TIME HISTORY ANALYSIS OF BUILDING STRUCTURES WITH WATER TANK AS PASSIVE TUNED MASS DAMPER

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Abstract

An earthquake is a natural phenomenon. Depending upon the intensity, itmay cause damageto life and property. Engineering community is striving hard to innovate different methods that can provide a solution to minimize this damage. 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. Analysis is carried for 5 storied and 10 storied buildings with and without water tanksand for different mass ratios varying from 5% to 25%.Water tank is placed at center and extreme corners of the building and columns of the tank with varying heights i.e., 1m, 2m, 3m and 3.5m are considered. 3 types of earthquake data(El Centro, N.Palm and Uttarkashi) are used for this study. Time history analysis is performed using SAP software. Results showed that tuning the parameters of water tank, it can be used as passive TMD to reduce the seismic response. Majority of the cases proved that results are appreciable when water tank is placed at center of the building, for columns of 3m height and 20% mass ratio.

Keywords: *Tuned Mass Damper (TMD), seismic response, earthquakes*

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1. INTRODUCTION

An earthquake is a natural phenomenon like rain.Descriptions as old as recorded history show the significanteffects they have had on people's lives. In simple terms, earthquakes are caused by theconstant motion of Earth's surface. This motion createsbuildup and releases energy stored in rocks at and nearthe Earth's surface. Earthquakes are the sudden, rapidshaking of the Earth as this energy is released. In a strong earthquake theground shakes violently. Buildings may fall or sinkinto the soil. Main aim of the study is to find the reduction of dynamic response of multistoried building using water tank as passive tuned mass damper. Observing the response reduction of multi storied building by varying the column height on which water tank is placed. By changing the mass ratio time history analysis is done. Tuned mass damper is one type of successful seismic response control devices.Using water tank as passive TMD is advantageous in control of seismic response of multistoried building. Idea of using water tank as seismic response control device is advantageous since water tank is an integral part of any type of building.

1.1 Need for the Present Study

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. Considering economy, an attempt has been made to study the feasibility of utilizing the water tank in the structure to resist seismic forces. Usually water tanks are placed at corners on the roof the buildings.The water tank is placed at centre, and also at extreme corner and the reduction in seismic response for varied positions of the water tank is discussed.The best position of water tank on the roof of the building is suggested.

1.2 Objectives of the Study

- To study the feasibility of implementing water tank as passive tuned mass damper for 5 and 10 storied structures by subjecting to real earthquake ground motions and by varying the position of the water tank at centre and at extreme corners of the building with a column height varying from 1m to 3.5m and mass ratios ranging from 5-25% in the increments of 5%.
- To Study the seismic behaviour of the structures implementing water tank as TMD using nonlinear time history analysis to reduce roof displacements, storey drifts and base shears and to find which columns are subjected to maximum forces.

1.3 Scope of Work

- Scope of the work is limited to nonlinear time history analysis of two symmetrical 5 and 10 storey buildings subjected to three real earthquake records namely EL Centro earthquake data, N.Palm earthquake data and Uttarkashi earthquake data using SAP-2000.
- The water tank column height is varied from 1m to 3.5m, mass ratios from 5% to 25% and water tank position is varied at centre and extreme corner on the roof of the building.
- Determining the Roof Displacements, Base Shear, Storey Drifts and Member Forces without water tank and with water tank at centre and extreme corner on the roof of the building.

2. METHODOLOGY

Time history analysis was carried out for structures without water tank and with water tank subjected to 3 types of earthquake data's (EL CENTRO, BHUJ, KOBE) with diff mass ratios and diff water tank column heights. SAP2000 software is used in carrying the analysis.

