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CFD Simulation of the Moonpool on the Total Resistance of a Drillship at Low Forward Speed

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Abstract

A moonpool is meant to access the underwater part of hull from onboard ship. Moonpools are openings right through the hull from deck to bottom, allowing equipments, ROVs, etc. to be put into the water at a location on the vessel under permissible ship motion condition. Open moonpools in a drillship are causing additional resistance when the ship is in forward speed. It was shown that the water inside the moonpool started to oscillate at forward speed. The drillship is mainly subjected to two types of motions of water mass inside the column namely, piston mode and sloshing mode. The later mode will be dominant in longer moonpools and piston mode in shorter. The amplitude of water particles inside the moonpool is correlated with the forward speed such that increased forward speed leads to increased amplitudes. The main objective of this study is to find the total resistance and the free surface flow caused by the moonpool when the drillship is at low forward speed condition. Drillship with and without moonpool are considered for the study. Proven packages are used to calculate the calm water resistance of the drillship with moonpool. The incremental change in resistance caused by the moonpool in forward motion is a measure of water motion inside the moonpool for that particular field.

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Keywords: Moonpool; Piston mode; Sloshing mode; Explicit Algebraic Stress model (EASM)

1. Introduction

As already mentioned a drillship is attached with moonpools for access to underwater region during operations. Although, moonpool like opening reduce the stability and strength of ship, they are preferred to based on various operational convenience onboard ships. Though the hull structure and the propulsion unit are same as that of other ocean going ships, drilling equipments and moonpool differentiate the drillship from other ships. The opening on the bottom of the drillship has influence on both the resistance when it is in transit and considerable water motions inside the moonpool. The water motion inside the moonpool will also cause uncomfortable condition to the crew members and will increase the down time of the drillship. The water motion mainly depends on geometry of the moonpool, speed of the drillship when it is in motion, and wave parameters. In rectangular moonpool the standing wave effect will be significant and in the case of square moonpool piston mode will be higher. Some results achieved from experimental and numerical studies on moonpool of a drillship are discussed here.

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Aalbers [1] paid attention on moonpool hydrodynamics and formulated a mathematical model for relative water motion inside the moonpool. In both the numerical and experimental study the influence of damping mechanism was also evaluated. Ahmed and Guedes Soares[2] simulated the free surface flow around the VLCC hull form with the use of potential flow code and viscous flow finite volume code and compared the same with the available results. The geometry of the moonpool is the one of the important parameter in the case of formation of vortices.

Nomenclature

ϕ	flow potential
R_p	pressure resistant
p	pressure
V	speed
ρ	density of sea water
R_T	total resistance
u_i	velocity components
S	wetted surface area
F_n	Froude number
μ	viscosity of sea water

Fukuda [3] conducted research on the behaviour of the water column oscillations in different shapes of moonpool and its effects on the vessel motion .The author observed that the flow inside the moonpool mainly depended on the shape of the moonpool. The flow inside the moonpool is turbulent which is further disturbed by the aft end of the drillship. To simulate the free surface around the hull a suitable model considered as Explicit Algebraic Stress Model (EASM) by Gatski and Speziale [4].The water motion inside the moonpool will cause the resonance when it is in a critical level. Gaillarde and Cotteleer [5] carried out experiments in moonpool with different motion minimizing attachments to reduce the free surface elevation inside the moonpool. The authors also attempted with varying cross section of moonpool along the depth of the ship to reduce the water motions.

The experimental and numerical study of resistance and flow field was carried out by Guo et al. [6] in KVLCC2 hull. The EASM and SST turbulence model were used in numerical study. The results of both the model have good agreement with the experimental study. Also the outputs achieved from turbulence models on resistance, sinkage, trim and the free surface are found to be good. The overall resistance of ship can be divided in to two as wave resistance and viscous resistance Larsson and Raven [7]. Out of these two resistance part, the drillship with moonpool does not affect the wave resistance considerably, but it affect the viscous pressure resistance due to pressure imbalance generated by the moonpool. Molin [8] derived theoretical formulas for both the piston mode and sloshing mode natural frequency of moonpool in two dimensional and three dimensional cases using linearized potential flow theory. In this study the author formulated the free surface shape for both the piston and sloshing mode.

