International Journal of Advance Research in Science and Engineering
Vol. No.4, Special Issue (01), September 2015
www.ijarse.com
IJARSE
ISSN 2319 - 8354

EFFECTS OF VOLUME FRACTION ON HEAVE MOTION OF SEMISUBMERSIBLE

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ABSTRACT

Offshore floating structures may experience resonant motions, which should be avoided as much as possible under installation, operation and survival conditions. In particular, the heave motion response of a floating structure should be kept adequately low to guarantee the safety of risers and umbilical pipes as most important components in the equipment of oil production. Therefore effort should be made to minimize vertical motion of floating structures. The configuration of semisubmersibles considered is twin pontoon semisubmersible having four vertical columns supporting the deck. Its heave motion response in waves are examined. The purpose of the present study is to find the effects of volume fraction of pontoons and columns on natural period and response amplitude operator (RAO) in heave motion. Results of theoretical formulae and numerical Analysis of heave motion is compared for base model GVA 4000 semisubmersible. Modelling was done in Solidworks and numerical analysis of semisubmersible model was done in Ansys Aqwa. Heave RAO for semisubmersible of different volume fractions are presented. It was found that the amplitude of heave motion response can be considerably suppressed by appropriately adjusting volume fraction so that the natural heave period keeps away from the range of wave period.

Keywords: Floating Structure, Heave RAO, Semisubmersible, Volume Allocation, Heave Period

I. INTRODUCTION

The Offshore Structures has been playing a vital role to fulfil the increasing demands of fuels and energy in today's world. Considering the fact that we are moving to deeper and harsher environments in looking for more hydrocarbon resources, the emphasis is on novel and robust design concepts of offshore floating structures from the initial concepts of fixed platforms. As we are moving further to the extreme climates in search of oil and gas requirements the environmental loading becomes the major part of the loading on the offshore floating structure used for operations. Many innovative floating offshore structures have been proposed for cost effectiveness of oil and gas exploration and production in water depths exceeding thousand meters in recent years. Floating structures may experience resonant motions, which should be avoided as much as possible under installation, operation and survival conditions. Heave response of floating structure should be kept low for the safety of risers and umbilical pipes. The natural period in heave motion can be effectively enhanced simply by adding structural mass, which, however, seems to be infeasible due to a number of restrictions in the design. Haslum and Faltinsen [1] proposed that heave response to wave frequency is reduced by increasing system damping.

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Tao [2] considered the suppression of heave resonant response by altering hull shapes with larger damping. Srinivasan et al. [3, 4]. tried to control heave motion by applying the concept of both hydrodynamic added mass and separated-flow damping intelligently. Chen et al. [5] demonstrated that the location or draft of heave plates exerted a significant effect on the heave motion of a semisubmersible. Rho et al. [6, 7] considered both heave and pitch motions of a spar platform with damping plate at its bottom. Clauss and Birk [8] proposed a hydrodynamic shape optimization procedure applicable to various types of offshore structures with improved seakeeping qualities. The main purpose is to study the effects of volume fraction (ratio of volume of pontoon to total volume of column and pontoon)on heave natural period and heave RAO of semisubmersibles. Hydrodynamic software package called Ansys Aqwa based on potential theorywas used for hydrodynamic analysis.

II.SEMISUBMERISBLE

Semisubmersibles are a common type of floating structure used in the exploration and production of offshore hydrocarbons. These platforms have hulls of sufficient buoyancy to cause the structure to float, but the structural/equipment weight of the platform and the mooring system keeps the structure upright. Semisubmersibles can be used in water depths from 200 to 12,000 feet. Based on another parameter of the way the platform is submerged in the water, there are two main types of semisubmersibles: bottle-type semisubmersibles, column-stabilized semisubmersibles. Column stabilized semisubmersible units design can be classified further into as follows ring pontoon semisubmersibles, twin pontoon semisubmersibles.Advantagesare mobile**,** stable**,** large deck area**.** Disadvantages are expensive to operate,expensive to build,stability concerns limit capacities, structure susceptible to fatigue,and rough seas can complicate moorage and well operations

