THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620, e-ISSN 2668-3156
DOI: https://doi.org/10.35219/AnnUgalShipBuilding/2023.46.24
2023

NUMERICAL SIMULATION FOR PREDICTING THE RESPONSE OF AN OFFSHORE HEAVY LIFT BARGE IN REGULAR AND IRREGULAR WAVES

Adham BEKHIT
“Dunarea de Jos” University of Galati,
Faculty of Naval Architecture, Galati,
Domneasca Street, No. 47, 800008,
Romania,
E-mail: adham.bekhit@ugal.ro

Sandita PACURARU
“Dunarea de Jos” University of Galati,
Faculty of Naval Architecture, Galati,
Domneasca Street, No. 47, 800008,
Romania,
E-mail: sorina.pacuraru@ugal.ro

ABSTRACT

This study case concerns the prediction of the hydrodynamic response of an offshore heavy lift barge in the regular and irregular waves. The study focuses on predicting the six degrees of freedom responses for the barge in the operation condition when the ship speed is equal to zero, at various heading angles (0~180˚) and for several wave frequencies (0.02~2.0 rad/s). The numerical simulation is carried out using the 3D diffraction/radiation motion solver Hydrostar software that is based on potential theory to predict the wave-body interactions. All the hydrostatics, loading and sailing aspects are initially estimated, and then introduced as an input in the simulation process corresponding to the ship speed and heading directions. For the irregular sea simulations, the ITTC spectrum is used to describe the wave for a generic study case in the Black Sea to make the study feasible for offshore applications in operational conditions where the ship speed is equal to zero.

Keywords: Seakeeping, 6 degrees of freedom, BEM, diffraction/radiation.

1. INTRODUCTION

With the increase in demands for the green energy, the offshore wind and the wave harvesting technology, a significant increase in the use of heavy lift vessels to transport the structural components in the operation sites is highly observed recently. The heavy lift vessels are one of the special type ships that are working in the offshore industry. Their scope is to transport heavy equipment, and sometimes entire platforms or platform deck to production areas. Their performance in open seas is extremely important to be extinguished to insure a safe operation for the platform and the vessel during the different operation conditions. One of the most important aspects of the offshore heavy lift vessels is to take into consideration their stability during operation and to ensure minimum responses in waves. Loading and offloading operations are also crucial from the stability and integrity points of view.

This study proposes the use of the simplest model of heavy lift vessel, being in the form of an almost box-shaped barge as an initial study for a further investigation that will be carried out by the authors soon, following a series of investigations that were carried out for the offshore oriented ship types, such as the Anchor Handling Tug Supply (AHTS) and the Offshore Supply Vessel (OSV)[1, 2].

The analysis is concerned with the stability of the barge during the operational process and its performance in open seas. This imposes an urgence to study the six degrees of freedom motions and their responses in irregular waves. However, to reach this step, the barge is initially analysed in regular wave then the data extracted from the regular waves are interpolated to give the barge performance in irregular waves.

2. GEOMETRY AND SIMULATION CONDITIONS

The geometry under investigation in this study is a simple geometry of a box shaped barge whose length, beam, depth, and draft are 152, 40, 8 and 4 m, respectively. The geometry is shown in Fig. 1, while the principal characteristics and the initial hydrostatics are listed in Table 1.

The study is carried out for the barge in operation condition, i.e., ship speed is set to zero. The wave heading is considered for directions of 0° to 180° with a step of 30°. The wave angular frequency ranges between 0.02 and 2.0 rad/s with a step 0.04 rad/s. This includes investigation of 7 headings and 50 frequencies. The simulation is carried out using the 3D diffraction radiation method using the Hydrostar motion program which is provided by Bureau Veritas under an academic licence.

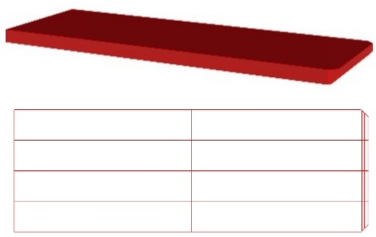


Fig. 1. Heavy lift barge geometry showing the 3D and top views.

