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Seismic Mitigation and Vibration Control of Multi Storey RCC Building with "Aqua- Damp" Concept

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***Abstract*- Aqua damper is a type of tuned mass damper (TMD) where the mass is supplement by a liquid (usually water). It is also referred to as tuned liquid dampers (TLD) and is a passive damping device which utilizes the motion of liquid in a container for dissipating the vibration energy from seismic activity. As the sloshing frequency of the water is tuned to the natural frequency of the structure, resonance will occur and this will cause large amount of sloshing and wave breaking hence dissipating a significant amount of energy. The natural frequency is controlled by adjusting water depth and tank dimensions. Implementing aqua dampers enhances the performance of the structures. The main aim of this project is to study the efficiency of aqua dampers when employed as seismic mitigation measures in a RCC multi storey building.**

***Keywords:-* Tuned Liquid Damper (TLD), Aqua Damp concept, sloshing frequency**

I. INTRODUCTION

The evolving landscape of urban architecture continually challenges engineers and researchers to develop innovative solutions to enhance the resilience and safety of multistory RCC buildings against seismic activities and structural vibrations. Earthquakes pose a significant threat to multi-storey buildings, particularly in regions with high seismic activity. The dynamic forces generated during an earthquake can lead to severe structural damage or even catastrophic failure, making seismic mitigation a critical concern in civil engineering. Reinforced Cement Concrete (RCC) buildings, widely used for their durability and load-bearing capacity, are no exception to these challenges. However, their rigid nature can result in substantial inertial forces during seismic events, necessitating effective strategies to enhance their resilience. Traditionally, seismic mitigation in buildings has relied on methods such as base isolation, which decouples the building from ground motion, and the use of various forms of damping systems that absorb and dissipate energy. While these methods have proven effective, they often involve significant alterations to the building's structure and can be costly or impractical, especially for retrofitting existing buildings.

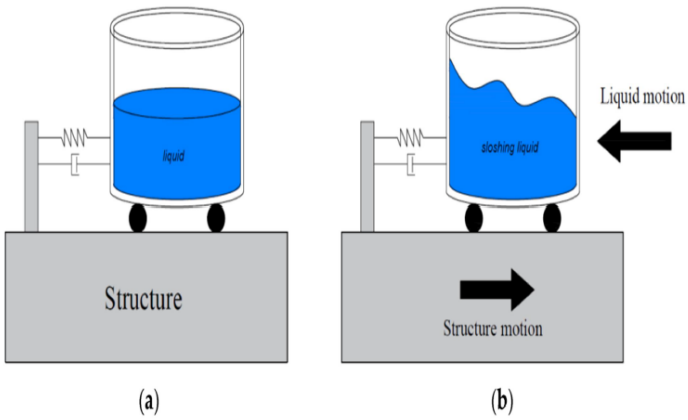

Fig. 1 – Working of aqua damper

The Aqua Damping concept in seismic mitigation refers to the use of water-based damping systems, particularly Tuned Liquid Dampers (TLDs), to reduce seismic vibrations in structures such as multi-storey Reinforced Cement Concrete (RCC) buildings. This method leverages the dynamic properties of liquid to counteract the forces induced by seismic activity, thereby enhancing the stability and integrity of the building during an earthquake. Aqua damping operates on the fundamental principles of fluid dynamics and resonance tuning. The core idea is to use a container filled with liquid, usually water, whose movement (sloshing) can be harnessed to generate counteracting forces against the building's motion. This sloshing action

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provides a passive and adaptable method of damping that can significantly reduce the amplitude of vibrations. The natural frequency of the liquid sloshing within the tank is tuned to match the building's primary vibrational frequency. When the building oscillates due to seismic forces, the liquid inside the damper also oscillates at the tuned frequency, creating a phase difference that counteracts the building's motion. As the liquid sloshes, it converts kinetic energy into potential energy and then dissipates it through friction and turbulence within the tank. This process reduces the overall energy of the system, dampening the vibrations and minimizing the building's sway.

II. OBJECTIVES

- Implementation of water tank as tuned liquid damper on a multi storey RCC building (G+12) using ETABS SOFTWARE.
- To study the effect of TLD on regular structure in different conditions by varying water depth, tuning ratio and location of tank.
- To analyze structures in terms of different parameters like storey displacement, storey drift, storey acceleration, base shear and time period.

III. SCOPE OF THE WORK

The scope of this study is to enhance the performance of RCC multi storey structure implementing aqua damper concept.

IV. PARAMETRIC STUDY

Multiple aspects were taken into consideration when conducting the investigation on the effect of implementing aqua damp concept in a multi storey RCC building. the horizontal ground motion records of the El Centro have been selected for performing the nonlinear dynamic Time History analysis. The Characteristics of the selected earthquake motion in terms of peak ground acceleration (PGA), moment magnitude (M) are 0.34g and 7.2 respectively. The effect of TLD on regular structure in different conditions by varying water depth, tuning ratio and location of tank are studied. Seismic parameters such as base shear, storey displacement and top storey acceleration are studied and compared with conventional structure.

