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MOONPOOL EFFECTS ON A FLOATING BODY

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ABSTRACT

Floating Drilling Production Storage and Offloading vessels (FDPSO) are used for the production of oil from remote fields, where the installation of pipelines is uneconomical. Moonpool is the main characteristic of the FDPSO. Barges offer cheap way for transportation and lifting of offshore structures. Installation barges are often fitted with moonpool for functional purposes. Motions of trapped water inside the moonpool are a subject of study for researchers. In the present study numerical analysis of barge with and without moonpool were carried out using commercial software namely WAMIT and STAR CCM+. Two different configurations (circular and rectangular shape) of the moonpool were selected to study its effect on the motions of a barge. The oscillations of water inside the moonpool and its effects were also investigated. The numerical results show that the moonpool oscillation changes the response of a barge and also the vessel responses influence the moonpool oscillation. The sloshing mode was found to be dominating in the rectangular moonpool.

Keywords: Barge, Moonpool, Response Amplitude Operators, Piston Mode Oscillations, Sloshing, Numerical Analysis.

1. INTRODUCTION

The demand for energy has increased in last few years and a major part of the energy is currently produced from non renewable energy sources like oil and gas. This has forced to increase research and development in offshore oil gas industry to increase production. In the early stages, the marine operations and researches were confined to shallow and intermediate water depths (less than about 600 m). At later stages the oil and gas industries have advanced with new concepts which are applicable for deep water. Structures of the offshore industries fall under three broad categories namely, fixed, compliant and floating structures which are applicable in shallow, intermediate and deep waters respectively. Examples of fixed structures are Jacket structures, Gravity structures etc. and the example of compliant structures are

TLP, guyed towers, articulated towers.etc. Some of the structures used in deep waters include TLPs, Spars, FPSOs, FDPSOs, Semi-submersibles etc. Seismic survey, pipe lay, module installation, drilling, inspection, maintenance and repair etc. are the main marine operations carried out in deep water field. All marine operations are performed with highly specialized vessels having advanced equipments and features and moonpools are one of the dominant features of certain vessels.

A moonpool is wall- sided opening in the bottom of a floating body and in the past these were used for launching and retrieving subsea modules. Through this opening, installation, repair and maintenance of subsea modules, equipments, tools etc. can be carried out. They have been generally designed with small dimensions. The moonpool system has its own advantages and disadvantages. The moonpool will reduce the dynamic forces due to waves during launching of equipments. The main disadvantage is the large water column oscillation inside the moonpool that interacts with the main vessel. The sloshing mode is the back and forth movement of water level and the piston mode or pumping mode is the mode wherein water plugged inside the moonpool moves up and down like heave motion of a rigid body. The

water column inside the moonpool can be excited its own natural frequency. This excitation will be large at resonance condition. The natural period of vertical oscillations of the water plug inside the moonpool is important for the dynamic forces on an object inside the moonpool.

Aalbers (1984) discussed about the water motion in a moonpool. Using diffraction theory, the excitation of moonpool water in a free floating body in waves was calculated accurately [1]. Molin (1984) developed a mathematical approach for piston mode oscillation in moonpool [2]. Madhani and Jehangir (1985) investigated about the sloshing motion of water inside the moonpool. Sloshing is predominant in moonpools with large dimensions [3]. Jakobsen (2008), discussed about the design of installation barge with moonpool and analysed motion responses using MOSES software [4]. Alsgaard (2010) discussed about the moonpool dynamics with help of CFD tool [5].

In the present study numerical analysis of barge model with and without moonpool have been carried out using commercial software namely WAMIT and STAR CCM+. Two different configurations (circular and rectangular shape) of the moonpool are selected to study its effect on the motions of a barge. The effect of moonpool geometry and dimensions on the barge response, the oscillations of water inside the moonpool and its effects are also investigated.

2. HYDRODYNAMIC ANALYSIS OF BARGE WITH & WITHOUT MOONPOOL

2.1 Barge & Wave Details

The barge has a length 180m ,beam 60m, and draft 7m with two planes of symmetry ($x=0$, $y=0$). The barge details are given in Table.1.The barge with rectangular moonpool has been modelled using Multisurf and is shown in Fig. 1. The dimension of the moonpool is 22m $\times$ 12m. The barge with circular moonpool having the same cross sectional area of the rectangular moonpool has been modelled using Multisurf and is shown in Fig. 2; the radius of the moonpool is 9.17m. Hydrodynamic analysis software WAMIT is used for obtaining Response Amplitude Operators (RAOs). The parameters consider for WAMIT run is given in Table 2. The origin of the body coordinate system is at the intersection of the free surface and mid ship section. Analysis is done with regular wave and the wave heading angle is zero degree. The water density is taken as 1025 kg/m³.

