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Prediction of Wave Induced Loads and its Responses on a Vessel (Barge) in West Africa Offshore Region

Chiorlu, John Imereoma and Ezebuchi Akandu
Marine Engineering Department, Rivers State University, Port Harcourt, Rivers State Nigeria.
Corresponding Author: Chiorlu, John Imereoma

ABSTRACT : *This research work is primarily aimed at developing a Matlab sort code that can be use to predict surge and heave motion of the barge, since the cost of acquiring or purchasing Naval Architecture and Offshore structure software today, runs into thousands of Dollars and millions of Naira as this has limit the usage by an individual and for research purposes, Owing to this facts and many more, this research work; predict of wave induced loads an its responses on a barge using West Africa water calculations with Matlab language was carried out to meet the need of barge responses in both academics and industry with less cost this is done by statistically analyze each region separately as the sort code is package in a way that allow the user to input the wave profile under consideration with the aim of calculating the wave length for such region that act on an offshore structure(barge) so long the wave profile of such region are known, the sort code are further use in calculating the wave surge and heave force on entire offshore structure(barge), which lead to calculating the surge and heave response amplitude operator and this response amplitude operator are use to predict the surge and heave motion (responses) of the barge at vary wave frequency, and the result shown some level of agreement with known fact as the surge response keep increasing in successive crest due to the fact that the barge length (54.86 m) is greater than the wave length (24.96 m) while the heave responses of the keep diminish in successive crest as wave frequency progresses because the barge depth (3.05 m) is far less than the wave length (24.96 m). As time goes interested researchers in this field can add to the development of this sort code until it gets to a stage where it will be commercially approved. To achieve this objective, specific areas of interest were reviewed; Computer and software utilization in Naval Architecture and Offshore Structure with respect to wave load (wave force) and responses as it apply to both academics and industry, general computer programming, programming language and the reason why Matlab language is preferred.*

KEY WORDS*: waves, linear waves, self propel barge, surge force, heave force, surge response amplitude operator, heave response amplitude operator, barge response.*

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I. INTRODUCTION

Vessels that navigate the various waterways within West Africa and across the waterways of the world are of different designs and are made for a particular purpose as well as the mechanism that supports their maneuverability and other factors that makes a vessel sea worthy, this vessels include container vessels, bulk carriers, barges, tanker vessels etc. which are of different sizes to suit a particular demand at a time and their route of navigation. This vessels encounter harsh and unfavourable condition during their voyage and are subjected to different wave load and this wave load cause the motions of the vessel, the about of motion the vessel experience is largely depended on the region of voyage and the size of the vessel. To this end it is primarily important that the approximate wave effect on vessel is know even before the voyage as this will make maneuverability very easy. Waves are generally generated by winds acting on the air-sea interface and is a basic feature that makes an area a marine territory or a coastal region. As wave energy is generated, it is dissipated along near shore region, beaches, moving bottom materials on shores, offshore and also 'exerts forces on marine structures. A basic understanding of the fundamental physical process in the generation and propagation of surface wave must precede any attempt to understand the complex motion in seas, lakes, and waterways. [1]. There are three types of water disturbance that can have effect on marine structures during their life at sea, this disturbance are wind, water current and waves, of all the disturbance the wave have the highest impart or effect on marine structure. However, there are also categories of wave at which it influences a marine structure, they are; Regular and Irregular wave. The regular wave provides detailed understanding of the mechanics of a wave field through examination of waves of constant height and period. It is also known as linear waves. While the irregular wave are successive waves which may have different periods and heights which are more of wave seen in nature. The irregular wave employs statistical and probabilistic theories. It is also known as then non-linear wave. However, emphasis will be laid on barges (a bulk carrying self-propelled barge) in this particular research. Barges are generally known as flat-bottom boat, which are use mainly for the carrying of cargo. They are designed in such a way as to enhance cargo-carrying capacity, thereby making more bulk to be hauled and transferred. These barges are built for different waterways to serve a particular purpose. As some are self propelled or been towed or pushed/pulled by a towboat. Also, barges are of various types which include; Barrack barges, Dry bulk cargo, Barges carrying liquid cargo, Car floats barges. Emphasis will be laid on dry bulk cargo self-propelled barge, because this are the most common type of barge as it render multi-purpose service, while on voyage this barges encounter wave motion that cause the barge to move in six (6) different direction when wave load or force impacts on a dry bulk cargo of a self-propelled barge, this six motion of the barge can be class as linear and rotational, the linear motion are the surge, sway and heave motion while the rotational motion are the roll, yaw and pitch. The combination of one linear and one rotational is known as couple motion and individual consideration of the six motion is known as the uncouple motion.

Waves

Waves is one of the environment conditions that affects a vessel. The knowledge of the waves and forces they generate is essential for the design of coastal projects, as they are the major factor and design geometry of beaches, the planning and design of marines, waterways, shore protection measures, hydraulic structures and other civil and military coastal works [1]. Estimate of wave conditions are needed in almost all coastal engineering studies. This implies that, wave does not only have impact on vessels, but also on engineering works (coastal structures), water recreational activities along the coastal zones, flooding and erosion along coastal settlements [2]. Recall, there are two essential type of wave, which are the regular and irregular wave. The regular wave outlines the fundamental principles governing the mechanics of waves motion which is essential in the planning and design of coastal works, while the irregular waves are waves that differ in periods and heights. Its analysis are described statistically, which is more descriptive of waves seen in nature. Ship maneuvering performance is typically predicted in calm water condition. This provides very valuable information at the initial ship design stage. However, since vessels sails in waves, the maneuvering performances of the ship in a sea way may be significantly different from the calm water condition. Therefore, if the effects of waves and corresponding motion responses can be induced in a mathematical model, the estimation will be much more reliable. [3]. Thus, ship motion sailing in waves can be decomposed into two kind of motion; wave induced motion regarded as high frequency motion and maneuvering motion regarded as low frequency motion.

Linear Wave

The linear wave is also known as the regular wave. Engineers have been able to develop theories that support this linear wave, which is known as linear wave theory. This linear wave theory is most used theory when considering the design of vessels and its analysis basically signify waves with small amplitude, wave length and other wave characteristics as it propagate in stable manner. Obviously if the wave amplitude creates an instability in its flow and such wave approaches a critical level, then its linearity assumption becomes unclear. [4]. Although the irregular wave is typical of a wave seen looking at the sea surface. This an alternative description of ocean waves. It is three-dimensional and employs statistical and probabilities theories. One of the approach, in the analysis of the irregular wave, is to describe the wave record at a point as a sequence of individual waves with different heights and approach, considering the variability of wave field in terms of the probability of individual waves. The ultimate criterion for the design of a vessel is the performance of the ship/vessel in a realistic seaway. Considering the importance of seaworthiness problem, it is very encouraging indeed to note the tremendous advancement. The well-known paper of St Denis & Pierson [5] on the application of the principle of superposition to the ship-motion problem started a new era in the field by hypothesizing that the responses be considered as the summation of the responses to the regular waves of frequencies. [6].