Code of references: Indian Standard codes IS 1893 (Part 2) (2014)

V. SUMMARY OF LITERATURE REVIEW

Various literatures have been reviewed including the base journal "Use of Water Tank as Tuned Liquid Damper (TLD) for Reinforced Concrete (RC) Structures" Muhammad Jamil Ahmad, Qaiser uz Zaman Khan, Syed Muhammad Ali (2021), SPRINGER

Installing water tanks in buildings in accordance with the Aqua-damping concept will help create an inbuilt and cost effective system for the structure to mitigate seismic shocks to the building. New researches in this field promise the development of more efficient and cost effective seismic mitigation techniques for improved efficiency of the buildings.

VI. MODELLING

Thirteen storey reinforced concrete moment-resisting frame building is considered. The considered building has a width of 16 m divided into 4 bays and length of 36 m divided into six bays as well. The associated storey height considered is of 3 m. The designed reinforced concrete beams have been set to be of 300 mm × 600 mm. The designed reinforced concrete columns have been set to be of cross sections 300 mm × 900 mm. The dimension of water tank has been set as 12 m × 8 m.

The water tank has been designed as a spring mass model for analysis in ETABS. The calculations for parameters like convective mass, impulsive mass, height of convective mass, height of impulsive mass and stiffness of spring was done in accordance to data from IS 1893 (part 2).

Modelling was done for three conditions:

1. Single tank condition
2. Two tanks condition
3. Three tanks condition

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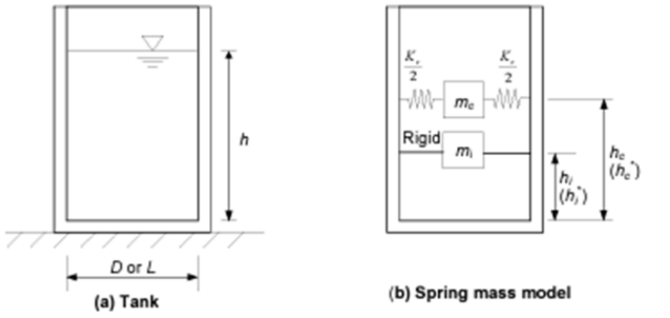

Fig. 2 – Spring mass model for water tank from IS 1893 (Part 2)

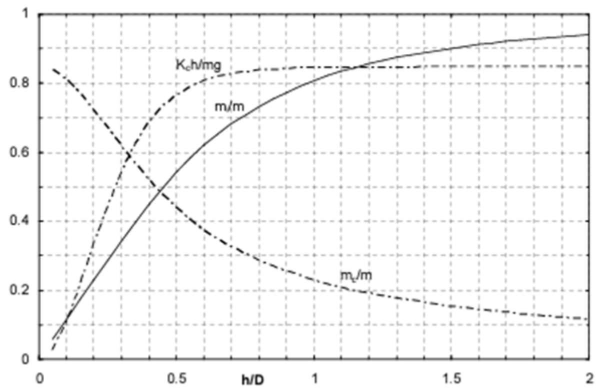

Fig. 3 – Graph data No.1 from IS 1893 (Part 2)

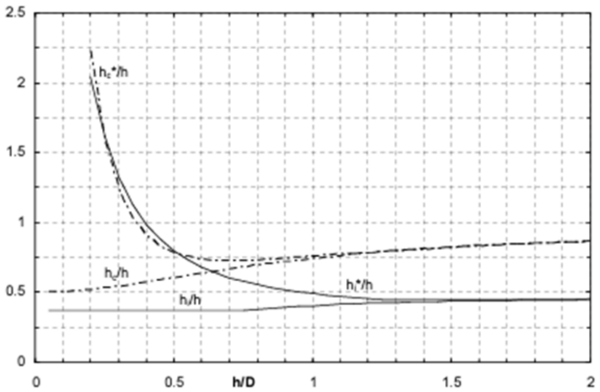

Fig. 4 – Graph data No.2 from IS 1893 (Part 2)

