(*Abstract for the 34th International Workshop on Water Waves and Floating Bodies, Newcastle, Australia, 2019*)

On Piston and Sloshing Mode Resonances in Three-dimensional Moonpool of Vessels in Fixed and Free-floating Conditions

Haiyang Huang*, Xin Xu, Xinshu Zhang†

State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration (CISSE) Shanghai, 200240, China

1 Introduction

'Moonpools' are referred to the vertical openings, through the hull of a ship or offshore oil and gas exploration platform, used for marine and offshore operations such as pipe laying, riser hang off and diver recovery. Being exposed to incident waves or harmonic ship motions, the fluid inside the moonpools may perform resonant motions (Faltinsen *et al.*, 2007). This fluid motion mostly occurs at the natural modes of the moonpool, including piston mode, where the water inside the moonpool heaves up and down, and sloshing modes, where the water insider the moonpool moves back and forth between the vertical walls (Molin, 2001). Since the resonance fluid motion can lead to negative impacts to the hull or deck structure, it's essential to predict the resonance frequencies for assisting the concept design and guiding the marine operation.

Assuming infinite water depth and infinite beam of a barge, Molin (2001) proposed a quasi-analytical method to predict the resonance frequencies and modal shapes via linearized potential flow theory. Recently, this method was extended to treat the three-dimensional and two-dimensional moonpools in finite water depth by Molin *et al.* (2018) and Zhang *et al.* (2019), respectively. On the other hand, Faltinsen *et al.* (2007) developed a semi-analytical method to compute the fluid motions in a two-dimensional moonpool and conducted an experiment for comparison, where the structure is undergoing forced heave motion. Ning *et al.* (2015) developed a two-dimensional fully nonlinear numerical wave flume to investigate the gap resonance formed by a array of rectangular cylinders. Zhao *et al.* (2017) investigated the first and higher harmonics of the resonant wave responses in the gap between two identical rectangular boxes through experiments in a wave basin.

However, most of the above-mentioned studies are based on the conditions where the structure is either fixed in incident waves, or oscillate harmonically in a calm water initially. McIver (2005) pointed out, when a structure is in free-floating condition (also called 'free condition' in this article), the moonpool resonance frequencies are different from the values in the cases where the structure is fixed (called 'fixed condition') or forced to move time harmonically. Focusing on resonant piston-mode motion in the moonpool and rigid-body motions, Fredriksen *et al.* (2015) studied the wave-induced behavior of a two-dimensional floating body with moonpool through experiments and hybrid numerical methods. It was found the piston-mode resonance frequency found in radiation problem is equal to that in diffraction problem, while the one in free-floating condition is relatively larger. Guo *et al.* (2016, 2017) performed experiments for a drillship with a moonpool and recess and measured wave responses inside the moonpool. Molin (2017) extended the theoretical model in Molin (2001) to compute the resonance frequencies for moonpools with recess, and compared the solutions with the measurements in Guo *et al.* (2016). The predicted the natural frequencies agree well with the experiments, expect for the first sloshing mode resonance frequency. More recently, Newman (2018) investigated the resonant natural modes for the same type of vessel through WAMIT and proposed approximation formula. It was found that variations of resonance frequencies between the fixed and free condition are small or even non-existent for that vessel, which shows some difference with the conclusion in Fredriksen *et al.* (2015). Further, Newman (2018) did not investigate the effect of vessel motion on the sloshing mode resonances, which is the one of the motivations for the present study.

The present study aims to investigate how the configurations of the vessel and moonpool affect the shift of the resonance frequencies (including piton mode and sloshing modes resonances) between the fixed and free-floating conditions. The effects of recess in moonpool are also examined and discussed.

2 Numerical Model

The computations are carried out using WAMIT which is based on boundary element method. In total, ten models are built for the computations. The sketch of the vessel with recess in moonpool and the definition of the main hull parameters are illustrated in Fig. 1. In order to remove the irregular frequencies, additional mesh is placed on the internal free surface (see Fig. 2). The main parameters for the different models without and with recess are summarized in Table 1 and Table 2, respectively. Three numerical wave probes are placed to measure the wave elevations inside the moonpool. Three probes are denoted as front point, central point and

*Presenting author

†Corresponding author, Innovative Marine Hydrodynamics Lab (iMHL) at SJTU (xinshuz@sjtu.edu.cn)

after point, respectively, as illustrated in Fig. 1. As shown, the central point is at the center of the moonpool, while the after point is located above the recess.