III. THEORETICAL FORMULAE FOR HEAVE PERIOD & HEAVE RAO:

The equation of heaving motion of a semi-submersible platform in regular waves can be written as:

$$(m + m_z)\ddot{z} + N_z\dot{z} + (\rho g A_w)z = F_0 \cos(\omega t + \sigma)$$

Where,

m- Mass of the platform

m_z - Added mass of the entrained water of the platform

N_{z} - damping coefficientassuming damping proportional to velocity

$\rho g A_w$ –Restoring coefficient

z- Linear vertical displacement of the platform in calm water position

$\dot{z}$-Heaving velocity of the platform

$\ddot{z}$-Heaving acceleration of the platform

F_0 – Amplitude of heave exciting force.

w - Circular frequency of wave

t – Time

σ–phase angle by which exciting force leads wave elevation when its value is positive.

The solution of heaving motion is given by:

$$z = z_a \cos(\omega t + \sigma)$$

$$z_a = \frac{F_0}{\sqrt{\{(\rho g A_w) - (m + m_z)\omega^2\}^2 + (N_z\,\omega)^2}}$$

ε – Phase angle by which heave motion lags wave elevation when its value is positive.

The natural undamped frequency in heave and the corresponding time period are:

$$\omega_z = \sqrt{\frac{\rho g A_w}{m + m_z}}$$

$$T_z = \frac{2\pi}{\omega_z}$$

$$T_z = 2\pi\sqrt{\frac{m + m_z}{\rho g A_w}}$$

The Amplitude of heaving motion is written as:

$$z_a = \frac{F_0/\rho g A_w}{\sqrt{\{1 - ((\frac{\omega}{w_n})^2\}^2 + (2\gamma\}^2(\frac{\omega}{\omega_n})^2}}$$

Where

$$\gamma = \frac{actual\ damping}{critical\ damping} = \frac{N_z}{2(m + m_z)\omega_n}$$

It can be seen from equation that the heave amplitude is directly proportional to the amplitude of exciting force F_0 and to magnification factor

$$Magnification\ factor = \mu = \frac{1}{\sqrt{\{1 - ((\frac{\omega}{w_n})^2\}^2 + (2\gamma\}^2(\frac{\omega}{\omega_n})^2}}$$

and inversely proportional to water plane area.

3.1 Wave Excitation Forces

The wave excitation forces on semi-submersible platform can be approximated by sum of following three forces:

- The undisturbed pressure force F_{Z1} arising from pressure change over the hull in a wave that is not disturbed by the pressure of the hull.
- The inertia force F_{Z2} arising from acceleration of water particles in wave which is not disturbed by the presence of hull, acting on the added mass of the hull.
- The damping force F_{Z3} arising from damping due to hull, velocity of water particles in a wave that is not disturbed by the presence of the hull.

The total wave excited force F_Z on the semi-submersible platform can be expressed as:

$$F_z = \sqrt{(F_{Z1} + F_{Z2})^2 + (F_{Z3})^2}$$

$$F_z = 2\rho g \varepsilon_a \frac{\pi}{4} d_1{}^2 \omega^2 e^{-Kh_1}\{Q_0 - 4\left(\frac{d_2}{d_1}\right)^2 e^{-k\frac{d_2}{2}}\} \sin\frac{kl_2}{2} \cos\omega t$$

$F_Z = F_0 \cos \omega t$

Neglecting the damping term the ratio of heave amplitude to wave amplitude can be obtained as:

$$\frac{z_a}{\varepsilon_a} = \frac{F_0 / \rho g A_W}{\varepsilon_a \left(1 - \frac{\omega^2}{{\omega_n}^2}\right)}$$

The plot of Heave RAO vs frequency can be plotted from above equation.

3.2 Semi-Submersible Hull Analysed

In the current piece of work a simplified model of a twin pontoon column stabilized semisubmersible with two sets of columns legs and bracing connecting the legs semi-submersible has been chosen to perform hydrodynamic analysis as the experimental results of same model was taken from reference paper for comparing the results.

