American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-8, Issue-2, pp-271-282
www.ajer.org
Research Paper Open Access

Wave Forces, Displacements and Stresses on Offshore Structures (Using Africa Waters)

Olusegun Samuel Dare, Ibiba Emmanuel Douglas and Ezebuchi Akandu
Marine Engineering Department, Rivers State University, Port Harcourt, Rivers State Nigeria.
Corresponding Author: Olusegun Samuel Dare

ABSTRACT : *This research work is primarily aimed at developing a software(JAVA Program) since the cost of acquiring or purchasing Naval Architecture and Offshore structure software today, runs into thousands of Dollars and millions of Naira and to the fact that those companies that produce offshore structure equipment relay on spectrum model analysis for North sea to manufacture there equipment without given due consideration to the region where the equipment is to be use, Owing to this facts and many more, this research work; wave forces, Displacement and Stresses on Offshore Structure using West Africa water spectrum using calculations with JAVA programming language was carried out to meet the need of wave spectrum analysis offshore structure(Jack up structure) design in both academics and industry with less cost by considering the region that use the offshore equipment instead of basing the design with the region with highest wave height (North sea), this is done by statistically analyze each region separately with the aim of calculating the wave maximum height that act on offshore structure(Jack up structure) so long the wave profile of such region are known, it further, the software are further use in calculating the wave force on entire offshore structure(Jack up structure), which lead to calculating the wave force on each member that make up the offshore structure and with each member force been calculated. The software was also used to determine each member stress using finite element with each member stress far less than 90mpa which is a known maximum stress for an iron material. As time goes interested researchers in this field can add to the development of this software until it gets to a stage where it will be commercially approved*
KEY WORDS*: Offshore, Jack-ups, Inertia force, Drag force, Member force, Nodal displacement, Member stress*

Date of Submission: 15-02-2019 Date of acceptance: 28-02-2019

I. INTRODUCTION

The aim of offshore structural engineering is to produce structures which are safe, functional, economical, and able to resist the forces included by man, wave and other environmental factor required over a period of time. The analysis of offshore structures are complicated because various uncertainty sources like uncertainty of dynamics strength of material used, dynamics strength of joint, wave load and other environment load. Most offshore structure produced or installed at the offshore are design based on the acceptability of the structure on the region with the maximum and minimum wave height. The believed is that if the offshore structure can withstand those region with the maximum and minimum wave load, then it should be able to withstand other region between the maximum and minimum wave load. These has made the offshore equipment very expensive as all offshore structures are design to withstand the maximum wave load of the region with maximum wave height without considering the region where the offshore structure is to be install. The structure design of offshore require knowledge of the maximum wave loads, a set of design waves or wave spectra are selected that either produce the largest wave load on a structure, the largest wave load is of a great concern for fixed and floating offshore structure. The number of offshore platform in the world is increasing yearly , this platform are mostly of fixed jacketed platform type located in 20meters to 200meters water depth, fixed offshore structure are subjected to different environmental loads during their life time, these loads are imposed on the structure through natural phenomena such as wave , current, wind, earthquake, and earth movement. But of the various types of environmental loads, wave force load is the dominated loads and most likely the frequently occur load. It is necessary to design an offshore structure such that it can respond to moderate environmental loads without damage, and it capable of resisting severe environmental loads without seriously endangering the occupants.

The earliest Jack-ups platform is the united states patent application filed by Samuel Lewis in 1869 [1]. and it took 85 years later in 1954 that Delong Mcdermolt No.1 became the first unit to utilize the Jack-up principle for offshore drilling. This was done by a pontoon with a number of tabular legs which could be moved up and down through cut-out in the pontoon and are towed to location with their legs drawn up. Once in position their legs could be lowered and the pontoon elevated off the water using the same principle as the modern Jack-ups.In 1956 a former entrepreneur in earthmoving equipment R.G LeTourneau redesign and revolutionized the design of the jack-ups by reducing the numbers of legs from four to three and presenting the jack-ups in triangular form instead of the usual pontoon(rectangular form) [2].

Another innovative design change was the electrically driven rack and pinion jacking system which allowed for continuous motion in any jacking operation. This replaced ‘gripper’ jacks where slippage often occurred on the smooth leg surface [3]. Both revolutionary features are common on today jack-ups.