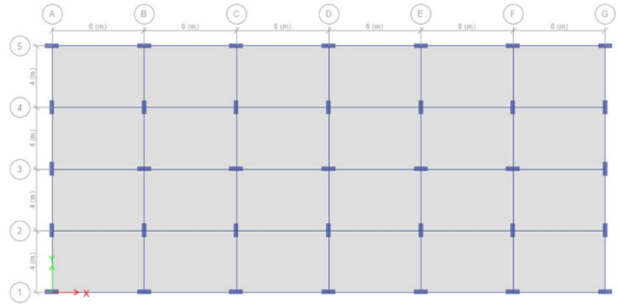

Fig. 5 – Plan of building model in Etabs

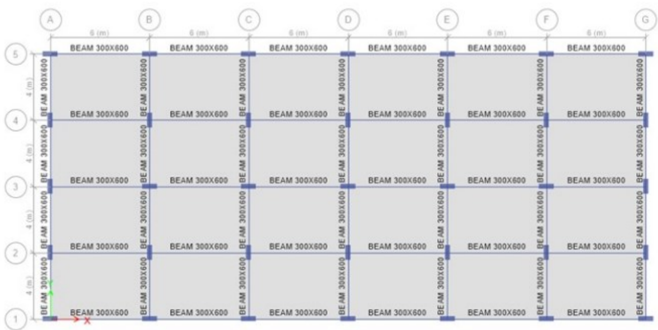

Fig. 6 – Beam details of model in Etabs

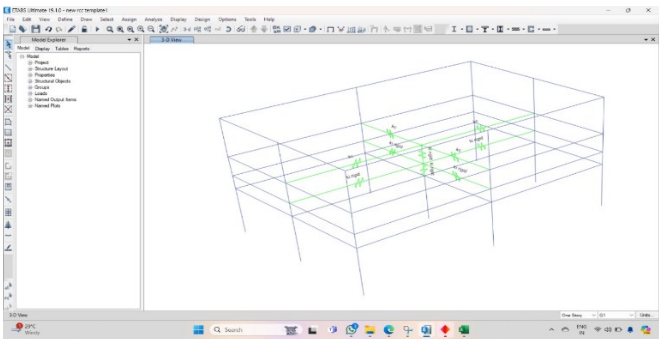

Fig. 7 – Water tank model for analysis

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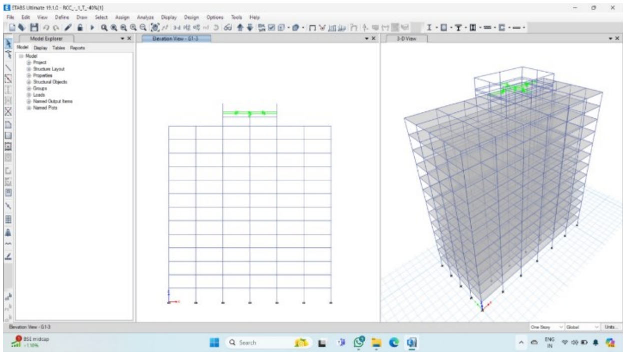

Fig. 8 – Building elevation model with 1 tank

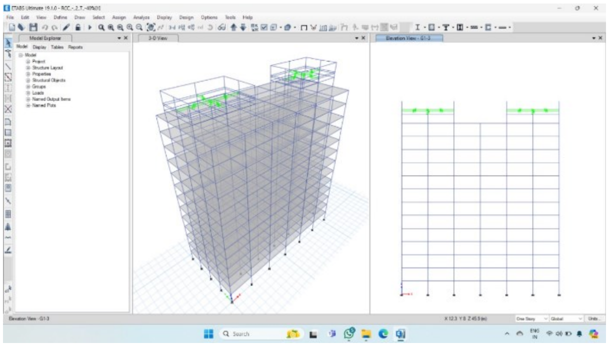

Fig. 9 – Building elevation model with 2 tank

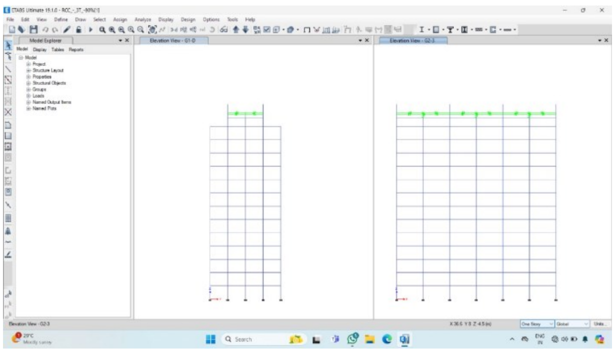

Fig. 10 – Building elevation model with 3 tanks

VII. TEST RESULT AND DISCUSSION

The results obtained from analysis of – single tank, two tank and three tank conditions with 20%, 40%, 60% and 80% capacity of water tank filled for each condition has been discussed. The values have been tabulated and trends of parameters in different conditions have been plotted in graphs using values obtained.

Table 1 – Tabulated values of parameters considered

		DISPLACEMENT(mm)		BASE SHEAR(Kn)		DRIFT		TIME PERIOD(s)		ACC
		X	Y	X	Y	X	Y	X	Y	MM/S2
NO TANK	BARE	137.464	151.898	11791	13255	0.005691	0.00565	1.33	1.28	5050
SINGLE TANK	20%	113.453	119.358	9667	10824	0.004649	0.00452	1.38	1.34	6517
	40%	134.166	145.725	11921	13380	0.00552	0.005447	2.02	2.19	6217
	60%	137.471	147.163	12243	13584	0.005589	0.005458	1.95	1.95	6427
	80%	146.867	152.547	12453	13590	0.005739	0.005492	1.81	1.8	6651
TWO TANKS	20%	102.135	103.062	8343	9192	0.004029	0.003855	1.43	1.39	6115
	40%	131.002	139.457	12211	13597	0.005329	0.005276	2.05	2.04	5357
	60%	135.618	141.289	12746	14012	0.005395	0.005447	2	1.99	5331
	80%	149.009	149.1	12986	14066	0.00553	0.005264	1.88	1.87	5536
THREE TANKS	20%	96.931	94.444	7736	8890	0.003727	0.003518	1.47	1.43	5582
	40%	128.37	135.322	12673	14019	0.005208	0.005167	2.08	2.07	4840
	60%	131.764	135.634	13344	14581	0.005215	0.00508	2.04	2.03	4833
	80%	143.022	140.947	13602	14608	0.005215	0.004927	1.95	1.93	4814

The values of parameters have been compared and comparison in changes in values of parameters has been tabulated in terms of percentage.