Table 1. Heavy lift barge characteristics and initial hydrostatics

Parameter	Value
Length (L_{WL}) [m]	152.0
Breadth (B) [m]	40.0
Depth (D) [m]	8.0
Draft (T) [m]	4.0
Volume () [m^3]	21354.2
Displacement (Δ) [t]	22082.0
Water plan area (A_w) [m^2]	5649.24
Prismatic coefficient (C_p)	0.948
Block coefficient (C_B)	0.948
Water-plan area coefficient (C_w)	0.995
Initial transverse metacenter (GM_t) [m]	36.717

3. GOVERNING EQUATIONS

Under the potential flow assumption, the flow is incompressible, inviscid and irrotational. The velocity can be obtained from the velocity potential function Φ as:

$$V = \nabla\emptyset \tag{1}$$

Hence, the potential function satisfies the Laplace condition, hence the conservation of mass equation can be written as:

$$V^2\varphi = 0 \tag{2}$$

The flow is assumed to be (fairly perfect fluid) as described by Guevel (1982) [1]; now, the momentum equation is written as:

$$(\partial/\partial t + V\nabla)V = -\nabla(P_r/\rho + gz) - \mu V \tag{3}$$

where P_r is the pressure and g is the gravitational acceleration.

Based on equation (1), the Bernoulli equation is written as follows:

$$P_r/\rho + gz + \varphi_t + \nabla\varphi\nabla\varphi/2 + \mu\varphi = C(t) \tag{4}$$

C(t) is an arbitrary function and usually omitted.

At the free surface, the dynamic condition requires that the pressure given by Bernoulli equation (4) should be equal to the atmospheric pressure. The kinematic condition refers to the fact that a particle in motion at the free surface stays always on the same surface. Considering the dynamic and kinematic conditions, the relation given below is obtained:

$$g\varphi_z + \varphi_{tt} + \mu\varphi_t + 2\nabla\varphi\nabla\varphi_t + \nabla\varphi \cdot \nabla(\nabla\varphi\nabla\varphi)/2 = 0 \quad (5)$$

and the free surface can be written:

$$\varepsilon(p,t)g = -\varphi_t - \nabla\varphi\nabla\varphi/2 - \mu\varphi \quad (6)$$

Since the ship is sailing in waves, the regular wave has the following expression:

$$\zeta(X,Y,t) = a\cos\left\{\omega t - k\begin{bmatrix}(X - X_{cal})\cos\beta + \\ (Y - Y_{cal})\sin\beta\end{bmatrix}\right\} \quad (7)$$

where ζ is the wave elevation, a is the wave amplitude, ω is angular frequency, t stands for the time, β is the wave heading angle and k is the wave number. The ship motion will have the expression:

$$U(t) = u\cos(\omega t + \varphi) \quad (8)$$

where u is the amplitude of the motion and φ is the phase.

For irregular waves, the ITTC wave spectrum is chosen for a maximum operational condition at Beaufort scale 6, where the significant wave height H_S=1, 2 and 3 m. The wave spectrum $S_\zeta(\omega)$ and the response encounter spectrum $S_R(\omega_e)$ equations are described as:

$$S_\zeta(\omega) = \frac{A}{\omega^5} e^{\frac{B}{\omega^4}} \quad (9)$$

where A=0.0081g^2, B=3.11/H_s^2 and H_s is the significant wave height retrieved from Beaufort scale.

$$S_R(\omega_e) = RAO^2 S_\zeta(\omega) \quad (10)$$

where the suffix R refers to the response and RAO stands for the response amplitude operator, where RAO is calculated as the ratio between the motion amplitude and the wave amplitude. As for the encounter frequency it can be estimated based on the following equation:

$$\omega_e = \omega\left[1 - \frac{\omega V}{g}\cos\mu\right] \quad (11)$$

and consequently, $\omega_e=\omega$ when V=0.