2.1 Material Properties

Item	**5 storied Building**	**10 Storied Building**
Grade of concrete	M 25	M 25
Grade of Steel	Fe 415	Fe 415
Density of concrete	25kN/m^3	25kN/m^3
Foundation Depth	1.5m	1.5m
Each storey height	3 m	3 m
Plan dimensions	4 m x 4 m for each bay	4 m x 4 m for each bay
No. of Bays	7 on both sides	7 on both sides
Dimension of Beam	0.23 m x 0.45 m	0.23 m x 0.45 m
Dimension of column	0.3 m x 0.3 m	0.3 m x 0.3 m
Slab Thickness	0.125 m	0.125 m
Live Load	2 kN/m^2	2 kN/m^2
Floor Finishes	1.5 kN/m^2	1.5 kN/m^2
Wall Loads (Exterior)	12.5kN/m	12.5kN/m
Wall Loads (Interior)	6.5kN/m	6.5kN/m

2.2 Time History Loading

- The El Centro 1940 earthquake data file loading is used in global-X direction with 8 points per line at a time interval 0.02 seconds.
- The N.Palm 1986 earthquake data file loading is used in global-X direction with 5 points per line at a time interval 0.005 seconds.
- The Uttarkashi 1991 earthquake data file loading is used in global-X direction with 8 points per line at a time interval 0.02 seconds.

2.3 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 height of columns on which the water tank is placed are optimized and the objective function is to reduce the peak structural response subjected to seismic excitation by varying the position of the water tank on the roof of the structure. For optimization the mass ratio was varied from 5-25% in increments of 5% and the height of the columns was varied from 1m to 3.5m.

Table: 2.1 Earthquake data details

Record	Station/Year	Magnitude	PGA(g)
Imperial Valley (E1)	ElCentro 1940	6.9	0.32
N-Palm	North Palm 1986	6.0	0.56
Uttarkashi	Uttarkashi 1991	6.6	0.31

2.4 Modelling

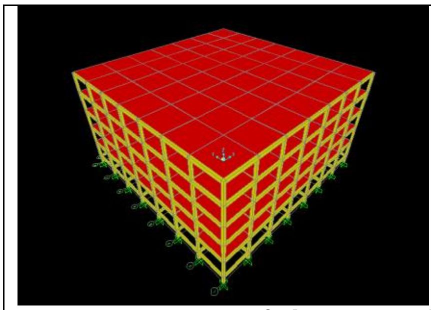
Fig 3.4 3-D View of the 5 storied building without water tank

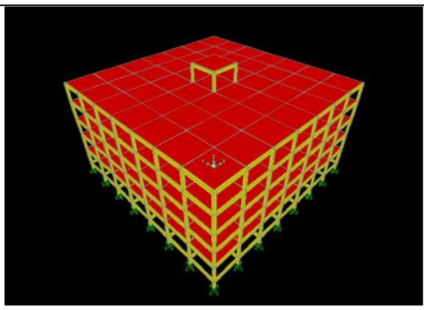
Fig 3.6 3-D View of 5 storied building with water tank at centre

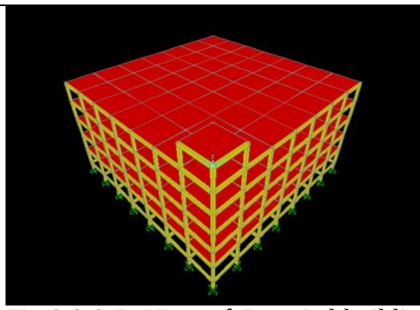
Fig 3.8 3-D View of 5 storied building with water tank at AB-12

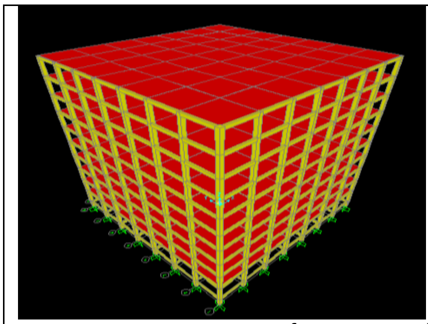
Fig 3.10 3-D View of 10 storied building without water tank

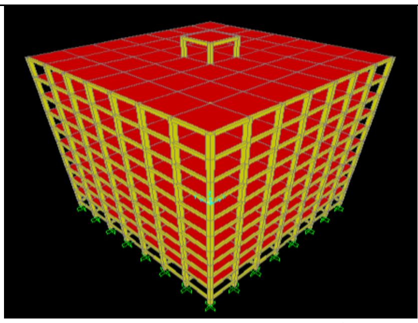
Fig 3.12 3-D View of 10 storiedbuilding with water tank at centre