Table 2 – Comparison of parameter values for Displacement and Base shear

		DISPLACEMENT(mm)				BASE SHEAR(Kn)			
		X		Y		X		Y	
NO TANK	BARE	137.464	1	151.898	1	11791	1	13255	1
SINGLE TANK	20%	113.453	-17.46712	119.358	-21.42227	9667	-18.014	10824	-18.34
	40%	134.166	-2.399174	145.725	-4.063911	11921	1.10254	13380	0.94304
	60%	137.471	0.0050922	147.163	-3.117223	12243	3.83343	13584	2.48208
	80%	146.867	6.8403364	152.547	0.42726	12453	5.61445	13590	2.52735
TWO TANKS	20%	102.135	-25.70055	103.062	-32.15052	8343	-29.243	9192	-30.653
	40%	131.002	-4.700867	139.457	-8.190365	12211	3.56204	13597	2.58016
	60%	135.618	-1.342897	141.289	-6.984292	12746	8.0994	14012	5.71105
	80%	149.009	8.3985625	149.1	-1.842026	12986	10.1348	14066	6.11845
THREE TANKS	20%	96.931	-29.48627	94.444	-37.82407	7736	-34.391	8890	-32.931
	40%	128.37	-6.61555	135.322	-10.91259	12673	7.48028	14019	5.76386
	60%	131.764	-4.14654	135.634	-10.70719	13344	13.1711	14581	10.0038
	80%	143.022	4.0432404	140.947	-7.209443	13602	15.3592	14608	10.2075

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Table 3 – Comparison of parameter values – Drift, time period and acceleration

DRIFT				TIME PERIOD(s)				ACC	
X		Y		X		Y		MM/S2	
0.00569	1	0.00565	1	1.33	1	1.28	1	5050	1
0.00465	-18.298	0.00452	-19.994	1.38	3.7594	1.34	4.6875	6517	29.0495
0.00552	-2.9819	0.00545	-3.5891	2.02	51.8797	2.19	71.0938	6217	23.1089
0.00559	-1.7834	0.00546	-3.3976	1.95	46.6165	1.95	52.3438	6427	27.2673
0.00574	0.86721	0.00549	-2.7883	1.81	36.0902	1.8	40.625	6651	31.703
0.00403	-29.2	0.00386	-31.763	1.43	7.5188	1.39	8.59375	6115	21.0891
0.00533	-6.3413	0.00528	-6.6125	2.05	54.1353	2.04	59.375	5357	6.07921
0.00539	-5.1889	0.00545	-3.5891	2	50.3759	1.99	55.4688	5331	5.56436
0.00553	-2.8033	0.00526	-6.833	1.88	41.3534	1.87	46.0938	5536	9.62376
0.00373	-34.495	0.00352	-37.74	1.47	10.5263	1.43	11.7188	5582	10.5347
0.00521	-8.4675	0.00517	-8.5565	2.08	56.391	2.07	61.7188	4840	-4.1584
0.00521	-8.3523	0.00508	-10.083	2.04	53.3835	2.03	58.5938	4833	-4.297
0.00521	-8.3523	0.00493	-12.804	1.95	46.6165	1.93	50.7813	4814	-4.6733

Table 4 - Displacement and Drift values for different stories from Etabs analysis with no water tank

