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EXPERIMENTAL INVESTIGATION OF MOONPOOL SHAPES ON A SHIP WITH FORWARD SPEED

Sharanabasappa C.Sajjan
Professor, Dept. of Mech. Engg.
KLE Inst of Tech Hubli, Karnataka, India
(Formerly Research scholar at IIT Madras)
sajjansc@gmail.com

S.Surendran
Professor, Dept. of Ocean Engg,
Indian Institute of Technology, Madras
Chennai, TN, India

ABSTRACT

A moonpool is a feature of marine drilling platforms, drillships and diving support vessels, some marine research and underwater exploration or research vessels, and underwater habitats, in which it is also known as a wet porch. A floating platform with a moonpool is subjected to different forces due to sloshing and movement of the entrapped fluid in it, while the body is subjected to environmental loads like waves, winds, currents etc.,. Inside a moonpool considerable relative motions may occur, depending on shape and depth of the moonpool and the frequency range of the waves to which it is exposed. The vessel responses are entirely different in zero and non-zero Froude numbers. Later situation is paid attention in this study. There will be different water column elevations in the moonpool depending on the shapes. Two modes of responses are possible based on the shape of the moonpool viz., piston mode for square and sloshing mode for rectangular shape. An aspect ratio of 1:1 for square, 1:1.5 and 1:2 in case of rectangular shapes is considered during experimentation. Circular shaped moonpool is also tested for finding the response. The vessel is initially tested in a towing tank with different drafts and speeds based on Froude scaling. The different modes of oscillations of water column are measured using wave gauge and the vessel resistance is also studied, with and without moonpool. The water column elevation in moonpool may provide better insight to the designer to consider operational and safety parameters.

Keywords— Drillship, Underwater exploration, sloshing, frequency range, Froude number

1. INDRUCTION

With the increased interest in offshore recovery of oil, various types of drilling platforms have been developed for drilling on the bottom of the ocean from drilling rigs supported above the surface of the water. One of the types of drilling platform is drillship with moonpool.

A drillship is simply an adaptation of a standard seagoing monohull ship with a moonpool or other means for carrying out drilling operations. A drillship has well known advantages of mobility and high storage capacity. A drillship can generally travel at a relatively high speed and can fit through narrow passageways. So it can travel easily from its construction site to a distant offshore location. Also a drillship has a relatively high storage or payload capacity. When the drilling operations are conducted in deeper and deeper water, it becomes very impractical and uneconomical to construct drilling platforms. Therefore, it has become practice to drill from floating vessels, and is known as drillship with moonpool.

Permanent opening (moonpool) in the water plane area is required for special types of platforms like exploration and drilling vessels, production barges, cable-laying vessels, rock dumping vessels, research and offshore support vessels. These vessels can be moved from one place to another after the mission requirements. The opening shape and size should be determined for less resistance and water elevation in the moonpool for better performance of the vessel.

2. EXPERIMENTAL PROCEDURE

Model fabrication with moonpool.

The model is fabricated with Fibre reinforced plastic (FRP). Main dimensions of a bulk carrier ship considered here is compatible with drill ships referred by RiaanVan‘t Veer and Haye Jan Tholen (2008). The principal dimensions of the scaled down model are given in Table 1. The prepared model is shown in figure 1. The moonpool shape and sizes are given in Table 2 and shown in figure 2. Ship model with moonpool are shown in figures 3 and 4.

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

Table 2: Moonpool shapes and sizes.