Wave load

Sea state is controlled by atmospheric wind, which comes in contact with the ocean sea surface. Wind is the primary cause of ocean waves due to interaction between atmosphere and sea surface. Wave load can be described as the force acting on a marine structure or vehicle. There action determines the kind of design or construction of any marine vehicle or engineering coastal project that is to be carried out. As each region and sea route have its own kind of wave impact, some could be very rough or mild, as a result of this, engineers and researchers have considerable put in measures to developed analysis, computer programs and model testing experimental analysis to ascertain and provide the needed data for such region. When marine structure or vehicle encounters surface waves, it responds to these waves in six degree of freedom. Translatory motion that is heave, sway and surge and the oscillatory angular motions about the same axis refered to as yaw, roll and pitch.[7]. However, it is a now a practice in ship design to determine wave load by applying its rules and standards. This design rules and requirement are important so as to obtain international quality standard and design basis for ships [8]. For example, unified requirements and common structural rules for bulkers and tankers have been developed within international association of classification societies (IACS) so as to improve safety of bulkers and tankers and to rationalize the rules and requirements between different classification societies. Although this standard rules standard rules can be sometimes difficult to apply for unconventional ships. The direct calculation of wave load in the structural analysis is a common practice in the offshore industry. However, the direct calculation procedure especially calculations of wave loads are seldom applied in the shipping industry. One reason is the large uncertainties in wave load prediction as well as lack of experiences. In addition, the theoretical basis of the calculation methods are not sufficient to get reliable predictions. The knowledge of magnitude and behavior of ocean wave at site is an essential prerequisite for almost all activities in the ocean including planning, design and construction and operation related to harbor, coastal structures [9], thus engineers and researchers have made of existing theories(linear and Non linear)to get the needed calculation and prediction of wave load. Wave load been describe as force are also accompanied with pressure velocity and acceleration acting on marine structures.

Wave spectra

Looking at the sea, it appears to have random waves of various length and periods. The simplication of this concept led to ocean wave spectrum. Wave spectrum is the measure of amount of energy associated with the fluctuation of the sea surface elevation per unit frequency band and per directional sector. Maritime or offshore activites has increased the need for a wave data for the designs of marine structures. it is generally believed today that the wave energy spectrum is able to express all the linear statistical properties of wind-wave surface.[10]. A sea state can characterized with a spectral formulation that is comprised of numerous individual wave component. The design sea state may come from intensification of local wind generated waves (sea) and /or swell propagating different directions.[11]. Researchers have been studying ocean waves have proposed several formulation for wave spectra dependent on a number of parameters (such as wind speed, Fetch or modal frequency) these formulation are very useful in the absence of measured data but they are subject to geographical and seasonal limitation [12].

II. MATERIALS AND METHODS

Sectional Unit of a Barge

The barge been an unconventional vessel due to its shape and size and for proper analysis and results, the barge is split into 3 sectional unit namely

A_1, A_2 and A_3 fore and $-A_1$, $-A_2$ and $-A_3$ Aft.

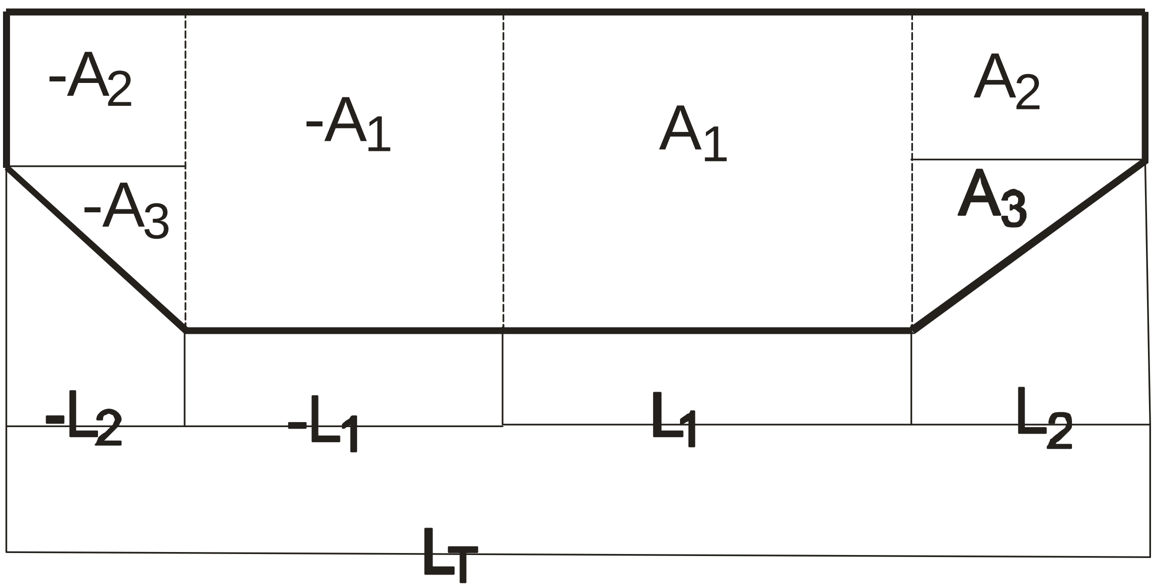

Figure 1 Front view of barge with sectional unit

Figure 1 show the sectional unit of a barge and this was done for easy analysis of the barge, as the barge was divided into three section (section one and two) is rectangular in shape as shown from figure 1 and section three is triangular in shape. The rectangular section is easy to model as they are several direct formula and approaches in text but the triangular section is complex because of the irregular shape and the similar triangle approach will be adopted while making some assumption.

2.1 Linear wave length

$$\lambda_0 = \frac{g\tau^2}{2\pi} \tag{1}$$

Where;

λ_0 - The water wave length

g - The acceleration due to gravity

T - The wave period

So, water condition test

$$\frac{d}{\lambda_0} > \frac{1}{2}$$

it means deep water

but,

$$\lambda_0 = \lambda_n$$

Also,

If $\frac{1}{2} > \frac{d}{\lambda_0} \leq \frac{1}{20}$ then it is in transitional water

Using the trial and error method to determine the actual wavelength thus

$$\lambda_n = \frac{(g \times T^2)}{2 \times \pi} \times \tanh \frac{(2 \times \pi \times d)}{\lambda_n - 1} \tag{2}$$

$\lambda_n - 1$ The wave length at the previous trial

λ_n The wave length at the current trial

d The sea water depth

Now to check for error of iteration

$$Error = \left[\frac{(\lambda_n - \lambda_{n-1})}{\lambda_n} \right] \times 100 < 0.1\% \tag{3}$$

but,

$\lambda = \lambda_n$, final wavelength

Again,

If $\frac{d}{\lambda_0} < \frac{1}{20}$ it means shallow water

Then same method of transitional is applied.

2.2 Wave Number (K).

This is the number of waves in a unit distance

$$k = \frac{2\pi}{\lambda} \tag{4}$$

Wave time (t)

$$t = \sqrt{\frac{2\pi\lambda}{g}} \tag{5}$$

Wave amplitude (ξ_a);which is the distance from the rest-position to the crest, which is twice the horizontal distance from crest to the nearest trough.