Table1: Main Dimensions of GVA 4000 Semisubmersible Analysed

GVA 4000 Semisubmersible:		
Parameters	Unit	Dimension
Pontoon		
Length	m	66.78
Breadth	m	13.3
Height	m	6.3
Volume of pontoons	m^3	11190.9924
Columns		
No of columns		4
Diameter	m	10.59002
Height of column @draft	m	10.43
Volume of columns	m^3	3672.886578
Distance between columns	m	45.58001
Distance between pontoons	m	45.15
Volume displacement	m^3	14920.843
Mass Displacement	tonnes	15293.86408
GMt	m	2.87
Gml	m	4.06
Kxx	m	31.64
Kyy	m	26.95
Kzz	m	35

Source: "Prediction of Semi-Submersible's Motion Response by Using Diffraction Potential Theory and Heave Viscous Damping Correction"

3.3 Manual Calculation of Heave Period

Manual calculation for Heave Frequency was made in MS Excel to check the Output of Ansys Aqwa:

Formula Used:

$$\omega_z = \sqrt{\frac{\rho g A_W}{m + a_z}} \qquad T_z = \frac{2\pi}{\omega_z} = 2\pi\sqrt{\frac{m + a_z}{\rho g A_W}}.$$

a_z –added mass in heave

Table2: Manual Calculation of heave period

Heave period without damping		
Added mass:	GVA 4000	units
Pontoon	25194.32831	tonnes
Column	3672.872705	tonnes
Total added mass	28867.20102	tonnes
Area at waterline	352.145034	m^2
Density of water	1.025	t/m^3
Acceleration due to gravity	9.81	m/s^2
Mass displacement	15293.86408	tonnes
Heave period	22.17799049	seconds
Heave Frequency	0.273163617	rad/s