Also Jack-ups are now operating for extended periods at one location, often in the role of a production unit (Bennett &Sharples, 1987). As in the case of the long-term use of jack-ups as in the Siri marginal field development in the Danish sector of the North Sea. A purpose built jack-ups is being used in 60 meter water depth as a production plat-form with an expected life of ten years [4]. A further example is the shear water development, where jack-ups drilling is planned to continue for two and a half year at a 90 meter depth in the North Sea.

Wave Force on Jack-Ups Offshore Structure

One basic problem in analyzing an offshore platform structure is the determination of force acting on it from it environment [5] as a result of their experiments postulated an empirical formula for computation of wave forces. Morrison’s equation are of two main forces mainly the drag force which is due to friction and form drag, and the magnitude of the drag force depend on shape of the structure, roughness of the member, intensity of turbulence on the flow and Reynolds number, and the inertia force which is due to water-particle acceleration.

Several wave theories such as linear wave theory, third and fifth order theories etc which are related to water particle velocity and acceleration in Morrison’s equation has been develop, [6] and made comparisons between linear wave theory and fifth order theories considering a wave of the same height and period, and both came to the conclusion that the linear theory is quite adequate for calculation of the wave force.

The effect of current and wind on the offshore structure are study and reported by [7], then recommended that the Tung’s formula be use to shown that the maximum wind load and current load acting on the upper part of fixed offshore platforms amounts to about 5% to 15% of the maximum wave load.

Jack-Ups Displacement, Stress and Fatigue

Research on the fatigue of offshore structures has attracted much attention during recent decades (Nolte & Hansford, 1976) developed closed form mathematical expressions for determining the fatigue damage of structure due to ocean waves. These expressions incorporated relationship between the wave height and the stress range, considering the stress range versus the number of cycles to failure and the probability distribution for the occurrence of wave heights, [8] discussed the most important subjects related to fatigue of the offshore steel structures, such as calculation of fatigue stresses and fatigue lives. [9]reviewed and summarized the knowledge in the area of stress concentration factor, fatigue and fracture mechanics of the tabular joints, damage assessment and reliability analysis of joint. [10]presented a modeling of jack-up response for fatigue calculation, by analyzing a mathematical model to obtain the transfer function of the response for a typical jack-up plat-form, they find out that the complex leg-soil interation can be adequately modeled using springs and assuming a rigid foundation. [11] and [12] performed several studies about fatigue of stiffened steel tubular joints, such as corrosion fatigue and fatigue behaviours. [13]discussed fatigue damage assessment and the influence of wave directionality, investigated for a rotationally symmetric structure and presented quantitative result based on the spectrum analysis theory. [14]presented a fatigue calculation of a tubular jacket structure located in south Chain Sea, by investigating the transfer function of joint stresses, it was concluded that the first order mode provides a primary contribution to the dynamic response and an appropriate selection of frequency and bandwidth has remarkable effect on the structural response.

Finite Element Method

To analysis frame structures, presently there are two classical beam theory that is widely accepted and used in structural analysis namely, the Euler-Bernoulli beam theory and Timoshenko beam theory. For the Euler-Bernoulli beam, it is assumed that plane cross section perpendicular to the axis of the beam remain plane and perpendicular to the axis after deformation, it neglects effect of the shear force, while the Timoshenko beam theory the shear force effect is included, so the cross section is not a plane because it is warped after deformation [15]. In 1950 the classical linear theory for thin wall was first introduced by Vlasov and later extended to torsional-flexural stability problem [16]. Generally solution based on classical theories are limited to simple geometry and loading because solving governing differential equation is very difficult and can not found solutions when geometry , boundary condition or loading of problem are complex.

