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Model tests on the moored vessel with different moonpool shapes

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Abstract. Moonpools are vertical wells in a floating body used onboard many types of vessels like cable-laying vessels and offshore support vessels. Moonpool gives passage to underwater activities for different types of ships as per their mission requirements. It is observed that inside a moonpool considerable relative motions may occur, depending on shape, depth of the moonpool and on the frequency range of the waves to which the ship is exposed. The vessel responses are entirely different in zero and non-zero Froude number. Former situation is paid attention in this study as the mission requirement of the platform is to be in the particular location for long period of operation. It is well known that there are two modes of responses depending on the shape of the moonpool viz., piston mode for square shape and sloshing mode for rectangular shapes with different aspect ratios of opening like 1:1.5 and 1:2 ratios. Circular shaped moonpool is also tested for measuring the responses. The vessel moored using heavy lines are modeled and tested in the wave basin. The moored lines are provided with pre-tension and the dynamic tensions on the lines are measured. The different modes of oscillations of water column are measured using wave gauge and the vessel response at a particular situation is determined. RAOs determined for various situations provide better insight to the designer. The experiments done in the wave basin may also be compared with a software package meant for handling moored floating bodies.

Keywords: moonpool; vessel response; piston mode; sloshing mode; pretension; dynamic tension

1. Introduction

An opening in the water plane area challenges the righting arm stability and reduces the reserve buoyancy of any floating platform. A permanent opening in the water plane area is required for special types of platforms and moonpools are provided for such ones. Such vessels can be self propelled or pushed after closing the bottom side opening of moonpools. Resistance is minimized under such conditions of voyage of platforms from point A to B, the point of destination. Power and hence fuel is saved by closing the opening of moonpool in the bottom side of the ship. In the operating point the vessel is moored to sea bottom and the catenary of the mooring causes variable stiffness to the floating body. Floating body dynamics has been studied by Rameswar Bhattacharyya (1978) and is widely referred by Naval Architects and Ocean Engineers in search of the fundamental parameters of ship shaped floating bodies. Newman (1977) discussed applications for a variety of topics in Marine Hydrodynamics.

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After fixing the bottom of all mooring lines, the vessel fitted with instruments suitably positioned to face the incoming waves. The catenary shape and sag of the mooring lines is maintained as per scaled down size. Inclinometer, accelerometer, wave probes and strain gauge on the upper part of line are connected to the circuitry through amplifiers and oscilloscope. Data acquisition system records all the digitized values of signals due to motion of platform by waves.

As drilling operations are conducted in deeper and deeper waters, it becomes very impractical economically to construct such platforms. In such deeper waters it is becoming common practice to drill from floating vessels. One of the problems in drilling from floating vessels is to maintain the ship within the permissible excursions. One type drilling ship has a moonpool conveniently provided in the midsection of the ship. It is through this moonpool usual drilling operations are conducted. In this case it is desired that the moonpool stay in fixed position with respect to the parent ship. The main reason is that the ship can get aligned with the incoming or head-on waves. The ship is secured with the mooring cables connected to the sea bottom.

2. Moonpool and mooring lines

Aalbers (1984) carried out model experiments at the Netherlands ship model basin in which the hydrodynamics with respect to a moonpool were investigated. A mathematical model describing the relative water motions inside a moonpool was developed. Day (1990) proposed a method for assessing the performance of the moonpool. Theoretical and experimental studies indicate possible geometries for the moonpool which may be used to improve the performance of the floating ship. Finally, a systematic procedure for designing moonpool is developed and illustrated with a worked example based on an actual design problem. English (1976) described a method of overcoming the oscillations without the use closing doors. Fukuda (1977) conducted experiments to show the behaviour of the water in the well (moonpool) and its effects on the motion of the ship, under forward motion. Fukuda and Yoshii (2009) discussed about the water motion in a two-dimensional vertical cavity with a free surface on the top and current on the bottom. Gaillarde and Cotteleer (2001) presented solutions to reduce the oscillations in the moonpool caused by the forward speed of the vessel. Numerical methods are also presented to solve the problem in transit and normal conditions in waves. Molin (2001) studied rectangular moonpools of large horizontal dimensions. The natural modes of oscillation of the inner free surfaces are determined, under the assumption of infinite water depth and infinite length and beam of the barges that contain the moonpools. The problem is treated in two and three dimensions, using linearized potential flow theory. Results are given for the natural frequencies and the associated shapes of the free surface, for wide ranges of the geometric parameters. Simple quasi-analytical approximations are derived that yield the natural frequencies. Molin (1999) concentrated on estimating the natural frequency of the piston mode of a moonpool. He paid attention to obtain the natural frequencies and Eigen vectors of the sloshing modes. van’t Veer and Tholen (2008) conducted model tests. The resonant oscillation mode can be piston or sloshing. The sloshing mode dominates in longer moonpool, while piston mode oscillations are dominant in shorter moonpool. Based on two model tests series carried out at Delft University of Technology, a resistance prediction model was constructed for piston type oscillations.

