

Rectangular and Cylindrical TLDs with Rotatable Baffles to Improve Seismic Behavior of Structures, a Numerical Study

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ABSTRACT: One of structural passive control methods is to use Tuned Liquid Damper (TLD). However, because of the nature of the TLD, only one tuning frequency can be created when the water is sloshing. To fix this problem, some installed rotatable baffles can be embedded inside TLD called Variably Baffled TLD (VBTLT) where by changing the angle of the baffles a tuning frequency range is created. This gives the passive control system the capability to be pre-tuned according to the desired frequency. In this paper, the effects of rectangular and cylindrical shapes of container on behavior of VBTLT are studied and numerically validated with experimental results. There are four baffles inside each damper tuned manually in different cases. In numerical investigation, the rectangular TLD created greater returning force than cylindrical TLD in all depth and angle selections. By increasing the baffle angle, from 0 ° to 80 ° at the water depths of 4, 5.2 and 6.4 cm, the control forces are increased 59.8%, 38.4% and 30.2% respectively for rectangular TLD and 58.4%, 50.4% and 46.1% for cylindrical TLD.

Keywords: Frequency, Rectangular And Cylindrical TLD, Returning Force, Rotatable Baffles, Water Pressure.

INTRODUCTION

With the advances in structural materials, the structures have been designed to be taller, lighter and more flexible. Thus the need to control such flexible structures has become more necessary using tuned dampers. Several studies have been conducted to optimize parameters of Tuned Mass Damper (e.g. Razavi and Shariatmadar, 2015). Another kind of such control devices is Tuned Liquid Damper (TLD) where a liquid (water) in a partially filled rectangular or circular tank is used for energy dissipation occurred through

fluid viscosity, wave breaking, and existence of screens and so like (Love and Tait, 2013).

Using TLDs for structural control has been the attention of a wide variety of research studies (Modi and Welt, 1987; Fujino et al., 1988). Also detailed theoretical, numerical and experimental investigations of the dynamic influence of TLDs mainly to mitigate wind effects has been presented in references (Wakahara et al., 1994; Tamura et al., 1995). Sheng et al. (2002) investigated the effectiveness of TLDs for suppressing the dynamic response of a platform structure subjected to wave loading and also to explore

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the applicability of TLDs for suppressing the structural vibration of fixed offshore platforms. The effects of a number of parameters including the container shape, container size, number of dampers, frequency ratio, mass ratio, and incident wave characteristics were investigated.

Using nonlinear time-history analyses, Zahrai and Kavand (2008) investigated the effects of earthquake characteristics such as frequency content and soil condition on the seismic behavior of TLCs. Selecting 16 records with different parameters, they showed that these characteristics have substantial role on the performance of TLCs and they should be accordingly considered in designing TLCs. Love and Tait (2010) used a model to describe the behavior of a TLD with damping screens and verified the model with shake table and structure-TLD system tests. As the fluid depth ratio decreased to 12%, some discrepancy was noticed between the model and test results. Thus, using nonlinear shallow water wave theory was suggested for smaller depth ratios.

The idea of using inclined slat screens to manage the damping ratio of TLDs was investigated by Cassolato et al. (2011). An approach to determine the pressure-loss coefficient for such inclined screens was introduced, to estimate the energy dissipated by the screens. The developed model could properly predict the energy dissipated per cycle. Using proper screen inclination, a single set of screens could induce the same damping ratio for various excitation amplitudes. Crowley and Porter (2012) described a method to accurately model these two effects by comparing the coefficients with equivalent and more appropriate models of flow passing a single slatted screen. Wu et al. (2012) numerically investigated liquid sloshing in tanks equipped with baffles using time-independent finite difference and fictitious cell method. The results indicated that the largest wave damping and the

smallest sloshing displacement would happen if the distance between two baffles is one fifth of length in rectangular TLD.

Zahrai et al. (2012) investigated the performance of TLD with rotatable baffles. Their results showed that using these baffles increases the damping ratio of TLD up to 20% while without baffles the damping ratio is 3%. Frequency of water sloshing increased to about 3 Hz while without baffles it was almost 1 Hz. They obtained that the rate of change in damping and frequency takes place in baffles orientation between 30 to 50 degrees and 40 to 50 degrees respectively. Lee and Juang (2012) experimentally studied a typical tension-leg type of floating platform incorporated with underwater tuned liquid column damper system (UWTLCD) to upgrade the structural safety using reduction of the wave induced vibrations and stresses on the offshore floating Platform. They realized that the properly designed UWTLCD system could effectively reduce the vibration amplitude and dynamic behavior of the offshore platform.

Hamelin et al. (2013) studied TLDs with a keulegan–carpenter number-dependent screen drag coefficient and their results indicated that a KC-dependent screen drag coefficient leads to a more robust TLD maintaining performance along a broader range of response amplitudes. Molin and Remy (2013) proposed a rectangular TLD with vertical installed perforated screens. They showed that by decreasing the porosity of screens the energy dissipation of water sloshing is increased.

Cheng et al. (2015) considered Magneto-Rheological (MR)-fluid viscosity by considering an equivalent linear damping rather than the non-linear one. To obtain reliable parameters for designing the MR-TLCD system and also to check its applicability to structures, they conducted some tests subjecting the system to strong ground excitations. They found that the

properly tuned MR-TLCD system could successfully reduce the dynamic response.

Ruiz et al. (2016) introduced a new type TLD with Floating Roof (TLD-FR). The results of their modeling and experimental studies indicate that, despite the case for TLDs, the response of the TLD-FR is essentially linear without experiencing an appreciable amplitude dependency. The TLD-FR performs mainly as a SDOF system, which is a consequence of the floating roof preventing wave breaking, and at the same time showing a considerable level of inherent damping. To study the overall effectiveness of TLD and specific effect of TLD parameters on structural response, Bhosale and Murudi (2017) conducted some experiments on flat and sloped bottom TLD, for different types of structures, mass ratio, and depth ratio. They experimentally showed that a properly designed TLD reduces structural response and observed that increasing mass ratio would increase the effectiveness of TLD. They found that sloped bottom TLD in reducing the response of structure has more efficiency.