4. RESULTS AND DISCUSSION

In the beginning, a special concern with the stability of the barge in loading condition was taken into consideration to understand the stability criteria and to estimate the initial GZ curve. The scope of this step is to grasp an understanding for the range of stability and the angle of inflection to make sure that the deck will remain dry during the roll oscillations. The static stability curve is represented in Fig. 2.

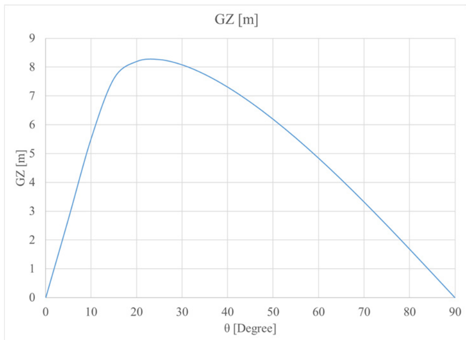


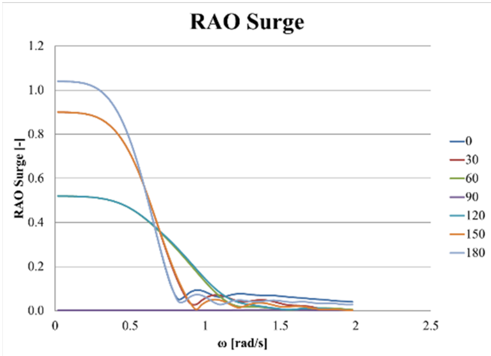
Fig. 2. GZ curve for loading condition

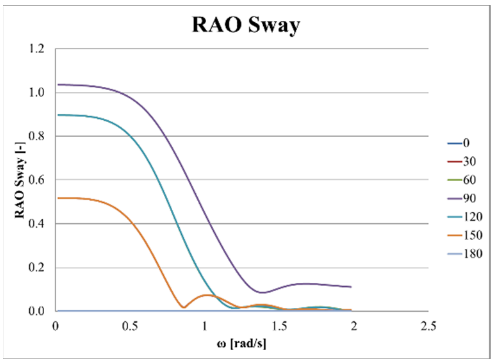
The diagram shows that the maximum GZ value occurs at an angle of inclination 23.6°, initial GM value is within 16.72 m and the angle of deck immersion (angle of inflection) happens after 12° of transverse inclination. These parameters are necessary for the upcoming investigation, especially while discussing the roll motion response.

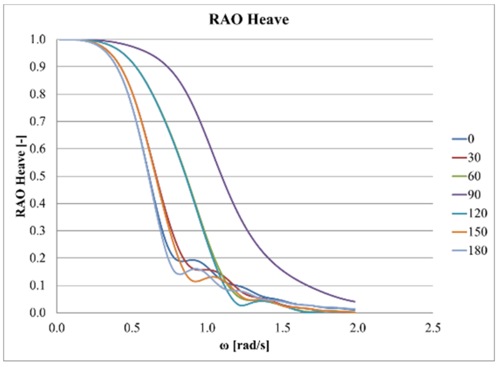
After the stability analysis, the barge performance in the wave takes place. The response results in this section will be divided in two subsections regarding the ship response analysis in regular and irregular waves. All the results are presented in terms of RAO for regular waves and Response spectrum for irregular waves. The response spectrum can be calculated based on equation 10 from section 3.