Inoue and Surendran (1994) paid attention to interaction of mooring line with the ocean bottom and discussed reduction in dynamic tension. The line is divided into finite number of lumped masses and linear springs without mass. Cross flow drag across line causes strain along the length due to stress caused by differential tensions at consecutive points. The surrounding fluid always tries to immobilize the moving chain. This process cause cross flow drag and creates further strain on the line. The line stretch and the resulting tension is dynamic in nature. This tension is composed of steady value, inertial effects and drag component. Such dynamic tension can be normalized by dividing by static tension value. The damping associated with the interaction of vibrating chain with the sea bed which was considered to be elastic, was incorporated in the computations. Surendran (1989) developed a computer program to determine the cable configuration, tension and various other parameters for safe tow. A number of curves have been presented based on different case studies to enable the designer to have better insight into the interesting behaviour of tow cables. Surendran and Goutam (2009) concentrated on the dynamic tension of upper point of cable fitted with a sub-surface buoy at a suitable location. Surendran and Pramod (2006) studied the non-linear behaviour of a moored floating platform in stochastic seaway generated using the Pierson-Moskowitz spectrum. Second-order wave or slow drift forces acting on the structure are considered as they contribute to a major percentage for the excursion of a large platform. Wave friction damping and skin friction damping have also been considered in their study to arrive at solution.

From the above literature survey, it is evident that the determination of oscillations in moonpool has been attempted by researchers through experiments and numerical simulations. In this paper, experimental study has been done to pin point the critical situations of the vessel motion response due to moonpool and mooring line oscillations and possible interactions.

It is understood that there are piston and sloshing modes of oscillations for the water trapped in the moonpool. The incoming waves interact with the moored floating body, and the water mass in the moonpool is excited and creating both circular and linear motions. Therefore the critical situations like resonant condition of heave, roll and pitch are to be investigated as they are important for a moored floating body. The line tension in its catenary shaped stage exerts stiffness which is modified due to the excursions of the body by the hit of incoming waves. The tensions on the line can be modified influencing the total vessel response. The entrapped water in the moonpool shows different excitations depending on the shape of the moonpool. A few shapes are to be tested in the wave flume and whole details are provided in the following sections. Results are presented in the non-dimensional form so that anyone working in this topic can use the results presented for their work.

3. Experimental set up

In this study shapes of the moonpool considered are Circular (Ø 12 cm), Square (12 cm x 12 cm), Rectangular (12 cm x 18 cm) and (12 cm x 24 cm).

Main dimensions of a bulk carrier ship considered here is compatible with drill ships referred by Riaan Van‘t Veer and Haye Jan Tholen (2008). The principal dimensions of the scaled down vessel are given in Table-1. The prepared model is shown in Fig. 1. The biggest size moonpool (12 cm x 24 cm) is fixed to the model with FRP sealing and other moonpool shapes are inserted in this and water sloshing is restricted with the help of wooden strips. Various moonpool shapes are shown in Fig. 2.

Scaled down model with 1:100 ratio is fabricated in Fiber Reinforced Plastic (FRP) and moonpool is fabricated using 3 mm aluminium sheet. Ship model with moonpool is shown in Fig. 3. Fig. 4 shows the opening at the bottom.

Table 1 Model particulars

Frame details for scale 1:100	
Length overall	2.37 m
Length between perpendiculars	2.19 m
Breadth	0.36 m
Depth	0.189 m
Draft	0.106 m