2.3 The wave amplitude ξ_a

$$\xi_a = \frac{H_{\max}}{2} \quad (6)$$

Instantaneous wave height z

$$z = \xi_a \; Sin\left(k \, {}^{L}\!/_{2} - wt\right) \quad (7)$$

2.4 Velocity potential

$$\theta = \frac{\xi_a g}{\omega} \; \frac{Cosh\, k\,(d+z)}{Sinh\,(kd)} \; Sin\,(kx - \omega t) \quad (8)$$

Using the exponential function

$$\theta = \frac{\xi_a g}{\omega} \, . \, e^{kz} . \, Sin\,(kx - \omega t) \quad (9)$$

Now, differentiating the equation (3.9) with respect to x

In x -direction

$$V_x = \frac{\partial \theta}{\partial x} = \frac{\xi_a g}{w} e^{kz} \; Cos\,(kx - \omega t) \times k$$

$$= \frac{\xi_a g \; k}{\omega} \; \cdot e^{kz} \; Cos\,(kx - \omega t)$$

$$= \frac{\xi_a \; \omega^2}{\omega} \; \cdot e^{kz} \; Cos\,(kx - \omega t)$$

$$V_x = \xi_a \omega \, . \, e^{kz} \;\; Cos\,(kx - \omega t) \quad (10)$$

V_x is the velocity of wave in x direction

In z- direction

Now, differentiating the equation (3.9) with respect to z

$$V_Z = \frac{\partial \theta}{\partial z} = \frac{\xi_a \cdot g}{\omega} \times \frac{1}{k} e^{kz} \; Sin\,(kx - \omega t)$$

$$V_Z = \frac{\xi_a \times g}{\omega} \times k e^{kz} \times Sin\,(kx - \omega t)$$

$$= \frac{\xi_a \; g}{\omega} \;\; e^{kz} \times Sin\,(kx - \omega t)$$

$$V_Z = g_a \; \omega \, . \, e^{kz} \;\; Sin\,(kx - \omega t) \quad (11)$$

V_z is the velocity of wave in z direction

Now acceleration in both directions

In the x-direction

Differentiating the equation (3.10) with respect to t

$$a_x = \frac{\partial v_x}{\partial t} = \xi_a \;\; \omega \, . \, e^{kz} \times - \; Sin\,(kx - \omega t) \times - \; \omega$$

$$a_x == \xi_a \;\; \omega \, . \, e^{kz} \times \;\; Sin\,(kx - \omega t) \;\; \omega$$

$$a_x = \xi_a \;\; \omega^2 . e^{kz} . \;\; Sin\,(kx - \omega t) \quad (12)$$

a_x is the wave acceleration in x direction

Also, in the z – direction

Now, differentiating the equation (3.11) with respect to t

$$V_Z = \xi_a \;\; \omega e^{kz} \times \;\; Sin\,(kx - \omega t)$$

$$a_Z = \frac{\partial v_Z}{\partial t} = \xi_a\ \omega e^{kZ}\ \ Cos\,(kx - \omega t) \times - \omega$$
$$= -\xi_a w^2\ e^{kz} \times\ \cos\,(kx - \omega t) \qquad (13)$$

a_z is the wave acceleration in z direction

2.5 Heave force computations

Incident wave potential

$$\nabla^2 \phi 1 = 0 \qquad (14)$$

$$\frac{\partial^2 \phi 1}{\partial t^2} + g\frac{\partial \phi 1}{\partial y} = 0\,, at\ y = 0 \qquad (15)$$

$$\left(\frac{\partial \phi}{\partial t}\right)_{y=0} + g\eta = 0 \qquad (16)$$

$$\frac{\partial \eta}{\partial t} = \left(\frac{\partial \phi}{\partial t}\right)_{y=0} \qquad (17)$$

Diffraction problem

$$\Delta^2 \phi = \Delta\left(\frac{\partial^2 \phi}{\partial x} + \frac{\partial^2 \phi}{\partial y} + \frac{\partial^2 \phi}{\partial z}\right) \qquad (18)$$

$$\phi = \phi\,(x, y, z, t)$$
$$= \phi_I\,(x, y, z, t) + \phi_D\,(x, y, z, t) \qquad (19)$$

Where ϕ_I and ϕ_D the velocity potential of the incident wave and diffraction wave respectively.

$$\phi_I\ \ (x, y, z, t) = \mathrm{Re}\left[\frac{ag}{\omega} \times \frac{\cosh k\,(y+h)}{\cosh kh} \times \mathrm{e}^{\mathrm{ik}}\,(\mathrm{x}\,\cos\theta + \mathrm{z}\sin\theta\ \text{-}\ \omega\mathrm{t}))\right] \qquad (20)$$

But

$$F_D = \iint_s \rho \frac{\partial \phi_D}{\partial t} n\ ds \qquad (21)$$

$$n = \frac{\partial \phi_k}{\partial n} \qquad (22)$$

Putting equation (3.22) into (3.21)

$$F_D = \iint \int_s \rho \frac{\partial \phi_D}{\partial t} \times \frac{\partial \phi_k}{\partial n} ds \qquad (23)$$
$$= i\rho\omega \iint_s \phi_{D \times} \frac{\partial \phi_k}{\partial n} \times ds$$
$$= i\rho\omega \iint_s \phi_{k \times} \frac{\partial \phi_D}{\partial n} \times ds$$

But

$$\frac{\partial \phi_D}{\partial n} = -\frac{\partial \phi_I}{\partial n}$$

$$F_D = -i\rho\omega \iint_s \phi_k \times \frac{\partial \phi_I}{\partial n} ds \qquad (24)$$

Also

$$F_I = -\rho \iint_s \frac{\partial \phi_I}{\partial t}\ (-n) ds \qquad (25)$$

$$\frac{\partial \phi_I}{\partial t} = \frac{\omega^2 \phi_I}{g} = i\omega\phi_z$$

$$F_I = \iint_s i\rho\omega\phi_I\, nds$$
$$= i\rho\omega \iint_s \phi_I \times \frac{\partial \phi_k}{\partial n} \mathrm{ds} \qquad (26)$$

But

Wave exciting force acting on a body is a combination of the froude- krylor force and the diffraction force.

$$F_I + F_D = -i\omega\rho \iint_s (\phi_I + \phi_D)\, n_i \times ds \qquad (27)$$

$= i\rho\omega \iint_s \left(\emptyset_I \frac{\partial \emptyset_k}{\partial n} - \emptyset_k \frac{\partial \emptyset_I}{\partial n}\right) ds$ (28)

The heave added mass

$A_{33} = \int_L a_{33}(x)\, dx = \sum_n a_{33} \times \Delta x_n$ (29)

The

$B_{33} = \int_L b_{33}(x)\, dx = \sum_n b_{33} \times \Delta x_n$ (30)

The restoring force coefficient

$C_{33} = \int_L c_{33}(x)\, dx = \sum_n b_{33} \times \Delta x_n$ (31)

So for the rectangular section of the barge

$A_{33} = a_{33} \times L$ (31)

$B_{33} = b_{33} \times L$ (32)

$C_{33} = C_{33} \times L = \rho g B l = \rho g A_{wl}$ (33)

The heave added mass for the rectangular section of the barge A_{33}

$$A_{33} = {Cm_3}/{2}\, \rho\lambda \left(\frac{B}{2}\right)^2 L \quad (34)$$

Where A_{33} is added mass for unit length of the rectangular section

The added mass coefficient Cm_3 [13].

