〈일반논문〉
Journal of the Korean Society of Visualization, Vol. 12, No. 1 (30~34), 2014
(투고일 : 2014.2.24/수정일 : 2014.3.27/심사완료일 : 2014.4.7)
DOI:http://jksv.or.kr/10.5407/JKSV.2014.12.1.030
ISSN 1598-8430 Print
ISSN 2093-808X Online

저주파수 하의 TLCD 시스템의 오리피스 형상 효과

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Orifice shape effect of the TLCD system under a low frequency

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Abstract. Bluff bodies under the external periodic force vibrate at their own natural or forced frequency. Rectangular bodies or similar structures such as high-rise towers and apartments, and recently a well-cited application - offshore floating bodies, usually needs to reduce these vibrations for stability and the mode control. Therefore, this study is aiming to reduce or control the vibration of a structure by a passive control method, i.e., TLCD (Tuned Liquid Column Damper). Controlling a moving body with a TLCD based on a variety of the orifice shape has been preliminary studied. In order to get a proper control, an optimized study is made on the design of the orifice shape, which has internal plates with the holes. The results show the force acting on the body due to the periodic movement highly depends on the number of holes on the plate and the height of the water level. Therefore, the optimum shape of the orifice and the height of the water level should be confirmed by a series of experiments.

Key Words: TLCD, Orifice shape, TLD

1. Introduction

With the development of modern society, more and more energy is consumed. We need to explore more energy for the years to come. In addition, after having the serious nuclear power catastrophe in Japan, wind energy is one of the more promising alternative energy sources and many scientists are currently in the development stages of what promises to be the world's largest wind turbine in the off-shore as well as the on-shore. Since the on-shore development of wind energy has been gradually decreased due to the technical and environmental problems such as the low-frequency noise, the available space of installation and the public complaint, the new business regarding to the large-scale wind farm would be a future barrier. Nonetheless, the offshore energy business will be one of the best candidates for the future development of energy harvesting, which is surely able to make a full size of stable facilities without any distraction to the surroundings.

In the off-shore wind development, the main study is highly focusing on the wind and wave load of the floating body. In addition, the behavior of upper and lower platform is very important to generate the stable energy from the oncoming wind. If the center of buoyancy is below to center of gravity the body will tilt due to the wind or wave load so that it is important to design the floating body has the center of buoyancy above the center of gravity. Therefore, the performance study of floating body under a variety of ocean environment is a prerequisite to operate the target floating body for a period.

Bluff bodies under a periodic movement vibrate at their own natural or forced frequency. In order to

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reduce these vibrations, various methods have been used in terms of stability and the mode control. One of the representatives is the passive method, which mainly include TLD (Tuned Liquid Damper), TMD (Tuned Mass Damper) and TLCD (Tuned Liquid Column Damper). TMD and TLD are usually used to reduce the wind-induced vibration in high-rise buildings. These passive control methods are a range of advantages including economical, reliable, durable and easy to apply for the vibration bodies. Controlling a moving body with a TLCD based on a variety of the orifice shape has been preliminary studied.

Regarding to the TLCD, Wu et. al.(2005), Gao and Kwok (1997) have optimized the TLCD. Wu et. al. formulated a prediction equation for the overall head loss in TLCDs with sharp-edged elbows and suggested the practical guideline for TLCD designs. Gao and Kwok reported that the optimum coefficient of head loss will depend on the intensity of the excitation with smaller coefficient of head loss associated with stronger excitation. In Yallad et. al. (2001), semi-active strategies provide better response reduction than passive systems for both random and harmonic excitations. In addition, the improvement is about 25~30% with the harmonic loading, while for random excitation the improvement is about 10~15%.

Regarding to the existing studies, we intend to make a careful design in the laboratory measurement and understand the effect of the internal panel with different porosities. Therefore, this paper focused on the detailed design of TLCD in the internal plate with the porous holes. In order to get a proper control, an optimized study is critical on the design of the orifice shape, which has internal plates with the holes.