Zahrai and Enayati (2017) proposed a variably baffled TLD to reduce seismic response of structures and evaluated its behavior under near and far field earthquakes. By changing the angles of baffles, they changed damping of structural models using an efficient semi-active control algorithm. Considering maximum roof displacement and its root mean squared value showed that TLD with variable baffles exhibits excellent performance under both near and far-field earthquakes while creates further response reduction under near field earthquakes. However, response reductions in angles of 0° and 20° were more than those in angles of 50° and 70° .

While many researchers highlighted the limitation and weakness of TLDs against different earthquakes with various frequency contents, in this paper, the effects of container

shape and baffle angle are investigated to improve the seismic performance of TLDs. The main purpose of this paper is to numerically investigate the effect of cylindrical and rectangular shapes of TLD with baffles adjusted at different angles. All the numerical conditions like quantity of cross section, position of installed baffles and the mass of water inside the dampers are identical for both TLDs.

NUMERICAL MODELING

For meshing the containers and the simulation of inside water sloshing, the software programs GAMBIT2.4.6 and FLUENT6.3.26 are used respectively. Since to consider modeling shallow water sloshing in containers it is necessary to use two-phase models, it is assumed that two fluids (air and water) do not mix during sloshing. So the best method for modeling fluid issues related to two non-compatibility is Volume of Fluid (VOF) modeling.

VOF Model

VOF model is used to simulate immiscible fluids with clearly defined interface but it is not appropriate if interface length is small compared to a computational grid. The VOF formulation relies on the fact that two or more fluids (or phases) are not interpenetrating. For each additional phase added to the model, a variable is introduced: the volume fraction of the phase in the computational cell. As long as the volume fraction of each phase is known at each location the fields for all variables and properties are shared by the phases and represent volume-averaged values. Thus the variables and properties in any given cells are either purely representative of one of the phases, or representative of a mixture of the phases, depending upon the volume fraction values. Therefore, if the q^{th} fluid's volume fraction in the cell is denoted by α_q , then the following three cases are possible:

$\alpha_q = 0$ The cell is empty (of the q^{th} fluid).
 $\alpha_q = 1$ The cell is full (of the q^{th} fluid).
 $0 \leq \alpha_q \leq 1$ The cell contains the interface between the q^{th} fluid and one or more other fluids.

VOF formulation is suitable for issues in which modeling of two or more non-mixing fluids is considered. Since the containers are modeled here with four internal baffles and two parallel walls at the direction of turbulent flow, the symmetry condition is established and at the other walls, the flow velocity is equal to zero. In the upper wall the relative pressure is always equal to zero.

Volume Fraction Relation

The solution of a continuity equation for the volume fraction of one (or more) of the phases can lead to the tracking of the interface(s) between the phases. For the q^{th} phase, such relation gets the following shape:

$$\frac{1}{\rho_q} \left[\frac{\partial}{\partial t} (\alpha_q \rho_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q) \right] = \sum_{p=1}^n (\dot{m}_{pq} - \dot{m}_{qp}) \quad (1)$$

$$\sum_{q=1}^n \alpha_q = 1 \quad (2)$$

where \dot{m}_{qp} : is the mass transfer from phase q to phase p and \dot{m}_{pq} : is the mass transfer from phase p to phase q and n is the number of phases.

After solving a single momentum equation throughout the domain, the resulting velocity field can be shared among the phases. The momentum equation, shown in Eq. (3), depends on the volume fractions of all phases through the properties ρ and μ :

$$\begin{aligned} \frac{\partial}{\partial t} (\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) \\ = -\nabla p \\ + \nabla \cdot [\mu (\nabla \vec{v} + \nabla \vec{v}^T)] + \rho \vec{g} \\ + \vec{F} \end{aligned} \quad (3)$$

where \vec{F} : is the body force. The energy equation, also shared among the phases, is shown below:

$$\begin{aligned} \frac{\partial}{\partial t} (\rho E) + \nabla \cdot (\vec{v} (\rho E + p)) \\ = \nabla \cdot (k_{eff} \nabla T) + S_h \end{aligned} \quad (4)$$

in which ρ : is density, k_{eff} : is effective thermal conductivity, v : is velocity, P : is pressure, S_h : is source term for energy transfer description, E : is energy and T : is the temperature. E and T are treated as mass averaged variables.

Design Modeling of TLDs with Rotatable Baffles

In this study, the rectangular and cylindrical containers are used and modeled by GAMBIT and FLUENT6.3.26 programs. The diameter of cylindrical damper is selected 46 cm (Figure 1a) and for rectangular damper length and width are selected 52 and 32 cm (Figure 1b) respectively. Two containers have the same cross sectional area equal to 0.166 square meters. The fixed criterion to compare two dampers is the amount of water, i.e. the main question here is that how different forms of dampers with the same cross sectional area can ensure maximum reduction in the structural response. It should be noted that, the baffle position at the 28% of cylinder TLD due to the geometry of the cylindrical damper would be appropriate. Therefore, for further integration with the TLDs, position of the baffles of rectangular TLD is considered at 28% of its length. Four baffles are used for both dampers. The lengths of baffles are 16 cm and 20.2 cm in rectangular and cylindrical TLDs respectively and the thickness and height of baffles are 5 mm and 45 cm respectively. The water heights inside the TLDs are 4, 5.2 and 6.4 cm and the angles chosen for numerical modeling are 0°, 30°, 45°, 70° and 80° for both TLDs.