$$Cm_3 = 1.014 \left({3}/{D}\right)^{-0.2692} + 0.674 \quad (35)$$

Where a_{33} is sectional added mass for unit length of the rectangular section

$a_{33} = \rho \times g \times B \times D \times L$ (36)

The sectional restoring heave force coefficient for the rectangular section b_{33}

$$b_{33} = \frac{\rho \times g^2 \times A^2}{\omega^3 \times \alpha^3} \quad (37)$$

where

$$A = 2 \sin\left(\frac{{\omega_e}^2 \times B}{2 \times g}\right) \times e^{\left(-\frac{{\omega_e}^2 \times D}{2 \times g}\right)} \quad (38)$$

Encounter frequency ω_e

$\omega_e = \omega - k \times V \times \cos\theta$ (39)

$\alpha = 1 - F_n \sqrt{k \times L \times \cos\theta}$ (40)

Froude number F_n

$$F_n = \frac{V}{\sqrt{k \times L}} \quad (41)$$

V is vessel forward speed

Wave phase angle θ

$\theta = kL - \omega t$ (42)

So the leave force in the rectangular section of the large

$F_{33} \int_{-l/2}^{1/2} PB dx + \int_{-l/2}^{1/2} a_x\, a_{33} dx + \int_{-l/2}^{1/2} V_x b_{33} d_x$ (43)

P = pressure at the box bottom

Putting equation 3.12 and 3.10 into 3.34

Then, the heave force equation become

$F_{33} = \int_{-L/2}^{L/2} \rho g \xi e^{-kD} \times \cos(kx - \omega t)\, dx + \int_{-L/2}^{L/2} -\xi \times \omega^2 \times e^{-kD} \times \sin(kx - \omega t) \times a_{33}\, dx + \int_{-L/2}^{L/2} -\xi \times \omega \times$ $e - kD \times b33 \times coskx - \omega tdx$

$F_{33} = \rho g \xi e^{-kD} \times \int_{-L/2}^{L/2} \cos(kx - \omega t)\, dx - \xi \times \omega^2 \times e^{-kD} \int_{-L/2}^{L/2} \times \sin(kx - \omega t) \times a_{33}\, dx + \xi\omega \times e^{-kD} \times$ $b_{33} \times \int_{-L/2}^{L/2} \cos(kx - \omega t)\, dx$ (44)

For the triangular section of the barge, a similar triangle rule is been adapted.

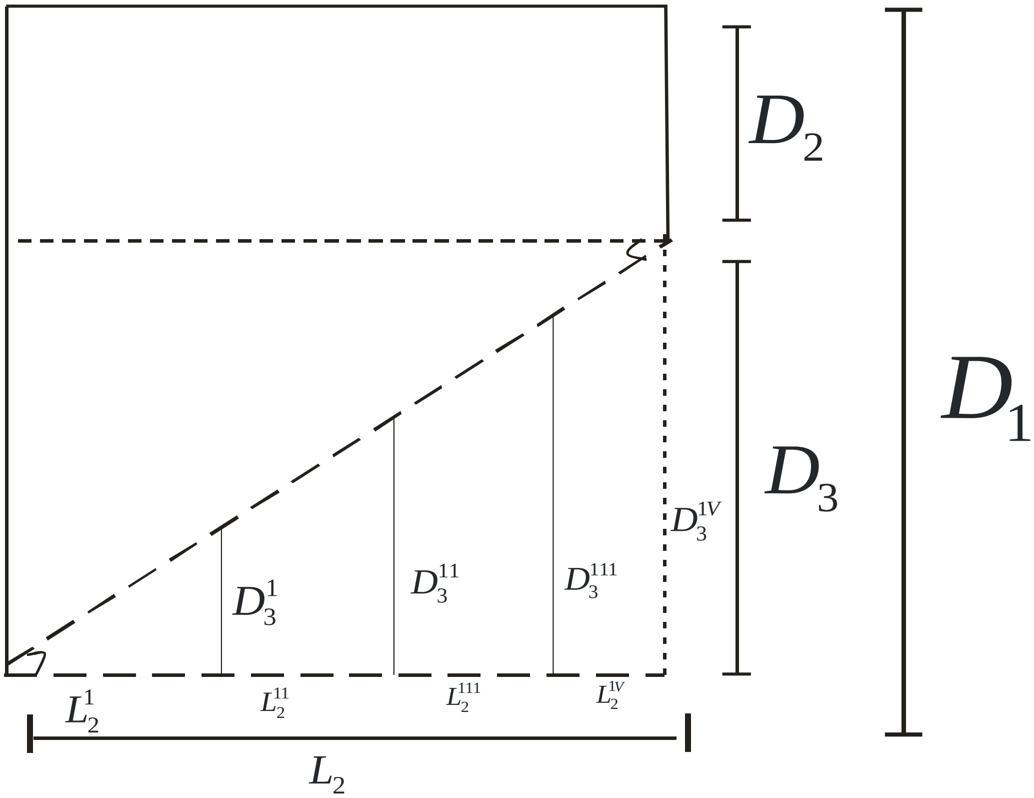

Fig. 3.3 is the triangular section of the barge using similar triangle

From figure 3.3 which show the triangular section of the barge, assuming $D_3 = L_2$, then

$$tan\,\theta = \frac{D_3}{L_2} = \frac{D_3}{D_3} = 1 \tag{45}$$

So in the same vein

$$tan\,\theta = \frac{{D_3}^n}{{L_2}^n} \tag{46}$$

Substituting equation 3.42 into equation 3.43

$$1 = \frac{{D_3}^n}{{L_2}^n}$$

$${L_2}^n = {D_3}^n \tag{47}$$

So for the triangular section of the barge

$$A_{33} = a_{33} \times {L_2}^n \tag{48}$$

$$B_{33} = b_{33} \times {L_2}^n \tag{49}$$

$$C_{33} = C_{33} \times {L_2}^n = \rho g B l \tag{50}$$

The sectional heave added mass for the triangular secType equation here.tion of the barge ${a_{33}}^n$

$${a_{33}}^n = \rho \times g \times B \times D \times {L_2}^n \tag{51}$$

The sectional restoring heave force coefficient for the triangular section ${b_{33}}^n$

$${b_{33}}^n = \frac{\rho \times g^2 \times A^2}{\omega^3 \times \alpha^3} \tag{52}$$

$$A^n = 2\,sin\left(\frac{{\omega_e}^2 \times B}{2 \times g}\right) \times e^{\left(-\frac{{\omega_e}^2 \times {D_3}^n}{2 \times g}\right)} \tag{53}$$

$$\omega_e = \omega - k \times V \times cos\,\theta \tag{54}$$

$$\alpha = 1 - F_n\sqrt{k \times {L_2}^n \times cos\,\theta} \tag{55}$$

$${F_n}^n = \frac{V}{\sqrt{k \times {L_2}^n}} \tag{56}$$

V is vessel forward speed

So the leave force in the triangular section of the large

$$F_{33}\ \int_{-l/2}^{1/2} P \times B dx + \int_{-l/2}^{1/2} a_x \times {a_{33}}^n dx + \int_{-l/2}^{1/2} V_x \times {b_{33}}^n d_x \tag{57}$$

