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Life cycle cost analysis of overhead water tank as a liquid damper

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Abstract - *This paper investigates the benefits of overhead water tank with respect to cost. There are three different types of dynamic vibration absorber which are sub types of passive damper such as tuned liquid damper, tuned liquid column damper, tuned mass damper. The water tank where used as damper will get the several benefits than the other two dampers. Every building is having water tank and if used it as damper will serve our purpose in both directions as damper and as storage of water also. The comparison is done between Tuned mass damper, Tuned liquid damper and Tuned liquid column damper which are the types of dynamic vibration absorbers which are passive dampers. The life cycle cost is considered during the study.*

***Key Words*: Tuned mass damper, Tuned liquid damper, tuned liquid column damper, Lifecycle, etc**

1. INTRODUCTION

The current trend toward buildings of ever increasing heights and the use of light weight, high strength materials, and advanced construction techniques have led to increasingly flexible and lightly damped structures. Understandably, these structures are very sensitive to environmental excitations such as wind, ocean waves and earthquakes. This causes unwanted vibrations inducing possible structural failure, occupant discomfort, and malfunction of equipment. Hence it has become important to search for practical and effective devices for suppression of these vibrations. This has opened up a new area of research in the last decade. Overhead water tank is important part of building.

Every building which is residential or nonresidential has an overhead water tank. The water is good source for absorbing the vibration if we use it in proper manner and which is proved in several studies such as Bhosale, Mondal, and Yannawar.

The devices used for mitigating structural vibrations are divided into separate categories based on their system requirements. Passive control devices are systems which do not require an external power source. These devices impart forces that are developed in response to the motion of the structure.

There are three different types of dynamic vibration absorber which is sub types of passive dampers are tuned liquid damper, tuned liquid column damper, tuned mass damper. The water tank is used as damper will get the several benefits than the other two dampers. Every building is having water tank and if used it as damper which will serve our purpose in both direction as damper and as storage of water also.

The paper shows the benefits of water tank as damper over the other two dampers. The comparison is done by keeping same structure for all the three types and the main focus is on cost over the different benefits of damper. Life cycle cost is considered during the comparison of the damper.

2. LITERATURE REVIEW

Mondal ET all (2014) [1] based on the experimental performance, showed the efficiency of the Tuned Liquid damper in dampening the acceleration and displacement of structure when the structure's base was excited. From the theoretical and experimental results obtained it was confirmed that TLD was most effective when the structure was excited at resonance frequency of the structure, reducing the ratio from 22 to 4 (80% reduction in vibration). Theoretical model was successful in modeling the behavior o f the building.

Bhosale, Patil, Maskar (2014) [2] different mass ratios ranging from 0.5 to 6 % of the structure to evaluate the effectiveness of TLD. The reduction in the displacement is significant as the mass ratio increases up to 4 %.The increase in mass ratio from 3% to 4% increase the efficiency in the displacement reduction only by 4%, though the considerable mass of the water is used.

Yannawar, Patil (2014) [3] observe that the displacement in the x-axis, y-axis and z-axis without water tank is more than the displacement with water tank placed at the top. Thus, it can be said that when the water tank is placed at the top of the frame and when the experiment is conducted it was proved that the water tank acts as a tuned liquid damper and it dampens the displacement to the minimum.

The damping ratio of the structure is evaluated experimentally with and without TLD corresponding to the resonance condition. They observed that the presence of TLD enhances the structural damping.

From this study, they inferred that properly designed TLD with efficient design parameters such as tuning ratio, depth ratio and mass ratio is considered to be a very effective device to reduce the structural response.

3. OBJECTIVE OF THE STUDY

The main objective of the study is to do the cost/benefits analysis of the passive dampers by considering the life cycle cost of the structure.

4. METHODOLOGY

The study of TLD is done with experimental setup. The model is prepared with aluminum bar. The result obtained is analyzed. The required size of water tank to use as liquid damper is decided for the structure. The cost is calculated for the different passive dampers. The life cycle cost is calculated for the entire passive dampers.

5. EXPERIMENTAL PROGRAM

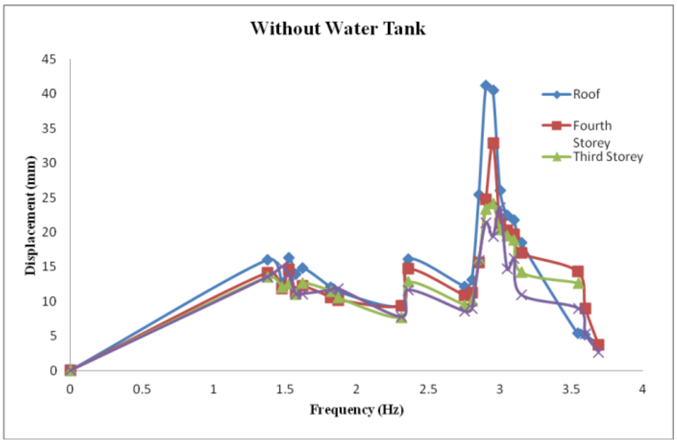

Chart -1: Structural response without water tank

Above graph (Chart 1) shows the displacement of structure against frequency of earthquake. The maximum displacement is 42mm seen in the graph at 3 hz frequency for top floor, which is at no liquid damper condition.