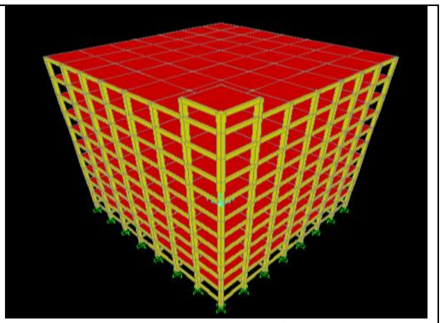
Fig 3.14 3-D View of 10 storied building with water tank at AB-12

3. RESULTS & DISCUSSIONS

Table 3.1- Roof Displacements, Base Shear for EL Centro Earthquake Data

Column Height (*mts*)	**Mass Ratio (%)**	**Roof Displacements(mm)**				**Base Shear (kN)**			
		5 Storey		**10 Storey**		**5 Storey**		**10 Storey**	
		Water tank at Center	**Water tank at Corner**	**Water tank at Center**	**Water tank at Corner**	**Water tank at Center**	**Water tank at Corner**	**Water tank at Center**	**Water tank at Corner**
Without Water Tank		12.32		12.47		1066		1066	
1	5	12.11	12.08	12.77	13.56	1036	1018	1552	1507
1	10	11.76	11.38	12.34	12.45	992.8	953.8	1478	1461
1	15	11.39	11.22	11.69	12.65	946.5	884.5	1379	1313
1	20	11.12	11.69	11.32	13.28	921.5	816	1313	1208
1	25	12.21	12.31	11.58	13.09	948.5	892.5	1452	1316
2	5	12.07	12.01	12.75	13.49	1044	1009	1691	1619
2	10	11.72	11.45	12.25	12.43	898.4	825.1	1513	1243
2	15	11.28	11.14	11.77	12.64	894.9	892.8	1182	1129
2	20	10.66	11.42	10.91	12.93	904.1	874.3	1230	1212
2	25	11.35	11.56	19.02	11.87	924.6	898.3	1560	1345
3	5	11.85	11.73	12.59	13.44	963.3	971.8	1376	1247
3	10	10.83	10.34	11.45	11.62	984.5	946.3	1462	1455
3	15	9.59	9.75	10.43	12.00	956.1	891.5	1224	1192
3	20	8.95	9.26	9.54	11.68	850.1	912.8	1445	1169

3	25	10.99	10.54	12.35	11.86	900.4	925.6	1670	1214
3.5	5	11.42	11.25	11.33	11.71	898.9	922.5	1250	1325
3.5	10	9.99	11.23	11.52	11.90	912.5	935.6	1362	1465
3.5	15	12.87	11.34	10.69	12.01	960.4	985.2	1425	1485
3.5	20	12.33	12.59	10.89	11.46	925.6	990.2	1562	1527
3.5	25	12.35	12.87	11.25	15.49	990.6	990.8	1590	1582

Table 3.2 - Storey Drift for EL Centro Earthquake Data

Column Height (*mts*)	**Mass Ratio (%)**	**Storey Drift (mm)**			
		5 Storey		**10 Storey**	
		Water tank at Center	**Water tank at Corner**	**Water tank at Center**	**Water tank at Corner**
Without Water Tank		3.37		0.001762	
1	5	3.32	3.32	0.001815	0.002022
1	10	3.26	3.26	0.001765	0.001767
1	15	3.19	3.19	0.00168	0.001749
1	20	3.13	3.13	0.00163	0.001786
1	25	3.25	3.25	0.001862	0.001847
2	5	3.27	3.27	0.001767	0.001945
2	10	3.14	3.14	0.001705	0.001615
2	15	2.65	2.65	0.001319	0.001463
2	20	2.79	2.79	0.001412	0.001442
2	25	2.75	2.75	0.001625	0.001568
3	5	3.04	3.04	0.001648	0.001672
3	10	3.23	3.23	0.001668	0.001732
3	15	2.73	2.73	0.001408	0.001545
3	20	2.43	2.43	0.001155	0.001409
3	25	2.65	2.65	0.001715	0.001687
3.5	5	3.13	3.13	0.001526	0.001698
3.5	10	3.01	3.01	0.001654	0.001745
3.5	15	2.54	2.54	0.001541	0.001712
3.5	20	3.22	3.22	0.001546	0.001701
3.5	25	3.32	3.32	0.001879	0.001799

