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Shake Table Testing of Tuned Liquid Damper Modified with Rubber Mesh to Control Seismic Vibration of Structure

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***Abstract*—The main focus of this paper is to minimize the response induced from seismic excitation using Tuned Liquid Damper (TLD) modified with rubber mesh. An over-head water tank was used as passive damper. A prototype structure with 20 inch by 20 inch steel plate slab and 6 ft height was constructed as a two storied prototype structural model to perform shake table experiment. Time history of El-Centro earthquake was applied as input ground motion using shake table. Different cases of rubber mesh with different water height were studied. From the uncontrolled and controlled data, it was found that in almost every case displacement decreases. Optimal water depth of rubber mesh was suggested on which displacement decreases most. From the results, it was concluded that the TLD modified with rubber mesh is very effective and efficient way to reduce structural vibration.**

Keywords:, *rubber mesh, shake table, sloshing**,** Tuned Liquid Damper*

I. Introduction

Vibration control is a crucial factor to consider while designing a structure, particularly if it is tall [1], [2]. Due to space constraints in cities, towering buildings are built, which are generally composed of light, flexible materials with little damping, thus prone to vibration. Several approaches exist now to reduce structural vibration. A large-scale investigation of a potential technology for strengthening of buildings includes attaching shallow water tanks to the structure's roof and relying on the resulting sloshing wave to absorb energy [3]. One is the use of liquid dampers [4]. Tuned Liquid Dampers are a type of structural vibration damper. The Tuned Liquid Damper (TLD) is a kind of Tuned Mass Damper (TMD) in which liquid replaces mass. TLD is made up of a liquid-filled tank with a sloshing motion that is tailored to the structure's inherent frequency. TLDs are frequently installed at the top of structures, and the TLD's liquid sloshing action counteracts and lowers structural vibration when the structure is subjected to external excitation. Experiments and numerical simulations have been conducted in recent years to demonstrate the efficiency of TLD as a vibration control device for buildings subjected to both harmonic and broad-band base excitations [5]–[8]. There has also been research done to increase the TLD's efficacy. The sloshing fluid of a TLD fitted with dampening screens was examined by Tait et al. (2005). Reed et al. (1998) used laboratory tests and computer modelling to explore the behavior of TLDs [9], [10]. The focus of his research was on large-amplitude excitations, whereas most previous experiments were on TLDs that were exposed to small-amplitude excitations [11]. The response of a TLD to large-amplitude excitations is found to be considerably different from that of small-amplitude excitations, attributed to the high possibility of surface-wave breaking. An analysis was conducted using Weighted Desirability Function (WDF) and Response Surface Methodology (RSM) paired central composite design and Weighted Desirability Function (WDF) to minimize the vibration caused by a pump on a steel floor (WDF) [12]. According to a research findings conducted by Rahman et al. (2020), the Stockbridge Damper is particularly successful in reducing vertical vibration, or floor vibration [1]. The analytical findings from the research conducted by Ashrafuzzaman et al.(2016) reveal that the features of earthquake ground motion recordings have a substantial impact on the seismic reactions of rubber bearings [13] . The research study conducted by Rahman and Hasnat (2018) focuses on applying the same approach as TMD to adapt the roof-top garden as a passive vibration controlling device (RTGD) [2]. A research was also carried out emphasizing on tuned liquid dampers (TLDs) that employ liquids with various properties that are optimized using the adaptive harmony search method (AHS) [14]. In this research, the researcher did not deal with the rubber mesh in the TLD system to increase the efficiency of TLD. Another research was done by exposing structure to an earthquake (the El-Centro Earthquake), and the frequency response was examined without and with TLDs [15] .

In this study, El-Centro earthquake data is applied to measure the vibration on a prototype two storied building structure using the shake table to analyse the displacement of the structure before and after installing the TLD. Tuned liquid

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dampers is used as dynamic vibration absorbers to minimize the vibration of structures. Then the TLD was modified with rubber mesh to reduce more vibration of the structure. Optimum water depth is suggested after experiments.

II. Methodology

Structural model set up was done by using a two-steel frame which is made by steel plate having a fixed support as support system. Dimension of the prototype structure was 50.8 cm length, 50.8 cm width, 91.44 cm story height (Fig. 1 and Fig.2). A rectangular water tank was set at the top of the steel frame structural model. The experimental program was done by filling up the water tank (Fig. 3) at three different depth of water - 3cm, 5cm, and 7cm. Dimension of the water tank was 45.72 cm length, 22.86 width, 45.72 cm height (Fig. 4).