Moonpool Shape	Ratio
Rectangular	1:2, 1:1.5
Square	1:1
Circular	-

Fig.1. Ship model

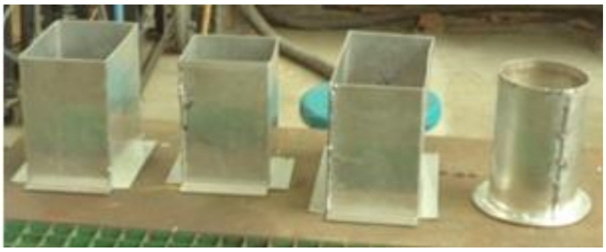

Fig. 2. Different moonpool sections

Fig. 3. Ship model with moonpool

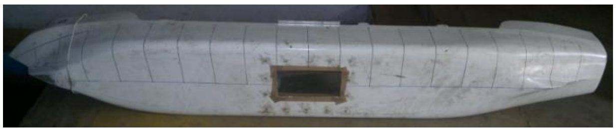

Fig. 4. Bottom view of ship model with moonpool

Towing tank Experimental setup.

Figure 5 shows the towing tank at Dept. of Ocean Engg., IIT Madras. Size of the tank 85m (length) x 3.2m (breadth) x2.8m water depth, selectable carriage speed 5 m/s.

Figure 6 shows experimental arrangement in the towing tank. With the shown setup, one can measure the resistance and water elevation in the moonpool with the help of instruments as shown in figure 7 of the model for a particular speed, at which the carriage runs.

Fig. 5. Towing tank at Dept. of Ocean Engg., IIT Madras.

Fig. 6. Model in towing tank with forward speed

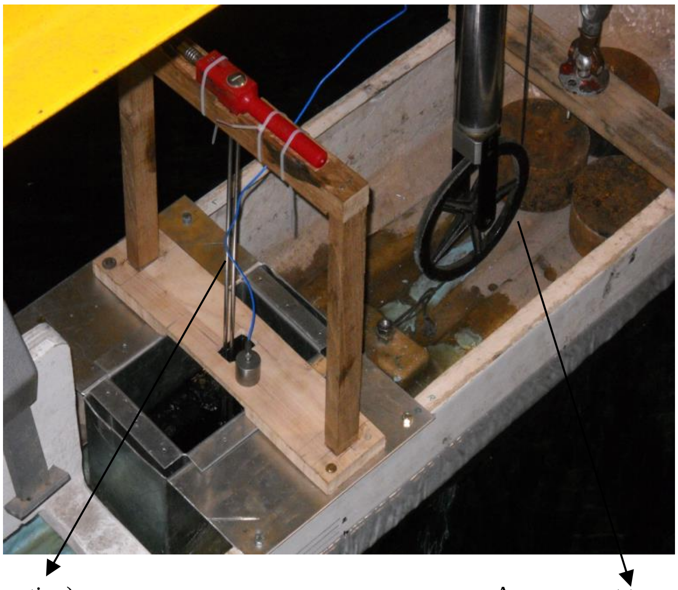

Fig. 7. Instruments for measurements

Theoretical back ground with results and discussion.

Numerical approach to find frequency and amplitude of water in moonpool.

Faltinsen (1990) considered a moonpool as shown in figure 8. He considered that resonance oscillations may occour in the moonpool. He analysed this by using a linear theory. It is assumed that the ship motions are known. The figure represents a longitudinal cross-section of the ship. The moonpool is assumed to have a constant horizontal circular cross-section with diameter D. He assumed the water motion does not vary across the moonpool. This means there is a constant vertical velocity $d\eta/dt$ in the moonpool, where η is the free surface elevation in the moonpool. By differentiating Bernoulli's equation, the vertical pressure gradient is related to vertical fluid acceleration.

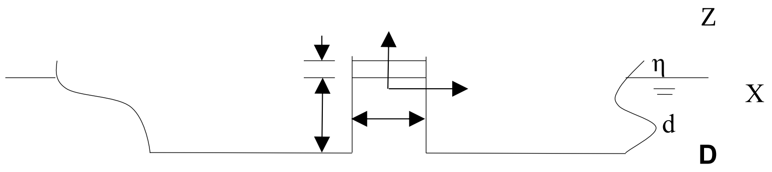

Fig. 8. Moonpool dimensions in a ship (Faltinsen 1990)