P = pressure at the box bottom
Putting equation 3.12 and 3.10 into 3.34
Then, the heave force for the triangular section equation becomes

$$F_{33}{}^{n} = \int_{-L/2}^{L/2} \rho g \xi e^{-kD_3{}^{n}} \times \cos(kL_2{}^{n} - \omega t)\, dx + \int_{-L/2}^{L/2} -\xi \times \omega^2 \times e^{-kD_3{}^{n}} \times \sin(kL_2{}^{n} - \omega t) \times a_{33}\, dx + \int_{-L/2}^{L/2} -\xi \times \omega \times e^{-k} D_3{}^{n} \times b_{33} \times \cos(kL_2{}^{n} - \omega t)\, dx$$

$$F_{33}{}^{n} = \rho g \xi e^{-kD_3{}^{n}} \times \int_{-L/2}^{L/2} \cos(kL_2{}^{n} - \omega t)\, dx - \xi \times \omega^2 \times e^{-kD_3{}^{n}} \int_{-L/2}^{L/2} \times \sin(kL_2{}^{n} - \omega t) \times a_{33}\, dx + \xi\omega \times e^{-kD_3{}^{n}} \times b_{33} \times \int_{-L/2}^{L/2} \cos(kL_2{}^{n} - \omega t)\, dx \qquad (58)$$

Total heave force on the entire barge F_{heave}
The total heave on the entire barge is gotten by adding equation 3.44 and 3.58

$$F_{heave} = F_{33} + F_{33}{}^{n} \qquad (59)$$

2.6 Heave Responses

The heave responses is the way the barge behave under heave wave force that cause the barge to move in the heave direction and this can be determine by knowing the energy deposited on the barge by the wave as time or frequency progresses and the responses amplitude operator.

2.6.1 Quasi-static force for heave

The quasi-static heave force is the dynamic load that causes the barge to vibrate under heave force.

$$F_{qheave} = \frac{F_{heave}}{\varsigma_a \times C_{33}} \qquad (60)$$

2.6.2 Frequency Ratio R_{heave}

The frequency ratio is the ratio of the wave frequencies to that of natural frequency.

$$R_{heave} = \frac{W}{W_n} \qquad (61)$$

Where,
W_n is the wave natural frequency

$$W_n = \frac{2\lambda}{T_{n\ heave}} = \sqrt{\frac{C_{heave}}{M + A_{33}}} = \sqrt{\frac{\rho g BL}{M + A_{33}}} \qquad (62)$$

Where m is the mass of the barge

$$M = \rho BL \times D \qquad (63)$$

2.6.3 Magnification factor Q_{heave}

The magnification factor is the amplitude of forced vibration motion with respect to the magnification of the static deflection as a function of the frequency ratio.

$$Q_{heave} = \frac{1}{\sqrt{(1 - R_{heave}^2)^2 + (2d_{heave} \times R_{heave})^2}} \qquad (64)$$

Where d_{heave} is the damping ratio (which is mainly 8% - 10%)

2.6.4 Heave Response amplitude operator RAO_{heave}

The heave response amplitude operator define the way the barge responded or reacted to wave heave force imparted on the barge.

$$RAO_{heave} = Q_{heave} \times F_{qheave} \qquad (65)$$

2.6.5 Wave spectrum S(w)

The wave spectrum gives the distribution of wave energy among different wave frequencies.

$$S(w) = \frac{124}{T_Z 4} \; H_S^2 \; W^{-5} \; \exp\left[-\frac{496}{T_Z^4} \; W^{-4} \right] \tag{66}$$

2.6.6 Heave responses of the Barge S_{Rheave}

The heave responses of the barge is the way the barge behave under wave heave force as time or frequency progresses.