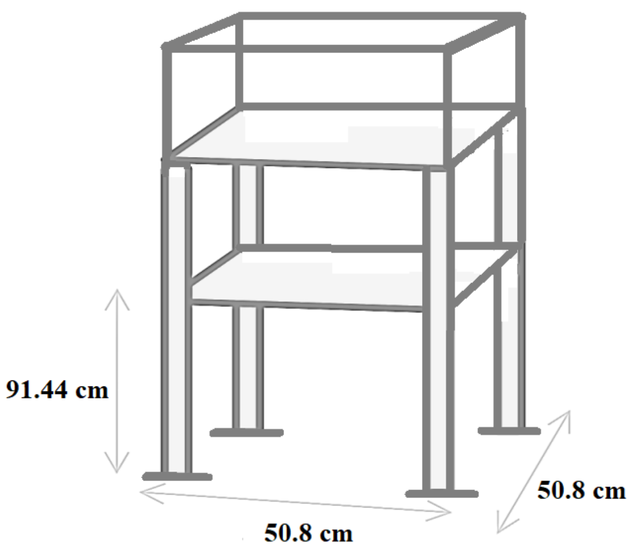


Fig. 1. Dimension of two storied Structural model

Fig. 2. Prototype of two storied Structural model

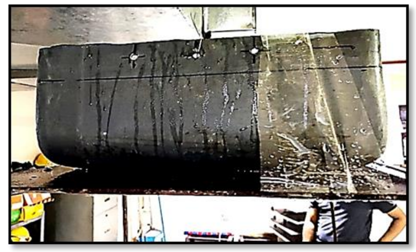


Fig. 3. Water tank

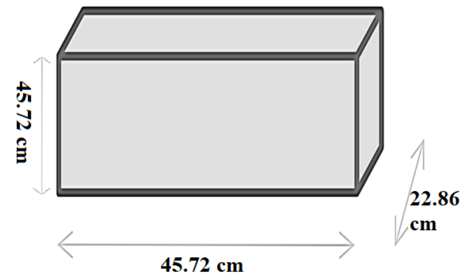
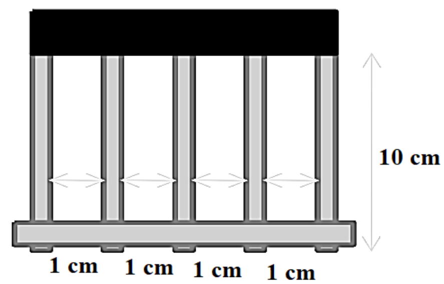
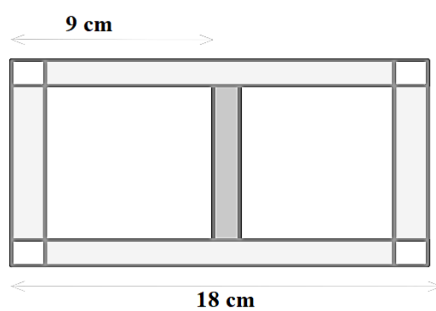


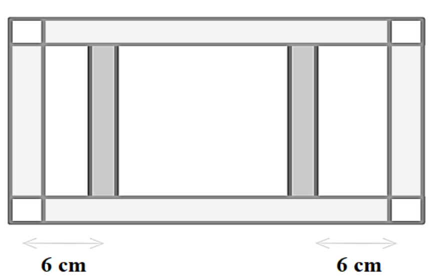
Fig. 4. Dimension of water tank



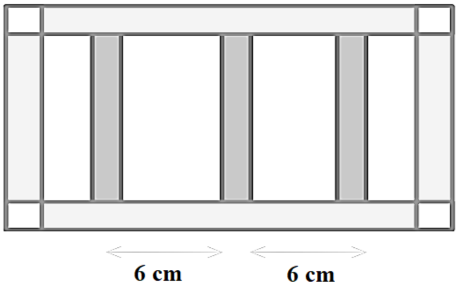
(a) Cross section of single row rubber tube