Faltinsen (1990) presents the water column in the moonpool as a spring-mass system without damping. He gives the following formula for the calculation of the natural period Tn of the moonpool is given in equation (1):

$$T_n = 2\pi\sqrt{\frac{d}{g}} \tag{1}$$

Where d is the draught of the ship in m and g is acceleration due to gravity. It is same as mass of the water mass (m) inside the moonpool, then the above equation can also be represented as in equation (2)

$$\mathrm{T_n} = 2\pi\sqrt{\frac{\mathrm{m}}{\mathrm{g}}} \tag{2}$$

Fukuda (1977) uses the same formula, but he makes use of an increased length, to take account of the added mass (m') and the increased draught (d') is given by equation (3) and natural frequency is given by equation (4).

$$\mathrm{T_n} = 2\pi\sqrt{\frac{\mathrm{d}+\mathrm{d}'}{\mathrm{g}}} = 2\pi\sqrt{\frac{\mathrm{m}+\mathrm{m}'}{\mathrm{g}}} \tag{3}$$

$$\omega_\mathrm{n} = \sqrt{\frac{g}{\mathrm{d}+\mathrm{d}'}} = \sqrt{\frac{g}{\mathrm{m}+\mathrm{m}'}} \tag{4}$$

This added draught is an empirical estimation and is established from experiments with large number of different moonpool geometries, rectangular and circular by Fukuda (1977) are given by equation (5):

$$\mathrm{d}' = \mathrm{m}' = 0.41\sqrt{\mathrm{S}} \tag{5}$$

Where S is water surface area of moonpool in m^2.

A theoritically based formulation is derived by Molin (2001)

$$\mathrm{d}' = \frac{\mathrm{b}}{\pi}\left\{\sinh^{-1}\left(\frac{\mathrm{l}}{\mathrm{b}}\right) + \frac{\mathrm{l}}{\mathrm{b}}\sinh^{-1}\left(\frac{\mathrm{b}}{\mathrm{l}}\right) + \frac{1}{3}\left(\frac{\mathrm{b}}{\mathrm{l}} + \frac{\mathrm{l}^2}{\mathrm{b}^2}\right) - \frac{1}{3}\left(1 + \frac{\mathrm{l}^2}{\mathrm{b}^2}\right)\sqrt{\frac{\mathrm{b}^2}{\mathrm{l}^2} + 1}\right\} \tag{6}$$

Where l and b are the length and breadth of moonpool respectively. Comparing equations (5) and (6) reveals that the added mass in Molin's formulation is larger than Fukuda's, leading to lower natural frequencies. Table 3 shows the piston natural frequencies for several moonpool geometry ratios as per Fukuda equation (5) and Molin equation (6).

Table 3 shows the piston natural frequencies for several moonpool geometry ratios as per Fukuda equation (5) and Molin equation (6).

Table 3: Piston mode natural frequencies

Moonpool geometry ratio		Piston Natural Frequency (rad/s)	
length/breadth	draft/breadth	Fukuda eq.(5)	Molin eq.(6)
2	0.966	7.270	7.109
2	1.05	7.082	6.933
2	1.133	6.907	6.769
1.5	0.966	7.460	7.357
1.5	1.05	7.257	7.162
1.5	1.133	7.070	6.982
1	0.966	7.706	7.534
1	1.05	7.482	7.325
1	1.133	7.278	7.132

Table 4 shows the sloshing natural periods for several moonpool geometry ratios.

Table 4: Sloshing mode natural frequencies

Moonpool geometry ratio		Sloshing Natural Frequency (rad/s)	
length/breadth	draft/breadth	Newman eq.(7)	Molin eq.(8)
2	0.966	11.329	11.872
2	1.05	11.329	11.745
2	1.133	11.329	11.647
1.5	0.966	13.081	13.310
1.5	1.05	13.081	13.242
1.5	1.133	13.081	13.194
1	0.966	16.021	16.058
1	1.05	16.021	16.043
1	1.133	16.021	16.034

As noted by Molin (2001), the natural frequency of the first sloshing mode is always higher than the first piston mode. The experimental data in figure 9 is obtained from different moonpool geometry ratios and at different forward speed. The water column oscillation frequencies are obtained from time history plots obtained in the experiments.

