Heave Motion Spectral analysis of a semi- ubmersible vessel adapted for offshore accommodations in deep water

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***Abstract*: Naval architect and marine hydrodynamist also seek to understand the motion response of floating structure and many approaches have been employed as well. One of such analysis is the spectral analysis of any mode of the vessel response. In this paper, the response spectral analysis of a heaving semi-submersible with two cylindrical pontoon and four columns and six columns will be examined. The analysis was carried out with the irregular sea modelled using the JONSWAP spectrum and it was seen that the area under the motion spectrum was narrow band as expected with a broadness parameter of 0.15 seconds and fourth spectral moments of the displacement response spectrum of the heave mode were also computed and agreed with the Rayleigh distributions model.**

***Keywords*: response, moment, spectrum, wave, semi-submersible**

I. INTRODUCTION

The dynamic behavior of floating vessel is one that has generated a lot of interest with researchers over the years. Considering how important the seaworthiness of a marine craft can impact on the crew in terms of performance and operational cycle, it only necessary to consider the spectral analysis of the experienced motion. The assumption that the motion most times are linear which indicate the corresponding similarity to the that of the way has been show severally that similar analysis carried out on wave spectrums can also be applied on vessel motion response. In this paper, the spectral analysis of the heaving response of a semi-submersible adopted for accommodation will be analyzed and the relevant motion response spectral parameters considered will be discussed. The offshore semi-submersible analyzed here is a hypothetical one, operating within the west African, particularly along the Niger delta water, with two pontoon and four column dimensions and a housing accommodation on the deck of mass

Theoretical formulations

Response spectrum of any vessel mode can be obtain from the combination of the vessels RAOs computations and the spectrum of the sea state used to model the seaway of the vessel in questions.as such this will not be any different.

1. Computation of the hydrodynamic potentials

The panel method is adopted for this research. The structure is paneled into a reasonable number of panels and the potential flow theory is applied in computing the hydrodynamic mass and damping in the heaving mode. The following assumptions were necessary for the formulation of the potentials used for these computations:

- The flow is irrotational
- The flow is incompressible
- The Laplace conditions, the body conditions and the sea bed condition

A lot of works has gone into these with relevant literatures found in [1],[2],[3],[4].

2. The restoring coefficients

The restoring coefficients of the semi-submersible can be computed by considering the different components of the structure or platforms. for easier computations, the pontoons can be idealized as rectangular floating structures with the columns as cylinders.

Hence the combined restoring coefficient fort the heaving mode is

C33 =c33pontoon+c33columns ($C_{33} = \rho g A_W$)

Since we have two pontoons and four columns the combined restoring factors can be considered as

C33_totoal = (2*c33pontoon)+(4*c33column).

3.RAO estimation

The transfer function for vessel response otherwise known as the RAO need be estimated. This is computed as

$$RAO_Z = \frac{F_O/_C}{\sqrt{(1+\lambda^2)^2 + (2\eta\lambda)^2}} \qquad (1)$$

Where

F_O= Total heave excitation

C = Restoring hydrostatic force, C33

$\eta = \frac{B_{33}}{2(m+A_{33})\omega_n}$

$$\lambda = \frac{\omega_e}{\omega_n} \quad (2)$$

ω_n = Natural frequency of the system

$$\omega_n = \sqrt{\frac{C_{33}}{M + A_{33}}} \quad (3)$$

ω_e =encounter frequency of the wave also given as

$$\omega_e = \omega - \frac{\omega^2 U}{g} \cos(\mu) \quad (4)$$

4. heave motion response spectrum

The heave response spectrum of any mode can be computed with the following steps in mind

- The spectrum describing the sea state of the concerned area established by choosing the appropriate sea spectrum. For our study the JONSWAP spectrum was adopted and is given as

$$s(\omega) = A.\omega^{-p} * \exp(-B * \omega^{-q}) \quad (5)$$

Where

A and B are constants respectively given as

$$A = \frac{124 h_s^2}{T_Z^4} \quad (6)$$

$$B = \frac{496}{T_Z^4} \quad (7)$$

h_s = significant wave height

And

T_z = up crossing wave period

- Encounter spectrum of the wave is obtained next. This spectrum is computed when each wave frequency of the spectrum is converted to the encounter frequency and subsequently, used in obtaining the energy density(spectrum) for the given range of frequency. The encounter frequency (ω_e) is thus given as