2. Theoretical background

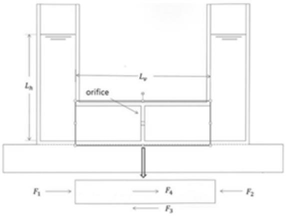

Fig. 1. Schematic diagram of a TLCD model set-up for periodic moving

Figure 1 shows the schematic diagram of a TLCD model filled with liquid (i.e., water) for testing the resultant movement of the body. In the figure, a TLCD model is placed on a moving plate at the frequency range of 0.83Hz to 1.11Hz. A variety of the internal orifice shapes (i.e., no hole, 1 hole, 9 holes and 16 holes) are used to observe the characteristics of the force acting on the TLCD model placed on 1-dimensional periodic external force. The theoretical prediction of the TLCD movement highly depends upon the external excitation frequency (see Kim, 2006) and it is expressed in the following equation:

$$\rho AL\ddot{y}+\frac{1}{2}\rho A\dot{y}|\dot{y}|+2\rho Agy=-\rho AL_h\ddot{X} \tag{1}$$

where y, ρ, A and η are the vertical displacement of the liquid, the density of the working fluid, the orifice area, and the coefficient of head loss, respectively. The equation (1) has the natural frequency as follows,

$$f_w=\frac{1}{2\pi}\sqrt{\frac{2g}{L}} \tag{2}$$

$$L=2L_h+L_v \tag{3}$$

where g, L, L_h and L_v are acceleration of gravity, total, horizontal and vertical column length of the TLCD, respectively.

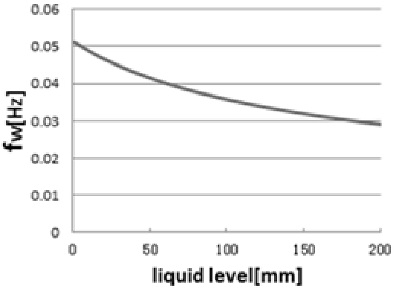

Fig. 2. Natural frequency for the TLCD model

3. Design of the TLCD experiment

Firstly, in order to obtain the periodic force acting on the TLCD model, the model is directly attached on the shaking table, which has a periodic movement by a stepping motor. For the further application of this system into the real vibration and structural system, some springs are placed between the upper and lower plates. For the comparison between these two sets of experiment, the internal passages on the panel inside the TLCD model have all the same porosity, but the different number of holes.

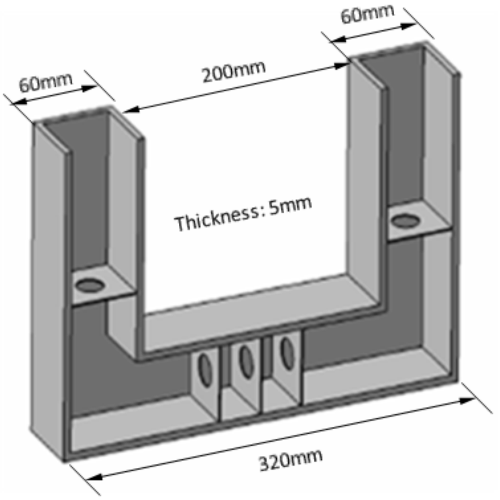

Fig. 3. TLCD models with internal orifices

Four different TLCD models are used in this study. Among these models, only one model does not have any internal orifice, but the other three models have them, which have all the same porosity of 80% and have the numbers of holes 1, 9 and 16, as shown in Fig. 4. The length, width and height of the TLCD model are 320mm, 60mm, and 200mm, respectively.

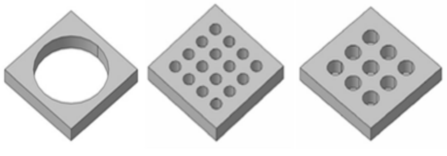

Fig. 4. The orifice models used in the internal passage (i.e., 1, 9 and 16holes)

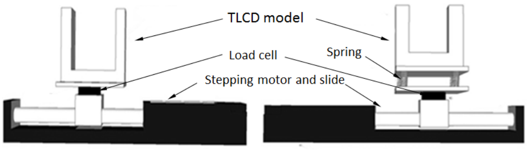

Fig. 5. The shaking tables without spring (left) and with spring(right)

The data acquisition system based on NI Labview software with a USB type analog-digital converter receives the raw data and transforms them into the well-treated data. The data was acquired with a sampling rate of 1,000 samples per second and the number of samples was 30,000 so that each experiment took around 30 seconds each. The shaker was built with a linear slide and a 5 phase stepping motor. The equi-space periodic motion had the same distance 5cm in different motor speeds, but used several different levels of water surface from 105mm to 120mm above the bottom of the TLCD. The frequencies of the stepping motor are 0.83Hz, 0.95Hz and 1.11Hz when the delays respectively are 15, 20 and 30.