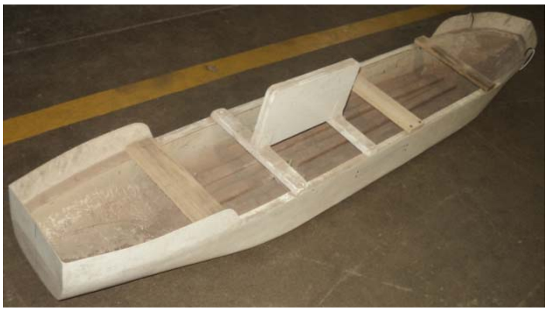

Fig. 1 Ship model

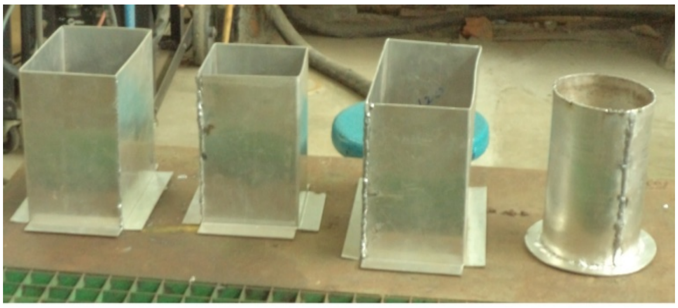

Fig. 2 Different moonpool sections

Fig. 3 Ship model with moonpool

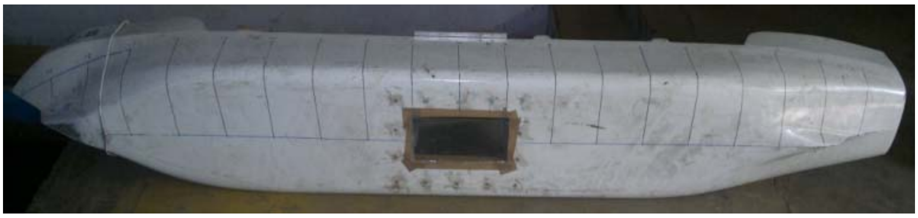

Fig. 4 Bottom view of ship model with moonpool

Fig. 5(a) is the plan view of the model in the wave flume. Fig. 5(b) is the instrumentation and catenary of the floating system with end connection of mooring.

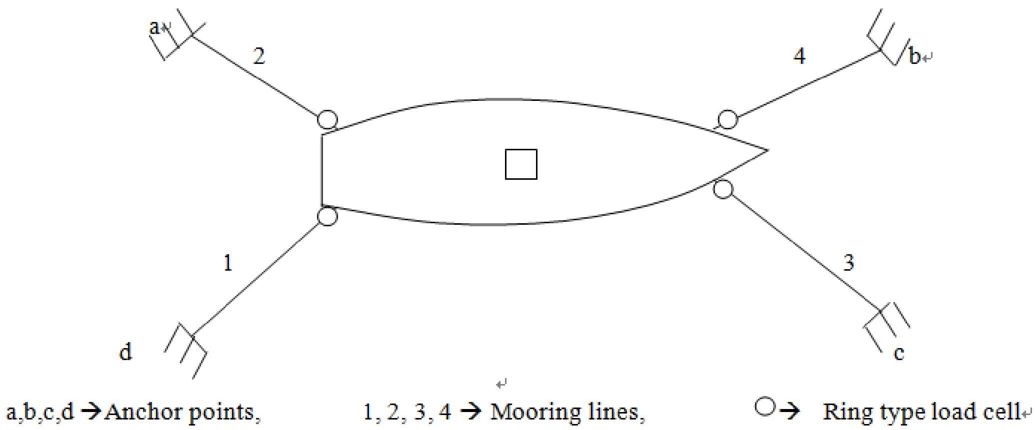

Fig. 5 (a) Plan view of model in the experimental setup

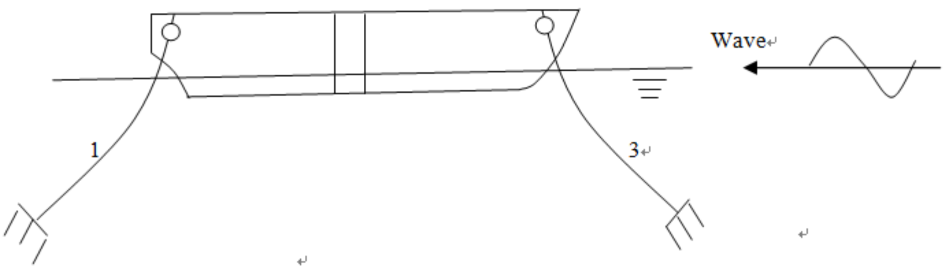

Fig. 5 (b) Schematic sketch of the experimental set up

These model tests were conducted in 30 m x 2 m x 1 m wave flume, which is shown in figure 6 below.