$$\omega_e = \omega - \frac{\omega^2}{g} u cos(\mu) \quad (8)$$

μ = wave direction

u = vessel speed

- The RAOs are computed for the range of the given encounter frequencies in which heave are obtained.
- The vessel response spectrum is obtained. This is done by the product of the vessel transfer function or RAO and the density function of the encounter spectrum. The vessel response is thus given as

$$S_z(\omega_e) = RAO_z(\omega_e)^2 S_\zeta(\omega_e) \quad (9)$$

Where

$S_\zeta(\omega_e)$ = encounter spectrum.

5.Spectral parameters

Since the spectrum follows the popular Rayleigh distribution curve most of the times and same spectral parameter computations are also applicable to normal wave spectrums, it is, in similar vein to apply same statistical parameters as used to describe the entire behavior of the response spectrum. The root mean square of the motion spectrum can be estimated as the area under the spectrum[14], hence

Rms of heave motion = (area under heave spectrum) ^1/2

It should also be noted that broadness of the spectrum can similarly be computed.

This is given as

$$e^2 = \frac{m_0 m_4 - m_2^2}{m_0 m_4} \quad (10)$$

Where

m_0 = area under the response spectrum

m_2 = second spectral moment of area under the spectrum/ heave velocity spectrum

m_4 = fourth spectral moment under the spectrum/heave acceleration spectrum

Generally, any of the above moments can still be computed as

$$m_n = \int_0^\infty \omega^n S_\phi(\omega_e) d\omega_e \quad (11)$$

Where n must be an integer.

In terms of the spectrum broadness, the heaving average amplitude, can be gotten as

$$\eta_{3a} = 1.253 m_0^{\frac{1}{2}} (1 - e^2)^{1/2} \quad (12)$$

Other parameters such as the mean of one-third highest heaving and mean of one-hundredth highest heaving amplitude can also be deduced as

$$\eta_{(3)1/3} = 2.545 m_0^{1/2} (1 - e^2)^{1/2} \quad (13)$$

$$\eta_{(3)1/100} = 3.336 m_0^{1/2} (1 - e^2)^{1/2} \quad (14)$$

Results and simulations

The analysis was carried out for a hypothetical semi-submersible operating along the Niger delta waters, warri south area with the following vessel particulars shown in the table below

Table 1: Showing vessel particulars of the vessel

Vessel Particulars	Number/Dimension	Units
Pontoon	2(cylindrical)/5.5	M

Columns	4(cylindrical) 3.4	M
Bracing	6(cylindrical) 1.2	M
Accommodation housing	1.6e6	

whose sea state was modelled using the JONSWAP spectrum with an up-crossing period of 0.5 seconds and a wave height of 3.89m with a maximum frequency of 2rad/s as depicted below

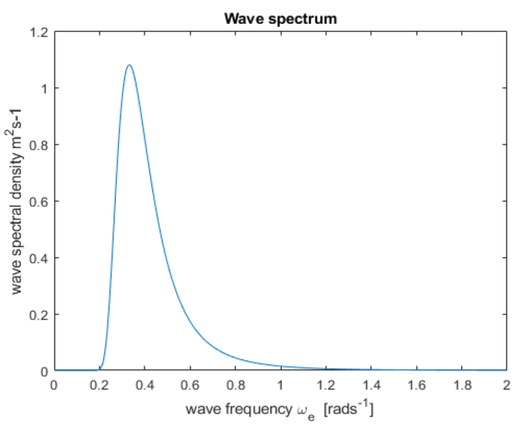

Fig 1: JONSWAP spectrum

The corresponding response spectrum of the heaving semi-submersible described above in table one is shown below.