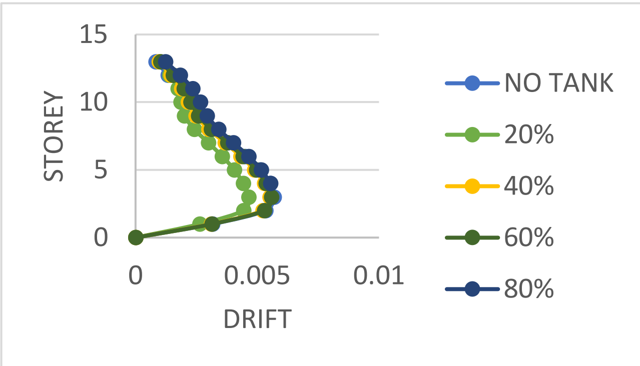

Fig. 11 – Storey drift in x-axis – 1 tank condition

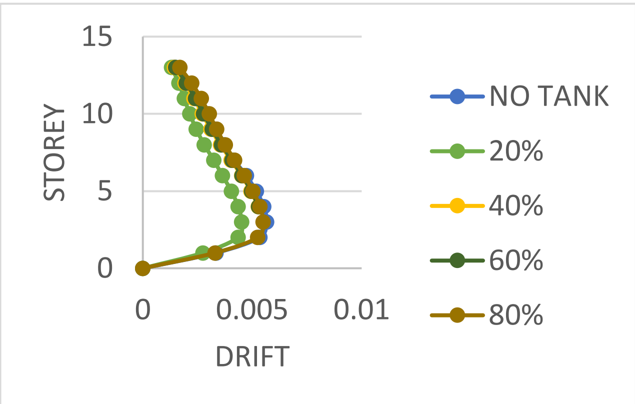

Fig. 12 – Storey drift in y-axis – 1 tank condition

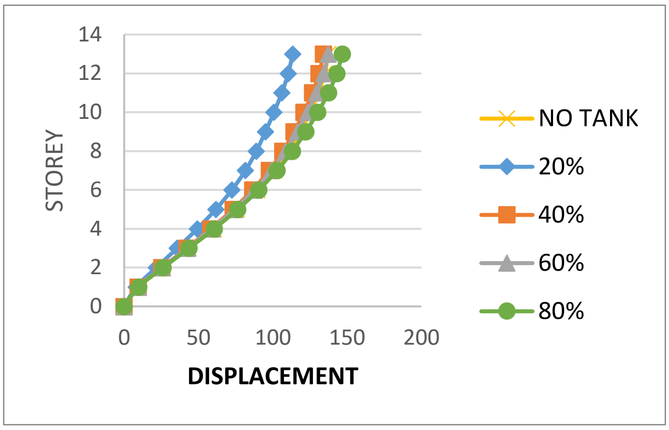

Fig. 13 – Storey displacement in x-axis – 1 tank condition

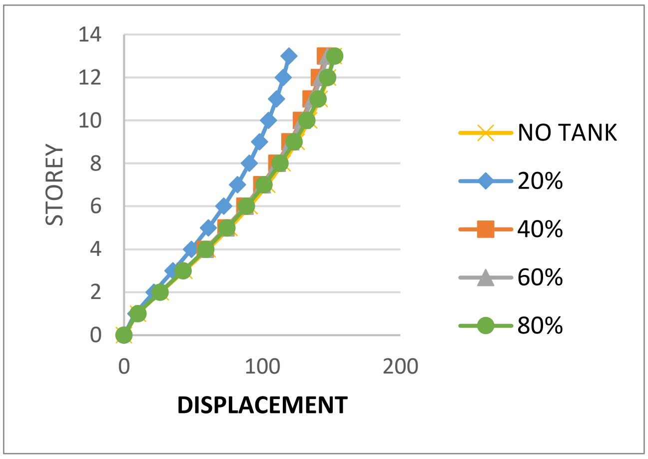

Fig. 14 – Storey displacement in y-axis – 1 tank condition

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For 2 tank condtiton,

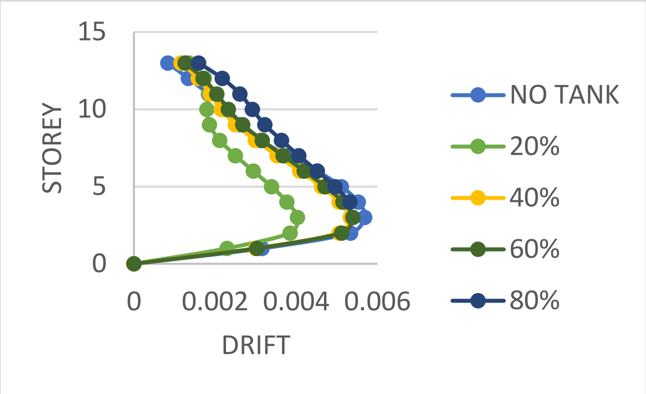

Fig. 15 – Storey drift in x-axis – 2 tank condition