3.4 Theoretically Estimated Heave Excitation Force and Heave Rao

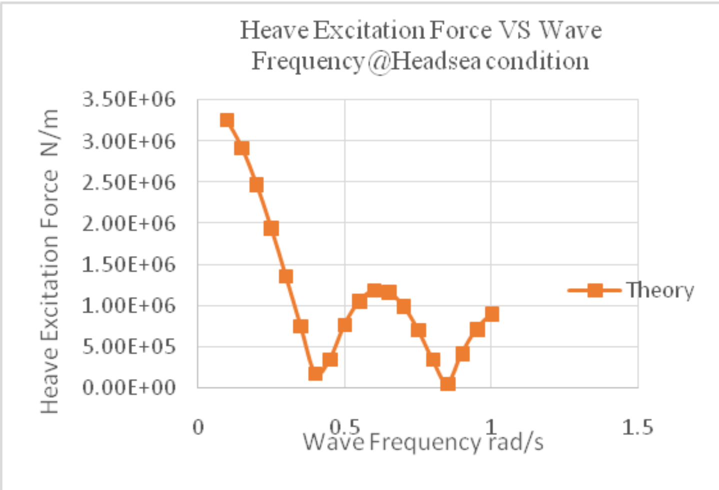


Figure 1: Heave Excitation Force Semisubmersible Hull

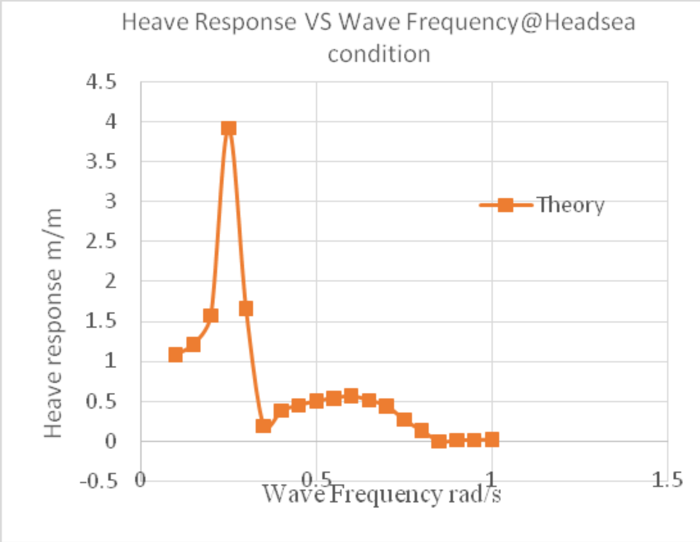


Figure 2: Heave RAO Semisubmersible Hull –Theoretical Calculation

IV. NUMERICAL ANALYSIS OF HEAVE MOTION IN ANSYS AQWA

4.1 Numerical Modelling and Analysis Procedure

- Semisubmersible hull modelled in Solidworks was imported in Ansys Aqwa through import geometry.
- Hull is translated to draft mark and sliced at draft level.
- Units are set to SI units.
- Water depth was given as 175m
- Hull parameters like displacement, centre of gravity, radius of gyration are given as input by selecting Point Mass.
- Hull was meshed .Mesh was program controlled. Care was taken that diffraction elements of the hull should be within 12000.Ratio of tolerance to Maximum element size should not be less than 0.3.
- In Analysis settings, options to calculate full QTF matrix is selected as yes. In Ignore modelling rule violations is selected as yes.
- Structure for analysis is selected and input of acceleration due to gravity is given as $9.81 m/s^2$
- The initial maximum frequency is determined by the mesh size; attempting to change this to a higher frequency will produce an error. If higher frequencies are required the mesh size will need to be reduced.
- In Output option Hydrostatics and Heave RAO at head sea condition is selected.
- Analysis is solved to get the required output.

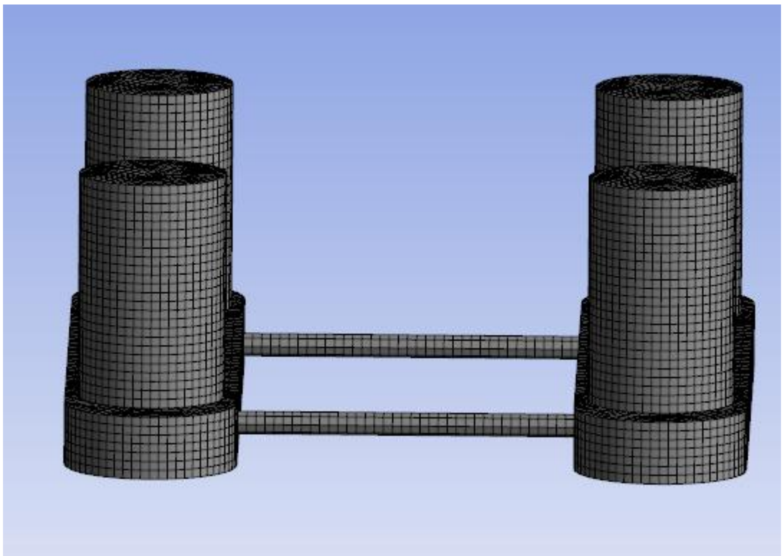
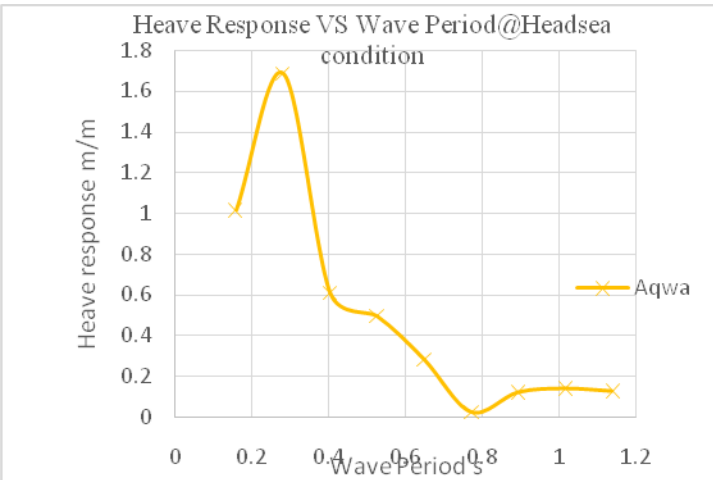