Fig. 1. a) Cylindrical TLD, b) rectangular TLD

Pulse Excitation

In this study, the TLDs are subjected to pulse excitation while the drag (returning) force is obtained by the software based on measurements of the water pressure. Pulse excitation is introduced by User-Defined Function (UDF) written in the C programming language. A constant acceleration of 1.3 m/s^2 is applied to the domain for 0.4 sec as a momentum source term. This excitation induces movement of the water inside the containers and after 0.4 sec in which the acceleration is zero, the water sloshing starts. Total duration of each simulation is 5 seconds. Since the base excitation is constant in all simulations, the results are comparable to each other.

Calibrating the Numerical Models

First the rectangular TLD is calibrated. Numerical modeling is calibrated in two forms: shape and size of the mesh elements.

Shape of the Mesh Elements

When the volume mesh is modeled with Hex elements, because of the baffles existence, inside the volume and upper and bottom faces are not meshed. Then the volume is meshed with Tet/Hybrid, and in the Fluent software the free surface of water is rippling. In the next step, the upper and bottom faces and the volume are meshed by Tri/Pave and Hex/Wedge respectively. This choice would not lead to two previous problems and this shape of the mesh elements is thus selected for cylindrical damper too.

Size of the Mesh Elements

To calibrate size of mesh element, key parameters must be compared to each other in different sizes of mesh elements for the TLDs. In this study, since the drag force acting on the TLD is an importance parameter, it is used here. For the rectangular TLD, the sizes 4, 8 and 16 mm are selected and the drag forces for these three sizes are compared in Figure 2.

According to Figure 2, the difference of accuracy in modeling with size of mesh elements 16 mm and 8 mm was much more than that for the size of mesh elements 8 mm and 4 mm, but the time required to run the model with size 4 mm was longer than that for the model with size 8 mm. Therefore, 8 mm was selected for the size of mesh elements in rectangular TLD.

For cylindrical TLD, the sizes 4, 8 and 16 mm were selected and the drag force for each of the three sizes as compared in figure 3 leads to a similar result like the rectangular TLD.

VALIDATING NUMERICAL MODELS BY EXPERIMENTAL WORK

Figure 4 shows the graphical layout of physical model in experimental work. The fixed criterion to compare two TLDs was the amount of their inside water. In this investigation the problem was that with a certain amount of water, how different shapes of TLD containers with the same cross

sectional area could influence to ensure maximum reduction in the structural response.

As mentioned before, the baffles position was 28% of the cylinder diameter due to the

geometry of the cylindrical TLD (Figure 5). Therefore, to maintain further integrity for the dampers, position of the baffles of rectangular TLD was considered 28% of its length (Figure 6).

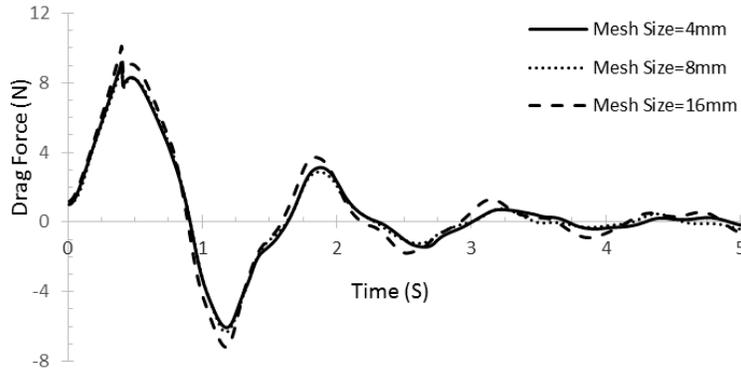


Fig. 2. Comparing drag forces of the rectangular TLD for different Size of the mesh elements

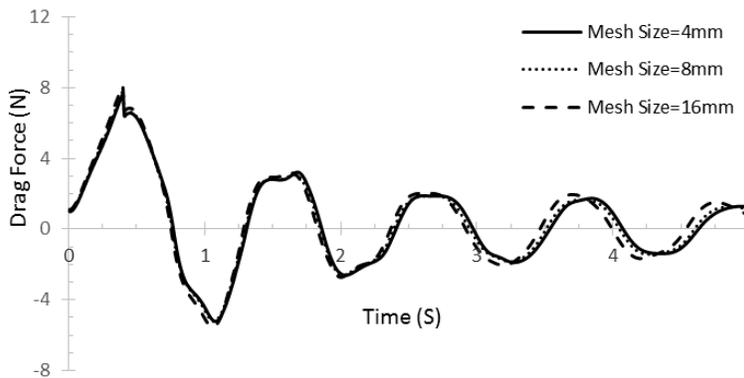


Fig. 3. Comparison drag force of cylindrical TLD for different size of the mesh elements