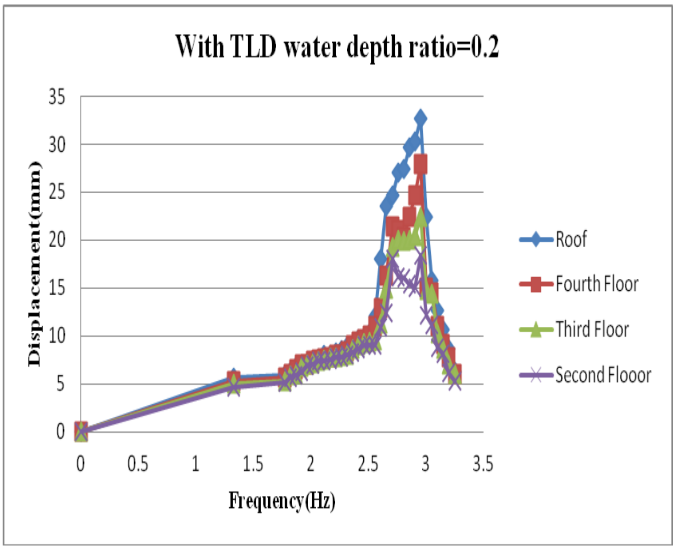

Chart -2: Structural response with water tank with W/D = 0.2

Above graph (Chart 2) shows the displacement of structure against frequency of earthquake. The maximum displacement is 33mm seen in the graph at 3 hz frequency for top floor, which is at 0.2 water depth ratio of water tank. In the previous graph it is seen that the displacement is 42mm which reduces to 33mm due to use of water tank as damper.

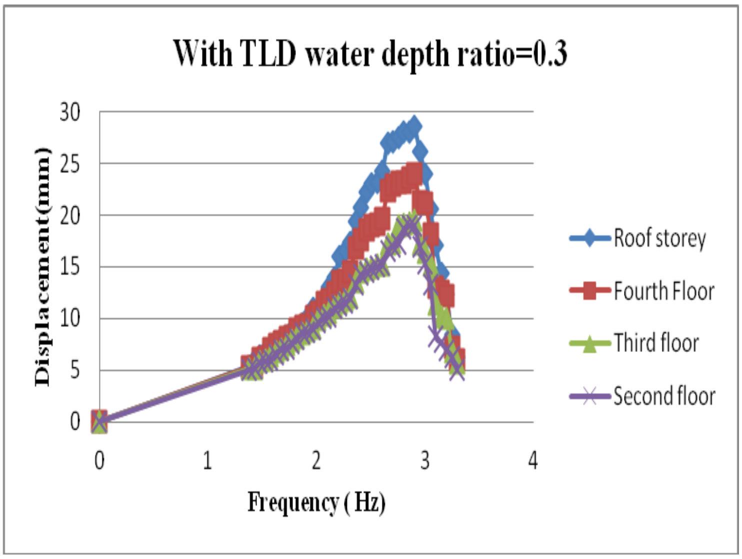

Chart -3: Structural response with water tank with W/D = 0.3

Above graph (Chart 3) shows the displacement of structure against frequency of earthquake. The maximum displacement is 28mm seen in the graph at 3 hz frequency for top floor, which is at 0.3 water depth ratio of water tank.

In the previous graph it is seen that the displacement is 42mm which reduces to 29mm due to use of water tank as damper.

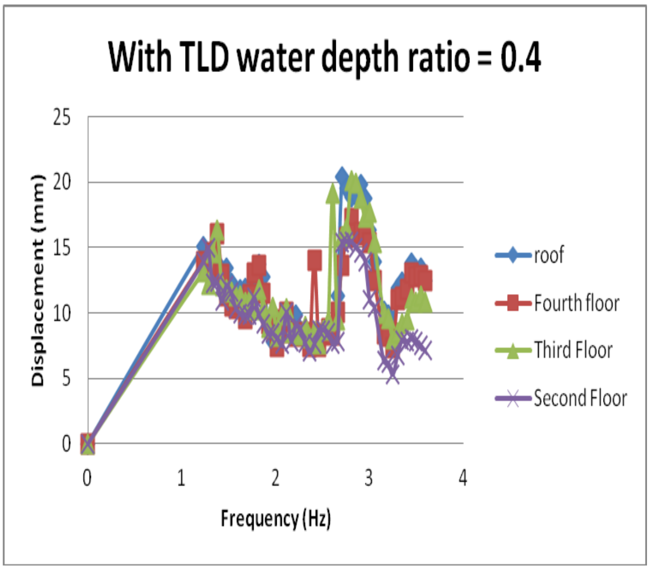

Chart -4: Structural response with water tank with W/D = 0.4

Above graph (Chart 4) shows the displacement of structure against frequency of earthquake. The maximum displacement is 20mm seen in the graph at 3 hz frequency for top floor, which is at 0.3 water depth ratio of water tank. In the previous graph it is seen that the displacement is 42mm which reduces to 20mm due to use of water tank as damper.