(b) Cross section single row rubber tube in water tank



(c) Cross section double row rubber tube in water tank



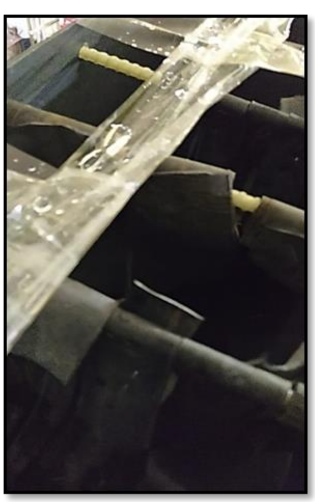
(d) Cross section triple row rubber tube in water tank

Fig. 5. Cross section of rubber mesh in water

The tuned liquid damper (TLD) was modified by the hanging floating rubber tube. Five rubber tubes were used in each row and each rubber tube height was 10cm and thickness of rubber was 2 mm. After setting up the water tank on top of the structure, El Centro ground motion was applied by shake table. Then the displacement of uncontrolled structural model was recorded. The time interval was 0.5 sec and total time of processing was 25 sec. Three types of analysis were performed for controlled structure to obtain the results: one row rubber mesh in the middle; two row rubber mesh in two side; three row rubber mesh (Fig. 5). Details of the rubber mesh in water tank is shown in Fig. 6.

(a) Single Damper

(b) Double Damper



(c) Triple Damper

Fig. 6. Damper set up in water tank at top of the structural model

III. EXPERIMENTAL ANALYSIS & RESULT

A. Uncontrolled Structure Analysis

In this study, for time history analysis North-South component of El-Centro 1940 earthquake was applied in the uncontrolled structure (Fig. 7). Acceleration time history of 1560 load steps with an equal spacing of 0.02 second and maximum PGA of 0.34g was applied on the uncontrolled structural model. After applying the electro ground motion, the displacement was measured. The time interval was taken 0.5 sec and total time of process is 25 sec. For the uncontrolled structure displacement was as Fig. 8. From the Fig. 8, maximum displacement was observed 53.9 mm at time 6 sec.

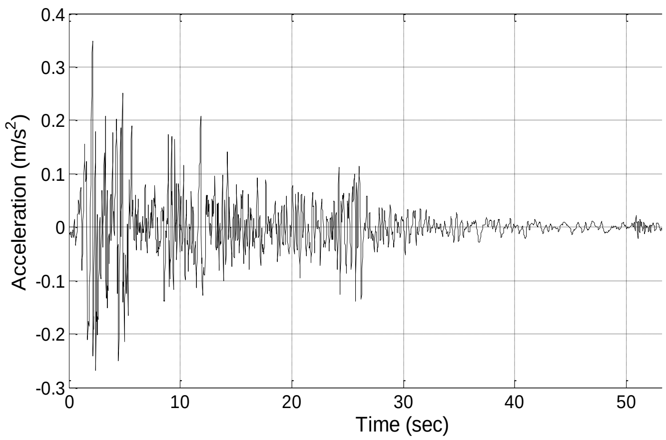


Fig. 7. Time history of El-Centro Earthquake

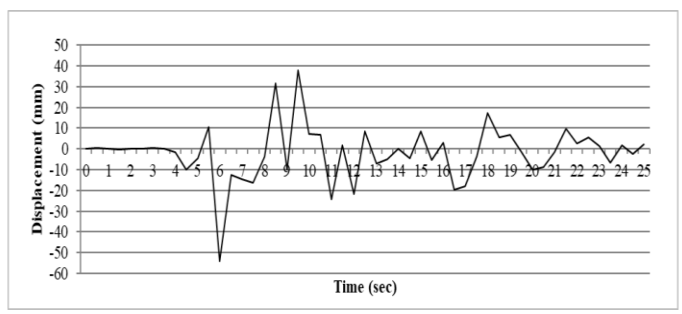


Fig. 8. Displacement vs. Time of Uncontrolled Structure

B. Control Structure Analysis with Water Tank

After setting the water tank on top of the structure, again El Centro ground motion was applied. Three type of water depth in tank was considered for analysis (3cm, 5cm, 7cm). After proceeding the process, displacement of the control structure with water at different water height was found as the Fig. 9.

From Fig. 9, values of maximum displacement extracted in Table I. Table shows the maximum displacement with respect to different water depth.

