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# EXPERIMENTAL STUDY ON VIBRATIONAL CHARACTERISTICS OF A RECTANGULAR BOTTOM PLATE IN CONTACT WITH FLUID

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The vibration of fluid-structure interaction system is a key problem in many fields. In this paper, the vibrational characteristics of a rectangular plate clamped at the bottom of a container filled with fluid is studied through experimental approach. The natural frequencies of the fluid-plate system with different fluid depth are derived by modal test. The frequency results show that the natural frequencies of the plate decrease greatly in contact with fluid compared to that in air. Dynamic response test of the plate subjected to mechanical excitation in the cases both in contact with fluid and in air are also carried out. When the plate is subjected to mechanical excitation, the acceleration frequency response peaks of the plate in contact with fluid wholly shift to the low frequency range with the fluid height increasing.

Keywords: fluid-plate interaction, natural frequencies, dynamic responses, added mass effect

## 1. Introduction

In many industry fields such as aerospace, ocean engineering, energy engineering and so on, the vibrational characteristics of fluid-structure interaction system is widely concerned by the engineers and researchers.

As the structures are in contact with fluid, the vibration characteristics are quite different from that in the air, which makes the structure design much more difficult. Up till now, a lot of efforts have been made on the relative works. Kwak[1,2] explained the frequencies decrease phenomena of structures in contacting with water as the added mass effects of the fluid, and derived the non-dimensionalized added mass incremental(NAVMI) factors of the uniform circular plates vibrating in contact with water, which can be used to predict the wet frequencies more conveniently. Then Kwak[3] derived the NAVMI factor of rectangular plates placed at an infinite rigid wall or resting on a free surface in contact with water, and found that mode shapes change slightly for lower modes. Amabili[4] studied the vibration characteristics of base plates in annular cylindrical tanks filled with fluid, and the hypotheses in the theoretical analysis is validated by the good agreement between theoretical and experimental results. The Rayleigh-Ritz method was employed by Amabili[5] to study the circular cylindrical shell coupled to an external unbounded fluid considering the effect of free surface waves. Cheung and Zhou[6] investigated the effects of the fluid-plate size and density ratios on the vibratory characteristics of an elastic rectangular bottom plate in contact with fluid, and confirmed the applicability of the AVMI factor solution. By the similar approach, they[7] also investigated the free vibration characteristics of vertical plate-fluid system and validated the AVMI factor solution. Based on the boundary integral equation method together with the method of images, Ergin and Temarel[8] presented the high-accurate free vibration characteristics of partially filled and submerged horizontal cylindrical shells. The natural characteristics of two identical rectangular pates coupled with an incompressible fluid is carried out by Jeong *et al.*[9], in which they found that two contrastive modes: the so-called out-of-phase and in-phase modes could be observed. On the basis of this, Jenong[10] presented the natural frequencies and modes evolution trends of two unequal annular plates coupled with a compressible fluid. Li *et al.*[11] theoretically studied the natural characteristics of stiffened bottom plate of a tank filled with fluid considering the effects of transverse shear and rotary inertia, revealing the phenomenon of "mode reversal" which matched well with the numerical and experimental results. Khorshid and Farhadi[12] derived the frequency equation of a laminated composite rectangular plate partially contacting with a bounded fluid considering different Shear Deformation theories, and detailedly discussed the effects of different parameters on the frequencies and modes change. Cho *et al.*[13] formulated a more general eigenvalue equations of a rectangular bottom plate in contacting with fluid, which can deal with a large wide of plates, such as thin plates, thick plates and stiffened panels with different edge constraints. Recently, Liao and Ma[14] discussed the compressibility effects on the resonant frequencies and mode shapes of an elastic plate coupled with compressible fluid on one side, revealing that resonant frequencies decrease with a decrease in sound velocity and several additional abnormal modes that do not appear in incompressible fluids were observed at low sound velocities and in higher resonant modes.