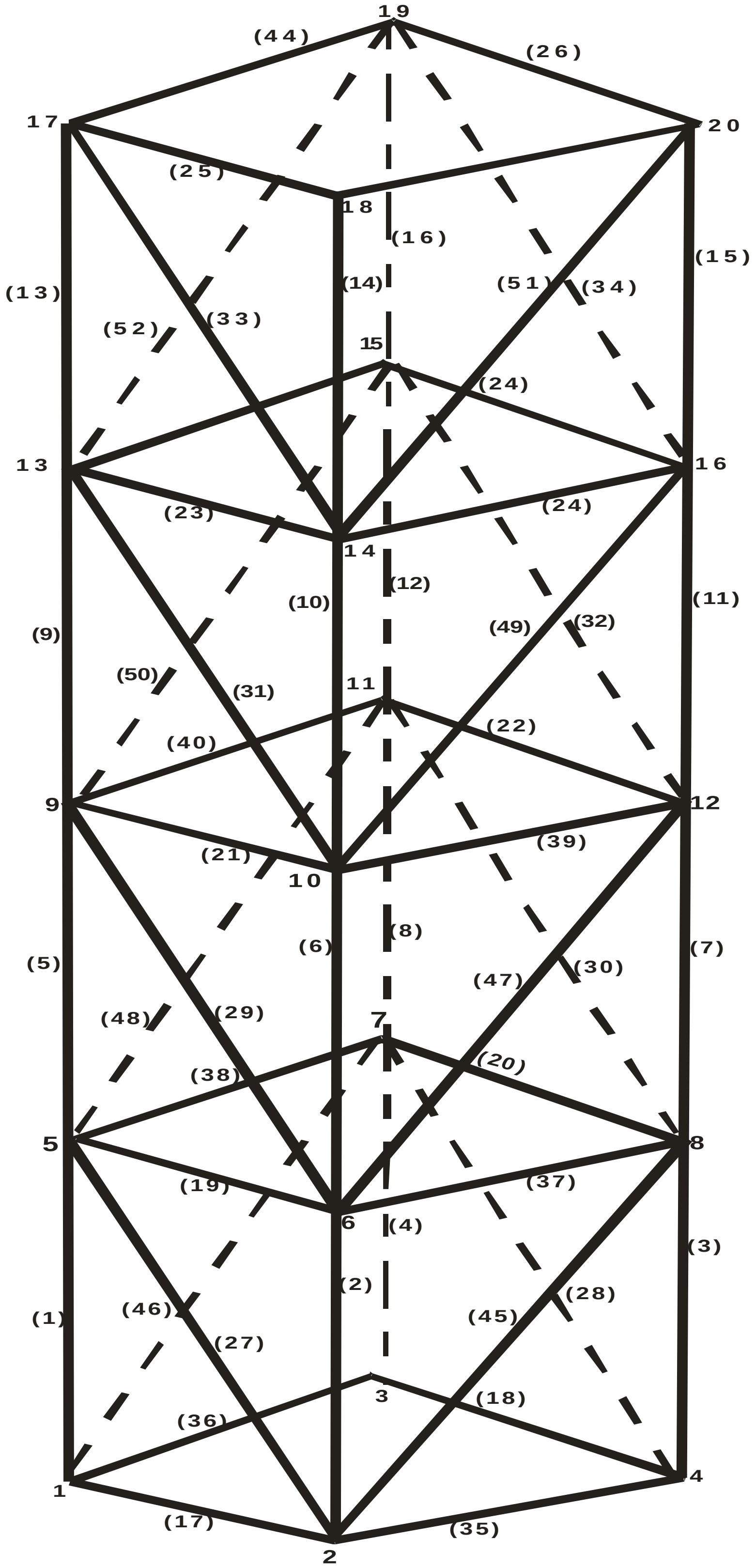

Figure 1: Model of Jack-Up Offshore Structure with more than Fifty Members

II. MATERIALS AND METHODS

Table 1: Statistical Analysis of Wave Spectrum which Resulted in Root Mean Square

Height Range(H)	Frequency (f)	$\frac{f}{\sum f}$	Mean Height(H_i)	H_{rmsi}
H_0-------H_1	f_1	$\frac{f_1}{\sum f}$	$H_{i1} = \frac{H_0 + H_1}{2}$	$\frac{f_1}{\sum f} \times H_{i1}^2$
H_0-------H_1	f_2	$\frac{f_2}{\sum f}$	$H_{i2} = \frac{H_1 + H_2}{2}$	$\frac{f_2}{\sum f} \times H_{i2}^2$
H_2-------H_3	f_3	$\frac{f_3}{\sum f}$	$H_{i3} = \frac{H_2 + H_3}{2}$	$\frac{f_3}{\sum f} \times H_{i3}^2$
H_3-------H_4	f_4	$\frac{f_4}{\sum f}$	$H_{i4} = \frac{H_3 + H_4}{2}$	$\frac{f_3}{\sum f} \times H_{i3}^2$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
H_{n-1}-------H_n	f_n	$\frac{f_n}{\sum f}$	$H_{in} = \frac{H_{n-1} + H_n}{2}$	$\frac{f_n}{\sum f} \times H_{in}^2$
	$\sum f$			$\sum H_{rmsi}$