$$S_{Rheave} = S(w) \times (RAO_{heave})^2 \tag{67}$$

III. RESULT AND DISCUSSIONS

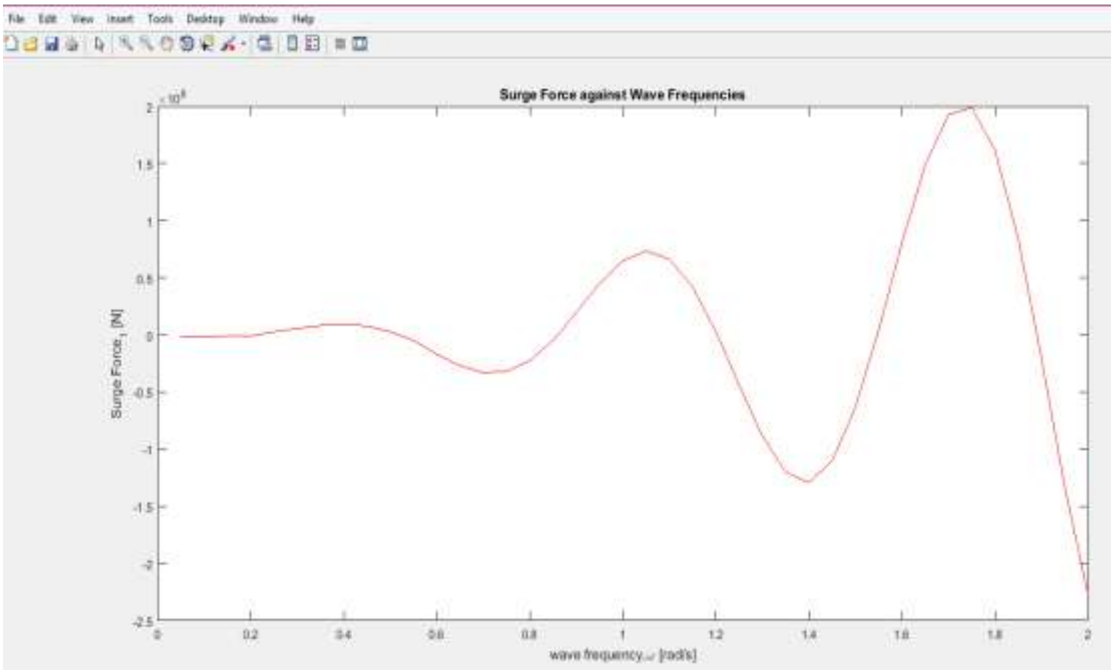

Figure 2: Surge Forces against Wave Frequencies

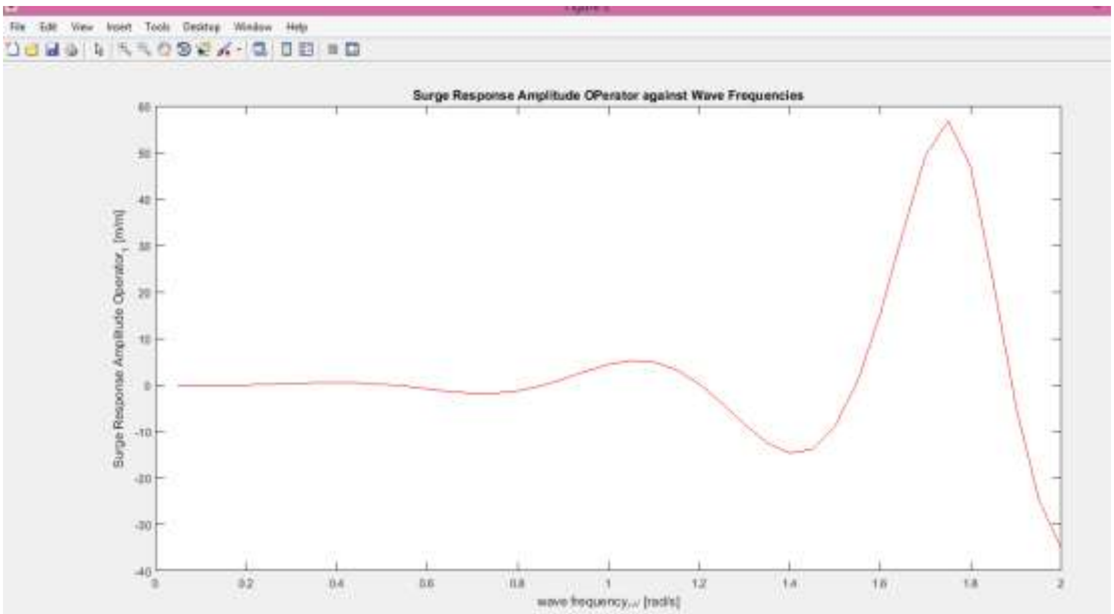

Figure 3: Surge Response Amplitude Operator against wave frequency

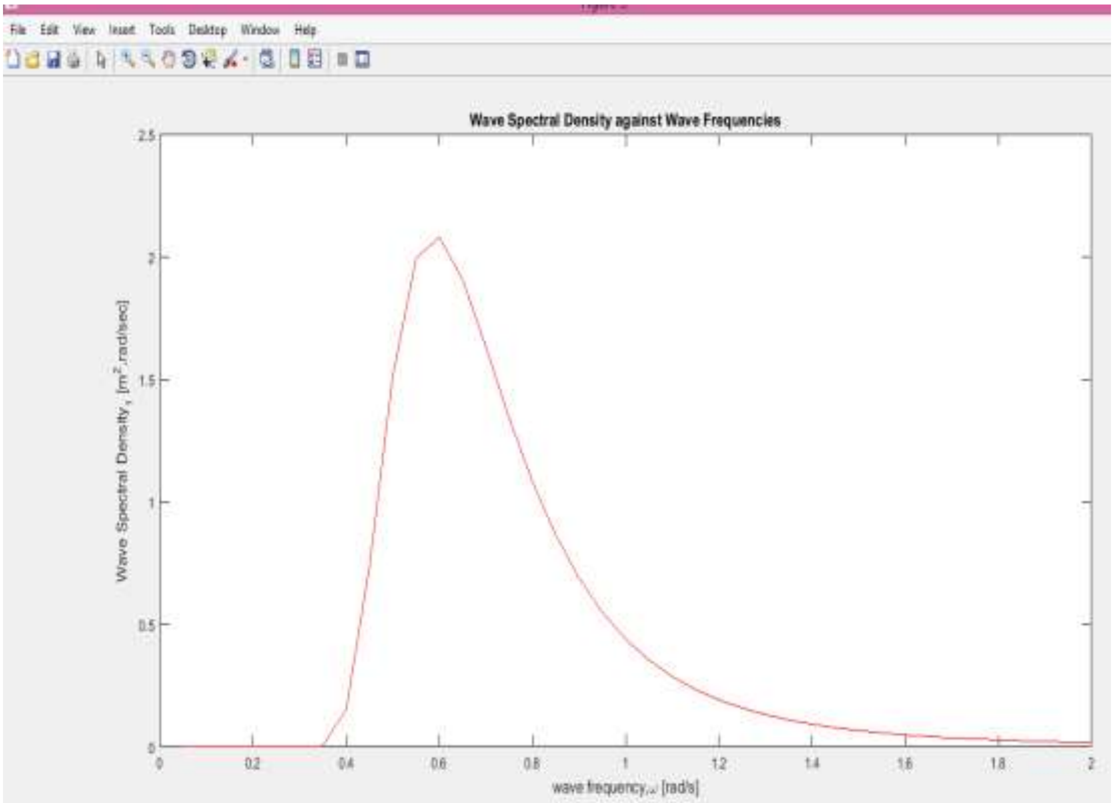