Fig. 6 Experimental setup in wave flume

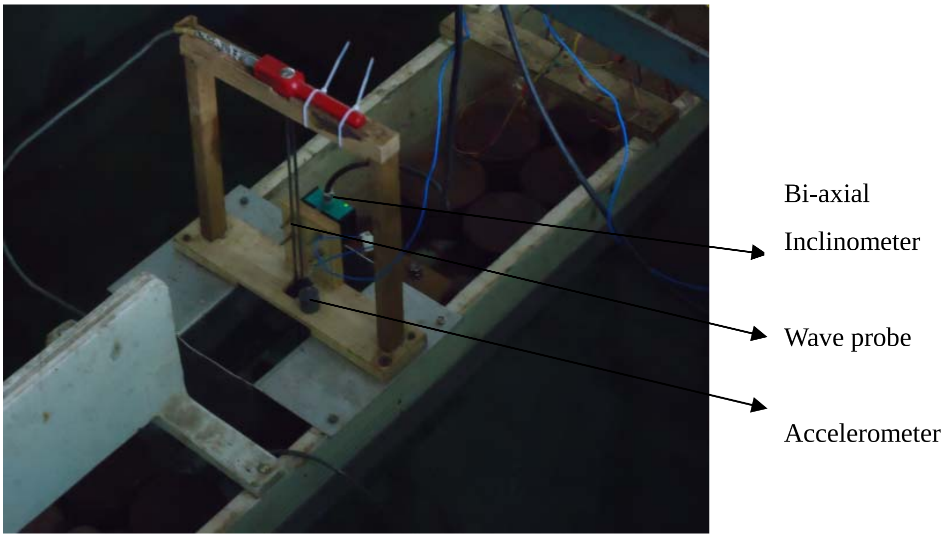

Fig. 7 Ship model with instruments for measurement

Fig. 8 Instruments used for recording

Determination and analysis of vessel response with different moonpool shapes. The response reading are recorded in oscilloscope and analyzed as follows

4. Results and discussions

Experiments are done with and without moonpool, considering different shapes of the moonpool; the results are shown for the same. Model connected with biaxial inclinometer, accelerometer and wave probe are shown in Fig. 7. Instruments used for recording the responses, mooring line tension and wave height are shown in Fig. 8.

4.1. Moonpool wave with respect to incident wave

Faltinson (2009) referred to piston mode for the to and fro oscillation of water column in the moonpool in up and down direction. The sloshing phenomenon is a still further complicated motion of the entrapped water which modifies the natural frequency of the floating body. Figure 9 shows the water column oscillation in the square (12 cm x 12 cm) moonpool with respect to incident wave height of 3cm, obviously moonpool wave height will be less than the incident wave; otherwise there will be more heave response of the model. The graph shows that there will be one third of the wave height in the moonpool with respect to incident wave.

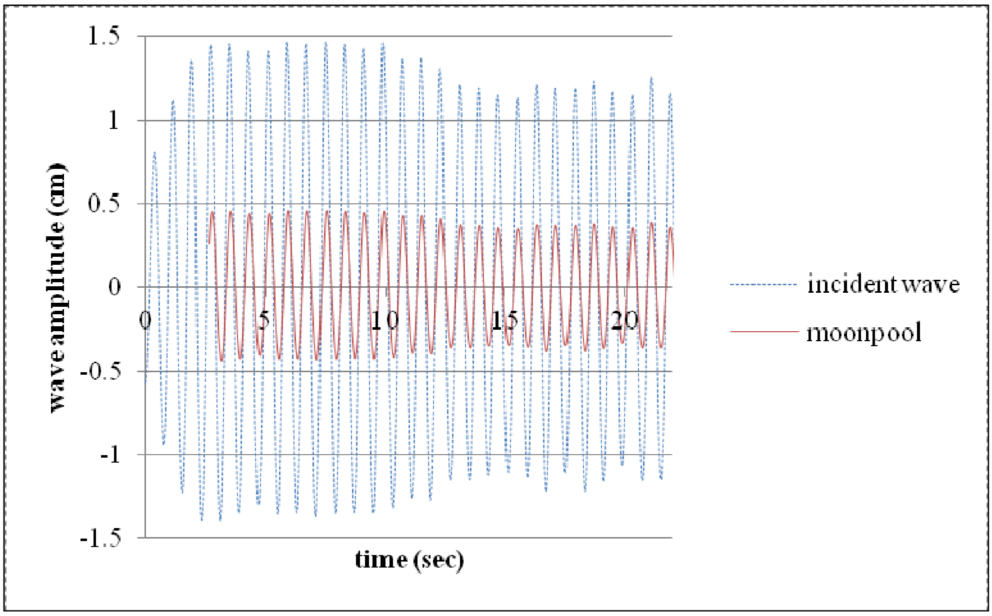

Fig. 9 Incident wave and moonpool water column oscillation for 3cm wave height

4.2. Heave, roll and pitch response amplitude operator of the ship

Response Amplitude Operator (RAO) defines the response of the model with respect to the incident waves. Response of the floating body is plotted and shown for heave, roll and pitch RAOs of the model with 3cm incident wave height.