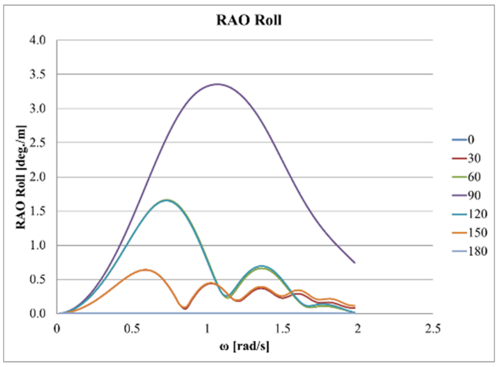
4.1 Regular wave results

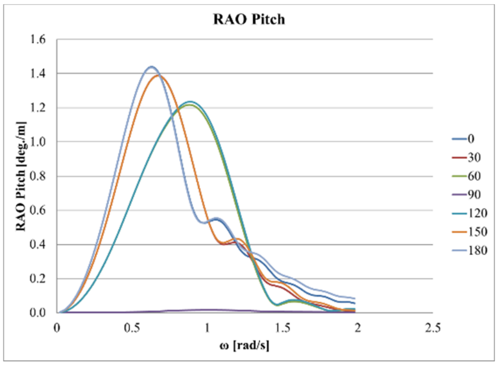
The response amplitude operators for the six degrees of freedom are represented in Fig. 3. The x-axis stands for the angular frequency ω in [rad/s] while the RAO is plotted on the y-axis with nondimensional representation [m/m] for surge, sway, and heave; and [degree/m] for roll, pitch, and yaw.











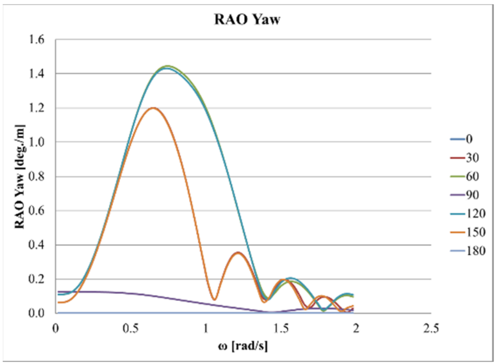


Fig. 3. RAO for the six degrees of freedom.

From the response amplitude diagram, it can be observed that the ship motion amplitudes are relatively small. The maximum responses for surge and pitch are obtained at following sea, the maximum responses for sway, heave and roll are obtained at beam sea, and finally the maximum response for yaw is obtained at oblique sea. The estimated maximum roll angle is within 3.4° at an angular frequency of 1.2 rad/s. The maximum pitch and yaw responses are within 1.42° at an angular frequency within 0.6 and 0.8, respectively. The other values are less or slightly over unity.

4.1 Irregular wave results

The ITTC spectrum is used for this study with a significant wave heights H_s= 1, 2 and 3 m. the wave spectrum is plotted in Fig. 4, while the characteristics of the irregular waves are listed in Table 2.

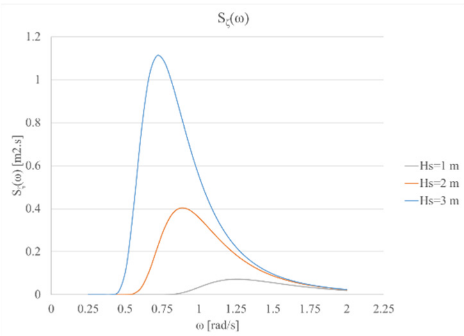


Fig. 4. ITTC spectrum for significant wave heights of Hs=1, 2 and 3 m.

The values chosen for the significant wave height correspond to a Beaufort scale up to 5, where the wind speed is up to 38 km/hr.

Table 2. Irregular wave characteristics obtained from the ITTC spectrum.

Characteristic	Hs=1m	Hs=2m	Hs=3m
m_0 [m^2]	0.053	0.241	0.556
m_1 [m^2/ s^2]	0.112	0.304	0.500
m_2 [m^2/ s^4]	0.275	0.523	0.676
H_{av} [m]	0.578	1.226	1.864
H_s [m]	0.924	1.962	2.983
$H_{1/10}$ [m]	1.176	2.497	3.796
$H_{1/100}$ [m]	1.154	3.272	4.974
T_z [s]	4.339	5.585	6.627
T_c [s]	4.012	4.796	5.403
λ_z [m]	27.177	41.818	55.896

where m_0, m_2 and m_3 are the 0th, second and the fourth moment of area under the spectral curve, respectively. H_{av} is the average wave height for the irregular waves. Hs, $H_{1/10}$, $H_{1/100}$ are the significant wave height of one third, one tenth and one, one hundredth of the highest recorded waves. T_z, T_c are the average zero up-crossing and the crest periods, respectively. And finally, λ_z is the average wavelength. These parameters can be obtained from the ITTC spectrum based on the following formulas [2]:

$$m_n = \int_0^\omega \omega^n S_\zeta(\omega) d\omega \qquad (12)$$

$$\bar{H} = 2.5\sqrt{m_0} \qquad (13)$$

$$\bar{H}_{1/3} = 4.0\sqrt{m_0} \qquad (14)$$

$$\bar{H}_{1/10} = 5.09\sqrt{m_0} \qquad (15)$$

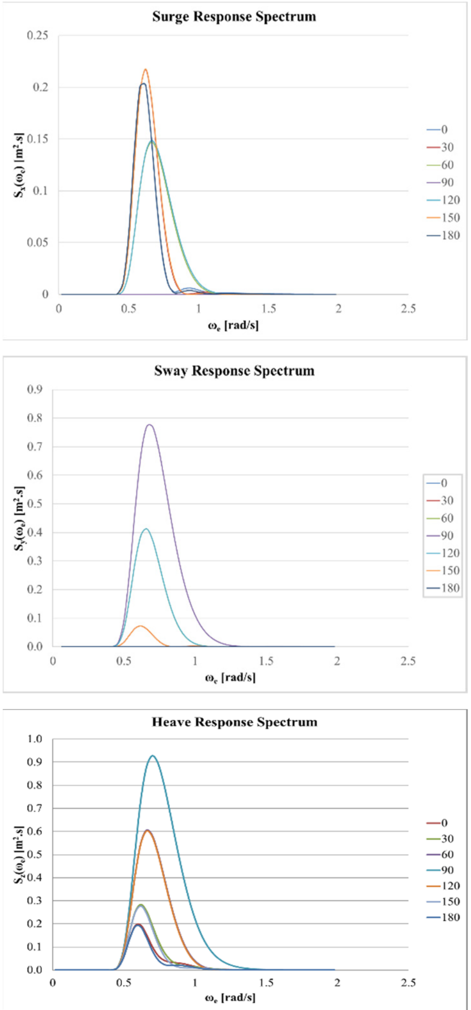
$$\bar{H}_{1/100} = 6.67\sqrt{m_0} \qquad (16)$$

$$\bar{T}_z = 2\pi\sqrt{\frac{m_0}{m_2}} \qquad (17)$$

$$\bar{T}_c = 2\pi\sqrt{\frac{m_2}{m_4}} \quad (18)$$

$$\bar{\lambda}_z = 2\pi g\sqrt{\frac{m_0}{m_4}} \quad (19)$$

The response spectrum for only the maximum significant wave height is plotted in Fig. 5. The six degrees of freedom are denoted with the suffix x, y and z for surge, sway and heave, respectively; while φ, ψ, and θ stand for the roll, pitch and yaw, respectively.



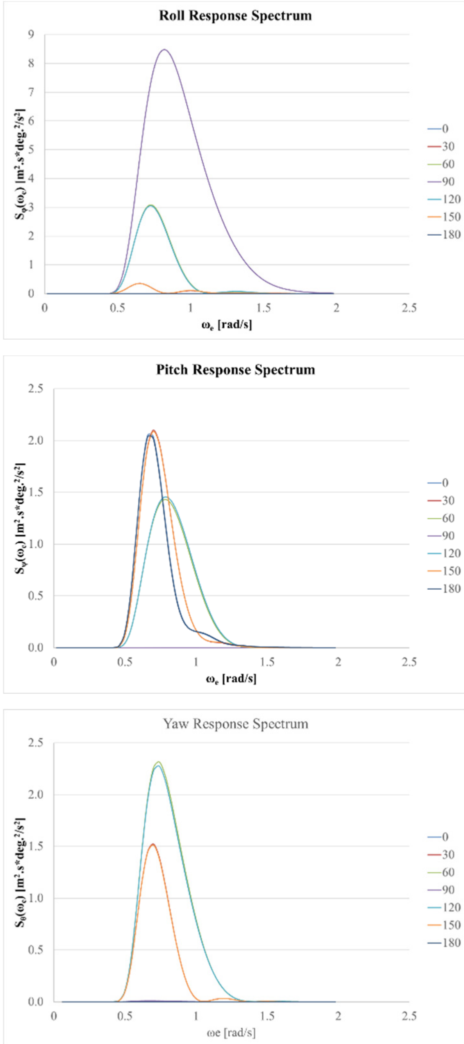


Fig. 5. RMS for significant wave height of Hs=1, 2 and 3 m.