Figure 4: Wave Spectral Density against Wave Frequencies

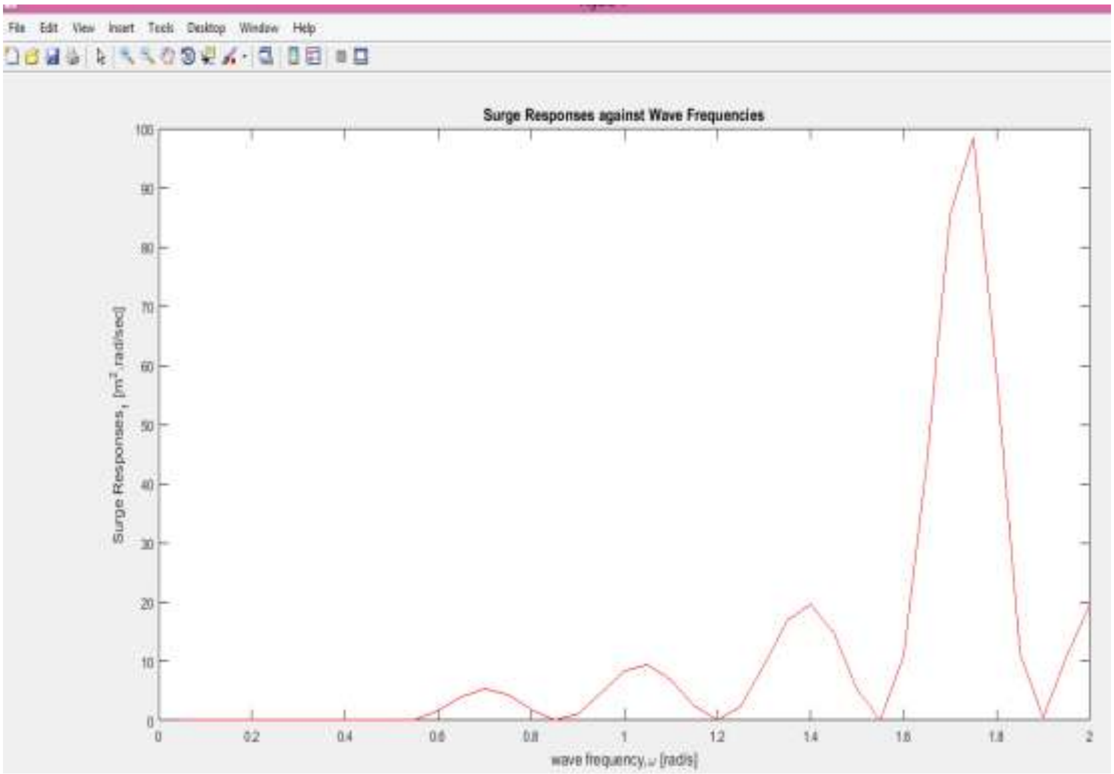

Fig. 4.6: Surge Responses against wave frequency

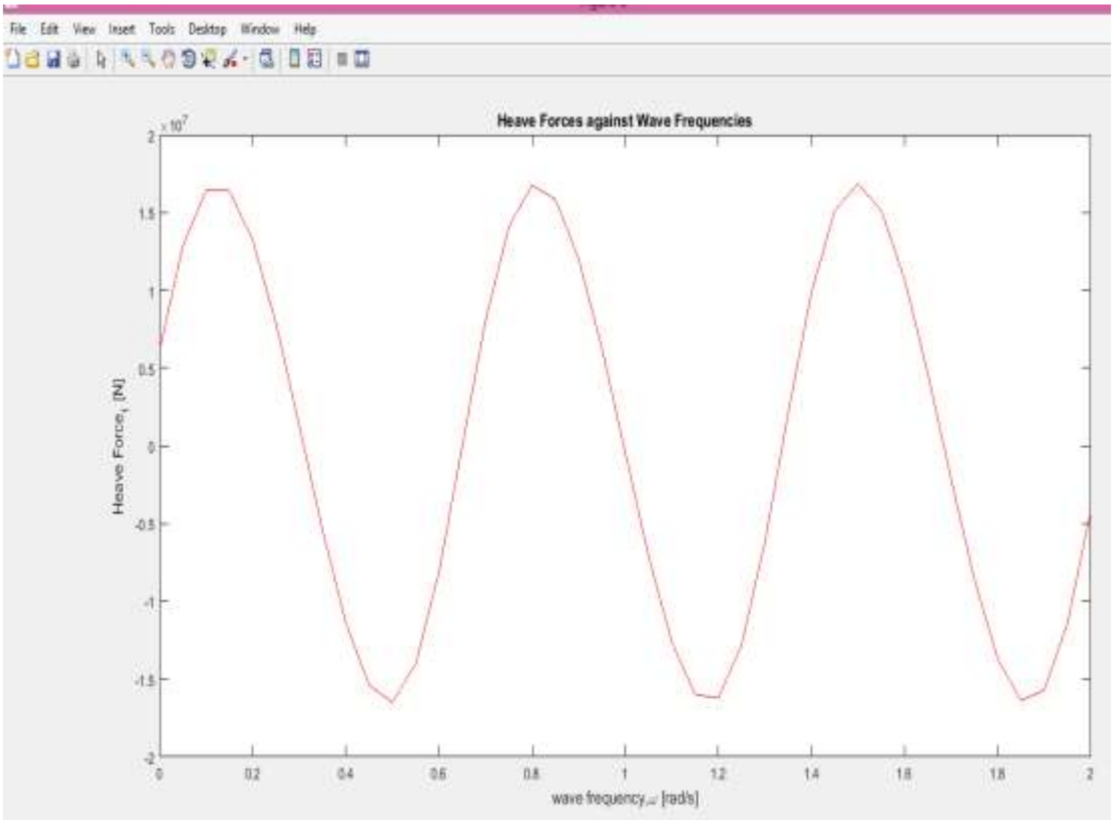

Figure 4.6: Heave Forces against Wave frequencies

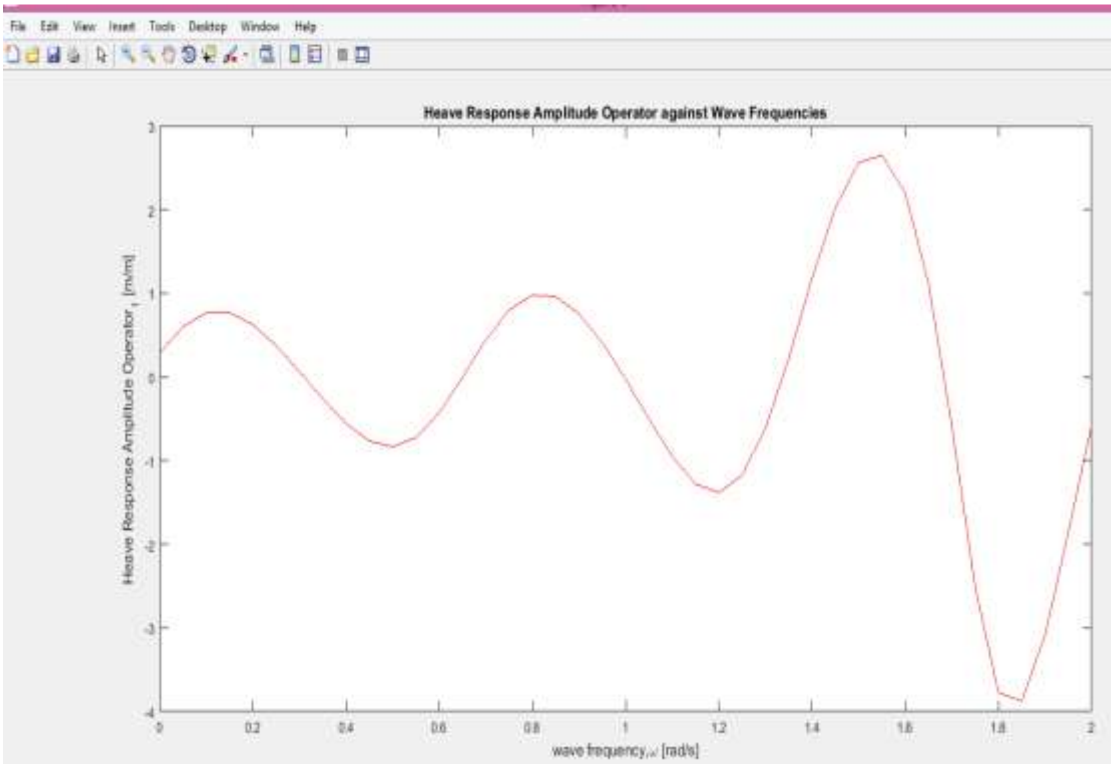

Figure 7: Heave Response Amplitude Operator against wave frequency.