Above all, the fluid-structures interaction system has attracted a lot of attentions, while few researchers conducted the experimental research for the vibration characteristics of the plate-fluid interaction system, especially the dynamic response characteristics of the plate under mechanical excitation. So in this paper, the vibration characteristics experiment of a bottom plate of a rigid tank filled with water is carried out. And both the natural frequencies and the dynamic response mechanical excitation of the plate in contact with fluid and in air are derived.

# 2. Experimental setup

## 2.1 Model description

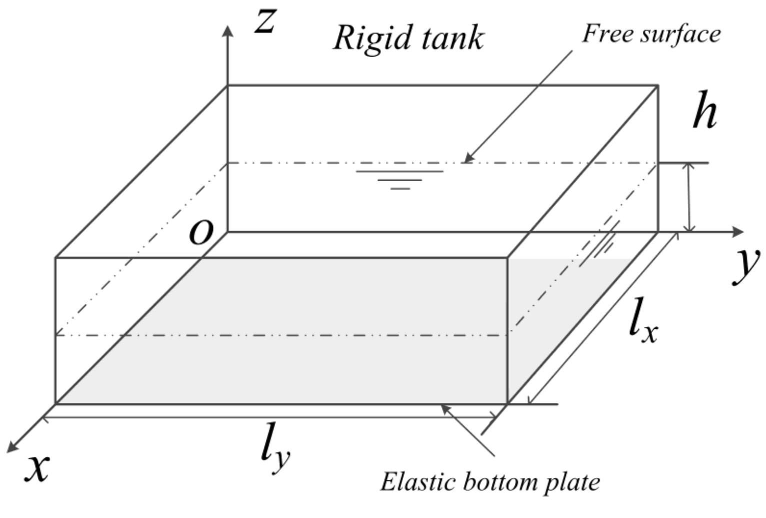


Figure 1: The elastic bottom plate in contacting with fluid

As shown in Fig. 1 is the theoretical model. An elastic plate is clamped at the bottom of a tank filled with water. Four vertical walls are assumed to be rigid. The up surface of the water is free surface.

## 2.2 Experimental scheme

The testing plate, made of aluminum, is 0.4m*0.3m*0.0015m. The rigid foundation is placed at the flat floor. Using 24 bolts and clamping fixture, the plate is fastened to the foundation on the edges 0.005m in width to achieve the clamped boundary condition. So the real test area is $0.3*0.2m^2$.

Model test is carried out via single-input single-output hammer based impact method in different fluid heights. The test area of the plate is divided into 24 blocks by five and three split lines along the length and the width. Fifteen intersections are marked as the testing points. An accelerometer(PCB 333B32) is located at a point to acquire the time-domain vibration signals under the impact of the hammer(PCB hammer 086CD4) on the points from No.1 to No.15. Specially, the points are impacted from under the testing plate, above which is in contacting with fluid. The impact testing module of LMS TEST. LAB is used for the signal processing. Each point is repeatedly impacted, and three groups of signal with good coherence are selected to make a better fitting of the natural frequencies and modes.

Dynamic responses subjected to mechanical excitations are also derived. A vibration exciter (MB Exciter Modal 2) is set under the plate to apply point mechanical excitation with periodical chirp signal. To acquire the vibration signal, an accelerometers(PCB 333B32) is fixed at the observation point. The excitation signal generating and vibration signal processing are dealt with Spectral analysis module of LMS TEST.LAB.

Both the modal test and the dynamic response test are conducted when the plate is in air, in contact with fluid 4mm in height and 8mm in height to make a comparison.

## 3. Experimental results

The first three order natural frequencies of the plate versus heights of the fluid are displayed in Fig. 2. The frequencies decrease greatly with the height increasing. Fig. 3 gives the acceleration frequency responses of the plate subjected to point mechanical excitation when the plate is in contact with fluid and in air. From the figure we can find that the frequency response peak wholly float to lower frequency range as the fluid height get higher. It is in corresponding with the decease of natural frequencies. In addition, the figure also shows that although the response peak floats to lower frequency range, the whole shapes of the frequency response curves change little, which means that the frequency response curve seems to be compressed to lower frequency as the height of the fluid increasing.