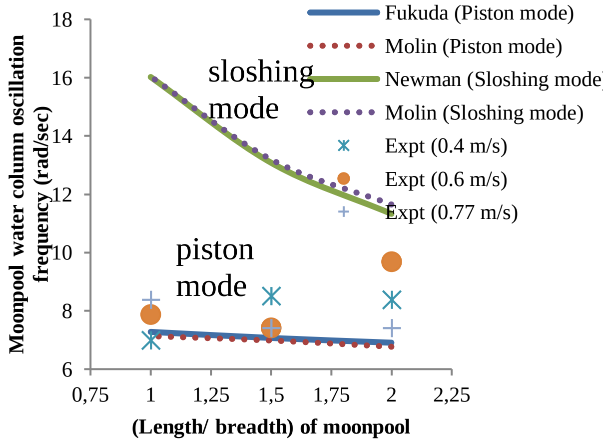

Fig. 9. Oscillation frequency of water level inside moonpool

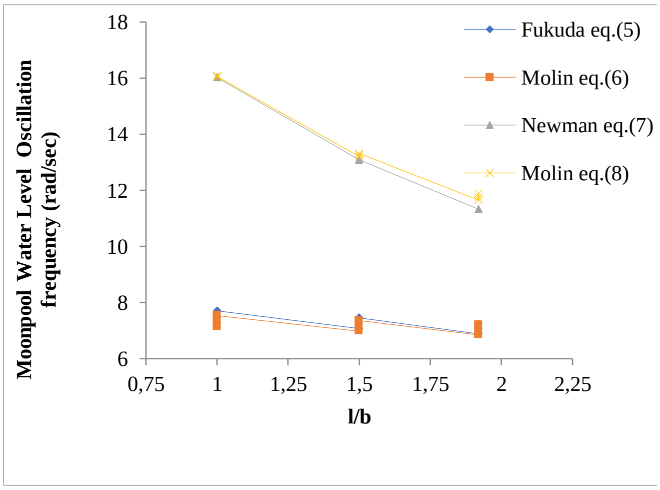

Fig. 10. Oscillation frequency of water level inside moonpool

The natural sloshing mode of a moonpool derived by Newman (1977) is given by equation (7) below

$$\omega_L = \sqrt{\frac{n\pi g}{l}} \tag{7}$$

Where n=1 represents the first sloshing natural frequency, Molin (2001) presents a more complicated formulation, based on the derivation of a velocity potential, which include the moonpool draft given by equation (8).

Where J_{n0} involves an intergral over the moonpool length and breadth which can be obtained through numerical integration given by Molin (2001) as in equation (9) and equation (10).

$$\omega_L = \sqrt{\frac{n\pi g}{l}}\sqrt{\frac{1 + J_{n0}\tanh(n\pi d/l)}{J_{n0}\tanh(n\pi d/l)}} \tag{8}$$

$$J_{n0} = \frac{n}{bl^2}\, I \tag{9}$$

$$I = 2b^2 l \sinh^{-1}\left(\frac{l}{b}\right) + 2bl^2 \sinh^{-1}\left(\frac{b}{l}\right) + \frac{2}{3}(b^3 + l^3) - \frac{2}{3}(b^2 + l^2)^{3/2} \tag{10}$$

For different length to breadth and draft to breadth ratios both piston and sloshing natural frequencies shown in the tables 3 and 4 are shown in figure 9. As noted by Molin, the natural frequency of the first sloshing mode is always higher than the first piston mode. More over both frequencies are closer to each other for longer moonpools compared to shorter which can be seen in figure 11.