2.1 Root Mean Square

$$H_{rms} = \sqrt{\sum H_{rmsi}} \tag{1}$$

2.2 Significant Wave Height

$$H_s = \sqrt{2} \times H_{rms} \tag{2}$$

H_s is the significant wave height

2.3 Maximum Wave Height

$$H_{max} = 1.86 \times H_s \tag{3}$$

H_{max} Maximum wave height

2.4 Wave Number

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

k The wave number

2.5 Wave Frequency

$$\omega = \sqrt{g \times k \times tanh(k \times d)} \tag{5}$$

ω The wave angular freguency

Calculate time t

$$t = \sqrt{\frac{2 \times \pi \times \lambda}{g}} \tag{6}$$

2.6 Wave Maximum Horizontal Velocity

$$U_{max} = \frac{H_{max} \times T \times g}{2 \times \lambda} \tag{7}$$

U_{max} The wave maximum horizontal velocity

2.7Keulegan-Carpenter Number

$$Kc = \frac{U_{max} \times T}{D} \tag{8}$$

Kc The Keulegan-Carpenter number

D The pile member diameter

2.8 Reynolds Number .

$$Re = \frac{U_{max} \times D}{\nu} \tag{9}$$

Re The Reynolds number

ν The kinematics viscosity of water

2.9Constant of Inertia Forces

$$A_1 = \frac{\pi \times D}{4 \times H_{max}} \tag{10}$$

A_1 The constant of inertia force

2.10 Constant of Drag Forces

$$A_2 = \frac{(2 \times k \times d) + (sinh(2 \times k \times d))}{16 \times sinh(k \times d)^2} \tag{11}$$

A_2 The constant of drag force

2.11 Constant of Inertia Moment about the Seabed

$$A_3 = \frac{\pi \times D \times [1 + (k \times d \times sinh(k \times d)) - cosh(k \times d)]}{4 \times H_{max} \times sinh(k \times d)} \tag{12}$$

A_3 The constant of inertia moment about the seabed

2.12 Constant of Drag Moment about the Seabed

$$A_4 = \frac{[(2 \times k^2 \times d^2) + (2 \times k \times d \times sinh(2 \times k \times d)) + 1 - cosh(2 \times k \times d)]}{64 \times sinh(k \times d)^2} \tag{13}$$

A_4 The constant of drag moment about the seabed

2.13 Inertia Wave Force

$$F_m = \frac{D \times \pi \times \rho \times {H_{max}}^2 \times \lambda}{T^2} \times [A_1 \times Cm \times sin(\theta)] \tag{14}$$

F_m The inertia wave force

ρ The sea water density

θThe wave phase angle in degrees

2.14 Drag Wave Force

$$F_d = \frac{D \times \pi \times \rho \times {H_{max}}^2 \times \lambda}{T^2} \times [(A_2 \times Cd \times |cos\,\theta| \times cos\,\theta)] \tag{15}$$

F_d The drag wave force

2.15 Total Wave Force

$$F_T = F_m + F_d = \frac{D \times \pi \times \rho \times {H_{max}}^2 \times \lambda}{T^2} \times [A_1 \times Cm \times sin\,\theta + (A_2 \times Cd \times |cos\,\theta| \times cos\,\theta)] \tag{16}$$

F_T The total wave force

2.16 Total Moment about the Seabed

$$M = \frac{D \times \pi \times \rho \times {H_{max}}^2 \times \lambda^2}{T^2} \times [A_3 \times Cm \times sin\,\theta + (A_4 \times Cd \times |cos\,\theta| \times cos\,\theta)] \tag{17}$$

2.17 Pile Members Forces

$$\theta = (k \times x) - (w \times t) \tag{18}$$

x The minimum and maximum value x- direction length

The instantaneous wave height is the additional height

$$z = \frac{H_{max}}{2} \times cos(\theta) \tag{19}$$

z The instantaneous wave height

Constant of inertia pile force

$$A_{11} = \frac{sinh\big(k \times (d + z)\big)}{2 \times k \times sinh(k \times d)} \tag{20}$$

A_{11} The constant of inertia pile force

Constant of drag pile force

$$A_{22} = \frac{\big[2 \times k \times (d + z) + sinh\big(2 \times d \times (d + z)\big)\big]}{32 \times sinh(k \times d)^2} \tag{21}$$