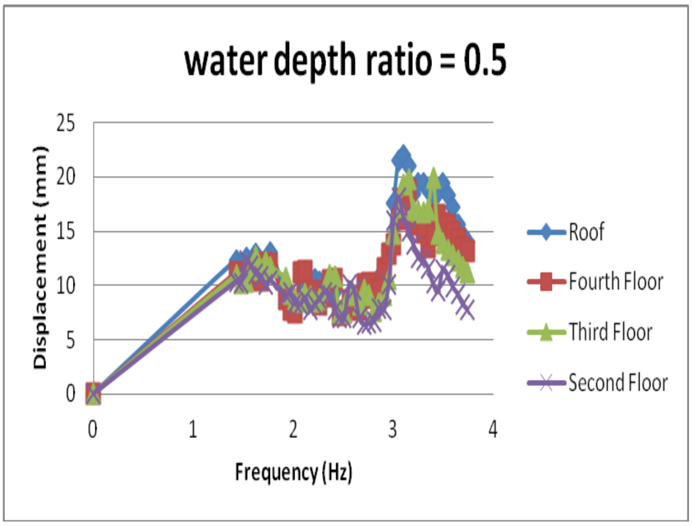

Chart -5: Structural response with water tank with W/D = 0.5

Above graph (Chart 5) shows the displacement of structure against frequency of earthquake. The maximum displacement is 23mm seen in the graph at 3 hz frequency for top floor. Which is at 0.5 water depth ratio of water tank. In the previous graph it is seen that the displacement is 42mm which reduces to 23mm due to use of water tank as damper.

6. DATA ANALYSIS

Table -1: Cost of dampers

Factors	TLD	TLCD	TMD
Initial investment used as cost of construction in Rs.	2,15,400	3,98,215	7,35,115
Cost of maintenance per year in Rs.	10,000	12,000	15,000
Cost of operation per year in Rs.	5,000	5,000	0

Above table shows the cost of passive dampers. The initial cost of TLD and TLCD is the construction cost of water tank and for TDM the cost is of manufacturing cost of dampers and its installation charges. The maintenance cost contain the lubrication and replacement of any part for TDM and for TLD and TLCD the cost for repair work of tank, also the maintenance of water supply system like pump and pipeline . The operation cost contains the water charges and the power requires lifting the water.

Table 2. Benefits of dampers

Factors	TLD	TLCD	TMD
Cost of construction	Low	Moderate	High
Cost of maintenance	No	No	Yes
Time require for construction	45 days	60 days	20 days
Ease of construction	Easy	Moderate	Hard
Skill required	Medium	Medium	High
Technological requirement	No	No	Yes
During earthquake displacement reduction	50 %	60 %	55 %
Power required	No	No	Yes
Effectiveness	Moderate	High	Moderate
Engineering and design	Easy	Moderate	Hard

Above table. 2 show the different benefits of the damper and their comparison. The TLCD is more effective in vibration reduction but the disadvantage of the TLCD over the TLD is the water level in TLCD is should be same while in TLD if it reduces in some amount it will not cause more effect on result. Also the extra water can be used for firefighting system. The above three dampers are the type of passive dampers so the external power is not required for any system to start or trigger the system.

Life cycle calculation for water tank as liquid damper
Design life 30 year.
Consider discount rate at 10%
10 % increase in operation and maintenance cost after every 5 year...

Table 3. NPV for TLD

Year	Initial investment	Maint. cost Annual + Periodic after 5 year	Operation cost	Disc. maint. cost	Disc. operation cost
0	2,15,400				
1		10,000	5,000	9091	4545
2		10,000	5,000	8264	4132
3		10,000	5,000	7513	3757
4		10,000	5,000	6830	3415
5		10,000	5,000	6209	3105
6		11,000	5,500	6209	3105
7		11,000	5,500	5645	2822
8		11,000	5,500	5132	2566
9		11,000	5,500	4665	2333
10		11,000	5,500	4241	2120
11		12,100	6,050	4241	2120
12		12,100	6,050	3855	1928
13		12,100	6,050	3505	1752
14		12,100	6,050	3186	1593
15		12,100	6,050	2897	1448
16		13,310	6,655	2897	1448
17		13,310	6,655	2633	1317
18		13,310	6,655	2394	1197
19		13,310	6,655	2176	1088
20		13,310	6,655	1978	989
21		14,641	7,320	1978	989
22		14,641	7,320	1799	899
23		14,641	7,320	1635	817
24		14,641	7,320	1486	743
25		14,641	7,320	1351	676
26		16,105	8,052	1351	676
27		16,105	8,052	1228	614
28		16,105	8,052	1117	558
29		16,105	8,052	1015	508
30		16,105	8,052	923	461
				107447	**53723**