Moonpool resonant oscillations are initiated by vortices that start at the upstream bottom end of the moonpool when the drillship in forward speed condition. Veer and Tholen [10] performed model test on moonpool of the drill ship with different length to breadth ratio and studied the correlation between the shape of moonpool and increase of resistance. The authors arrived at the variation of free surface elevation inside moonpool according to the ratio of draft to moonpool breadth. Although the ship model experiments are important in the case of finding the resistance, the computational fluid dynamics (CFD) simulations can be used for the same efficiently. In this study with the use of SHIPFLOW package, the resistance of the drillship, trim, sinkage and free surface pattern are evaluated. The body plan of the ship which is used for the simulation is shown in Fig. 1. The results of drillship with rectangular moonpool are compared with and without moonpool. In this simulation, non-linear Rankine source panel method and viscous flow finite volume code have been used to find the total resistance of the drillship. The Explicit Algebraic Stress model (EASM) with Alternating Direction Implicit (ADI) solver and single-block structured grid was used in viscous flow code. The outer boundary limit was located at a radius of three times the ship length from the centre axis. A full-scale drill ship hull is used for the CFD simulation; all the simulations are done for the loaded draft of the vessel. Main particulars of the ship are given in Table 1. The moonpool considered for the study has the dimensions of 12 m breadth and 24 m length, which is located at the centre of the drillship. In these kinds of moonpool the vortices will initiate the sloshing motion, when the ship is running at higher Froude number. These vortices are formed because of the separation of the shear layer at the bottom of the moonpool, when the ship is in forward speed condition.

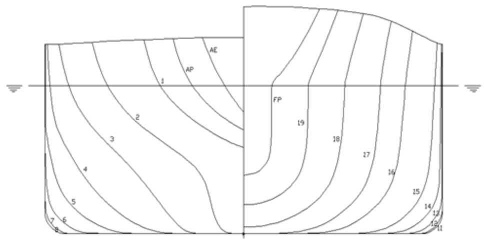

Fig. 1: Body plan

Table 1: Main particulars of ship

Length (L_{OA})	292m
Length(L_{BP})	280m
Breadth	50m
Draft	16.5m
Depth	25.48m
Displacement	1,94,156 tons

In the present study simulation were run for eight different Froude numbers and all the simulation solve the problem by potential flow solver code and the viscous flow code. Most of the case the potential flow code converged less than eight iterations and the later one runs up to 5000 iterations.

2. Computer simulation

The effect of rectangular moonpool, when the ship is in transit with different Froude numbers is attempted in this paper. The Froude numbers are 0.0196, 0.0393, 0.0589, 0.0785, 0.0982, 0.118, 0.137, and 0.157. This study may be useful in drill ship operation zone with open condition of moonpool. The additional resistance caused by the moonpool may reduce the speed of the ship at lower forward speed condition.

2.1. Shipflow theory

The features of the SHIPFLOW CFD code has discussed here. The solver solves the flow problem in Fig. 2 zonal approach. In overall view it consists of three zones with three different solution methods. The zone 1 uses the potential flow solver with Rankine source panel method. In the potential flow method the SHIPFLOW code can be run in both linear and non-linear mode.

In this zone the flow is potential flow means that fluid is assumed to be steady, incompressible, inviscid and irrotational. Therefore the governing equation for this zone is

$$\nabla^2\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} \tag{1}$$

In Zone 2 in SHIPFLOW the boundary layer is computed using a momentum-integral method. It is based on streamlines, which are automatically traced from the potential-flow solution. In Zone 3 the governing equations are the Reynolds-Navier-Stokes (RANS) equations, obtained by averaging the time dependent Navier-Stokes equations

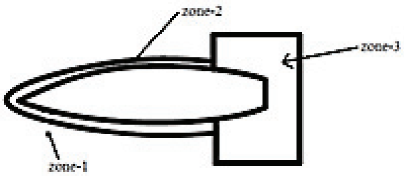

Fig. 2: Shipflow calculation zone

over the entire length and time scales of the turbulent fluctuations given in equation 2 and 3.

$$\frac{\partial}{\partial t}(\rho) + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{2}$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_i}(-\rho \bar{u_i'} \bar{u_j'}) + \frac{\partial}{\partial x_j}[\mu(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}] \tag{3}$$

3. Results and discussion

3.1. Pressure distribution

The pressure coefficient from XCHAP and XPAN are shown in Fig. 3 and 4 at Froude number of 0.078.