A_{22} The constant of drag pile force

Inertia pile member force

$$F_{mp} = Cm \times \rho \times \frac{\pi \times {D_0}^2}{4} \times H_{max} \times \omega^2 \times A_{11} \times sin(\theta) \quad (22)$$

F_{mp} The Inertia pile member force

Drag pile member force

$$F_{dp} = \frac{Cd \times \rho \times D_0 \times \omega^2 \times {H_{max}}^2}{k} A_{22} \times |cos(\theta)| \times cos(\theta) \quad (23)$$

F_{dp} The Drag pile member force

Total pile member force

$$F_{Tp} = F_{mp} + F_{dp} \quad (24)$$

F_{Tp} The Total pile member force

So at each of depth and x value specify on the input, the total pile force on the member would be calculated.

2.18 Horizontal y Bracing Members Forces

Calculate velocity constant

$$C = Cd \times \rho \times \frac{D_0}{2} \quad (25)$$

C The pile velocity constant

Calculate acceleration constant

$$K^a = Cm \times \rho \times \frac{\pi \times D_0}{4} \quad (26)$$

K^a The pile acceleration constant

For $x = 0 \; and \; x = X_{max}$

If $d_i < d$

Phase angle of water wave on horizontal member

$$\theta_H = (k \times x) - (w \times t) \quad (27)$$

θ_H The Phase angle of water wave on horizontal member

Instantaneous wave height on horizontal members

$$z_H = \frac{H_{max}}{2} \times cos(\theta_H) \quad (28)$$

z_H The Instantaneous wave height on horizontal members

Velocity in x-direction

$$V_x = \frac{\pi \times H_{max}}{T} \times \frac{cosh\left(k \times (d_i + z_H)\right)}{sinh(k \times d_i)} \times cos(\theta_H) \quad (29)$$

V_x The velocity in x-direction

d_i The sea water depth based on section under consideration

Velocity in z-direction

$$V_z = \frac{\pi \times H_{max}}{T} \times \frac{sinh\left(k \times (d_i + z_H)\right)}{sinh(k \times d_i)} \times sin(\theta_H) \quad (30)$$

V_z The velocity in z-direction

Acceleration in x-direction

$$a_x = \frac{2 \times \pi^2 \times H_{max}}{T^2} \times \frac{cosh\left(k \times (d_i + z_H)\right)}{sinh(k \times d_i)} \times sin(\theta_H) \quad (31)$$

a_x The acceleration in x-direction

Now, let solve for normal velocity in respect to each axis using below matrix equation

$$\begin{Bmatrix} V_{nx} \\ V_{ny} \\ V_{nz} \end{Bmatrix} = \begin{bmatrix} 1 - {C_x}^2 & -C_x \times C_y & -C_x \times C_z \\ -C_x \times C_y & 1 - {C_y}^2 & -C_y \times C_z \\ -C_x \times C_z & -C_y \times C_z & 1 - {C_z}^2 \end{bmatrix} \times \begin{Bmatrix} V_x \\ V_y \\ V_z \end{Bmatrix} \quad [17] \quad (32)$$

Co-ordinate in x-direction $C_x = 0$

Co-ordinate in y-direction $C_y = 1$

Co-ordinate in z-direction $C_z = 0$

V_{nx} The normal velocity in x-direction

V_{ny} The normal velocity in y-direction
V_{nz} The normal velocity in z-direction
From equation 3.35 values of $V_{nx}, V_{ny}, and\ V_{nz}$ are gotten
Velocity magnitude

$$|V_n| = \sqrt{V_x{}^2 + V_z{}^2} \tag{33}$$

$|V_n|$ The velocity magnitude
Now, let solve for normal acceleration in respect to each axis using below matrix equation, but since there is no velocity on the y-axis there is corresponding no acceleration on the y-axis.
So, $a_y = 0$

$$\begin{Bmatrix} a_{nx} \\ a_{ny} \\ a_{nz} \end{Bmatrix} = \begin{bmatrix} 1 - C_x{}^2 & -C_x \times C_y & -C_x \times C_z \\ -C_x \times C_y & 1 - C_y{}^2 & -C_y \times C_z \\ -C_x \times C_z & -C_y \times C_z & 1 - C_z{}^2 \end{bmatrix} \times \begin{Bmatrix} a_x \\ a_y \\ a_z \end{Bmatrix} \tag{34}$$

a_{nx} The normal acceleration in x-direction
a_{ny} The normal acceleration in y-direction
a_{nz} The normal acceleration in z-direction
From above equation values of $a_{nx}, a_{ny}, and\ a_{nz}$ are gotten
Total force per unit length on horizontal member bracing below waterline section

$$F_{hi} = (C \times |V_n| \times V_n) + (K^a \times a_x)\left(\frac{N}{m}\right) \tag{35}$$