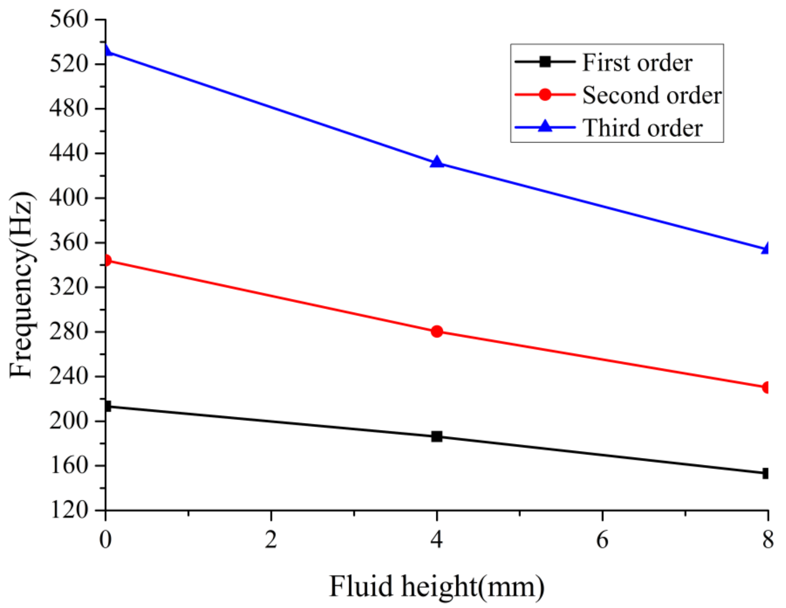


Figure 2: First three order frequencies of the plate versus fluid height

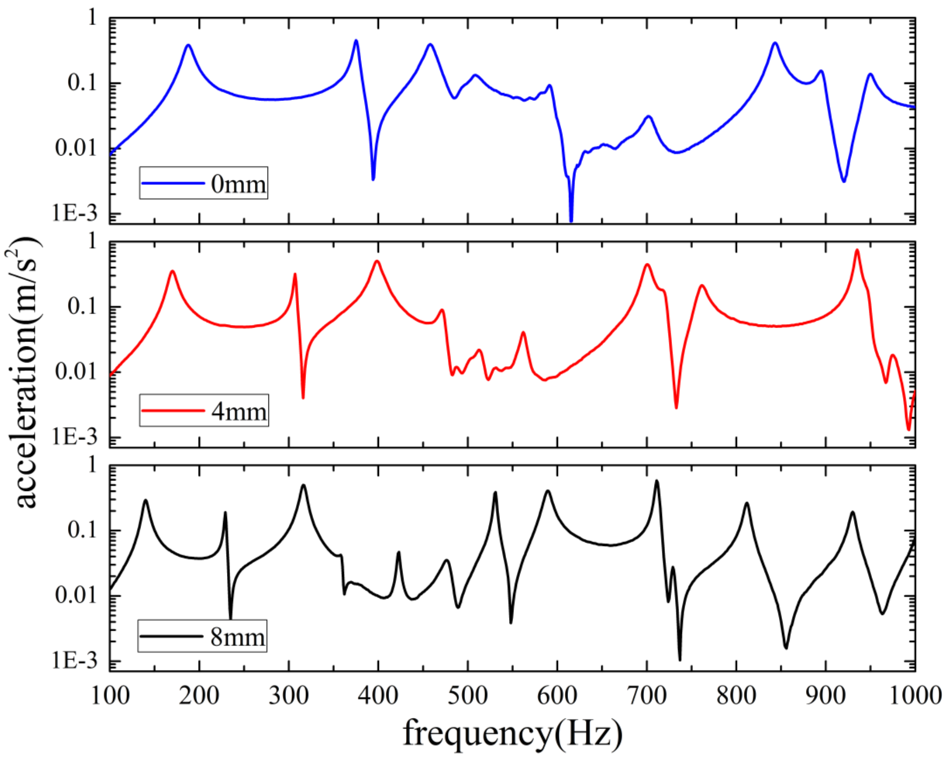


Figure 3: Acceleration frequency responses of the plate in contacting with fluid subjected to point mechanical excitation