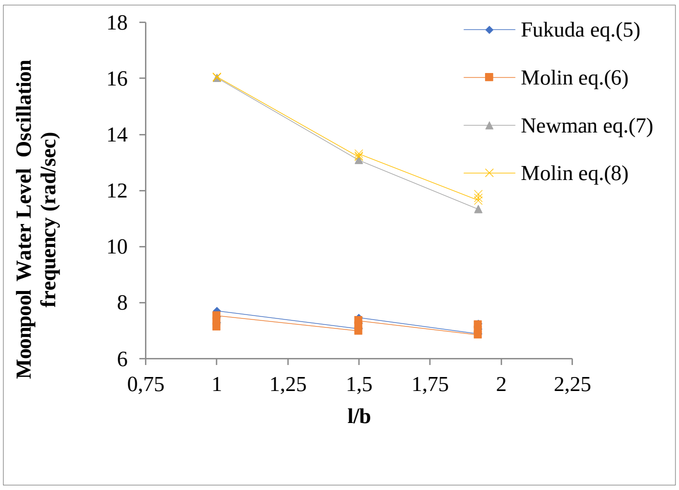

Fig. 11 Oscillation frequency of water level inside moonpool

Fukuda (1977) has suggested a method to calculate the amplitude of the heaving mode of the water column using a measured value of the ship speed where the oscillation starts. The equation (11) gives the dimensionless amplitude:

$$\frac{h}{l} = \frac{3\pi}{16}\frac{U - U'}{2l\omega_0} \tag{11}$$

where h= amplitude of oscillation (m), l= length of moonpool (m), U= ship velocity (m/s), U'=Ship speed where oscillation starts (measured) (m/s), ω_0 = natural frequency of oscillation of water column (rad/s). In the above relation U' is the ship speed where oscillation starts may be obtained from the model tests. This relation can be used in design stage to check the probable speed at which the oscillation problem may occur, given the ship speed and main dimensions of the vessel.

Ship resistance in forward speed.

The total resistance (R_T) can be split into a number of different components, which are due to a variety of causes and which interact one with the other in an extremely complicated way. In order to deal with resistance in a practical way, it is necessary to consider the total resistance in a practical way, it is necessary to consider the total resistance as being made up of components which can be combined in different ways. The components of total resistance are Frictional Resistance (R_F) is the component of resistance obtained by integrating the tangential stress over the wetted surface of the ship in the direction of motion. Residuary Resistance (R_R) is a quantity obtained by subtracting from the total resistance of a hull, a calculated friction resistance obtained by any specific formulation. Viscous Resistance (R_V) is the component of resistance associated with the energy expended due viscous effects. Pressure Resistance (R_P) is the component of resistance obtained by integrating the normal stresses over the surface of a body in the direction of motion. Viscous Pressure Resistance (R_{PV}) is the component of resistance obtained by integrating the components of the normal stresses due to viscosity and turbulence. Wave making Resistance (R_W) is the component of resistance associated with the energy expended generating gravity waves.

ITTC 1957 Method: The main discussion at all the International Towing Tank Conference (ITTC) has been how to transform the model test result from model scale to full scale. The ITTC 1957 method is based on Froude's principle and on the "ITTC 1957 model-ship correlation line". In 1957 the ITTC (1959) decided that the line given by the formula

$$\mathrm{C_F} = \frac{0.075}{(\log_{10}\mathrm{R_e} - 2)^2} \tag{12}$$

where $R_e$is the Reynolds number and is given by

$$\mathrm{R_e} = \frac{\rho \mathrm{V_M} \mathrm{L_M}}{\mu} \tag{13}$$

ρ is the density of water in the towing tank, V_M is the speed of the model, L_M is length of the model and μ is the dynamic viscosity of water.

The total resistance for the model is determined by the towing tests and from the formula

$$R_{TM} = \frac{1}{2} C_{TM} \rho_M {V_M}^2 S_M \tag{14}$$

where R_{TM} is the model resistance, C_{TM} is coefficient of resistance taken from the graph given by ITTC 1957 method. S_M is the wetted surface of the model and other notations are already explained above remains same.