F_{hi} Total force per unit length on horizontal member bracing below waterline section
Total force on horizontal member bracing below waterline section

$$F_H = F_{hi} \times Y_{max} \quad N \tag{36}$$

F_H Total force on horizontal member bracing below waterline section

2.19 Displacement at each nodal point on the Jack-up

$$\begin{Bmatrix} F_{xn} \\ F_{yn} \\ F_{zn} \\ F_{xn} \\ F_{yn} \\ F_{zn} \end{Bmatrix} = \frac{E \times A}{L} \times \begin{bmatrix} C_x{}^2 & C_x \times C_y & C_x \times C_z & -C_x{}^2 & -C_x \times C_y & -C_x \times C_z \\ C_x \times C_y & C_y{}^2 & C_y \times C_z & -C_x \times C_y & -C_y{}^2 & -C_y \times C_z \\ C_x \times C_z & C_y \times C_z & C_z{}^2 & -C_x \times C_z & -C_y \times C_z & -C_z{}^2 \\ -C_x{}^2 & -C_x \times C_y & -C_x \times C_z & C_x{}^2 & C_x \times C_y & C_x \times C_z \\ -C_x \times C_y & -C_y{}^2 & -C_y \times C_z & C_x \times C_y & C_y{}^2 & C_y \times C_z \\ -C_x \times C_z & -C_y \times C_z & -C_z{}^2 & C_x \times C_z & C_y \times C_z & C_z{}^2 \end{bmatrix} \times \begin{Bmatrix} \dot{x}_n \\ \dot{y}_n \\ \dot{z}_n \\ \dot{x}_n \\ \dot{y}_n \\ \dot{z}_n \end{Bmatrix} \tag{37}$$

2.20Stress on each Member on the Jack-up Offshore Structure
The stress on each member can be calculated using the general formula for stress calculation

$$\sigma_m = \frac{E}{L} \times \{C_x \quad C_y \quad C_z \quad -C_x \quad -C_y \quad -C_z\} \times \begin{Bmatrix} \dot{x}_n \\ \dot{y}_n \\ \dot{z}_n \\ \dot{x}_n \\ \dot{y}_n \\ \dot{z}_n \end{Bmatrix} \tag{38}$$

σ_m Stress of each member
The solution should use the scalar multiplication approach to resolve as shown below for each member stress

$$\sigma_m = \frac{E}{L} \times [(C_x \times \dot{x}_n) + (C_y \times \dot{y}_n) + (C_z \times \dot{z}_n) + (-C_x \times \dot{x}_n) + (-C_y \times \dot{y}_n) + (C_z \times \dot{z}_n)] \tag{39}$$