Table3.3 Roof Displacements, Base Shear, Storey Drift – N.Palm EQ Data

Water Tank Position	Column Height (m)	Mass Ratio (%)	Displacements (mm)		Base Shear (kN)		Storey Drift (mm)	
			5 Storey	10 Storey	5 Storey	10 Storey	5 Storey	10 Storey
Without Water Tank			18.19	15.23	1829	2982	5.60	2.55
At Centre	3	20	13.59	10.74	1341	1905	3.42	1.79
Extreme Corner (AB -12)	3	20	11.18	11.11	1363	2056	2.83	1.34

Table3.4 Roof Displacements, Base Shear, Storey Drift –Uttarkashi Earthquake Data

Water Tank Position	Column Height (m)	Mass Ratio (%)	Displacements (mm)		Base Shear (kN)		Storey Drift (mm)	
			5 Storey	10 Storey	5 Storey	10 Storey	5 Storey	10 Storey
Without Water Tank			91.06	41.76	8923	10330	30.1	8.73
At Centre	3	20	36.04	36.12	3898	8709	14.24	8.42
Extreme Corner (AB -12)	3	20	42.68	36.59	4206	8687	14.02	8.48

4. DISCUSSIONS

4.1 Roof Displacements

4.1.1 EL Centro Earthquake Data

- From Table 3.1for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the roof displacement is reduced by 27.32% and 24.79% when the water tank is placed at centre and extreme corner respectively.
- From Table 3.1 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the roof displacement is reduced by 23.45% and 6.33% when the water tank is placed at centre and extreme corner respectively.

4.1.2 N.Palm Earthquake Data

- From Table3.3 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the roof displacement is reduced by 25.23% and 38.53% when the water tank is placed at centre and extreme corner respectively.
- From Table3.3 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the roof displacement is reduced by 29.46% and 27.12% when the water tank is placed at centre and extreme corner respectively.

4.1.3 Uttarkashi Earthquake Data

- From Table 3.4 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the roof displacement is reduced by 60.43% and 53.13% when the water tank is placed at centre and extreme corner respectively.
- From Table 3.4 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the roof displacement is reduced by 13.5%and 12.37% when the water tank is placed at centre and extreme corner respectively.

4.2 Base Shear

4.2.1 EL Centro Earthquake Data

- From Table 3.1 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the base shear is reduced by 20.25% and 14.37% when the water tank is placed at centre and extreme corner respectively.
- From Table 3.1 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the base shear is reduced by 11.19% and 28.15% when the water tank is placed at centre and extreme corner respectively.

4.2.2 N.PalmEarthquakeData

- From Table 3.3 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the base shear is reduced by 26.68% and 25.48% when the water tank is placed at centre and extreme corner respectively.
- From Table3.3 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the base shear is reduced by 36.12% and 31.05% when the water tank is placed at centre and extreme corner respectively.

4.2.3 Uttarkashi Earthquake Data

- From Table 3.4 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the base shear is reduced by 56.32% and 52.32% when the water tank is placed at centre and extreme corner respectively.
- From Table3.4 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the base shear is reduced by 15.69% and 15.90% when the water tank is placed at centre and extreme corner respectively.

4.3 Storey Drifts

4.3.1EL Centro Earthquake Data

- From Table 3.2 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the storey drift is reduced by 27.9% and 32.94% when the water tank is placed at centre and extreme corner respectively.

- From Table 3.2 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the storey drift is reduced by 34.09% and 19.89% when the water tank is placed at centre and extreme corner respectively.

4.3.2 N.Palm Earthquake Data

- From Table 3.3 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the storey drift is reduced by 38.93% and 49.46% when the water tank is placed at centre and extreme corner respectively.
- From Table3.3 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the storey drift is reduced by 29.80% and 47.50% when the water tank is placed at centre and extreme corner respectively.