Figure 3: Mesh in Ansys Aqwa

Details of Mesh	
Name	Mesh
Defeaturing Tolerance	0.5 m
Max Element Size	1.35 m
Max Allowed Frequency	2.758 rad/s
Meshing Type	Program Controlled
Generated Mesh Information	
Number of Nodes	14919
Number of Elements	14999
Number of Nodes (Diffract...	11763
Number of Elements (Diffr...	11743

Figure 4: Mesh Details Ansys Aqwa



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ISSN 2319 - 8354

V. EFFECTS OF VOLUME ALLOCATION ON HEAVE RAO

- Dimensions of semisubmersible for different volume fraction are fixed taking in some constraints and variables. Volumetric displacement, draft, distance between pontoons, distance between columns are taken as constraints. Length, breadth, height of pontoon, diameter of column, height of column at draft, volume fraction (ratio of volume of pontoon to total volume displacement of hull) were taken as variables. Different models were modelled in Solidworks and analysed in Ansys Aqwa.

Table 3: Dimensions of Semisubmersible Hull for Various Volume Fraction from Parametric Model

x	Model	Pontoon			Column	
		Length (m)	Beam(m)	Height(m)	Diameter(m)	Height(m)
0.6	a	66	13.5	5	12.7	11.72
	b	66	12.22	5.525	13	11.2
	b	63	12.8	5.525	13	11.2
0.65	a	64	12.11	6.23	12.56	10.5
	b	65	11.92	6.23	12.56	10.5
	c	66	11.748	6.23	12.56	10.5
0.7	a	66	13	6	11.53	10.66
	b	66	12.7	6.2	11.61	10.52
	c	64	12.7	6.4	11.72	10.32
0.75	a	66	12.21	6.91	10.98	9.81
	b	66	12	7.03	11.04	9.69
	c	66	11.5	7.34	11.22	9.38
0.8	a	66	11.5	7.83	10.31	8.89
	b	66	12	7.5	10.13	9.22
	c	65	11	8.31	10.6	8.41

VI. RESULTS & DISCUSSIONS

6.1 General

The heave response of the Semisubmersible obtained for Base model at head sea condition has been discussed both for experiment, numerical and Theoretical calculations. The comparisons heave response of Semisubmersible with different volume fractions have been done and it is reported.

6.2 Heave Response of Gva 4000 Comparison Between Numerical, Theoritical and Experimental Work

Theoretical estimation overestimates the heave amplitude in damping dominated region when compared to actual experimental results. This is because damping force is neglected in theoretical estimation. But in wave frequencies from 0.4 to 1 rad/s theoretical estimation of heave amplitude is very close to experimental results. This is because the damping force is very negligible when compared to inertia force and Froude-Kriloff force in wave frequencies of 0.4-1 rad/s Aqwa output shows good agreement with experimental results except in region of resonance. Outside the region of resonance the % of error between Aqwa results and experimental results is less than 5%