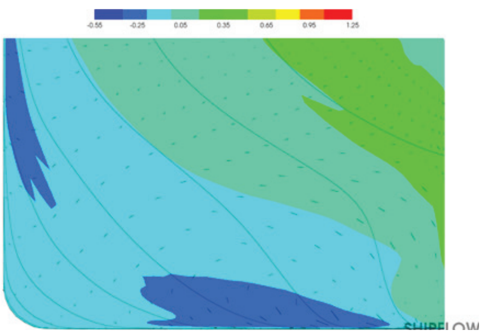

Fig. 3: XCHAP pressure distribution

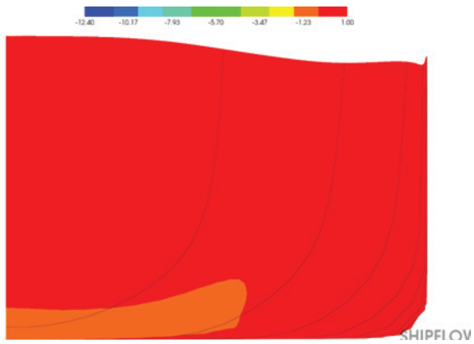

Fig. 4: XPAN pressure distribution

Also the Fig. 5 shows the XPAN pressure distribution over the hull with a rectangular moonpool for the same Froude number. The pressure distribution output for both the potential flow code and the viscous flow code from the SHIPFLOW software is in the form of pressure coefficient. This pressure coefficient will give the pressure resistant act on the drillship hull.

$$C_P = \frac{R_P}{0.5\rho S V^2} \tag{4}$$

3.2. Free surface

The free surface around the hull of without moonpool case at Froude number 0.0982 as shown in Fig. 6.The one half of the free surface is shown in figure with the maximum disturbance at the forward and aft end of the ship.

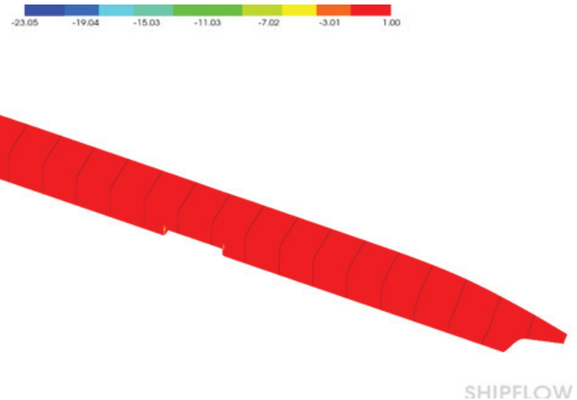

Fig. 5: XPAN pressure distribution of hull with moonpool

Free surface around the hull for other Froude numbers are given in Fig. 7. The flow condition around the hull for the Froude number 0.0196,0.0393 and 0.0589 are similar in nature, after that for the higher Froude number the flow nature is quite different. The free surface wave profiles are very useful to study about the wave resistance.

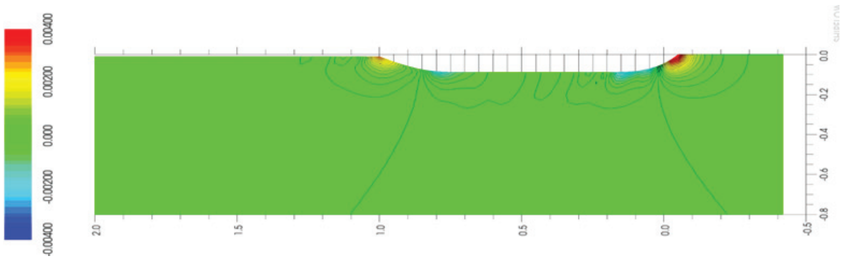

Fig. 6: Free surface from XPAN

3.3. *Total resistance*

The total resistance which acts on the hull against different Froude number is given in Fig. 8.This will be evaluated for the both the without moonpool condition and the rectangular moonpool from the total resistance coefficient (C_T).

$$C_T = \frac{R_T}{0.5\rho S V^2} \tag{5}$$

At the lower Froude number the resistance caused by the moonpool is very nominal. Once the Froude number increases the resistance is also increased considerably. After crossing the Froude number 0.1 the resistance caused by the moonpool is much higher than that without moonpool hull. This will leads to increase the fuel consumption of the drillship.

As discussed earlier computer simulation runs for eight different Froude numbers and the resistance components of Froude number 0.0982 are tabulated in Table 2. This incremental change is caused by the water motion inside the moonpool. The total resistance coefficient will give the resistance force which act on the hull. This is the summation of frictional and residual components of resistance. From the table, all the resistance components of drillship have higher values in particular the wave resistance coefficient of the drill ship is considerable amount higher than that of the hull without moonpool. The moonpool, which is presence at the bottom of the hull changes the flow pattern and also induce eddies inside the moonpool. This is because of the discontinuity in shear layer at the bottom of the hull.

