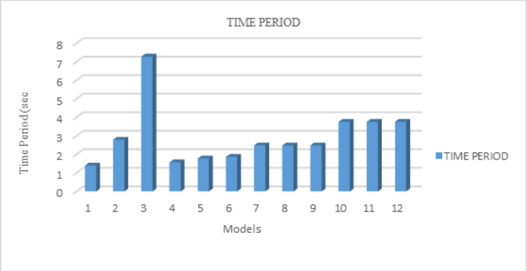

Fig 16: Fundamental natural time period for different types of models

D. *Storey Drift*

ZONE	MODEL TYPE	STOREY DRIFT		
		SOIL TYPE		
		HARD	MEDIUM	SOFT
ZONE 3	MODEL 1	0.000805	0.001095	0.001319
	MODEL 2	0.000796	0.001082	0.001329
	MODEL 3	0.001479	0.002012	0.002475
	MODEL 4	0.000743	0.000846	0.001051
	MODEL 5	0.000669	0.000804	0.001051
	MODEL 6	0.000628	0.000923	0.001054
	MODEL 7	0.000622	0.000842	0.001033
	MODEL 8	0.000623	0.000846	0.001098
	MODEL 9	0.000625	0.000849	0.001040
	MODEL 10	0.000630	0.000852	0.001043
	MODEL 11	0.000635	0.000857	0.001052
	MODEL 12	0.000639	0.000861	0.001053

Table 10: Maximum drift for different types of models in x directions of static analysis

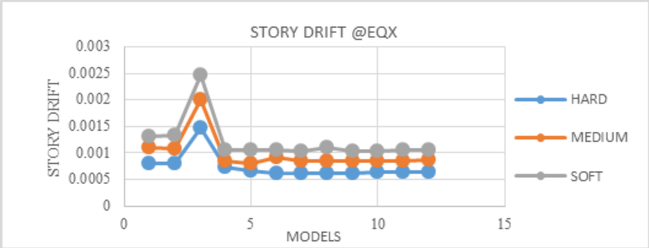

Fig 17: Maximum drift for different types of models in x directions of static analysis

ZONE	Model Type	Storey Drift		
		Soil Type		
		Hard	Medium	Soft
ZONE 3	MODEL 1	0.000805	0.001095	0.001319
	MODEL 2	0.000821	0.001117	0.001371
	MODEL 3	0.002491	0.003387	0.004159
	MODEL 4	0.000885	0.001005	0.001256
	MODEL 5	0.000786	0.000983	0.001219
	MODEL 6	0.000724	0.001064	0.001208
	MODEL 7	0.000779	0.001050	0.001299
	MODEL 8	0.000766	0.001052	0.001369
	MODEL 9	0.000769	0.001046	0.001283
	MODEL 10	0.000794	0.001079	0.001323
	MODEL 11	0.000791	0.001074	0.001338
	MODEL 12	0.000789	0.001071	0.001314

Table 11: Maximum drift for different types of models in y directions of static analysis

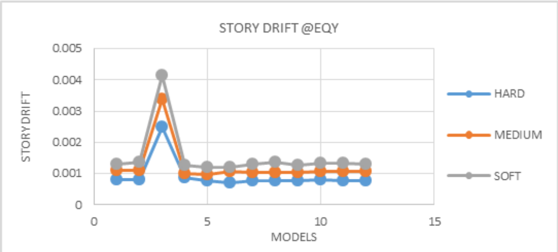

Fig 18: Maximum drift for different types of models in y directions of static analysis

ZONE	Model Type	Storey Drift		
		Soil Type		
		Hard	Medium	Soft

ZONE 3	MODEL 1	0.000636	0.000858	0.001209
	MODEL 2	0.000821	0.000824	0.001012
	MODEL 3	0.001028	0.001398	0.001717
	MODEL 4	0.000790	0.000962	0.001103
	MODEL 5	0.000668	0.000899	0.001092
	MODEL 6	0.000657	0.000895	0.001085
	MODEL 7	0.000658	0.000888	0.001085
	MODEL 8	0.000660	0.000871	0.001142
	MODEL 9	0.000661	0.000891	0.001088
	MODEL 10	0.000685	0.000924	0.001126
	MODEL 11	0.000691	0.000930	0.001110
	MODEL 12	0.000691	0.000930	0.001133