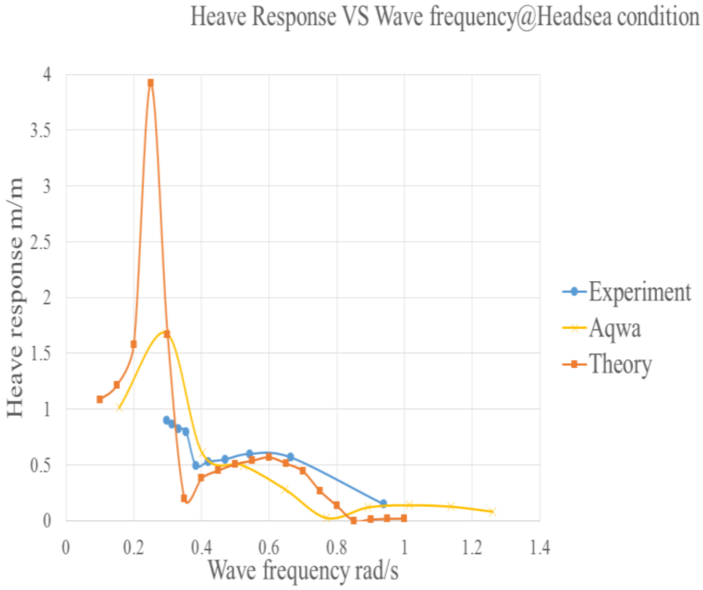

Figure 6: Heave RAO Comparison for GVA 4000

Experiment Results Source**:** "Prediction of Semi-Submersible's Motion Response by Using Diffraction Potential Theory and Heave Viscous Damping Correction"

6.3 Effect of Volume Fraction on Heave Response of Semisubmersible

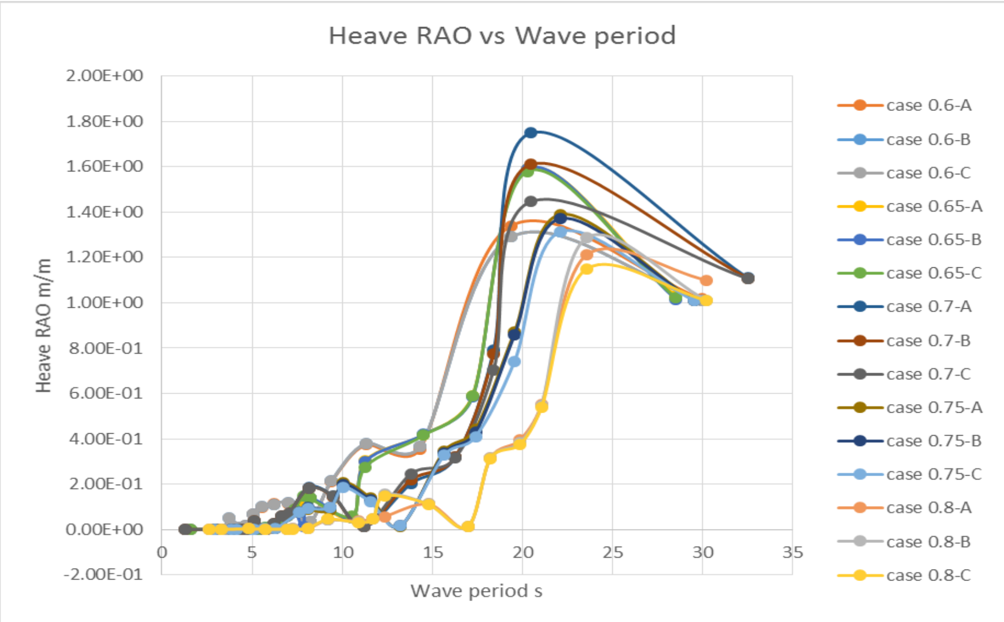

Figure 7. Heave RAO for all Cases of Different Volume Fraction

Heave RAO of semi-submersible for different volume fraction is obtained from Ansys Aqwa.It is observed that natural period of heave is almost same for same volume fraction.Heave amplitude varies for different cases of same volume fraction.Heave RAO is less when height of the pontoon increases.i.e for same volume fraction semisubmersible hull with higher pontoon height has the least heave amplitude.