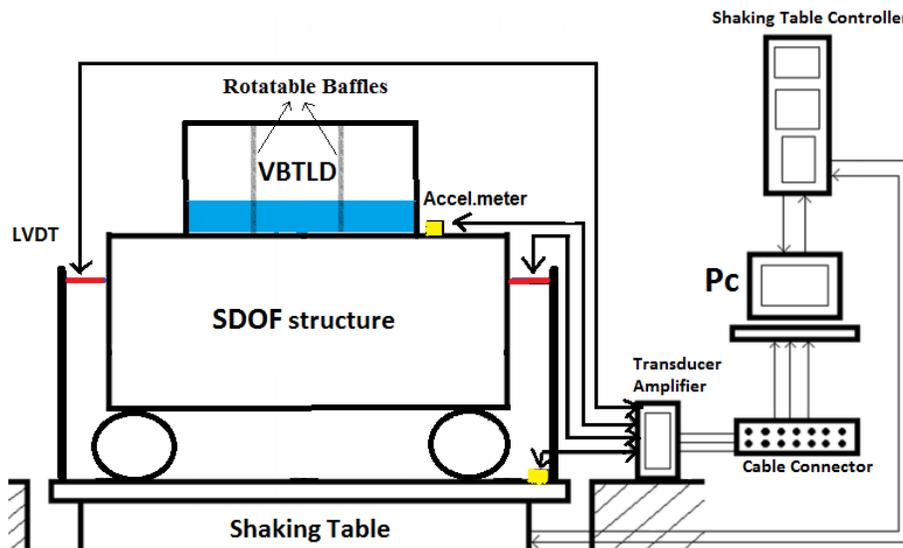


Fig. 4. Schematic view of test set-up and instrumentation



Fig. 5. Designed cylindrical TLD with 4 standing rotatable baffles



Fig. 6. Designed rectangular TLD with 4 standing rotatable baffles

Four baffles were used for both dampers and after rotating them manually in these experiments, they get fixed at specific angles. The material of these baffles is made of Plexiglas. The length of baffles is 16 cm and 20.2 cm in rectangular and cylindrical TLDs respectively and the thickness and height of baffles is 5 mm and 45 cm respectively. The water height inside the dampers is 6.4 cm.

To verify the numerical results, a rigorous benchmark test using shaking table was used. The length and width of electro-magnetic shaking table is 1.8 m and 1.2 m respectively. Single Degree-Of-Freedom (SDOF) structure employed in this study (Figure 7) includes a mass of 260 kg and 14 springs. Some instruments were considered to measure the response of SDOF structure, such as two accelerometers and two displacement transducers (LVDT). One accelerometer is placed on the shaking table (Figure 8a) to

record its actual acceleration and another one is placed on SDOF structure (Figure 8b) for determining its related acceleration. One of the LVDTs is used at the right of structure while the other one is placed at the left side (Figure 9) for recording the displacement of SDOF structure.

A 3D rectangular TLD with four installed vertically rotatable baffles was subjected to pulse excitations. This validation test was conducted on 70 degree baffle angle and the water height inside the dampers was 6.4 cm. The level of water surface was measured with piezometer. Before the experiment, the piezometer was calibrated and for each water surface level, the monitor displayed its specific voltage and finally using these voltages, the level of water surface was obtained. Pressure gauges embedded on the walls of the TLD (Figure 10) were connected on a shaking table. Pulse excitation was

applied to the table causing the fluid to begin sloshing. Variations of the water level in the container are recorded by the data logger.

The liquid filled containers are mounted on the shake table excited harmonically at a particular frequency. While the sloshing motion of liquid is observed, a change is made in the frequency of excitation. The excitation amplitude is kept the same for all excitations with different frequencies. When the excitation frequency is so close to the

sloshing frequency of liquid, then the liquid sloshes with large amplitude for the same excitation amplitude. The excitation frequency at which the liquid sloshes with large amplitude is considered as the sloshing frequency of liquid. It is noted that at frequencies on lower and higher sides of sloshing frequency, the amplitude of sloshing is less. Using this procedure; the first sloshing frequency of liquid is measured.

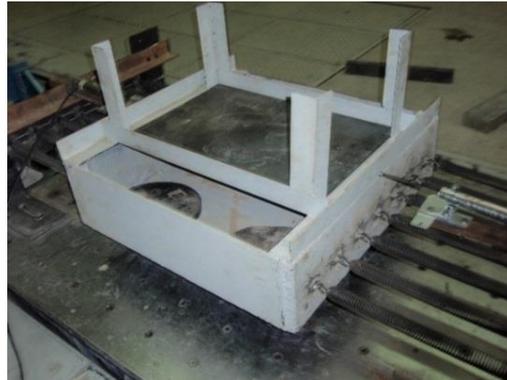


Fig. 7. Single Degree-Of-Freedom (SDOF) structure (mass-spring system) used for the test specimen



(a)



(b)

Fig. 8. Accelerometers mounted on the a) shaking table, b) SDOF structure



(a)



(b)

Fig. 9. LVTDs used on the a) left of the SDOF structure, b) right of the SDOF structure

Figure 11 shows the comparison of experimental and numerical results on variation of the water level inside the rectangular TLD under pulse excitation. The period of sloshing is about 0.705 and 0.75 seconds in experimental and numerical models respectively with 6% difference. The reason for difference between the experimental and numerical periods of sloshing is that there is no fluid leakage from bottom of the baffles in the numerical model while leakage is possible in experimental model. Also there are some errors to apply the displacement by shaking table and some errors to measure water pressure using pressure gauges.

NUMERICAL RESULTS

First two TLDs are compared at 0° , 30° , 45° , 70° and 80° baffle angles while water depth in both dampers is 6.4 cm. According to Figures 12-16, it can be observed that the drag force exerted on the containers in the first 0.4 sec arising from compulsory acceleration applied to the containers and after 0.4 sec in which the acceleration is zero the water inside the containers began sloshing. The drag force exerted on the rectangular damper is more than that of cylindrical damper at all angles.