Model No.	L (m)	B (m)	l (m)	b (m)	d (m)	D (m)
1	180.8	32.2	45.6	11.2	11	22.8
2	180.8	32.2	45.6	11.2	11	32.8
3	180.8	32.2	45.6	11.2	4	22.8
4	180.8	32.2	45.6	11.2	20	22.8
5	180.8	32.2	30.0	11.2	11	22.8
6	180.8	32.2	60.0	11.2	11	22.8
7	115.6	32.2	45.6	11.2	11	22.8

Table 1: Model sizes of vessels without recess in moonpool

Model No.	L (m)	B (m)	l (m)	b (m)	d (m)	D (m)	R (m)	h(m)
8	180.8	32.2	45.6	11.2	11	22.4	16.0	7.2
9	180.8	32.2	45.6	11.2	11	22.4	8.0	7.2
10	180.8	32.2	45.6	11.2	11	22.4	4.0	7.2

Table 2: Model sizes of vessels with recess in moonpool

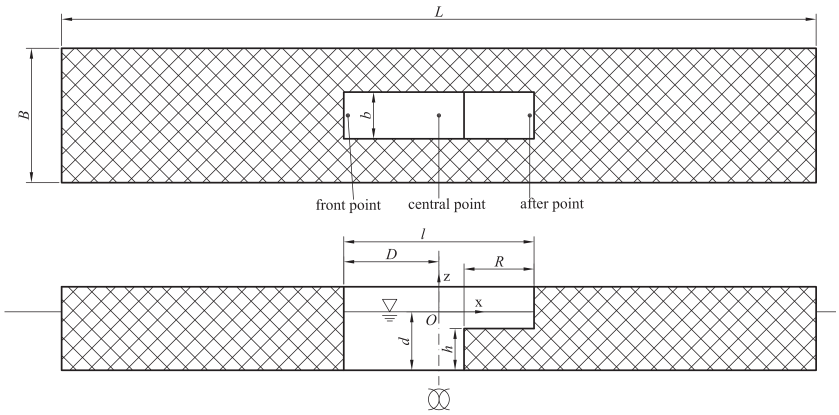


Figure 1: Sketch of the vessel with recess in moonpool with the locations of the wave probes.

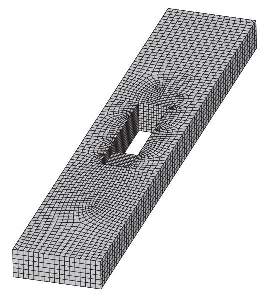


Figure 2: Panelization on the vessel with recess in moonpool adopted in WAMIT computations.

3 Results and Discussion

Validations are performed by comparing the present results for Model 1 with the those by using the single mode approximation (SMA) (See Molin *et al.* (2018)). It is found that the predicted piston mode resonance frequencies agree well with those using SMA.

In addition, the present results for moopool with recess are compared with those in Molin (2017) and Guo *et al.* (2016), which are based on the eigenfunction matching method and experiments, respectively. The same model size is adopted in Model 8 for comparison. Fig. 3 illustrates the variation of the free surface elevation at the front point (FP) and the after point (AP) with respect to the incident wave frequency ω. It should be noted that the case studied in Molin (2017) can be considered as the fixed condition, while the experiments in Guo *et al.* (2016) can be considered as the free-floating condition. As shown in the plots, the resonance frequencies