In the publication Ship Resistance (Guldhammer and Harvald, 1965, 1974) an assembly of published results from towing tests have been summarized. The "ITTC 1957 model-ship correlation line" has been used to determine the frictional resistance coefficient C_F given by equation (15), based on Reynolds number R_e.

$$\mathrm{C_F} = \frac{0.075}{(\log_{10}\mathrm{R_e} - 2)^2} \tag{15}$$

where $R_e$is the Reynolds number and is given by

$$\mathrm{R_e} = \frac{\rho \mathrm{V_M} \mathrm{L_M}}{\mu} \tag{16}$$

where ρ is the density of water in the towing tank, V_M is the speed of the model, L_M is length of the model and μ is the dynamic viscosity of water.

The total resistance for the model is determined by the towing tests and from the formula

$$R_{TM} = \frac{1}{2} C_{TM} \rho_M {V_M}^2 S_M \tag{17}$$

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Using already calculated C_F values for different R_e and finding residual resistance coefficient coefficients C_R from the standard graphs given by Guldhammer's and Harvald's Diagrams (Harvald 1983) for the ratio of length of model/(volume)$^{1/3}$. Total resistance C_T is found by summing C_F and C_R . However, resistance values as per Maxsurf and Guldhammer's and Harvald's approaches are not included in the thesis as the provisions for moonpools are not included in the methods.

Variation of ship model resistance without moonpool and with different moonpool shapes.

Variation of ship model resistance is found with different moonpool shapes and without moonpool, results are shown below. Fig. 12, 13 and 14 show the variation of resistance (experimental) for 11.6 cm, 12.6 cm and 13.6 cm draft respectively.

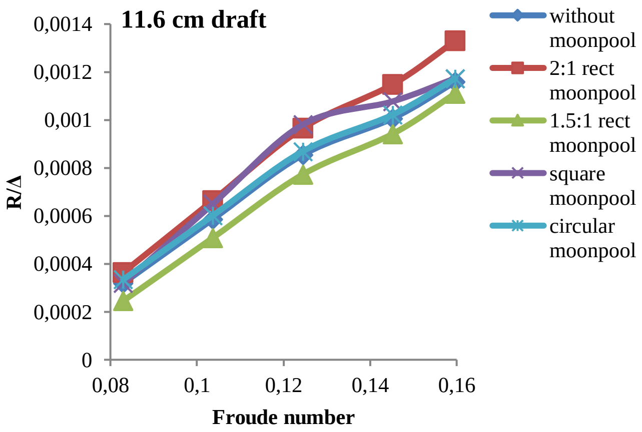

Fig. 12. Variation of resistance (experimental) with different moonpool shapes for 11.6 cm draft

The model test is run for small speed range as the mission requirement of the vessel is mainly for the zero speed condition. Hence in Fig. 15 the model test result is shown using a short line. However the resistance as per ITTC 1957 formula is shown for longer range of speed. Intact ship is considered for the calculation already discussed.

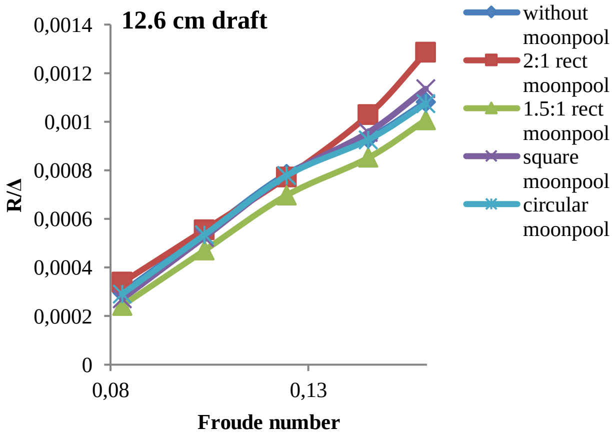

Fig. 13. Variation of resistance (experimental) with different moonpool shapes for 12.6 cm draft