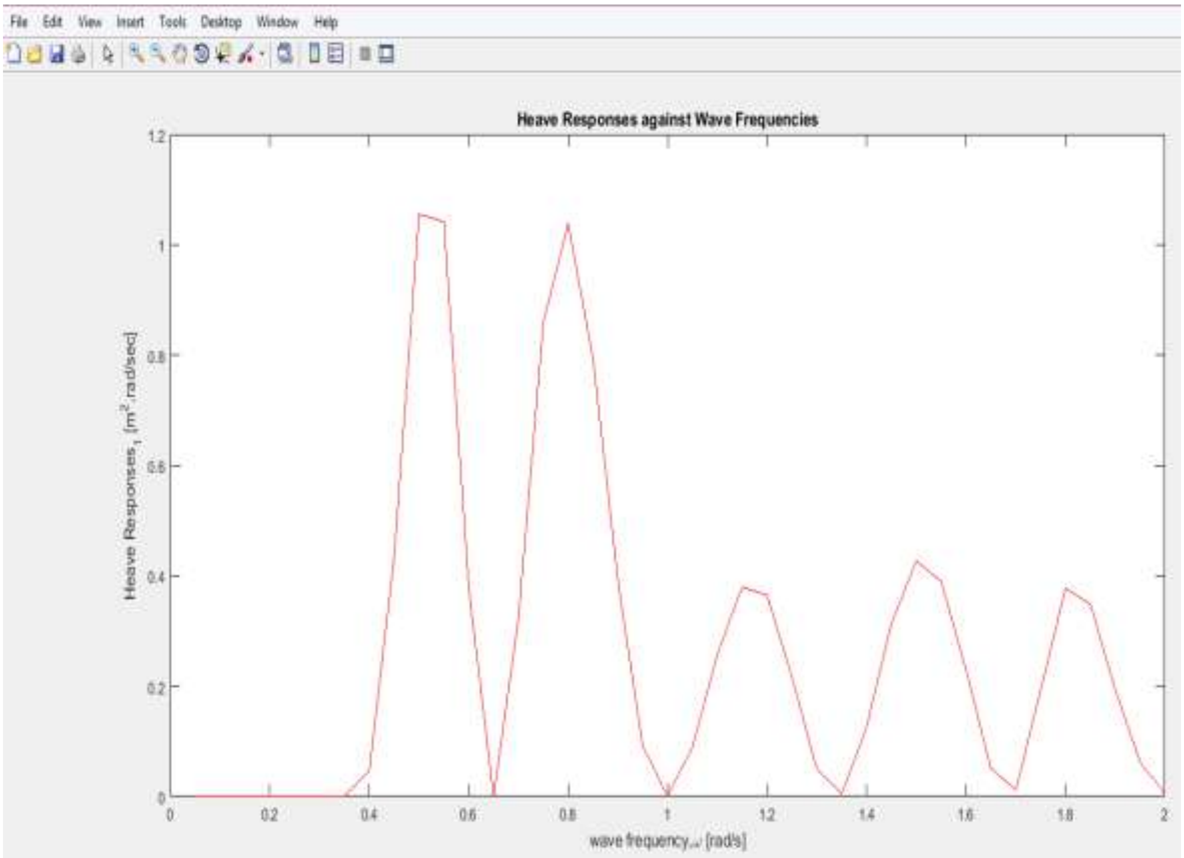

Figure 8: Heave Responses against Wave frequency

The Matlab sort code was program to run with an input values, though this input values are class into barge parameters, wave (Met-Ocean) parameters and other parameters. This three class of input gave the results presented above with figure 2 showing the wave surge force on the barge as wave frequency progresses with the barge surge force increasing both in magnitude and successive crest as wave frequency increases and the maximum surge force (-2.5×10^{8}N) is also at the maximum wave frequency, next is the computation of the surge amplitude operator by the matlap sort code figure 3 which show the effect of wave frequency on the surge amplitude operator which are factor or values that determine how the barge will behave or react to surge force and the surge response amplitude operator take a shape similar to that of the surge force and the maximum can be find close to maximum wave frequencies. Then, the wave spectral density against the wave spectrum figure 4 is computed for, this spectral density define the wave and tell about of energy store in the wave as wave frequencies progresses and are use together with the response amplitude operator to compute the responses with the maximum spectral density 2.0 $\mathrm{m^2rad}/_{\mathrm{S}}$ been attained at 0.6 $\mathrm{rad}/_{\mathrm{S}}$, and figure 5 show the barge surge responses to the surge force and follow a wave like pattern with the surge response and the successive crest keep increasing as wave frequency progresses until the surge response get to maximum, note the surge response is maximum at wave frequency that the surge response amplitude operator is also maximum.

The three class parameter continue to run through the sort code with figure 6 showing the wave heave force on the barge as wave frequency increases with the barge heave force continue to move through the positive and negative with equal magnitude and successive crest as wave frequency increases and the maximum heave force (1.7×10^{7}N) and also the same at successive crest as wave frequency progresses. Then, the computation of the heave amplitude operator by the Matlab sort code figure 7 which show the effect of wave frequency on the heave amplitude operator which are factor or values that determine how the barge will behave or react to heave force and the heave response amplitude operator take a shape similar to that of the heave force but with increase in magnitude at successive crest. Lastly figure 8 show the barge heave responses to the surge force and follow a wave like pattern with the heave response and the successive crest keep decreasing as wave frequency progresses until the surge response get to maximum such that if the wave frequency is increase to certain level the surge responses will diminish and this can be said to be due to the damping effect of the barge.

IV. CONCLUSIONS

Based on the results generated and discussions so far, I can conclude that the surge force, surge response amplitude operator and the surge responses of the barge all increases as wave frequency progresses this is so because on the surge side (x direction) which is the length side of the barge, the barge length (54.86 m) is greater than the wave length (24.96 m) wish means that it required more than one wave length to go through the barge and this will cause a corresponding steady surge force on the barge such that the before the restoring force could properly restore the barge another cycle of wave have begin.

I can also conclude that since the heave force remain same for successive crest, the heave response amplitude operator increases for successive crest and the heave responses diminishes for successive crest, I can conclude that the heave responses result is valid for a barge, this is so because on the heave side (z direction) which is the depth side of the barge, with barge depth of (3.05 m) is far lesser than the wave length (24.96 m) wish means that it required less than one wave length to go through the barge depth and this will give the restoring force time to properly restore the barge before another cycle of wave will begin.

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REFERENCES

[1]. Demirbilek.Z. & Linwood.C. (2008) water wave mechanics,
[2]. Gbuyiro, S.O E. Olaniyan (2002), Nature of marine winds, waves and swells over West Africa coast- case study of Victoria Island Lagos Nigeria. p.4.
[3]. Min-Guk. S, Yonghwan, K., (2011). Effect of Ship Motion on Ship Maneuvering In Waves. Seoul National University, Seoul, Korea, (2011). 26th International Workshop on Water Waves and Floating Bodies Athens,Greece, 2011, p.1.
[4]. Andreas, D & Nappo. J.C (1996). A Note on the Application of Linear Wave Theory at a Critical Level.p. 399.
[5]. Denis .M., Pierson W.S., (1953). The Motion of Ships in Confused Seas.
[6]. Nils S., Tuck. O.E., Faltingen, O., (1970) Ship Motions and Sealoads. p.1-2
[7]. Ngina.M.P., Manyanga, O.D., & Njenga, J.K. (2015) Wave Exciting Forces on A Floating Rectangular BargeDue to Surface Wave. pg1480.
[8]. Journee, J.M.J., Pinkster.J. (2002). Introduction in Ship Hydrodynamics Delft University of Technology. P.9.
[9]. Deo, M.C. (2013). Wave and Structures Indian Institute of Technology, Bombay, 2013.pg4.
[10]. Rye, H. & Swee, R. (1976). Parametric Representation of Wind-Wave Field, 12, p. 183-184.
[11]. Booki kim,Xiaozhi wang,Yung-sup shin (2007). Extreme Load and Fatigue Damage on FPSO In CombinedWaves And Swells. Research and Product Development Corporate Technology, America Bureau of ShippingHouston, Texas, USA. p.204.
[12]. Techet, A.H. (2005). Design Principle of Ocean Vehicles. p. 495.
[13]. Akandu, E. (2015). Optimal Design of FPSO Vessel for Extreme Metocean Conditions. University OfStrathelyde Naval Architecture, Ocean and Marine Engineering, Glasgow United Kingdom.

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