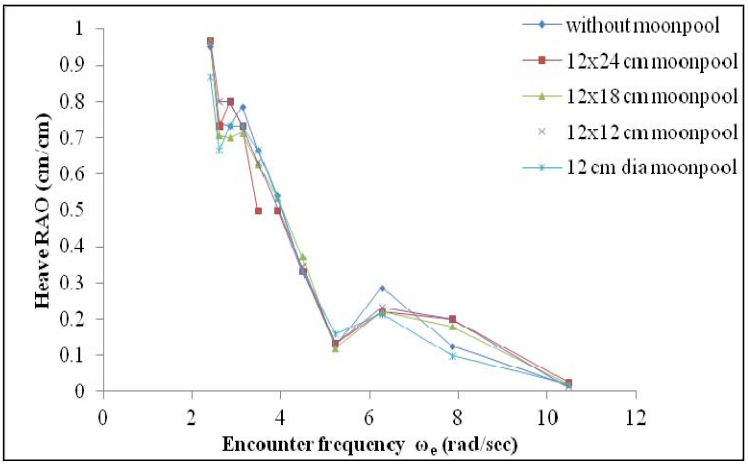

Fig. 10 Heave RAO for different shapes of the moonpool for 3 cm wave height

As per Fig. 10 heave RAO of the model is less for more frequency which is inversely proportional to time period of the wave. For lesser time period waves heave RAO is very less and it increases with higher time period waves. Such trend is critical when waves are with higher steepness.

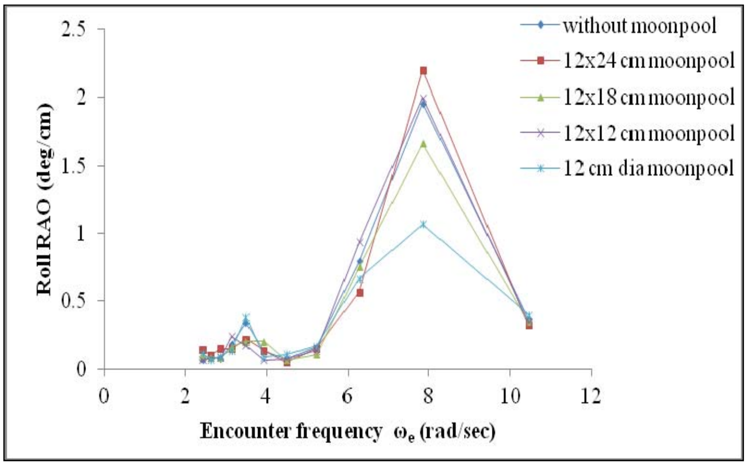

Fig. 11 Roll RAO for different shapes of the moonpool for 3 cm wave height

Fig. 11 shows that roll RAO is of opposite to heave RAO, only difference is that for lesser time period it is less and increases with higher time period waves and there is abrupt decrease in roll RAO as time period increases.