Table1. Barge Details

Length	180m
Breadth	60m
Depth	11m
Moonpool Length	22m
Moonpool breadth	12m
Draft	7m
VCG	-2m
Radii of Gyration r_{xx} , $r_{yy}=r_{zz}$	20.4 m, 48.6 m

Table 2. Wave Specifications

Water depth	infinity
Wave period	5s to 25s
Wave heading angle	0°
Panel size	4m

Figure 1. Multisurf Model of Barge with Rectangular Moonpool

Figure 2. Multisurf Model of Barge with Circular Moonpool

2.2 Heave & Pitch Responses of the Barge with Circular Moonpool, Rectangular Moonpool and Without Moonpool

Hydrodynamic analysis of barge for the three cases namely, (i) Barge without moonpool, (ii) Barge with rectangular moonpool and (iii) Barge with circular moonpool have been carried out using WAMIT for a wave period ranging from 5 s to 25 s with an increment of 1s. Table 3 lists the natural period for the three cases including the two modes of motion namely the pumping and sloshing mode of the moon pool.

Table 3. Natural Period

Mode of the motion	Barge with circular moonpool	Barge with rectangular moonpool	Barge without moonpool
Heave	7.4 s	7.14 s	9.52 s
Pitch	7.95 s	7.76 s	8.06 s
Moonpool ,Pumping mode	7.5 s	7.4 s	
Moon pool Sloshing mode	5.11 s	5.51 s	

Heave and pitch RAOs for the barge were obtained is shown in Fig. 3 and Fig. 4 respectively. From Fig. 3 it is observed that for wave periods above 10s the barge with rectangular moonpool shows significant reduction in heave response as compared with circular moon pool as well as barge without moonpool. It is also observed that there is no significant reduction in heave RAO for barge with circular moonpool as compared with barge without moonpool beyond 10 s. The percentage of reduction is found to increase as wave period increases, beyond 10.2s. The maximum percentage is found to be about 30% at 25s, for the range of wave periods considered. Significant reduction of heave RAO is seen for waves below 12s and maximum percentage of reduction is about 20% occurring at wave period of 10 s. The reason for less reduction of heave RAO of circular barge is attributed to the potential damping. Barge with a moonpool will be affected by excitation forces and radiation damping from the moonpool. Near resonance the heave response is more in barge with rectangular moonpool when compared to circular moonpool. At higher periods, greater than 7sec, the heave response is more in barge with circular moonpool. At smaller wave periods the potential damping is very less in barge with rectangular moonpool.

Figure 3. Comparison of Heave RAO of Barge with Rectangular, Circular & Without Moonpool

Figure 4. Comparison of Pitch RAO of Barge with Rectangular, Circular & Without Moonpool

From Fig. 4 it is observed that for wave periods above 7.5s the barge with rectangular moonpool shows significant reduction in pitch response as compared with circular moon pool as well as barge without moonpool. It is also

observed from this figure there is no significant reduction in pitch RAO for barge with circular moonpool as compared with barge without moonpool beyond 10 s. The maximum percentage is found to be about 27% at 7.5s, for the range of wave periods considered. Significant reduction of pitch RAO is seen for waves below 9.5s and maximum percentage of reduction is about 64% occurring at wave period of 7.5 s. The reason for reduction of pitch RAO of rectangular moonpool barge is attributed to the potential damping. Barge with a moonpool will be affected by excitation forces and radiation damping from the moonpool. At resonance the pitch response is more in barge with rectangular moonpool. At higher periods, greater than 7sec, the pitch response is more in barge with circular moonpool. At smaller wave periods less than 9s the potential damping is very less in barge with rectangular moonpool. At higher periods the amplitude of motion is more in body with circular moonpool.

3. HYDRODYNAMIC ANALYSIS OF MOONPOOL OSCILLATIONS

The column of water inside the moonpool can be excited its own natural frequency. The vertical excitation is called as piston mode oscillation. Internal sloshing can also occur, resulting in transverse breaking waves that are added to the vertical motions. The natural frequency of the vertical oscillation depends on the height of the water column.

The resonance period (T_0) of vertical oscillation (piston mode) of moonpool water column is calculated by Fukuda's formula (1974) as given below [6]:

$$T_0 = 2\pi \sqrt{\frac{h + k\sqrt{A}}{g}} \quad (9)$$

Where A is the cross sectional area of moonpool, h is the draft and k is 0.479 for circular and 0.460 for rectangular. Using Eq. (1) the resonance period obtained is given below:

$T_0 = 7.70$ sec for circular moonpool

$T_0 = 7.62$ sec for rectangular moonpool

The above values are close to those values in Table 3.

3.1 Hydrodynamic Analysis of Moonpool Oscillations in a Barge using WAMIT

Hydrodynamic analysis of water column oscillation has been carried out for wave period ranging from 5s to 40s at an increment of .1s. The variation of piston mode RAO has been presented for both rectangular and circular moonpool. The piston mode RAO for circular and rectangular moonpool is shown in Fig.5 (a) and (b) respectively.