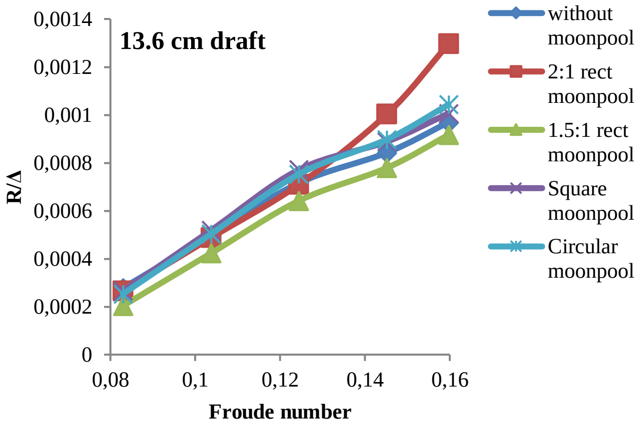

Fig. 14. Variation of resistance (experimental) with different moonpool shapes for 13.6 cm draft

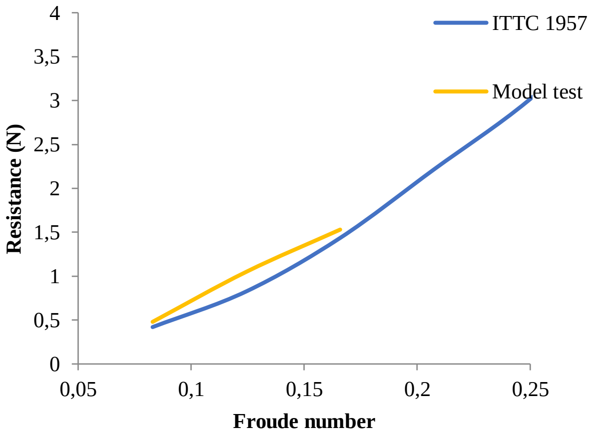

Fig. 15. Variation of resistance for the considered ship

Variation of water column elevation in different moonpool shapes.

Variation of water column elevation in different moonpool shapes are shown below. Fig. 16, 17, 18 and 19 shows the variation of water column elevation for circular, square, 1.5:1 rectangular, and 2:1 rectangular shapes with 85%, 93% and 100% draft respectively.