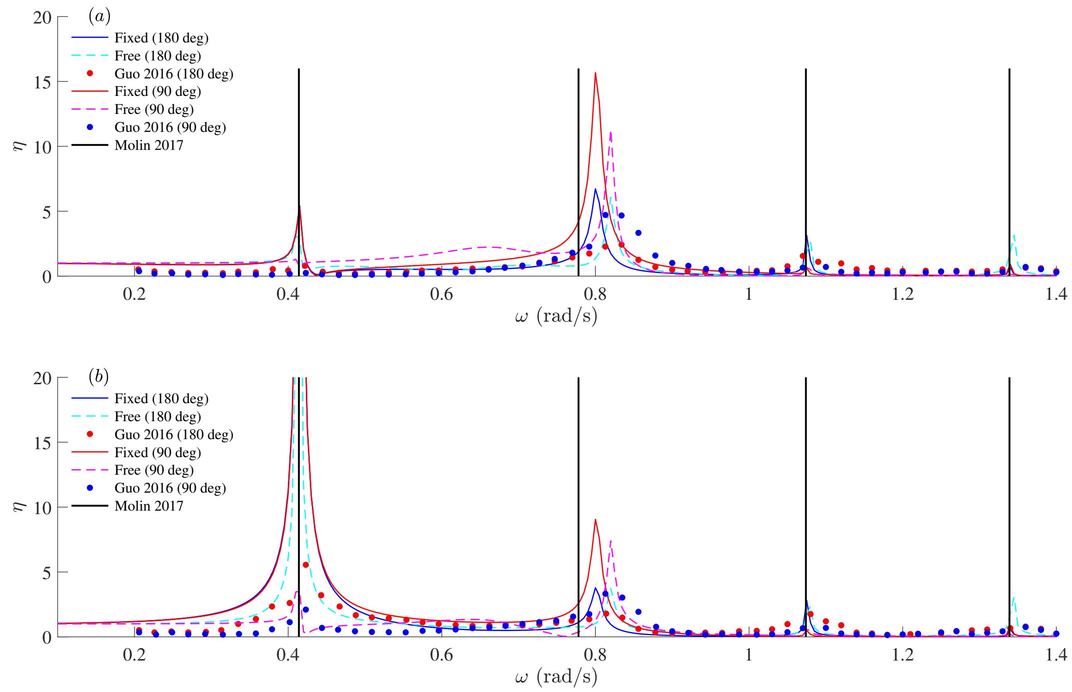
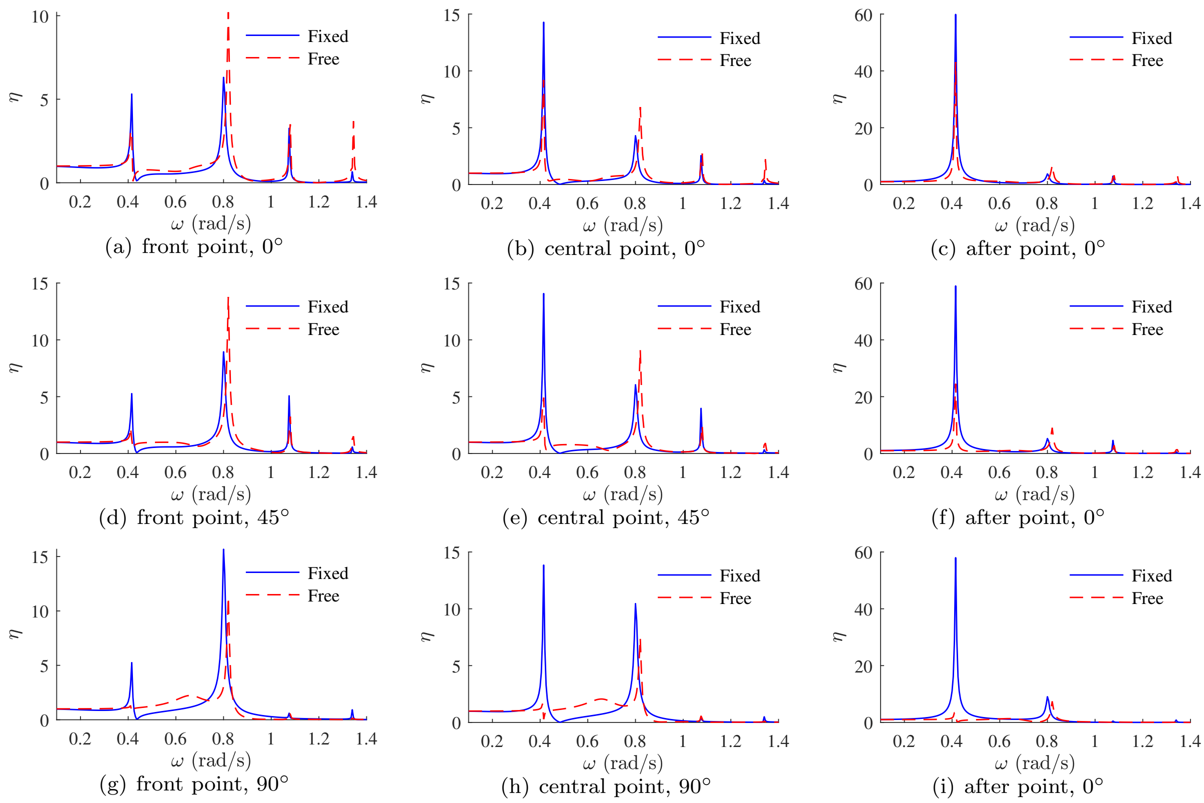