Figure 5. Piston Mode Oscillation RAO of Circular & Rectangular Moonpool Without Considering Viscous Damping

From Fig. 5 (a), the resonance period of the water column inside the circular moonpool is 7.5 s. Heave RAO exhibits two adjacent resonant peaks and the second peak is near to the heave resonance period of the vessel without moonpool. Beyond 20s, the piston mode RAO is found to be constant. The very large responses at resonance are non-physical, and this is due to the neglecting of viscous damping associated with flow separation. The magnitude of the potential damping is small. From the Fig. 5 (b) the resonance period of the water column inside the rectangular moonpool is 7.4 s. The peak value of response is more in circular moonpool compared to rectangular moonpool. The peak response in circular moonpool is around 70% greater than rectangular moonpool. This is because the magnitude of the damping in a smooth moonpool is small. Physically the potential damping is related to outgoing waves generated by the

motion a moving body. Here the radiation damping is more in rectangular moonpool. Beyond 17s the piston mode RAO is found to be constant. The resonance period of piston mode oscillation from Figs.5 (a) and (b) obtained from WAMIT matches with the equation suggested by Fukuda (1974) [6]. Also the very large response of Fig. 5 (b) are non-physical and their existence in the calculation is mainly due to the neglect of viscous damping associated with non linear effects due the flow separation at the outer and inner corner of the moonpool edge.

3.2 Analysis of Water Column Oscillations in Moonpool of Barge using Star CCM+

A 3-D geometry of barge with moon pool whose details given in Table 1 was created in Multisurf and then imported to STAR CCM+. The trimmed type of volume mesh is used for meshing. A physical model in STAR CCM+ defines how a physical phenomenon in a continuum is represented. It can solve a physical model of moving mesh. Several physical models are activated in order to simulate the forces acting on the hull. The simulation will model the behaviour of two fluids (air and water) within the same continuum, and is used the Volume of fluid model to do so. As there are two fluids in different phases, the Eulerian Multiphase model has been activated, and the effect of gravity acting on both is included using the Gravity model. The effect of turbulence on the fluid is modelled using the default K-Epsilon turbulence model. The wave conditions considered for STAR CCM+ run was same as in WAMIT. The scalar scene of the model is shown in Fig. 6.

Figure 6. Scalar Scene of Barge in STAR CCM+

Hydrodynamic analysis of moonpool was done for a wave period ranging from 5 s to 25 s. Piston and sloshing RAOs for the moonpool were obtained as shown in Fig. 7 and Fig. 8 respectively.

Figure 7. Comparison of Piston Mode RAO in Rectangular and Circular Moonpools

From Fig. 7 it is observed that for wave periods above 12s, rectangular moonpool shows significant reduction in piston mode response as compared with circular moon pool. The reduction is maximum at 25s. The percentage of reduction is found to increase as wave period increases, beyond 12s. The maximum percentage is found to be about 90% at 25s, for the range of wave periods considered. The reason for the reduction of piston mode RAO of rectangular moonpool is attributed to the viscous damping and the non-linear damping is due to the flow separation near the bottom of the moon pool (keel). The major part of the damping experienced by the oscillating water column is due to eddy generation during in and out flow. Generally the edge between keel and inner moonpool wall is sharp. The eddy formation depends on the geometry of the moonpool and for rectangular moonpool this is very high and hence the damping. Besides, the inertia forces due to the body heave motion will act as body force on control volume (moonpool water column), that will affect the moonpool response.

Figure 8. Comparison of Sloshing Mode RAO in Rectangular and Circular Moonpools

Sloshing RAO obtained from the Star CCM+ analysis is shown in Fig. 8. From Fig. 8 we can see that the geometry of the moonpool defines the sloshing resonant modes and sloshing is dominated in rectangular moonpool. At higher periods the sloshing RAO in circular moonpool was found to be very less.

4. SUMMARY & CONCLUSIONS

Numerical analyses of barge with and without moonpool were carried out using commercial software namely WAMIT and STAR CCM+ for three different cases having rectangular and circular moonpool. For the chosen size and configuration of the barge and moonpool, the hydrodynamic analysis using WAMIT showed that the heave and pitch RAOs of the barge with rectangular moonpool are less than that of the barge with circular moon pool for wave periods above 10 s. The maximum percentage of Heave RAO reduction is found to be about 30% at 25s, for the range of wave periods considered. The pitch RAOs of the barge with circular moonpool is relatively unchanged with that of the pitch RAOs of the barge without moonpool. For wave periods above 12s, rectangular moonpool shows significant reduction in piston mode response as compared with circular moon pool. STAR CCM+ analysis yielded significantly less values of piston mode RAOs due to the inclusion of viscous effects when compared to WAMIT analysis. The piston mode RAOs of barge with rectangular moonpool are less than that of the corresponding RAOs of barge with circular moonpool beyond 12s whereas the sloshing mode RAOs of barge with circular moonpool are less than that of the corresponding RAOs of barge with rectangular moonpool beyond 10 s. Further analysis of the moonpool configurations with different sizes and wave heading angle have to be done to ascertain the behavior of the moonpool effects on the vessel.

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