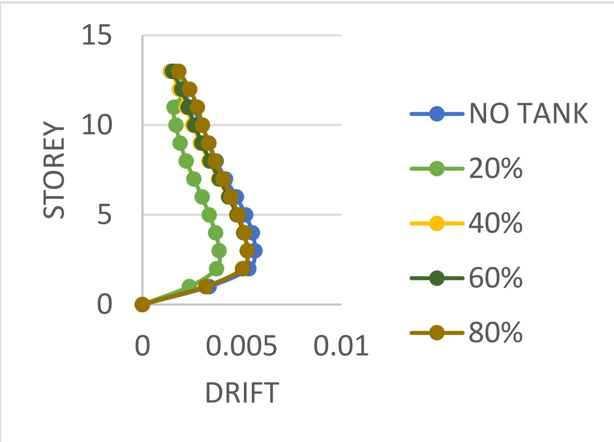

Fig. 16 – Storey drift in x-axis – 2 tank condition

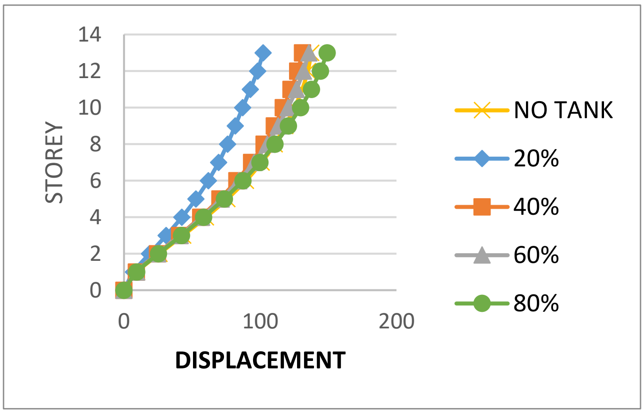

Fig. 17 – Storey displacement in x-axis – 2 tank condition

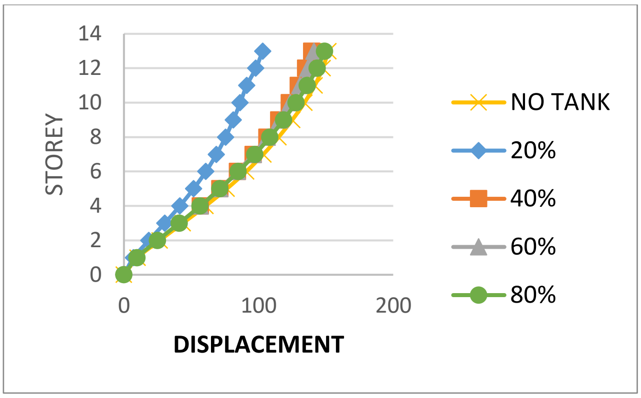

Fig.18 – Storey displacement in y-axis – 2 tank condition

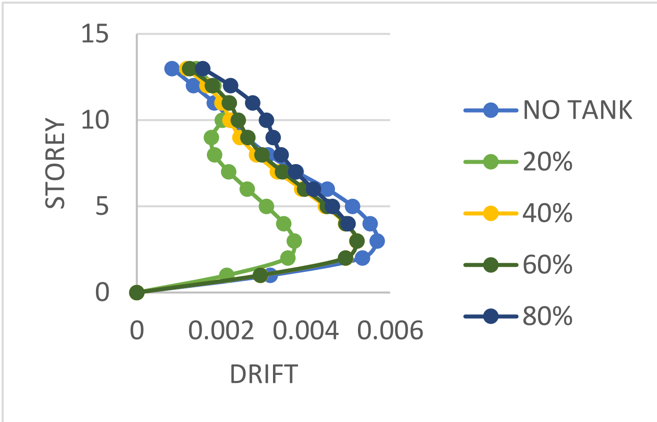

Fig. 19 – Storey drift in x-axis – 3 tank condition

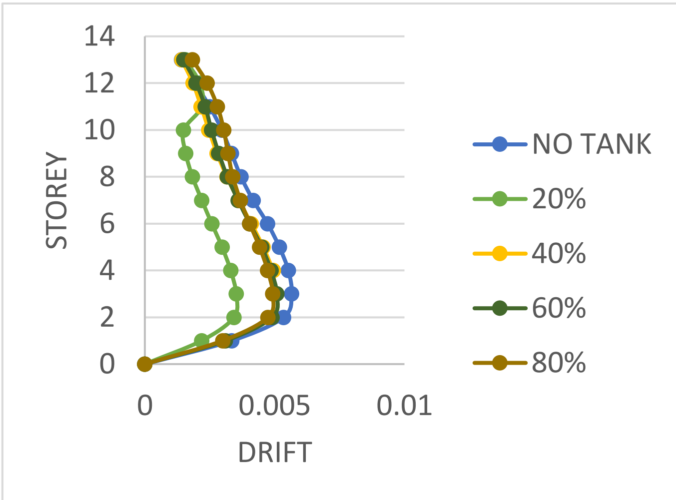

Fig. 20 – Storey drift in y-axis – 3 tank condition

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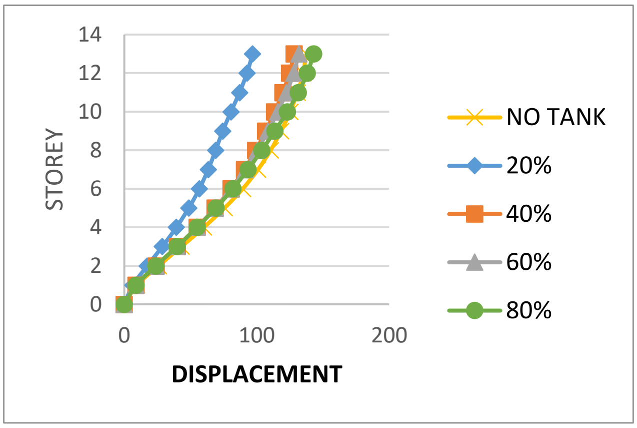