Figure 3: RAOs of relative free surface elevation compared with Molin (2017) and Guo *et al.* (2016). (a) at the front point (FP); (b) at the after point (AP).



(a) front point, 0° (b) central point, 0° (c) after point, 0°

(d) front point, 45° (e) central point, 45° (f) after point, 0°

(g) front point, 90° (h) central point, 90° (i) after point, 0°

Figure 4: Model 8. RAOs of relative free surface elevation at the front point, central point and after point in wave directions of 0°, 45° and 90°.

in fixed condition and in free condition are almost the same, for the piston mode, the second sloshing mode and the third sloshing mode. At the same time, the present results are in excellent agreement with those in Molin (2017) and Guo *et al.* (2016). However, there is relatively large difference between the resonance frequencies of the first sloshing mode in fixed condition and in free condition. The resonance frequency of the first sloshing mode in free-floating condition predicted by the present model agrees well with the measurement in Guo *et al.* (2016). Further, the resonance frequency of the first sloshing mode in the fixed condition predicted by the present model is slightly larger than that in Molin (2017).

More detailed results are illustrated in Fig.4 for three wave headings. As can be seen, the resonance

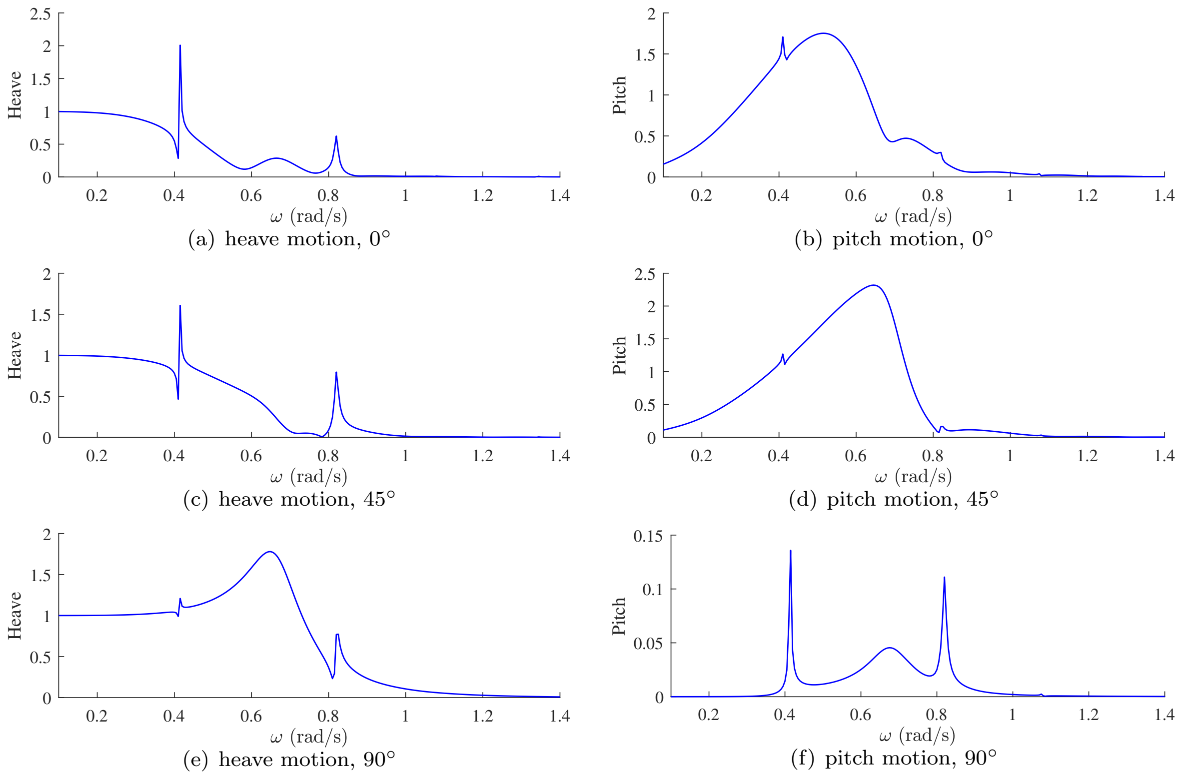


Figure 5: Model 8. RAOs of heave and pitch motion in wave directions of 0°, 45° and 90°.

frequencies of piston mode in fixed and free condition are both around 0.415 rad/s. The resonance frequency of the first sloshing mode in fixed condition is 0.8 rad/s, while that in free-floating condition is 0.82 rad/s. The relative difference is about 2.5%. The resonance frequency of the second sloshing mode in fixed condition is 1.075 rad/s, while the one in free condition is 1.08 rad/s. The relative difference is 0.47%, which is less than that for the first sloshing mode resonance. Moreover, as can be observed in the plots, the first sloshing mode resonance can be excited in beam sea (wave heading 90°), which is different from the case for symmetric hull without recess in moonpool.