4. Results and Analysis

4.1 Effect of the orifice and the water level (without a spring)

Figure 6 shows the peak to peak displacement against the base water level, which is the water height at the beginning. The measurement was made by using a high-speed CCD camera. As shown in the figure, no orifice model has the maximum displacement level during the measurement. In Fig.6, it can be seen that with the orifice panel in TLCD, the displacement of the wave level in TLCD was significantly decreased. In addition, with the decrease of the frequency (from 1.11Hz to 0.83Hz), the reduced displacement between the TLCDs with and without orifice panel was decreased. The reduced displacement is 60mm, 15mm and 5mm when the frequencies are 1.11Hz, 0.95Hz and 0.83Hz, respectively.

Figure 7 shows the results of the force variation (i.e.,STDV-F[N] represents the peak- to-peak force variation) acting on the TLCD model without spring with a range of movement frequencies at 1.11Hz, 0.95Hz and 0.83Hz, respectively.

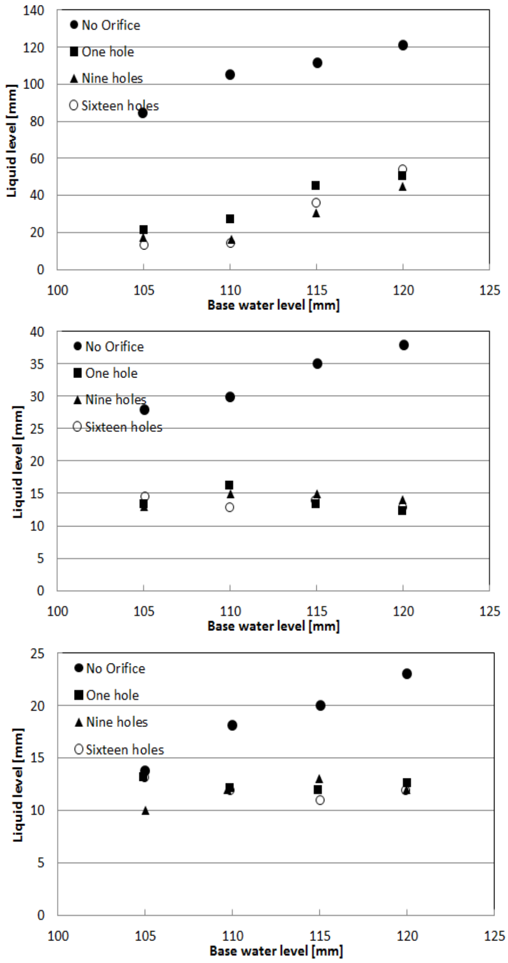

Fig. 6. Peak to peak displacement against the base water level on the (a) Shaking frequency of 1.11Hz. (b) Shaking frequency of 0.95Hz. (c) Shaking frequency of 0.83Hz.

Note here that we used a commercial load balance to get a force signal, which was already calibrated by a proper weight. In the figure, the standard deviation of the force was mainly plotted for the comparison.

In Fig.7(a), it seems that the standard deviation of force is the lowest when the orifice has 16 holes under the 1.11Hz shaking frequency. However, Fig.7(b) shows that when the shaking frequency changes to 0.95Hz, the standard deviation of force is the lowest without orifices. In addition, if we keep the delay time continuously decreasing until shaking frequency is 0.83Hz, the results can be seen in Fig.7(c). In the figure, generally, the standard deviation of force increases as the base water level increases.