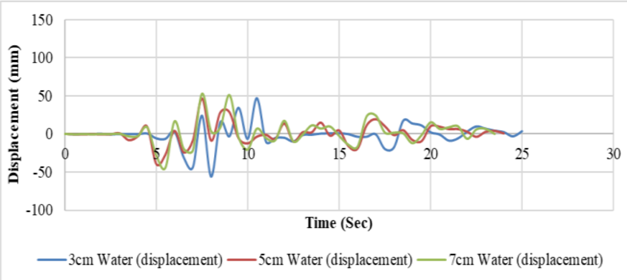


Fig. 9. Displacement vs Time (at different water depth)

TABLE I
MAXIMUM DISPLACEMENT AT DIFFERENT WATER DEPTH

Water Depth (cm)	Maximum Displacement (mm)
3 cm	-56.0641
5 cm	46.54
7 cm	52.698

From Table I, it is evident that for 5 cm water depth the displacement is less than 3 cm and 7 cm. So, 5 cm is considered as optimum water depth for the structure to control.

C. Control Structure Analysis with Water Tank and Rubber Mesh

Three cases of rubber mesh (damper) were considered for analysis.

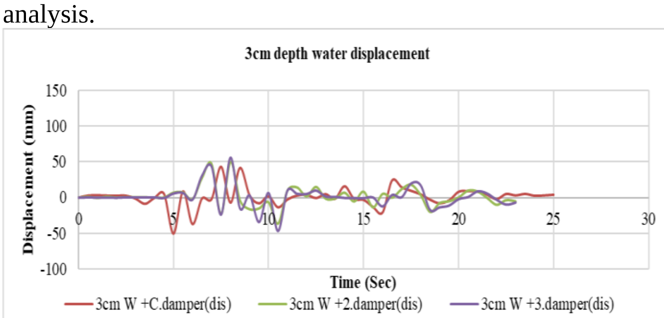


Fig. 10. Displacement vs Time (3 cm water depth with various rubber mesh)

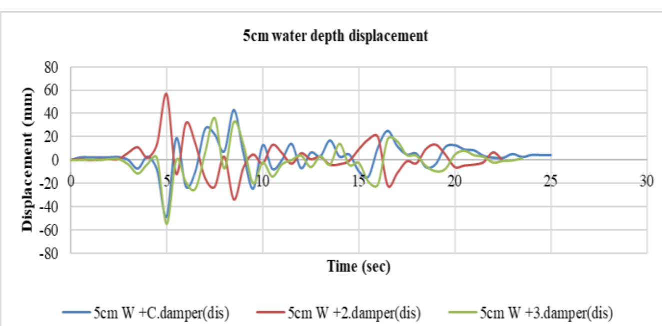


Fig. 11. Displacement vs Time (5 cm water depth with various rubber mesh)

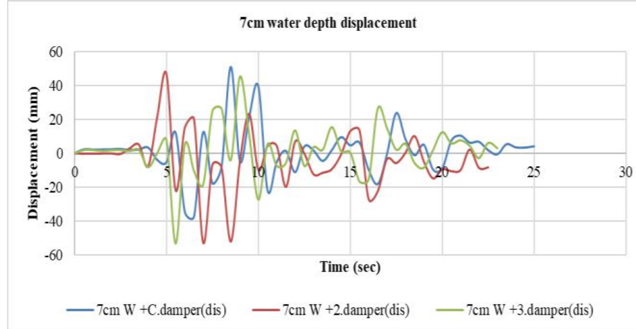


Fig. 12. Displacement (7cm with various rubber mesh)

From Table II, it was observed that, at 5 cm water depth, single row rubber mesh and three row rubber mesh performed better. and two row rubber meshes give better performance at 3 cm water.

TABLE II
MAXIMUM DISPLACEMENT AT WATER DEPTH AND RUBBER MESH

	3cm	5cm	7cm
Single row rubber mesh	52.443	42.993	50.876
Two row rubber mesh	50.0283	56.6234	46.7503
Three row rubber mesh	56.0641	36.103	45.147

IV. COMPARATIVE ANALYSIS

A. Uncontrolled structure and control structure with various water depth

After installing the water tank, the displacement of the structure has been measured at 3 cm, 5 cm, and 7 cm water depth. From Fig. 13 and Table III, it is observed that the displacement decrees most in control structure with 5 cm water depth is 13.6% than the uncontrolled structure.