Life cycle cost over 30 year = Net present cost
= 2, 15,000 + 1, 07,400 + 53,723
= 3, 76,123/-

Life cycle calculation for TLCD
Design life 30 year.
Consider discount rate at 10%
10 % increase in operation and maintenance cost after every 5 year.

Table. 3 NPV for TLCD

Year	Initial investment	Maint. cost Annual + Periodic after 5 year	Operation cost	Disc. maint. cost	Disc. operation cost
0	398215				
1		12,000	5,000	10909	4545
2		12,000	5,000	9917	4132
3		12,000	5,000	9016	3757
4		12,000	5,000	8196	3415
5		12,000	5,000	7451	3105
6		13,200	5,500	7451	3105
7		13,200	5,500	6774	2822
8		13,200	5,500	6158	2566
9		13,200	5,500	5598	2333
10		13,200	5,500	5089	2120
11		14,520	6,050	5089	2120
12		14,520	6,050	4627	1928
13		14,520	6,050	4206	1752
14		14,520	6,050	3824	1593
15		14,520	6,050	3476	1448
16		15,972	6,655	3476	1448
17		15,972	6,655	3160	1317
18		15,972	6,655	2873	1197
19		15,972	6,655	2612	1088
20		15,972	6,655	2374	989
21		17,569	7,320	2374	989
22		17,569	7,320	2158	899
23		17,569	7,320	1962	817
24		17,569	7,320	1784	743
25		17,569	7,320	1622	676
26		19,325	8,052	1621	676
27		19,325	8,052	1474	614
28		19,325	8,052	1340	558
29		19,325	8,052	1218	508
30		19,325	8,052	1107	461
				128936	**53723**

Life cycle cost over 30 year = Net present cost

5, 80,874 = 3, 98,215 + 1, 28,936 + 53,723

Life cycle calculation for TLCD
Design life 30 year.
Consider discount rate at 10%
10 % increase in operation and maintenance cost after every 5 year...

Table. 3 NPV for TMD

Year	Initial investment	Maint. cost Annual + Periodic after 5 year	Operation cost	Disc. maint. cost	Disc. operation cost
0	7,35,115				
1		15,000	0	13636	0
2		15,000	0	12397	0
3		15,000	0	11270	0
4		15,000	0	10245	0
5		15,000	0	9314	0
6		16,500	0	9314	0
7		16,500	0	8467	0
8		16,500	0	7697	0
9		16,500	0	6998	0
10		16,500	0	6361	0
11		18,150	0	6361	0
12		18,150	0	5783	0
13		18,150	0	5257	0
14		18,150	0	4779	0
15		18,150	0	4345	0
16		19,965	0	4345	0
17		19,965	0	3950	0
18		19,965	0	3591	0
19		19,965	0	3264	0
20		19,965	0	2968	0
21		21,961	0	2968	0
22		21,961	0	2698	0
23		21,961	0	2453	0
24		21,961	0	2230	0
25		21,961	0	2027	0
26		24,157	0	2027	0
27		24,157	0	1843	0
28		24,157	0	1675	0
29		24,157	0	1523	0
30		24,157	0	1384	0
				161170	**0**

Life cycle cost over 30 year = Net present cost
= 7, 35,115 + 1, 61,170 + 0
= 8, 96,285/-

7. CONCLUSION AND DISCUSSION

Earthquake causes loss of life and wealth. In the developing country like India the initial investment over the earthquake resisting system is not possible also the construction cost should be minimum is the prior demand of owner while constructing building or while purchasing home or flat. To satisfy their demands and also keep the structure safe the main challenge in front of the engineers. To overcome from this problem water tank can be used as liquid damper. This is important and essential part of each public and residential building. While doing the experimental study of water tank as liquid damper it shows the positive result.

The displacement of building started reducing from 43mm at 0.2 water depth ratio to 21mm at 0.4 water depth ratio. 0.4 water depth ratio is acceptable for the building.

It is found that during literature study the other systems also show effective results. But the cost of water tank is less than TLCD and TDM and the benefits of water tank as liquid damper more than TLCD and TMD.

Also the extra water place in water tank can be used in firefighting system.

8. REFERENCE

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