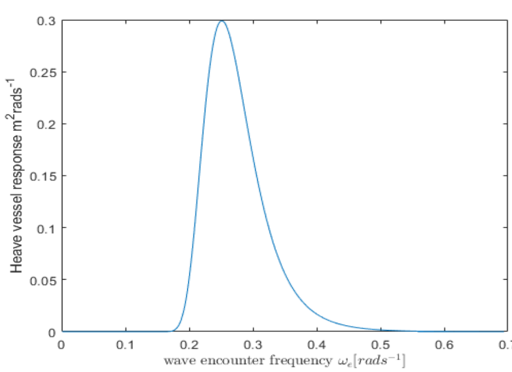

Fig2: Heave response spectrum

This response spectrum was generated by the combination of the irregular sea state depicted here by the JONSWAP spectrum and the heaving RAO. Much of the details can be seen in [13]. As earlier stated, the spectral moments of the displacement spectrum can also be obtained as with regular or irregular spectra area under the displacement response of the heaving response is shown below

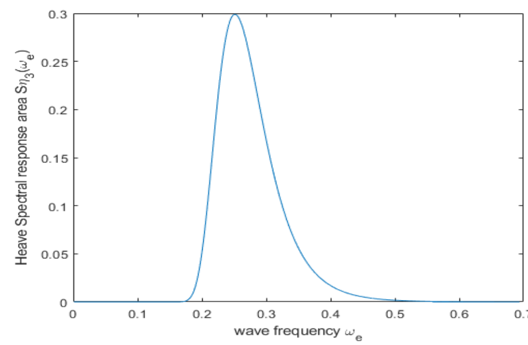

Fig 3: Zero Spectral moment of heave displacement response

The broadness parameter of the above area diagram is found to be 0.1565. Indeed confirms why the Rayleigh distribution analogy is used for ship motion as this is a narrow band spectrum. Other parameters such as the significant displacement amplitude was also deduced in terms of the area of the above figure and it is found to be 1.1543m. Again, this is also in confirmation of the linear theory of small amplitudes of waves to vessel response.

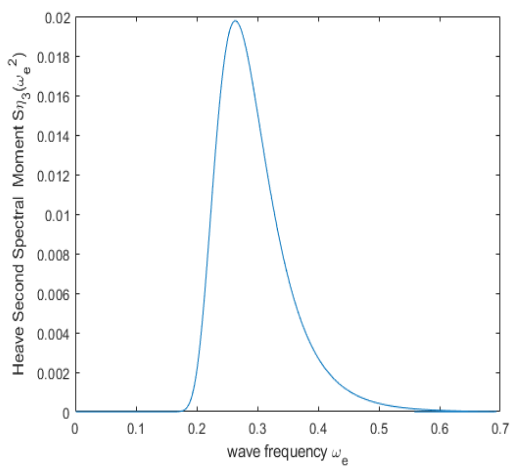

Fig 4: Second Spectral moment of heave displacement response

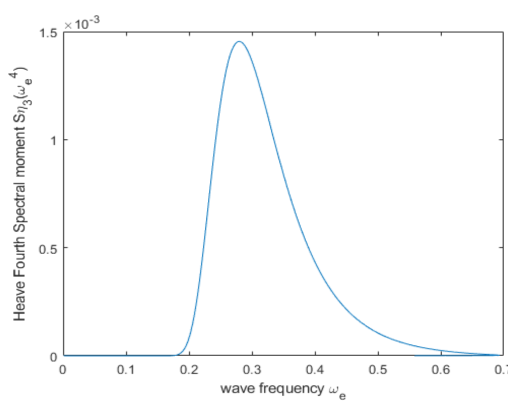

Fig 5: Fourth Spectral moment of heave displacement response

Area under this graph gives the velocity amplitude of the heaving response of the vessel. Again, similar response parameters of significant amplitudes and average amplitudes of both velocity and acceleration can be deduced from the respective moments graphs of the velocity and acceleration graphs of figure 2 and figure 3 above.

II. CONCLUSIONS

The following conclusions were drawn from the research

- The spectral analysis of the heaving displacement response was carried out
- It was shown that the spectral moments are narrow bands.
- Similar analysis of computing spectral parameters such as the average and significant. amplitudes can be investigated for both the acceleration and velocity spectral moments.

RECOMMENDATIONS

The following recommendations were deduced from the research

- Since spectral analysis can be carried out for motion amplitude response, it would be recommendable to carry out spectral analysis of the various modes especially those notable for seakeeping in pitch and heave modes and in other modes of maneuverability.
- Customized wave spectra of varying local regions should be used rather the idealized/standard ones. This will give a true picture of the amplitude spectrum of the sea state of the location of interest, hence proper spectral analysis of such location.
- Also various configurations of the vessels along with different operating conditions especially with regards to forward speeds can be considered for more elaborate investigation

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