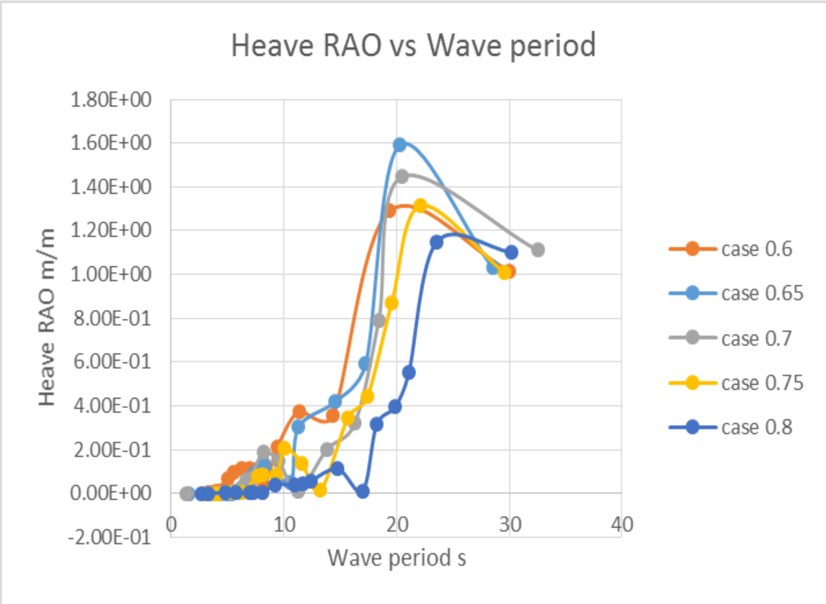

Figure 8 Heave RAO for Different Volume Fraction

Table 3: Results for Various Volume Fraction

Case	Pontoon Dimensions				
	Length(m)	Breadth(m)	Height(m)	Heave RAO(m/m)	Heave Period (s)
0.6-A	66	13.5	5	1.34	19.385
0.6-B	66	12.22	5.525	1.29	
0.6-C	63	12.8	5.525	1.29	
0.65-A	64	12.11	6.23	1.59	20.28
0.65-B	65	11.92928	6.23	1.592	
0.65-C	66	11.748	6.23	1.5894	
0.7-A	66	13	6	1.75	21.4
0.7-B	66	12.7	6.2	1.611	
0.7-C	64	12.7	6.4	1.447	
0.75-A	66	12.21	6.91	1.39	22.14
0.75-B	66	12	7.03	1.3719	
0.75-C	66	11.5	7.34	1.314	
0.8-A	66	11.5	7.83	1.212	24.23
0.8-B	66	12	7.5	1.2875	
0.8-C	65	11	8.31	1.15	

It can be seen that semisubmersible hull with different volume fraction exhibit different heave natural period. It changes from 19,20,21,22 and 24s for different for volumefraction of0.6, 0.65, 0.7, and 0.8 respectively. All these variations are observed for hull with same total volumetric displacement and by increasing only volumetric displacement of pontoons. This shows that natural period is sensitive to volumetric fraction variation. So to keep natural period away from wave period, volumetric fraction can be increased.The natural periods are dependent upon volumetric fraction of pontoons to the total displacement of the semisubmersible instead of their specific geometric distribution.

Case 0.8C has the least heave amplitude and natural period is away from the wave period so it is the most efficient structure from the point of view of increasing natural period and decreasing heave RAO as much as possible.

VII. CONCLUSIONS

Heave motion of semisubmersible GVA 4000 determined numerically through Ansys Aqwa and theoretically to find heave excitation force and heave RAO. Results are compared with experimental results taken from reference paper. Effects of volume fraction i.e. ratio of volume of pontoon to total volume of the structure to heave period and Heave response is studied in detail. Heave RAO and Heave Period is found numerically for different volume fraction. Following conclusions have been made from numerical and theoretical study on Heave Motion of semisubmersible

1. Numerical and Theoretical estimation of Heave RAO agrees with experimental results except in damping dominated region.
2. With increase in volume fraction heave period increases and stays away from wave period. Heave amplitude is independent of volume fraction i.e. for different dimensions of same volume fraction, heave amplitude varies but heave natural period is almost same.
3. For a fixed displacement and for particular volume fraction, with increase in pontoon height, heave amplitude can be decreased.
4. Semisubmersible hull with higher volume fraction and higher pontoon height shows least heave motion.

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