Fig. 10. Installation of the pressure gauges on the bottom of the rectangular TLD

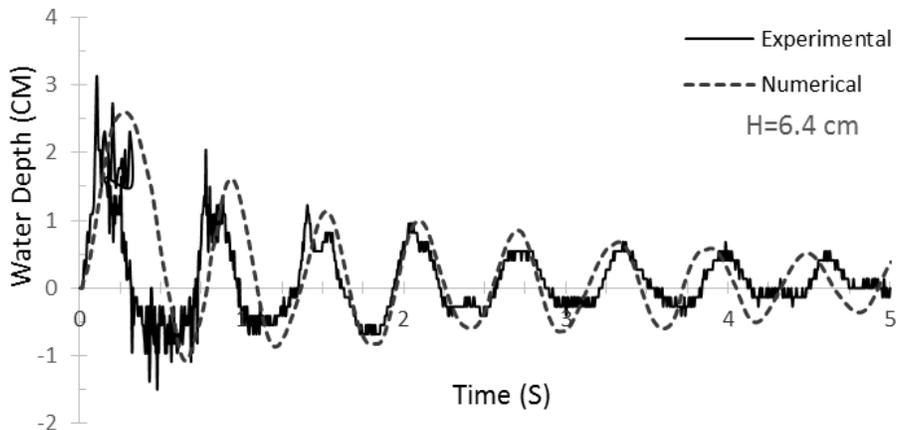


Fig. 11. Comparison of experimental and numerical results on variation of the water level inside the rectangular TLD under pulse excitation

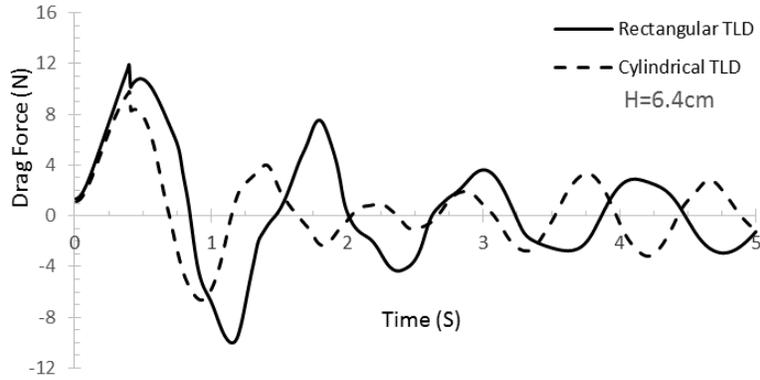


Fig. 12. Variations of drag force exerted on the TLDs at an angle of 0°

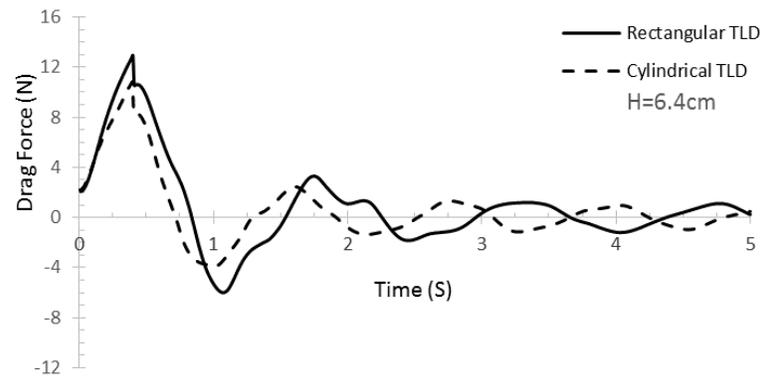


Fig. 13. Variations of drag force exerted on the TLDs at an angle of 30°

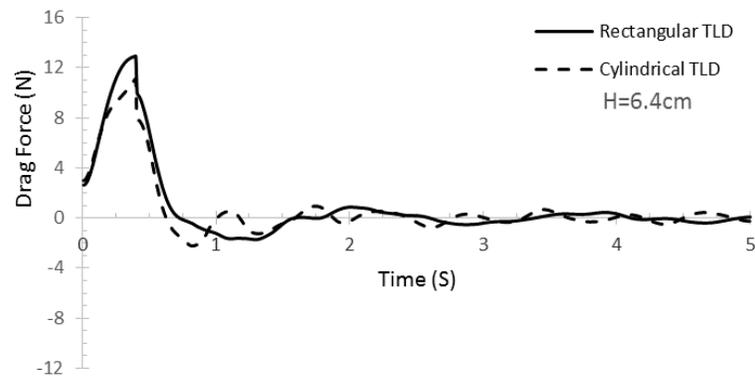


Fig. 14. Variations of drag force exerted on the TLDs at an angle of 45°

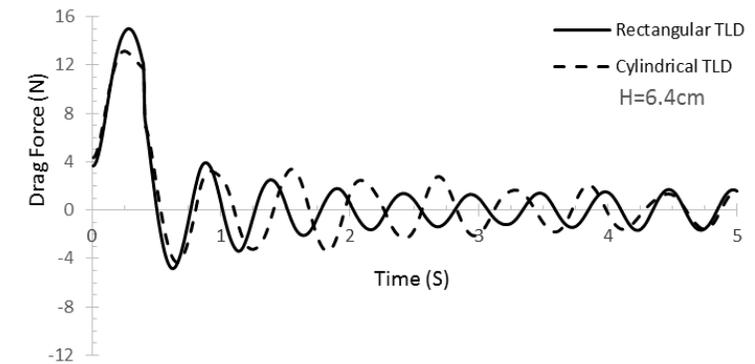


Fig. 15. Variations of drag force exerted on the TLDs at an angle of 70°

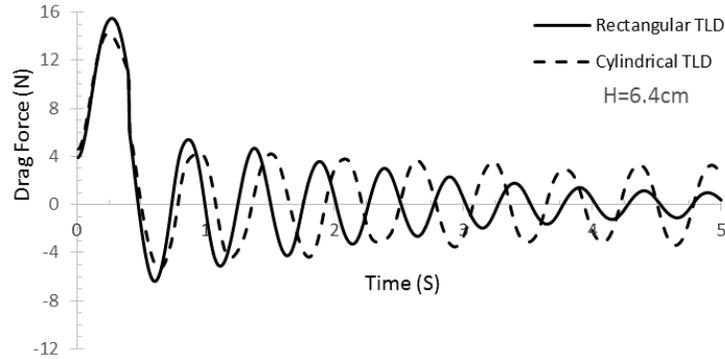


Fig. 16. Variations of drag force exerted on the TLDs at an angle of 80°

The reason why the drag force in rectangular damper is more than that of cylindrical damper at primary seconds is that velocity of the water in the rectangular damper is higher than that in cylindrical damper in the initial seconds of water sloshing. Also the effective cross section of rectangular damper is less than that of the cylindrical damper. Given that the drag force is directly related to the square of velocity, the impact of velocity is greater than that of the

cross section on the drag force. However, after about 2 seconds, the quantity of drag force in cylindrical TLD is more because the water velocity is decreased and the cylindrical TLD has more effective cross section.