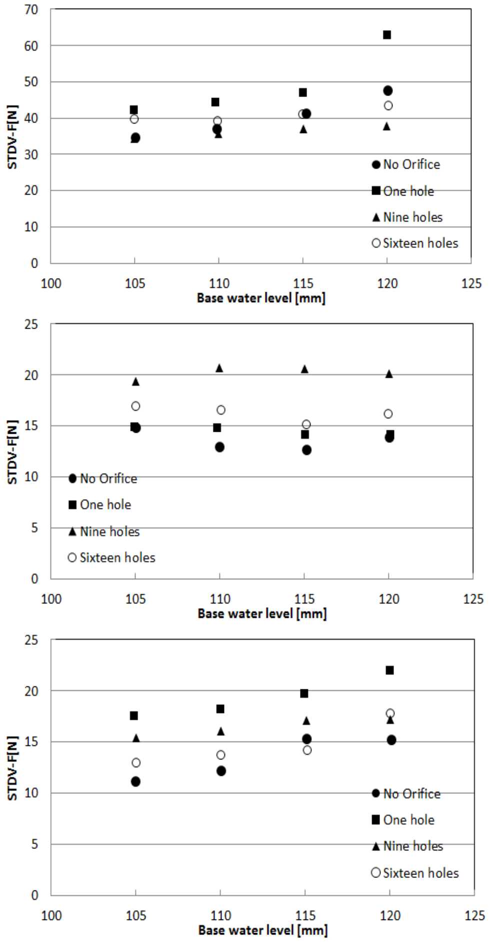

Fig. 7 The force variation acting on the TLCD model without spring placed on the (a) Shaking frequency of 1.11Hz. (b) Shaking frequency of 0.95Hz. (c) Shaking frequency of 0.83Hz.

4.2 Stability analysis of the TLCD movement with the spring

Based on the above TLCD models, we observed the effect of stiffness (i.e., springs) between the shaking table and the TLCD model. The standard deviations of force with this system including the external periodic force are shown in Fig. 8.

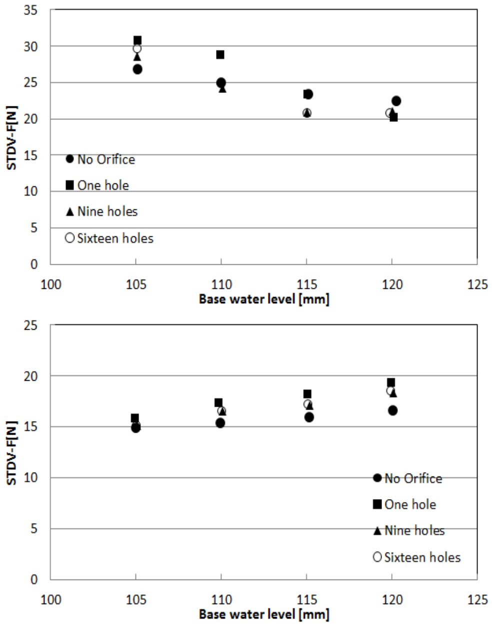

Fig. 8. The force variation acting on the TLCD model with spring placed on the (a) Shaking frequency of 1.11Hz. (b) Shaking frequency of 0.95Hz.

In the figure, the standard deviation decreases which is obviously due to the effect of spring. As the spring absorbs the excess movement and the turning force, so that it seems to reduce the force dissipation of the TLCD. In case of the orifice panel with 16 holes, the standard deviation reaches to the minimum value at the shaking frequency of 1.11Hz. In addition, the standard deviation of force decreased with the increasing of the base water level. However, in the case of 0.95Hz, the standard deviation of the force is increased with the base water level.

5. CONCLUSION

As a passive damping device, TLCD, we set up the orifice panels with porous holes for the experiments. The summary of this study based on the experiments is provided as below.

1. Even though there are some variation, the peak to peak displacement against the starting water level under the scenario of setting the panel is usually smaller than the values while the panel is not setting. Obviously, the shock absorption effect is much better while the panel is setting.
2. Regarding to the stability analysis, it is reliable way to obtain the standard deviation of the forces from the TLCD models with the same porosity and different amount of holes.
3. The overall standard deviation of the resultant force measured by a load balance generally decreases due to the effect of spring. There is always a spring effect in the high frequency region, but the spring effect in the low frequency is not dominant.

6. ACKNOWLEDGEMENTS

이 논문은 2013년도 정부(교육부)의 재원으로 한국연구재단의 지원을 받아 수행된 기초연구사업입니다(NRF-2013R1A1A2005347). 또한, 본 연구는 "산업통상자원부", "한국산업기술진흥원", "동남지역사업평가원"의 "광역경제권 선도산업 육성사업"으로 수행된 연구결과입니다.

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