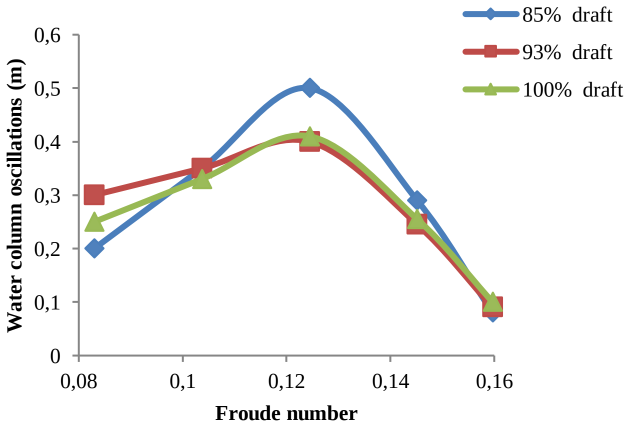

Fig.16. Variation of water column elevation in Circular moonpool

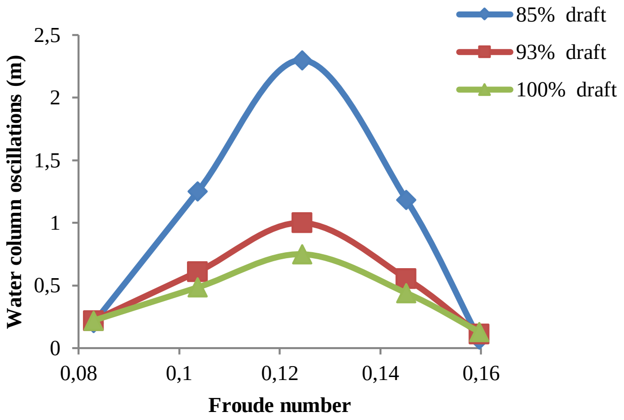

Fig.17. Variation of water column elevation in Square moonpool

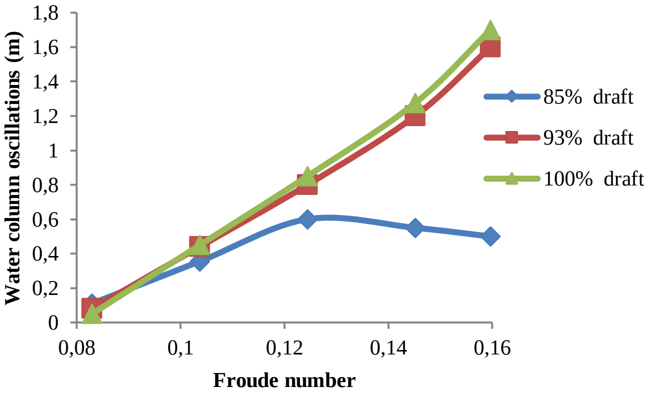

Fig.18. Variation of water column elevation in 1.5:1 rectangular moonpool

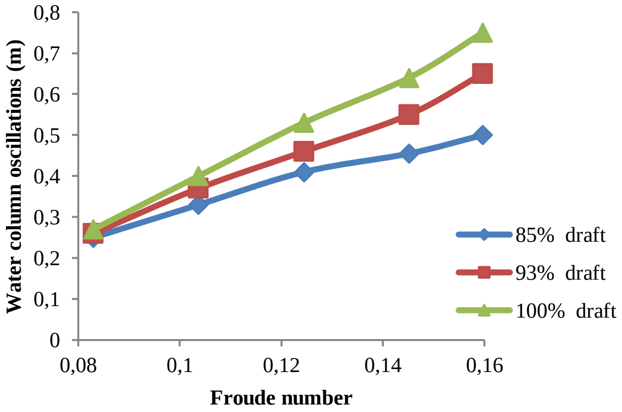

Fig.19. Variation of water column elevation in 2:1 rectangular moonpool

3. DISSCUSSIONS

Ship in forward speed condition

Resistance is comparatively more for 2:1 rectangular moonpool since the discontinuity of hull surface due to moonpool cause more water fill in the moonpool space.

Up and down motion of the surface of water column is also reason for increase in resistance.

It is felt that the generated data and plots presented will serve as a data bank, from experiment, for the future use by researchers and analysers.

4. CONCLUSIONS

The main focus of this work is on hydrodynamics of a vessel with moonpools. Some of the important conclusions based on this work are given below.

Water column oscillations in forward condition are insignificant. The resistance values are found to be of no much variations.

Forward speed condition is only for academic interest; as the vessel is supposed to be in a particular location to complete its mission requirements.

The effect of moonpool on resistance is more for bigger moonpool in forward motion of the ship.

Since moonpool water plane area is small compared to the ship's water plane area, there is insignificant variation of response of the ship irrespective of shape of the moonpool in forward speed condition.

Experimental results are recommended for bench marking as the results are consistent.

In fluid dynamics, drag, sometimes called air resistance, a type of friction, or fluid resistance, another type of friction or fluid friction is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid.

Total resistance of a ship is that of including that from surrounding air above the waterline. The study in a towing tank will give a measure of power required to overcome the loads due to hydrodynamic forces and moments. It will be a benchmark for getting the total power required to propel the ship. Hence, the component of air resistance experienced by the ship is to be added separately to get the total propelling power.

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