The impacts of water depths in rectangular and cylindrical TLDs on the drag force are shown in Figures 17-26. Three water depths are studied in this part including 4, 5.2 and 6.4 cm.

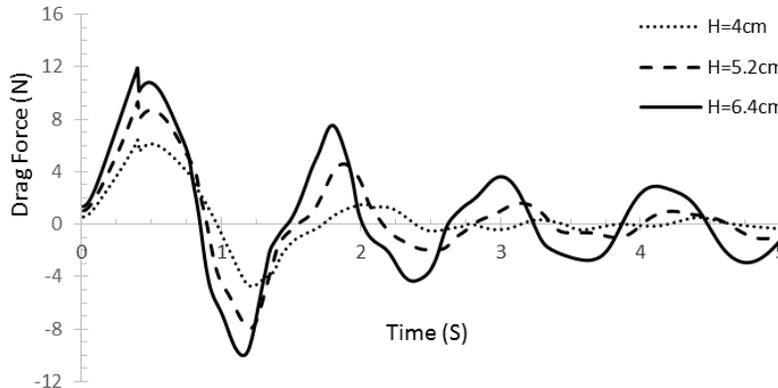


Fig. 17. Impact of water depth on variations of drag force exerted on the rectangular TLD at 0° angle

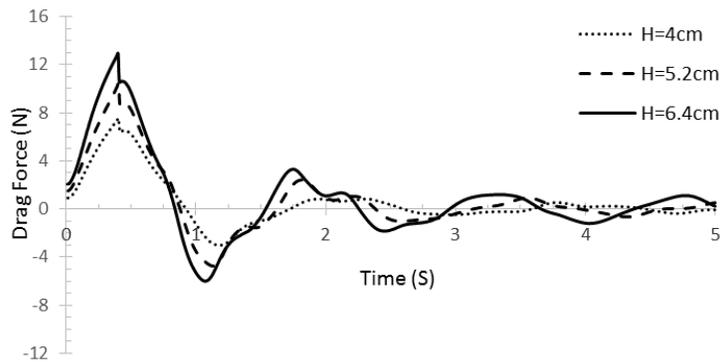


Fig. 18. Impact of water depth on variations of drag force exerted on the rectangular TLD at 30° angle

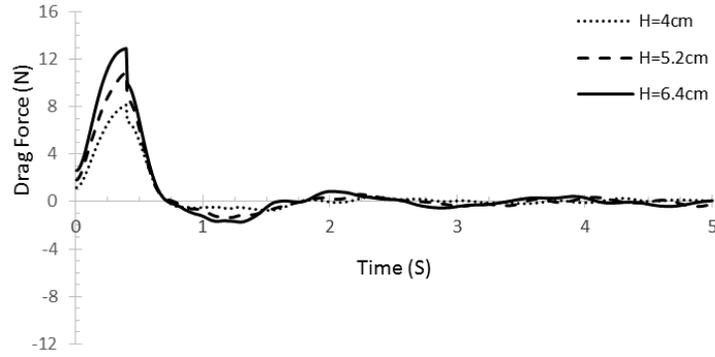


Fig. 19. Impact of water depth on variations of drag force exerted on the rectangular TLD at 45° angle

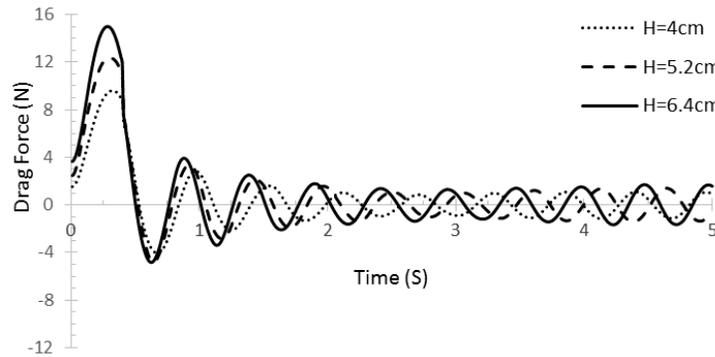


Fig. 20. Impact of water depth on variations of drag force exerted on the rectangular TLD at 70° angle

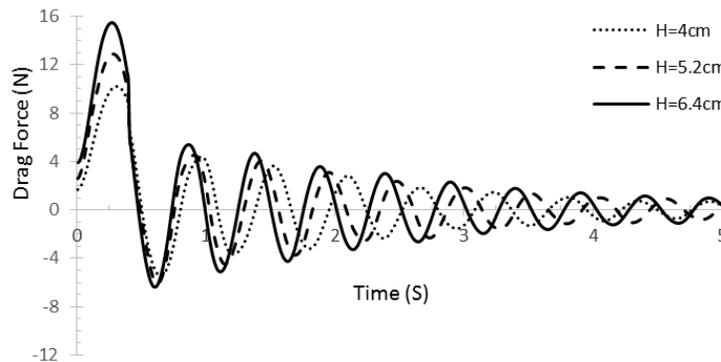


Fig. 21. Impact of water depth on variations of drag force exerted on the rectangular TLD at 80° angle

According to Figures 17-21, when the baffle angle is less than 45 degrees, the direction of water flow changes slightly, therefore, the energy dissipation is not much and the drag force has sinusoidal shape over times. Also when the baffle angle is more than 45 degrees, flow rate through the baffles is reduced and again the energy dissipation is small.