Fig. 5 illustrates the heave and pitch motion RAOs in different wave directions for Model 8. It is observed that there is a local maximum point at 0.415 rad/s in the heave RAO, which is the resonance frequency of the piston mode in free-floating condition. Unlike the cases without recess, the local maximum point at 0.82 rad/s corresponding the first sloshing mode in free condition also occurs in heave RAO. This implies that the first sloshing mode in free condition has an obvious effect on heave motion due to the recess. It can be explained that, in the first sloshing mode, the fluid in the moonpool applies dynamical pressure on the upper surface of recess, and this dynamical pressure gives rise to the heave motion. Similarly, the piston mode also has an effect on the pitch motion as illustrated in pitch RAO. More comprehensive results including modal shapes and more detailed analyses will be presented in the workshop.

References

Faltinsen, O.M., Rognebakke, O.F. & Timokha, A.N. 2007 Two-dimensional resonant piston-like sloshing in a moonpool. *J. of Fluid Mech.* **575**, 359–397.

Fredriksen, A.G., Kristiansen, T. & Faltinsen, O.M. 2015 Wave-induced response of a floating two-dimensional body with a moonpool. *Phil. Trans. R. Soc. A* **373**, 20140109.

Guo, X., Lu, H., Yang, J. & Peng, T. 2016 Study on hydrodynamics performances of a deep-water drillship and water motions inside its rectangular moonpool. In *Proceedings of the 26th ISOPE*. Rhodes, Greece.

Guo, X., Lu, H., Yang, J. & Peng, T. 2017 Resonant water motions within a recessing type moonpool in a drilling vessel. *Ocean Eng.* **129**, 299–239.

McIver, P. 2005 Complex resonances in the water-wave problem for a floating structure. *J. of Fluid Mech.* **536**, 423–443.

Molin, B. 2001 On the piston and sloshing modes in moonpools. *J. of Fluid Mech.* **430** (5), 27–50.

Molin, B. 2017 On natural modes in moonpools with recesses. *Applied Ocean Res.* **67**, 1–8.

Molin, B., Zhang, X., Huang, H. & Remy, F. 2018 On natural modes in moonpools and gaps in finite depth. *J. of Fluid Mech.* **840**, 530–554.

Newman, J.N. 2018 Resonant response of a moonpool with a recess. *Applied Ocean Res.* **76**, 98–109.

Ning, D., Su, X., Zhao, M. & Teng, B. 2015 Numerical study of resonance induced by wave action on multiple rectangular boxes with narrow gaps. *Acta Oceanologica Sinica* **34** (5), 92–102.

Zhang, X., Huang, H. & Song, X. 2019 On natural frequencies and modal shapes in two-dimensional asymmetric and symmetric moonpools in finite water depth. *Applied Ocean Res.* **82**, 117–129.

Zhao, W., Wolgamot, H.A., Taylor, P.H. & Taylor, R. Eatock 2017 Gap resonance and higher harmonics driven by focused transient wave groups. *J. of Fluid Mech.* **812**, 905–939.