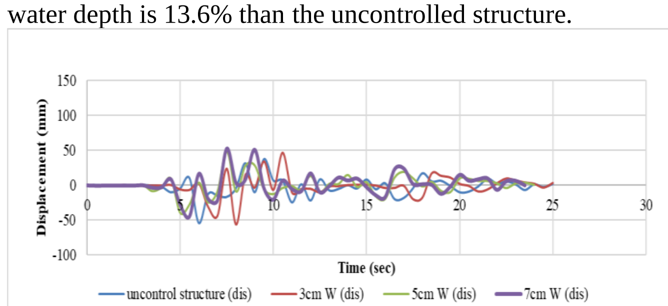


Fig. 13. Uncontrolled structure vs. controlled structure with various water depths

TABLE III
MAXIMUM DISPLACEMENT

	Maximum Displacement(mm)	Changes in displacement %
Uncontrolled structure	-53.9	
Controlled with 3 cm water depth	-56.064	-4.01484%

Controlled with 5 cm water depth	46.54	13.65492%
Controlled with 7 cm water depth	52.698	2.230056%

B. Uncontrolled structure and control structure with 3 cm water depth with various rubber mesh

In this step, single rubber mesh, double rubber mesh and triple rubber mesh were installed in 3 cm water depth of water tank. From Fig. 14 and Table IV, it is seen that the displacement decrees most in 3 cm water depth with double row rubber mesh. The value decrees 7.18% than the uncontrolled structure.

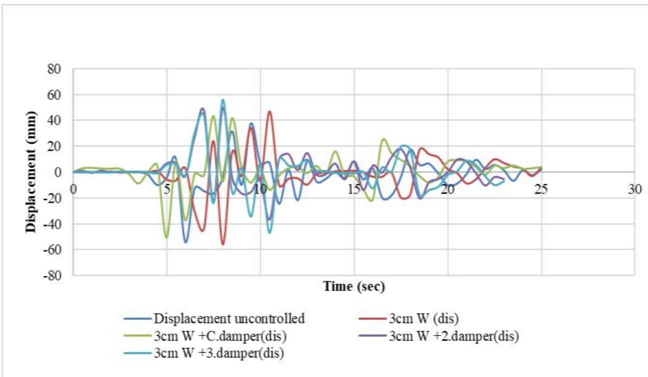


Fig. 14. Uncontrolled structure vs. controlled structure with 3 cm water depth with various rubber meshes

TABLE IV
MAXIMUM DISPLACEMENT

	Maximum Displacement(mm)	Changes in displacement %
Uncontrolled structure	-53.9	- -
Control structure with 3 cm water	-56.0641	-4.01503%
Controlled structure with Single row damper with 3 cm water	52.443	2.703154%
Controlled structure with Double row damper with 3 cm water	50.0283	7.183117%
Controlled structure with Triple row damper with 3 cm water	56.0641	-4.01503%

C. Uncontrolled structure and control structure with 5 cm water depth with various rubber mesh

In this step, single rubber mesh, double rubber mesh and triple rubber mesh were installed in 5 cm water depth of water tank.

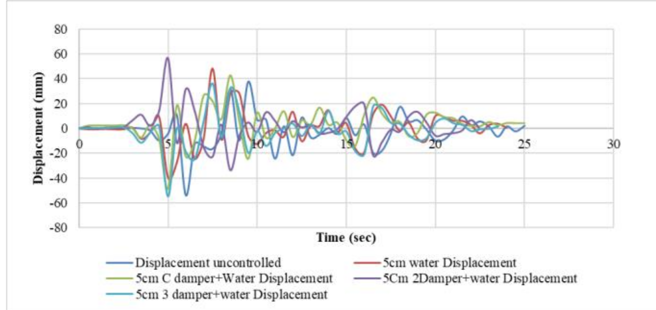


Fig. 15. Uncontrolled structure vs. controlled structure with 5 cm water depth with various rubber meshes

From Fig. 15 and Table V, it is observed that the displacement decrees most in 5 cm water depth with triple row rubber mesh. The value decrees 33.19% than the uncontrolled structure.