On the other hand, when the baffle angle is exactly 45 degrees, the direction of water flow changes quickly and the flow rate

through the baffles is increased and as a result the energy dissipation is very high. Therefore since the maximum energy dissipation occurs at 45 degree angle, the curve in Figure19 loses the usual sinusoidal shape.

According to Figures 17-26, it can be observed that by increasing the water depth inside the TLDs, the drag force increases. Also according to Table 1, since the baffles are located inside the TLDs, by increasing the baffle angle, from 0° to 80°, the drag force increases.

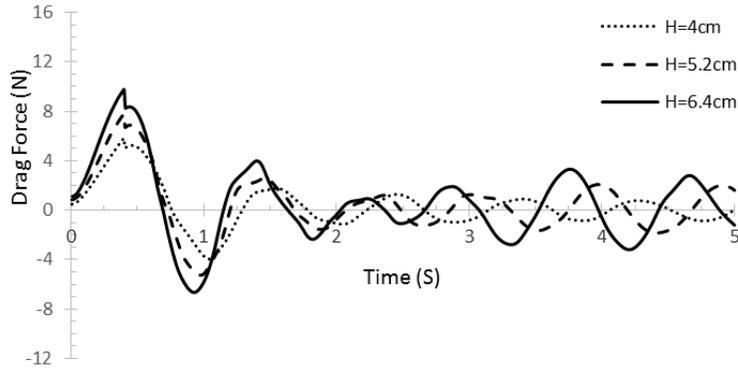


Fig. 22. Impact of water depth on variations of drag force exerted on the cylindrical TLD at 0° angle

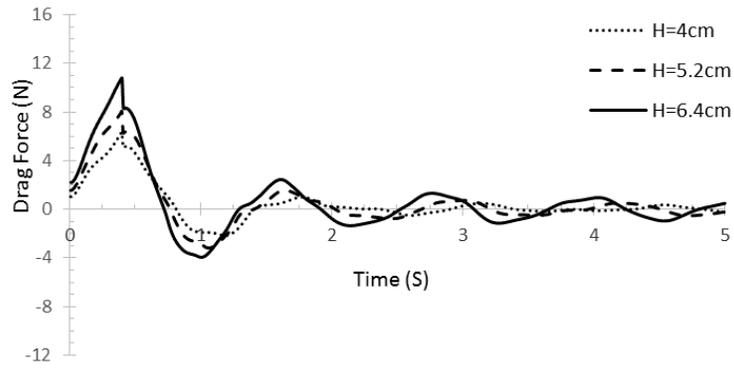


Fig. 23. Impact of water depth on variations of drag force exerted on the cylindrical TLD at 30° angle

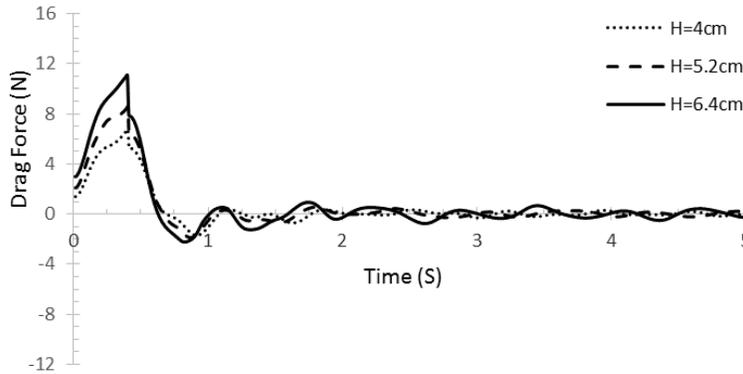


Fig. 24. Impact of water depth on variations of drag force exerted on the cylindrical TLD at 45° angle

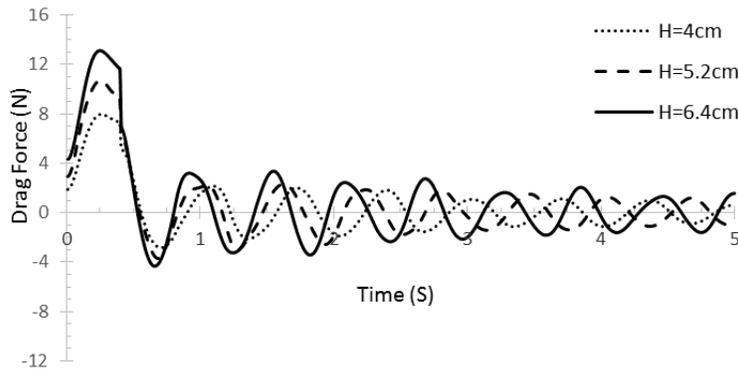


Fig. 25. Impact of water depth on variations of drag force exerted on the cylindrical damper at 70° angle