4.3.3 Uttarkashi Earthquake Data

- From Table 3.4 for 5 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the storey drift is reduced by 52.69% and 53.42% when the water tank is placed at centre and extreme corner respectively.
- From Table3.4 for 10 storied building, the maximum reduction is found when water tank is placed on 3m height column and with 20% mass ratio and the storey drift is reduced by 3.55% and 2.86% when the water tank is placed at centre and extreme corner respectively.

4.4 Member Forces

4.4.1EL Centro Earthquake Data

- For the 5 storied building without water tank, the maximum value of Shear force was observed on the ground floor columns in the outer periphery of the building, and when water tank is placed at 3m column height and of 20% mass ratio the maximum shear force was observed on tank columns for both the positions of the tank(i.e.,centre and extreme corner).
- For the 10 storied building without water tank, the maximum value of Shear force was observed on the ground floor columns in the outer periphery of the building, and when water tank is placed at 3m column height and of 20% mass ratio the maximum shear force was observed on tank columns for both the positions of the tank(i.e., centre and extreme corner).

4.4.2 N.Palm Earthquake Data

- For the 5 storied building without water tank, the maximum value of Shear force was observed on the ground floor columns in the outer periphery of the building, and when water tank is placed at 3m column height and of 20% mass ratio the maximum shear force was observed on tank columns for both the positions of the tank (i.e., centre and extreme corner).
- For the 10 storied building without water tank, the maximum value of Shear force was observed on the ground floor columns in the outer periphery of the building, and when water tank is placed at 3m column height and of 20% mass ratio the maximum shear force was observed on tank columns for both the positions of the tank (i.e., centre and extreme corner).

4.4.3 Uttarkashi Earthquake Data

- For the 5 storied building without water tank, the maximum value of Shear force was observed on the ground floor columns in the outer periphery of the building, and when water tank is placed at 3m column height and of 20% mass ratio the maximum shear force was observed on tank columns for both the positions of the tank(i.e., centre and extreme corner)
- For the 10 storied building without water tank, the maximum value of Shear force was observed on the ground floor columns in the outer periphery of the building, and when water tank is placed at 3m column height and of 20% mass ratio the maximum shear force was observed on tank columns for both the positions of the tank (i.e., centre and extreme corner).

5. CONCLUSION

- It has been found that water tank can be successfully used as passive TMD to control the vibrations of the structure subjected to earthquakes.
- When the water tank of mass ratio 20% resting on columns of height 3m, placed at centre on the roof of the building considering the minimum response reduction subjected to any kind of earthquake data, the roof displacements, base shears and storey drifts are reduced up to 25%, 20% and 27% respectively for 5 storied building.
- When the water tank of mass ratio 20% resting on columns of height 3m, placed at extreme corner on the roof of the building considering the minimum response reduction subjected to any kind of earthquake data, the roof displacements, base shears and storey drifts are reduced up to 24%, 14% and 30% respectively for 5 storied building.
- When the water tank of mass ratio 20% resting on columns of height 3m, placed at centre on the roof of the building considering the minimum response reduction subjected to any kind of earthquake data, the roof displacements, base shears and storey drifts are reduced up to 23%, 15% and 5% respectively for 10 storied building.
- When the water tank of mass ratio 20% resting on columns of height 3m, placed at extreme corner on the roof of the building considering the minimum response reduction subjected to any kind of earthquake data, the roof displacements, base shears and storey drifts are reduced up to 6%, 15% and 3% respectively for 10 storied building.
- Maximum response reduction was observed for the water tank of 20% mass ratio resting on 3m height columns placed at centre on the roof of the building.

- Considerable reduction in the response is observed when the water tank of 20% mass ratio resting on 3m column height, placed at extreme corner on the roof of the building. So, water tank placed at corner can also be used as passive TMD.

6. SCOPE FOR FURTHER WORK

- Both the structures considered in this study are symmetrical; this provides a further scope to study this problem using Unsymmetrical buildings.
- Behaviour of water tank as TMD was studied for two positions only, which provides a further scope of studying the behaviour at various positions on the roof the building.
- Sloshing effect of water in the tank can also be studied to reduce seismic response.

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