Fig. 21 – Storey displacement in x-axis – 3 tank condition

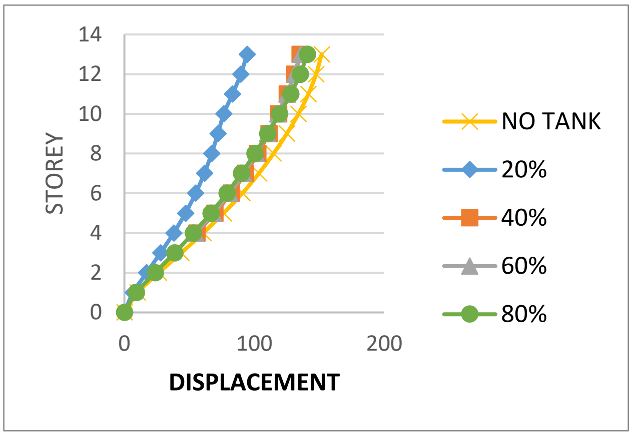

Fig. 22 – Storey displacement in y-axis – 3 tank condition

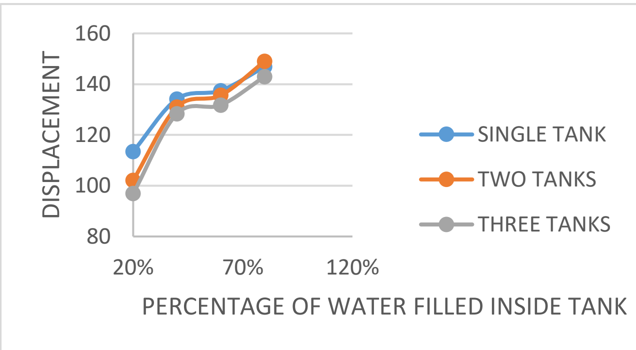

Fig. 23 – Displacement trends along x-axis

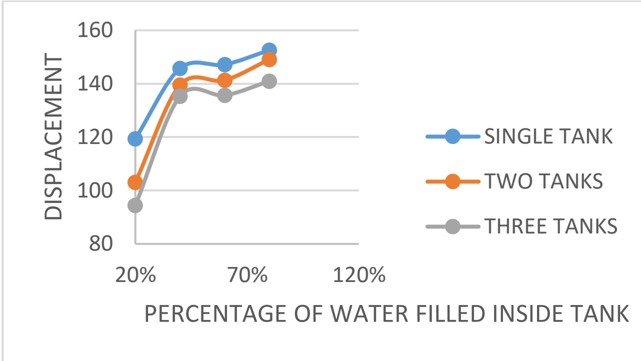

Fig. 24 – Displacement trends along y-axis

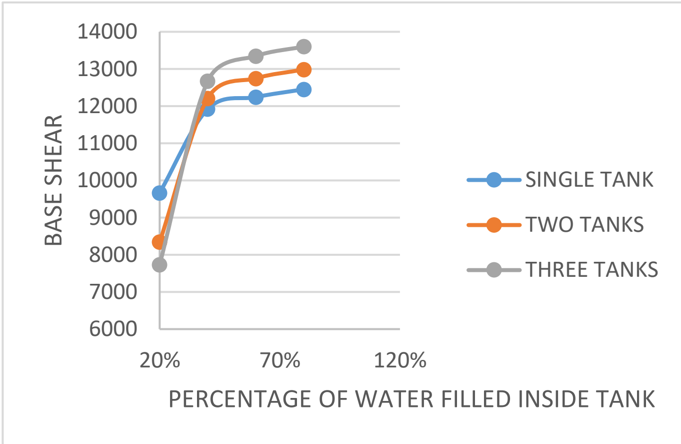

Fig. 25 – Base shear trends along x-axis

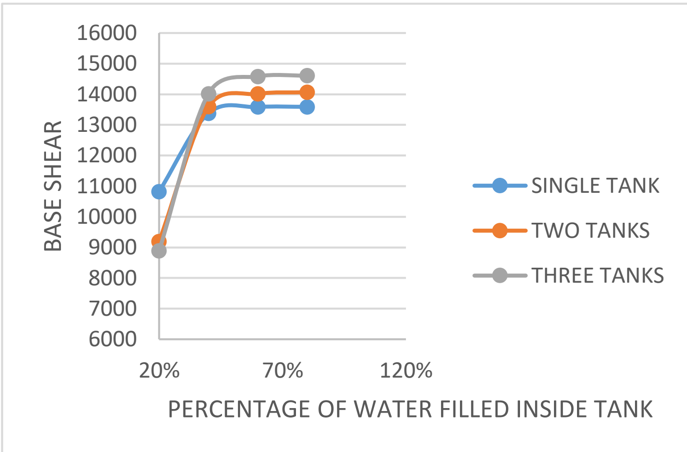

Fig. 26 – Base shear trends along y-axis

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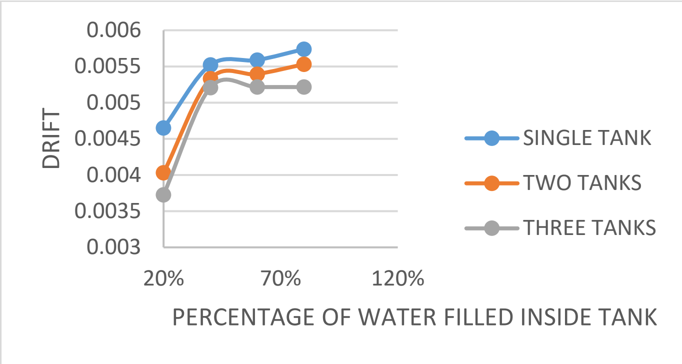