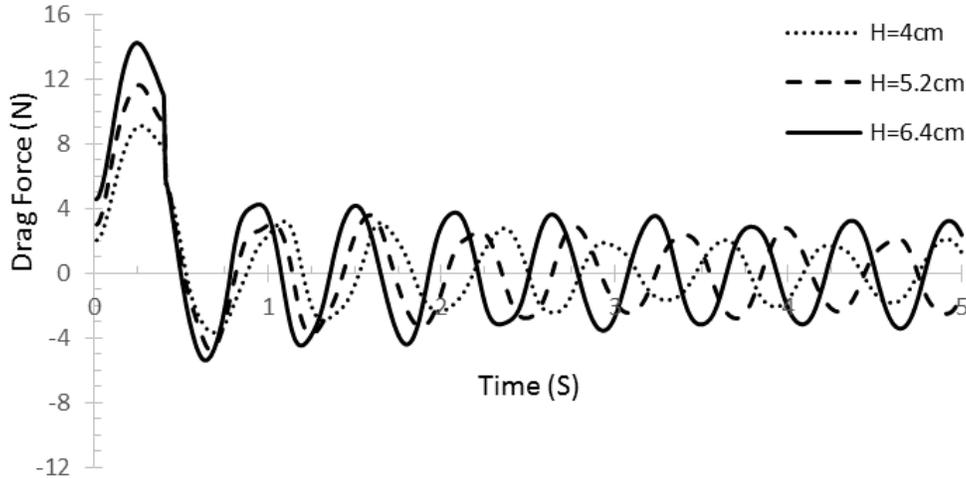


Fig. 26. Impact of water depth on variations of drag force exerted on the cylindrical TLD at 80°angle

Tables 2 and 3 indicate the natural periods of water sloshing in the TLDs at different depths and angles of baffles extracted from FLUENT6.3.26 software. According to Tables 2-3, it is observed that the period of water sloshing from 0° to 45° and 0° to 30° respectively in the rectangular and cylindrical dampers increases. The reason of increasing the period is due to the baffles inside the TLDs. In fact, the baffles cause a slowdown in the water sloshing leading to increasing period of water sloshing.

Also as indicated in Tables 2-3, the period of water sloshing from 45° to 80° and 30° to 80° respectively in the rectangular and cylindrical dampers decreases. Since with closing the baffles, the length of dampers is decreased, the movement direction of water is decreased resulting to a decrease in the period of water sloshing.

VALIDATION OF NUMERICAL MODELS WITH THE ANALYTICAL FORMULA AND EXPERIMENTAL WORK

The natural frequency of water sloshing in the rectangular and cylindrical TLDs without baffles can be obtained using Eqs. (5) and (6) (Housner, 1963) and results are presented at Table 4.

For the rectangular TLD:

$$f = \frac{1}{2\pi} \sqrt{\frac{\pi g}{l} \tanh\left(\frac{\pi h}{l}\right)} \quad (5)$$

For the cylindrical TLD:

$$f = \frac{1}{2\pi} \sqrt{\frac{3.68g}{D} \tanh\left(\frac{3.68h}{D}\right)} \quad (6)$$

where h : is height of water in TLD (m), L : is length of rectangular TLD along direction of excitation (m), D : is diameter of cylindrical TLD (m) and g : is acceleration of gravity (m/s^2).

According to Tables 2-4, the periods of water sloshing in numerical and analytical cases have negligible difference arising from baffles that have 5 mm thickness interfering in the water sloshing.

For the experimental work, the frequency and amplitude of excitations are controlled using a computer. The period of water sloshing in dampers at 0° is shown in Table 5.

According to Table 5, the periods of water sloshing in experimental work for each damper had negligible difference from those obtained from numerical models and analytical formula.

Table 1. The effect of baffles on the drag force from angle of 0° to 80°

Water Depth (cm)	Rectangular TLD			Cylindrical TLD		
	Drag Force (N)		Drag Force Increase (%)	Drag Force (N)		Drag Force Increase (%)
	$\theta = 0^\circ$	$\theta = 80^\circ$		$\theta = 0^\circ$	$\theta = 80^\circ$	
4	6.4057	10.239	59.84	5.7711	9.1421	58.41
5.2	9.3182	12.8988	38.43	7.7648	11.6746	50.35
6.4	11.8803	15.4699	30.21	9.7499	14.2483	46.14

Table 2. The period of water sloshing in the rectangular TLD at different depths and angles of baffles (s)

Water Depth (cm)	Angle of Baffles				
	0°	30°	45°	70°	80°
4	1.73	1.77	1.81	0.78	0.75
5.2	1.54	1.63	1.72	0.76	0.73
6.4	1.44	1.57	1.61	0.75	0.70

Table 3. The period of water sloshing in the cylindrical TLD at different depths and angles of baffles (s)

Water Depth (cm)	Angle of Baffles				
	0°	30°	45°	70°	80°
4	1.29	1.4	1.07	0.89	0.81
5.2	1.18	1.34	1.04	0.83	0.78
6.4	1.1	1.29	1	0.78	0.76

Table 4. The natural period of water sloshing in dampers at 0° (Analytical formula)

Water Depth (cm)	4	5.2	6.4
Natural period of water sloshing in rectangular TLD (sec)	1.68	1.48	1.34
Natural period of water sloshing in cylindrical TLD (sec)	1.27	1.13	1.03

Table 5. The period of water sloshing in TLDs at 0° (Experimental work)

Water Depth (cm)	4	5.2	6.4
Period of water sloshing in rectangular TLD (sec)	1.81	1.57	1.3
Period of water sloshing in cylindrical TLD (sec)	1.25	1.1	1.05

CONCLUSIONS

In this paper, some baffles were proposed and installed inside rectangular and cylindrical TLDs and their impacts on changing tuned frequency and also the effect of TLD shape on drag force was numerically investigated and validated with experimental results. Results showed that the drag force exerted on the rectangular TLD is more than that of cylindrical TLD at all angles and water depths, and the drag force increased when utilizing four installed rotatable baffles in TLDs. By increasing the baffle angle, from 0°

to 80° at the water depths of 4, 5.2 and 6.4 cm, the control forces are increased 59.8%, 38.4% and 30.2% respectively for the rectangular TLD and 58.4%, 50.4% and 46.1% respectively for cylindrical TLD. Therefore, while the proposed TLD is still a passive control system it has the capability to be pre-tuned according to the desired frequency.

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