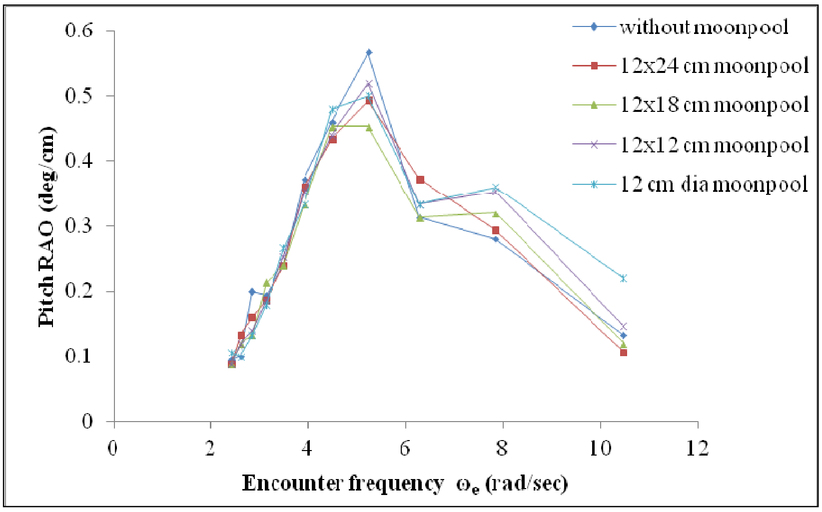

Fig. 12 Pitch RAO with different moonpool shapes for 3cm wave height

Fig. 12 is the pitch RAO following roll RAO trend, only difference is that peaks are not exactly matching, this is favorable with respect to ship coupled motions.

The peak in pitch occurs at around 5.2 rad/sec of incoming wave and the peak in roll is at near 8 rad/sec. The pitch radius of gyration and that of roll is modified by the tension on lines, moonpool size and material distribution along the length and athwartship direction of ship. The study throws light into the safe operation of platform for various wave conditions. In other words, the pitch and roll radii of gyration can be altered by modifying material distribution. Such situation will save the platform from dangerous condition like parametric roll.

4.3. Normalized mooring line tension for head-on sea condition

The length of mooring line considered is 2 m to maintain the catenary shape, and the initial tension in the mooring line is 60 kg. The following graph shows variation of the normalized tension with respect to non-dimensional frequency. Where ‘L’ is length of the mooring line in meters and ‘g’ is acceleration due to gravity in m/sec^2. It can be clearly observed that there is least tension for intact ship without moonpool, which is obvious because no water is entrapped. But for the ship with moonpool tension is more because water entrapped in the moonpool will increase the tension on the mooring lines. Also we can observe from the graph that for biggest moonpool shape which is 12 cm x 24 cm, the tension is highest because entrapped water column is more in this particular section. Fig. 13 shows the measure of dynamic tension against non-dimensional frequency.

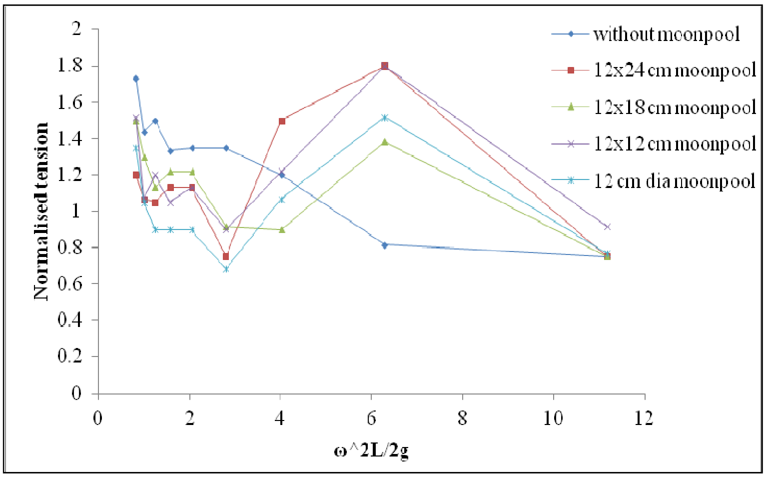

Fig. 13 Mooring line normalized tension for head on side

5. Conclusions

By considering different shapes of the moonpool, it can be seen that circular section is responsible for least heave and roll RAO, but the RAO for pitch is slightly higher. In this case the dynamic tension is reasonable and it is plotted against non dimensional frequency as a function of catenary length. The experimental value of dynamic tension in non-dimensional form is important to analysts in general as the computation of the same is not so straight forward.

Considering all the motion RAOs of the model, heave RAO is having two peaks. Intact ship heave RAO is maximum compared to ship with moonpool. This shows that water entrapped in the moonpool will dampen the heave motion of the ship. Roll RAO is also having two peaks. For a wave frequency of 8rad/sec, roll is found least for ship with circular moonpool, and for the same frequency, the ship with biggest (24 cm x 12 cm) moonpool is found to be maximum. For intact vessel, the value of roll at this frequency is found to be almost middle of the extreme values. Pitch RAO is also having two peaks. It is maximum for intact ship and this is almost average of the extreme values for ship with circular moonpool.

Mooring line tension is least for the intact ship and maximum for ship with biggest (12 cm x 24 cm) moonpool, the sloshing mode of water column oscillation will create the more tension in the mooring lines.

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