The result for the maximum Root Mean Square (RMS) of the motion responses in irregular waves are summarized in Table 3.

Table 3. RMS for maximum motion responses in irregular waves.

Motion	RMS	Heading
Surge	0.06 [m]	30° and 150°
Sway	0.26 [m]	90°

Heave	0.33 [m]	90°
Roll	3.53°	90°
Pich	0.66°	30° and 150°
Yaw	0.83°	60° and 120°

The RMS values show that the responses are also not so significant in irregular waves. The maximum roll angle at a sea state 5 with the significant wave height of 3 m is recorded within 3.53°, which is considered safe for the operation, since the inflection point of the barge is above 12°. A special consideration for the wind loads should be taken into account, especially for the equipment with high lateral areas, such as deck equipment and similar flat side surfaces, which might tend to increase the roll angle.

It is worth mentioning that the motion accelerations were within an acceptable limit, however the roll acceleration was slightly higher, considering the high initial transverse initial metacentric height, GM_0 value.

5. CONCLUDING REMARKS

The motion response of a simple geometry offshore heavy lift barge in regular and irregular waves were investigated and presented. The study focussed on predicting the six degrees of freedom motions in several headings and at various wave angular frequencies. The results obtained for both regular and irregular waves in terms of RAO, spectral response, and RMS, respectively.

The motion responses showed that the motion is influenced with the wave direction and wave angular frequency.

The amplitude of the motions show that the barge has minor responses for the wave during the simulation. Maximum value obtained for roll motion in regular wave is about 3.4° and 3.53° for irregular wave in terms of RMS. The maximum pitch and yaw responses are within 1.42°.

Since the hull had a significant initial value for GM, the motion accelerations were relatively high, this requires further investigation in the future to ensure safe operation, especially if the barge will include passengers onboard.

As these studies were considered as an initial investigation for this category of ships in the offshore domain, the future plan for this study includes an extended enhancement for the geometry of the barge as an initial stage. The second phase includes an investigation for the viscous effect on the motion damping using a viscous flow solver in order to understand the damping influence on the ship motions.

Further validation is also compulsory to investigate the accuracy and efficiency of the numerical solver.

REFERENCES

[1]. **Pacuraru, F., Pacuraru, S., Bekhit, A., (2020)**. *Numerical analysis of ship motions for an offshore vessel, AIP Conf. Proc. 2293, 420091, 1–4.*

[2]. **Pacuraru, S., Domnisoru, L. Bekhit, A. (2022).** *Numerical simulation for the motion response of an Offshore AHTS ship in regular and irregular waves, International Journal of Modern Manufacturing Technologies, ISSN 2067–3604, Vol. XIV, No. 3 / 2022.*

[3]. **Guevel, P., Bougis, J., (1982),** *Ship-motions with forward speed in infinite depth, Int. Shipbuilding Progress, 29(332), 103-117.Dan Obreja, 2004*, *"Hydrodynamic Peculiarities of Small Ship Design".*

[4]. **Hossein Mousavizedegan S.,** *" Dynamics of Marine vehicles. Faculty of Marine Technology. Amirkabir University of Technology, No. 424, Hafez Ave., Tehran, Iran, available online: https://faculty.kmsu.ac.ir/file/download/course/1582099786-waves.pdf. Last accessed on: 21.11.2023*

[5]. **Queutey P, Visonneau M**, *2007 An interface capturing method for free-surface hydrodynamic flows Computers & Fluids;*

Paper received on November 22nd, 2023