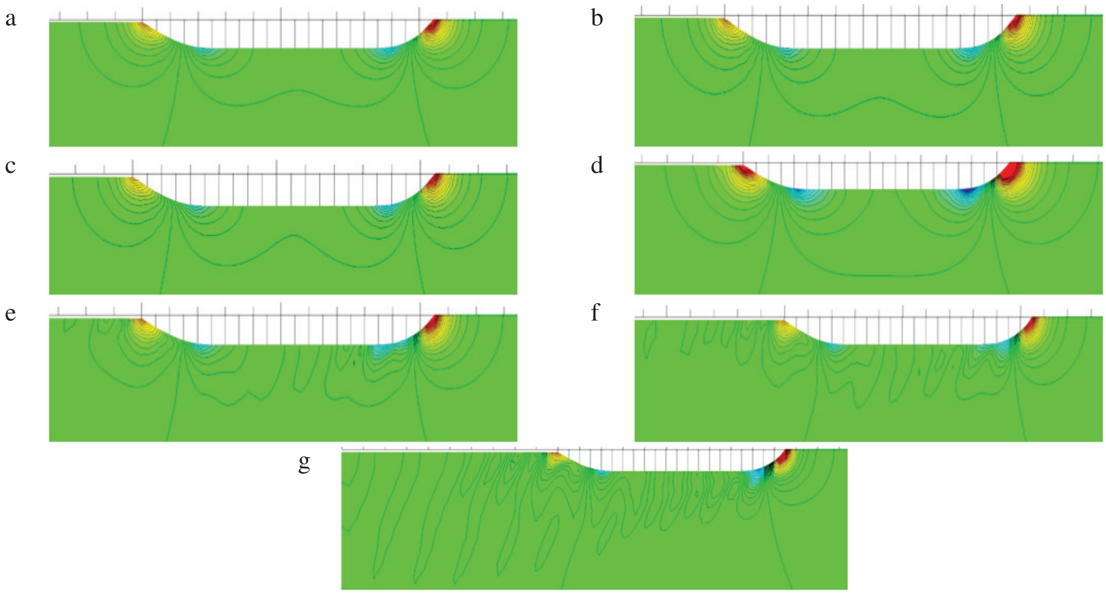

Fig. 7: (a) F_n = 0.0196 ; (b) Fn = 0.0393 (c) Fn = 0.0589 ; (d) Fn = 0.0785; (e) Fn = 0.0118; (f) Fn = 0.0137; (g) Fn = 0.0157

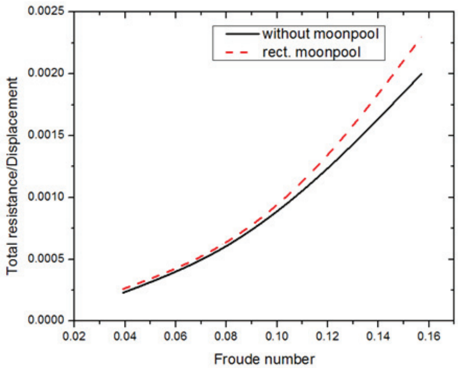

Fig. 8: Total resistance with and without moonpool

Table 2: Resistance components

Froude No.	Coefficient	Without moonpool	With moonpool
0.0982	C_F	2.764E-03	2.703E-03
	C_{PV}	1.528E-03	1.736E-03
	C_V	4.292E-03	4.439E-03
	C_W	1.644E-03	8.851E-03
	C_T	5.936E-03	1.329E-02

4. Conclusions

To know the effect of rectangular moonpool in the view of resistance and free surface, a CFD simulation is done for the drillship hull. In the potential flow code totally 7529 panels are used and in the case of viscous code 1742262 cells are considered for solutions. Such cell sizes numbers leads to optimum use of computational resources. The variation in the resistance, wave making characteristics around the hull were observed with low forward speed conditions. The free surface around the hull, while the ship is in forward speed condition mainly depends on the shape of the hull and it is found to have a higher wave elevation at the forward and aft end of the ship. In the case of drillship during transit it is observed that this increment of free surface also found near by the moonpool area. From the CFD simulation it is clear that the moonpool geometry with the hull changes the flow at the bottom of the hull and increases the resistance of the ship. This increment in resistance will increase the fuel consumption of the drillship in transit.

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