Fig. 27 – Drift trends along x-axis

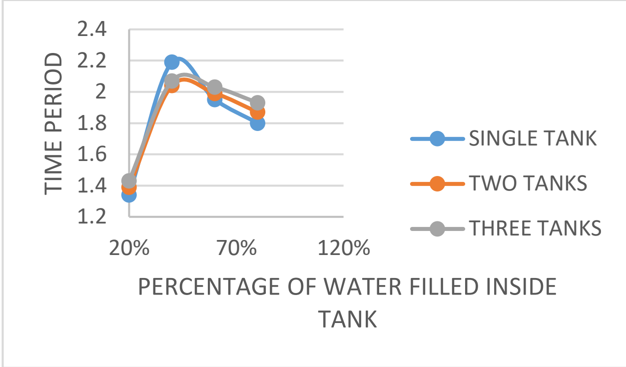

Fig. 30 – Time period trends along y-axis

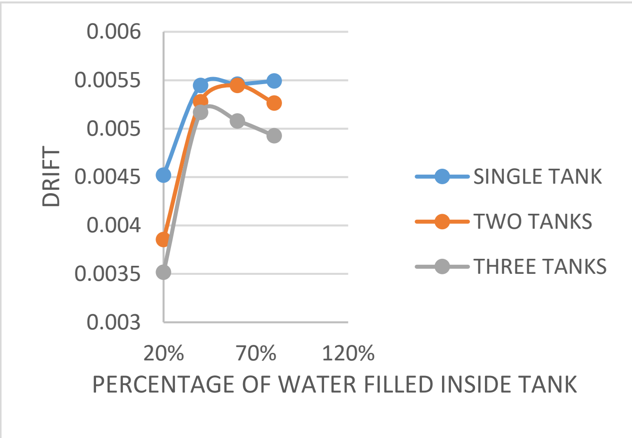

Fig. 28 – Drift trends along y-axis

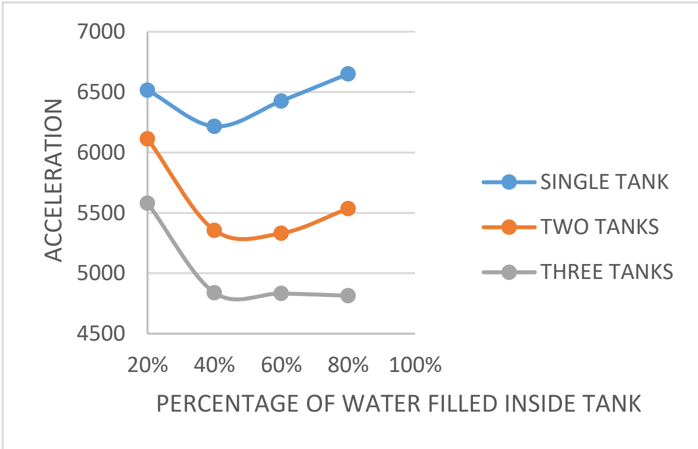

Fig. 31 – Acceleration trends

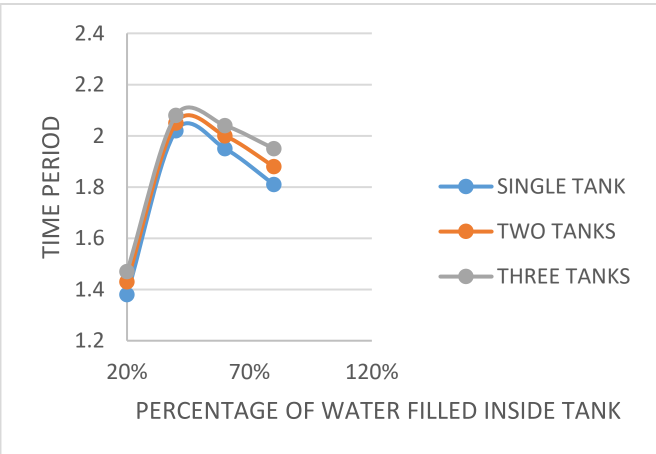

Fig. 29 – Time period trends along x-axis

VIII. CONCLUSION

From the results, it can be seen that for single tank condition,

- On observing the displacement values, providing a water depth ratio of 20% gives the least displacement with 17.46% reduction in x-direction and 21.42% reduction in y-direction while compared to the displacement happening in condition of bare frame without water tank.
- On observing the base shear values, providing a water depth ratio of 20% gives the least base shear value with 18.01% reduction in x-direction and 18.34% reduction in y-direction while compared to the base shear values of bare frame without water tank.
- On observing the drift values, providing a water depth ratio of 20% gives the least drift values with 18.29% reduction in x-direction and 19.99% reduction in y-direction while compared to the drift values of bare frame without water tank.
- On observing the time period values, providing a water depth ratio of 20% gives the least time period value with 3.76% increment in x-direction and 4.68% increment in y-direction while compared to the time period value of bare frame without water tank.

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- On observing the acceleration values, providing a water depth ratio of 40% gives the least acceleration with 23.1% increment in x-direction while compared with acceleration value of bare frame without water tank.

From the results, it can be seen that for two tank condition,

- On observing the displacement values, providing a water depth ratio of 20% gives the least displacement with 25.7% reduction in x-direction and 32.15% reduction in y-direction while compared to the displacement happening in condition of bare frame without water tank.
- On observing the base shear values, providing a water depth ratio of 20% gives the least base shear value with 29.24% reduction in x-direction and 30.65% reduction in y-direction while compared to the base shear values of bare frame without water tank.
- On observing the drift values, providing a water depth ratio of 20% gives the least drift values with 29.2% reduction in x-direction and 31.76% reduction in y-direction while compared to the drift values of bare frame without water tank.
- On observing the time period values, providing a water depth ratio of 20% gives the least time period value with 7.51% increment in x-direction and 8.59% increment in y-direction while compared to the time period value of bare frame without water tank.
- On observing the acceleration values, providing a water depth ratio of 60% gives the least acceleration with 5.56% increment in x-direction while compared with acceleration value of bare frame without water tank.

From the results, it can be seen that for three tank condition,

- On observing the displacement values, providing a water depth ratio of 20% gives the least displacement with 29.48% reduction in x-direction and 37.82% reduction in y-direction while compared to the displacement happening in condition of bare frame without water tank.
- On observing the base shear values, providing a water depth ratio of 20% gives the least base shear value with 34.39% reduction in x-direction and 32.93% reduction in y-direction while compared to the base shear values of bare frame without water tank.
- On observing the drift values, providing a water depth ratio of 20% gives the least drift values with 34.49% reduction in x-direction and 37.74% reduction in y-direction while compared to the drift values of bare frame without water tank.
- On observing the time period values, providing a water depth ratio of 20% gives the least time period value with 10.52% increment in x-direction and 11.71% increment in y-direction while compared to the time period value of bare frame without water tank.
- On observing the acceleration values, providing a water depth ratio of 40% gives the least acceleration with 4.15% reduction in x-direction while compared with acceleration value of bare frame without water tank.
- On analysis of all the conditions, it has been found that the building gives its best seismic mitigation response on placing of three tanks as done in the model with the water tanks filled with 20% of their total capacity with water.

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