TABLE V
MAXIMUM DISPLACEMENT

	Maximum Displacement(mm)	Changes in displacement %
Uncontrolled structure	-53.9	--
Control structure with 5cm water	46.54	13.65%
Control structure with Single row damper with 5 cm water	42.93	20.35%
Control structure with Double row damper with 5 cm water	56.62	5.04%
Control structure with Triple row damper with 5 cm water	36.01	33.19%

D. Uncontrolled structure and control structure with 7 cm water depth with various rubber mesh

In this step, single rubber mesh, double rubber mesh and triple rubber mesh were installed in 7 cm water depth of water tank.

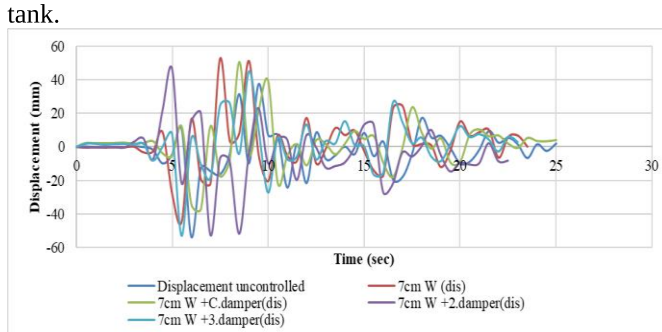


Fig. 16. Uncontrolled structure vs. controlled structure with 7 cm water depth with various rubber meshes

TABLE VI
MAXIMUM DISPLACEMENT

	Maximum displacement(mm)	Changes in displacement %
Uncontrolled structure	-53.9	-
Controlled structure with 7cm water	52.698	2.230056%
Controlled structure with Single row mesh with 7 cm water	50.876	5.61039%
Controlled structure	46.7503	13.26475%

with Double row mesh with 7 cm water		
Controlled structure with Triple row mesh with 7 cm water	45.147	16.23933%

From Fig. 16 and Table VI, it is evident that the displacement decrees most in 7cm water depth with double row rubber mesh. The value decrees 13.28% than the uncontrolled structure.

E. *Uncontrolled and optimum controlled structure*

Form the results, it was found that the optimum depth of water for control structure is 5 cm. And at the 5 cm water depth with triple rubber mesh, the displacement decreases most.

	Maximum Displacement(mm)	Changes in displacement %
Uncontrolled structure	-53.9	-
Controlled structure with 5 cm water	46.54	13.65%
Controlled structure with Triple row damper with 5 cm water	36.01	33.19%

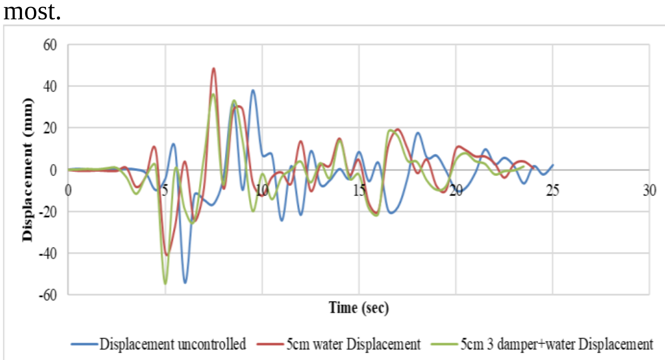


Fig. 17: Uncontrolled structure vs. optimum controlled structure

TABLE VII
MAXIMUM DISPLACEMENT

From Fig. 17 and Table VII, it is clear that the displacement decreases 13.65 % in 5 cm water depth than the uncontrolled structure. And after using modified triple rubber mesh in 5cm water depth, it decreases 33.19%.

V. CONCLUSIONS

The conclusions derived from experimental tests are:

1. The optimum water depth of the structure for TLD is 5 cm for given prototype structure. At 5 cm depth of water, the structure displacement decreases by 13.65% than the uncontrolled structure.
2. After modifying the TLD with rubber mesh damper, it gives better performance in single row damper in centre and triple row damper with 5 cm water. But two row rubber tube damper performed unsatisfactory.
3. Three row rubber mesh dampers with 5 cm water depth, show less displacement than any other case. The structure's displacement decreases by 33.19% than the uncontrolled structure.
4. TLD with 5 cm water depth with three row rubber tube mesh damper yields better performance.

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