## 4. Conclusion

In this paper, the vibrational characteristics of a bottom elastic plate of a rigid tank filled with fluid is studied by experimental approach. An effective experiment scheme is designed and implemented. Modal test is conducted to obtain the natural frequencies of an aluminium plate both in air and in contact with fluid. The results show that the frequencies decrease greatly in contact with fluid compared to that in air. The acceleration frequency response peak of the plate shifts to lower frequency range as the height of the fluid increasing. The whole shapes of the response curves nearly remain the same in three cases, and only seems to be compressed to lower frequency range with the increase of the fluid height. The experimental phenomenon can be explained as the added mass effect of the fluid on the plate.

## REFERENCES


1 Kwak, M. K. Vibration of Circular Plates in Contact with Water, *Journal of Applied Mechanics*, **58**(2): 480-483, (1991).

2 Kwak, M. K. Hydroelastic Vibration of Circular Plates, *Journal of Sound and Vibration*, **201**(3): 293-303, (1997).

3 Kwak, M. K. Hydroelastic Vibration of Rectangular Plates, Journal of Applied Mechanics, **63**: 110-115, (1996).

4 Amabili, M. Vibrations of Base Plates in Annular Cylindrical Tanks: Theory and Experiments, *Journal of Sound and Vibration*, **210**(3):329-350, (1998).

5 Amabili, M. Vibrations of Circular Tubes and Shells Filled and Partially Immersed in Dense Fluids, *Journal of Sound and Vibration*, **221**(4): 567-585, (1999).

6 Cheung, Y. K., Zhou, D. Coupled Vibratory Characteristics of A Rectangular Container Bottom Plate, *Journal of Fluids and Structures*, **14**: 339-357, (2000).

7 Zhou, D., Cheung, Y. K. Vibration of Vertical Rectangular Plate in Contact with Water on One Side, *Earthquake Engineering and Structural Dynamics*, **29**: 693-710, (2000).

8 Ergin, A., Temarel, P. Free Vibration of a Partially Liquid-Filled and Submerged, Horizontal Cylindrical Shell, *Journal of Sound and Vibration*, 254(5): 951-965, (2002).

9 Jeong, K. H., Yoo, G. H., Lee, S. C., Hydroelastic Vibration of Two Identical rectangular plates, *Journal of Sound and Vibration*, **272**: 539-555, (2004).

10 Jeong, K. H. Hydroelastic Vibration of Two Annular Plates Coupled with a Bounded Compressible Fluid, *Journal of Fluids and Structures*, **22**:1076-1096, (2006).

11 Li, P. L., Shyu, R. J., Wang, W. H., Cheng, C. Y. Analysis and Reversal of Dry and Hydroelastic Vibration Modes of Stiffened Plates, *Ocean Engineering*, **38**: 1014-1026, (2011).

12 Khorshid, K., Farhadi, S. Free Vibration Analysis of a Laminated Composite Rectangular Plate in Contact with a Bounded Fluid, *Composite Structures*, **104**:176-186, (2013).

13 Cho, D. S., Kim, B. H., Vladimir, N., Choi, T. M. Natural Vibration Analysis of Rectangular Bottom Plate Structures in Contact with Fluid, *Ocean Engineering*, **103**:171-179, (2015).

14 Liao, C. Y., Ma, C. C. Vibration Characteristics of Rectangular Plate in Compressible Inviscid Fluid, *Journal of Sound and Vibration*, **362**:228-251, (2016).