Table 12: maximum drift for different types of models in x directions of dynamic analysis

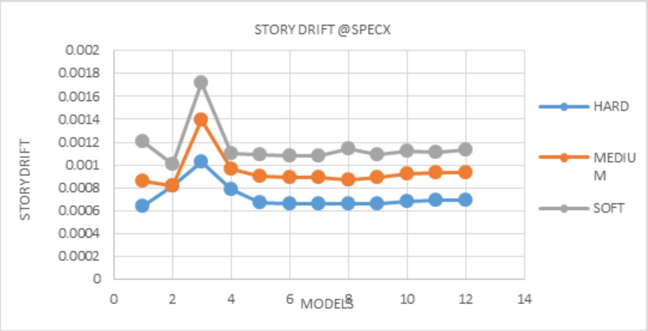

Fig 19: maximum drift for different types of models in x directions of dynamic analysis

ZONE	Model Type	Storey Drift		
		Soil Type		
		Hard	Medium	Soft
ZONE 3	MODEL 1	0.000636	0.000858	0.001209
	MODEL 2	0.000659	0.000895	0.001098
	MODEL 3	0.001853	0.002520	0.002520
	MODEL 4	0.000788	0.000958	0.001153
	MODEL 5	0.000699	0.000935	0.001158
	MODEL 6	0.000671	0.000947	0.001162
	MODEL 7	0.000691	0.000938	0.001150
	MODEL 8	0.000692	0.000939	0.001224
	MODEL 9	0.000693	0.000940	0.001152
	MODEL 10	0.000687	0.000932	0.001144
	MODEL 11	0.000689	0.000935	0.001142
	MODEL 12	0.000690	0.000936	0.001148

Table 13: Maximum drift for different types of models in y directions of dynamic analysis

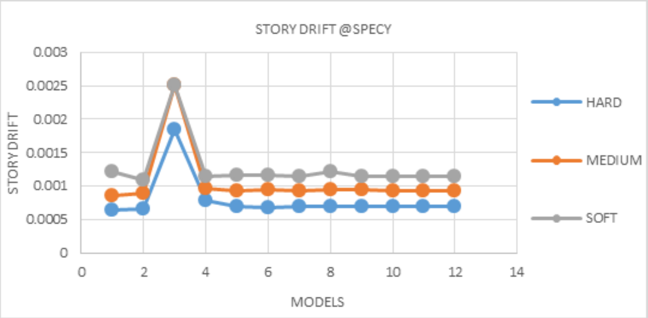

Fig 20: Maximum drift for different types of models in y directions of dynamic analysis.

VII. CONCLUSION

- It was shown that the water tank is more effective for structures with low damping ratios where structural displacements decrease with the introduction of water tank. It is observed that for lightly damped structures the water tank is effective to reduce structural displacement.
- By observing the above results the displacement of the structure varies with varying the seismic zones and different soil types. Displacement is more for structure without tank than the structure with tank, as the depth of water increases displacement gets decreases vice-versa.
- In the comparison of the, structure without tank models and structure with tank models, the design base shear is more for structure without tank than structure with tank models. The percentage variation is found to be from 18-25%.
- Time period is more for structure without tank, it observed from the analysis as the structure height increases time period also increases. Time period linearly varying with the water depth.
- The natural time period increases as the height of structure increases, irrespective of type of structure viz. without tank structure, with tank structure. In comparison of the without tank model and with tank model, the time period is more for without tank model than with tank, since the structure with tank is stiffer than the structure without tank. The difference between the two varies from 32-50%.
- In comparison, the structure without tank model and with tank model, the storey drift is more in structure with tank structure than without tank structure. It can be observed from the analysis, maximum drift occurs at middle height of the structural models.
- As the result of comparison between two mentioned analysis it is observed that the Lateral displacement, base shear and storey drift obtained by static analysis is higher than dynamic analysis. Hence the structure design is governed by static analysis for the models considered for the analysis.

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