III. RESULT AND DISCUSSIONS

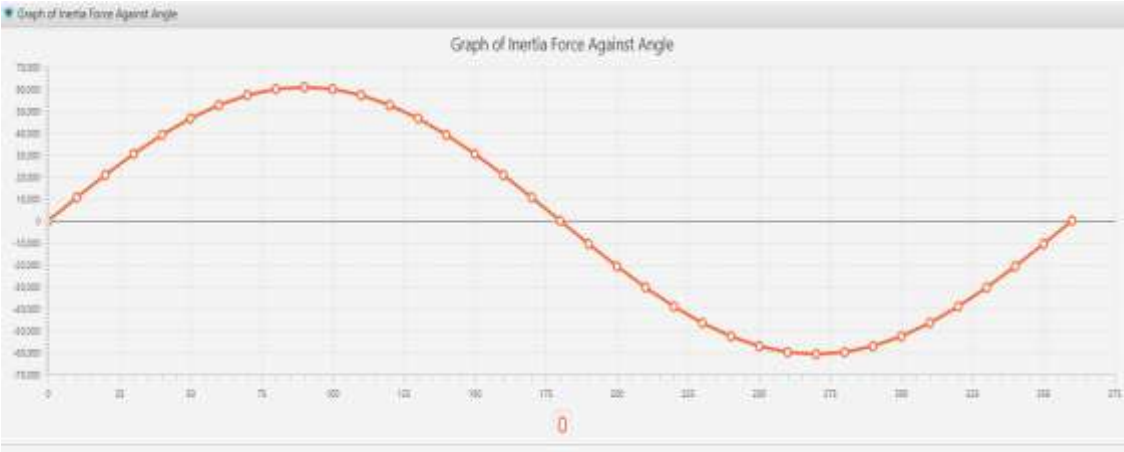

Figure 2:Plot of Inertia Wave Force against Wave Phase Angle

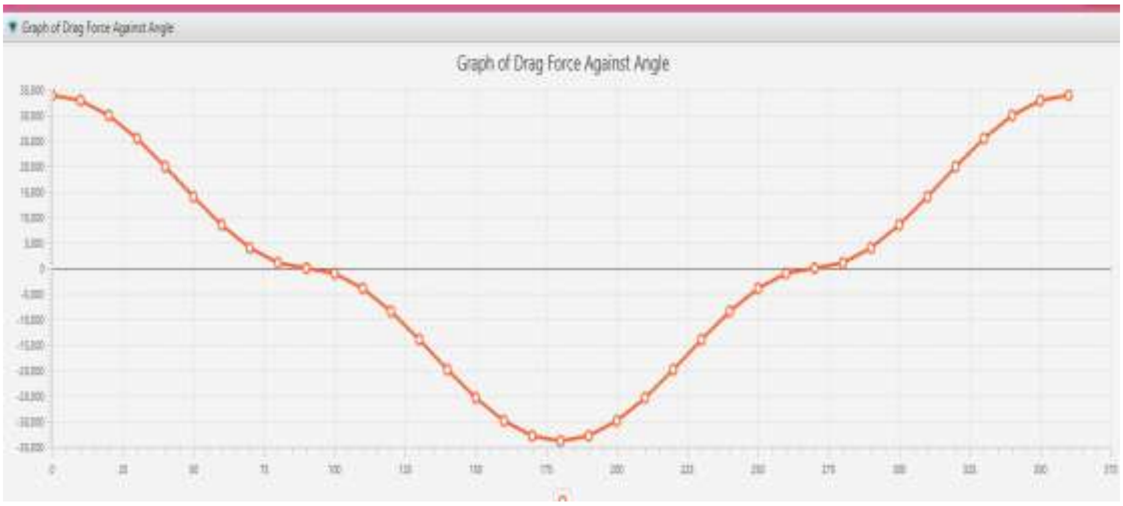

Figure 3: Plot of Drag Wave Force against Wave Phase Angle

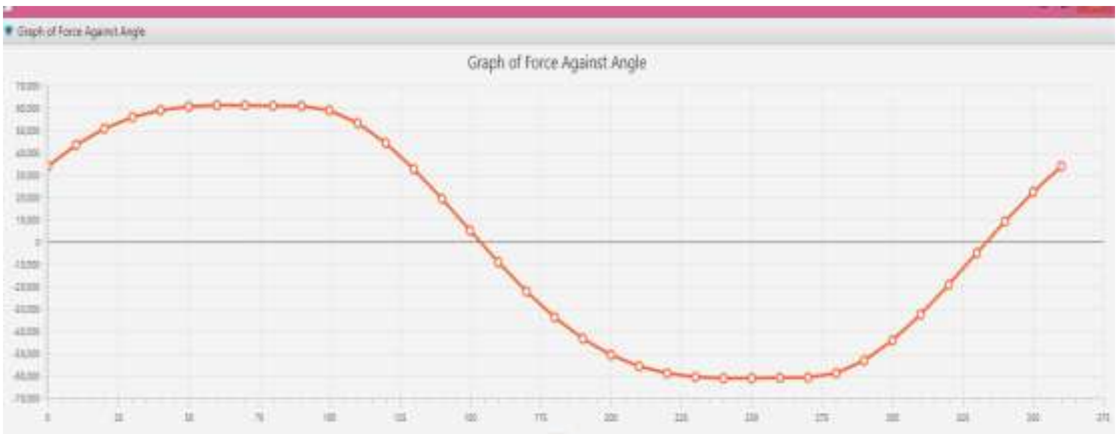

Figure 4:Plot of Total Wave Force against Wave Phase Angle

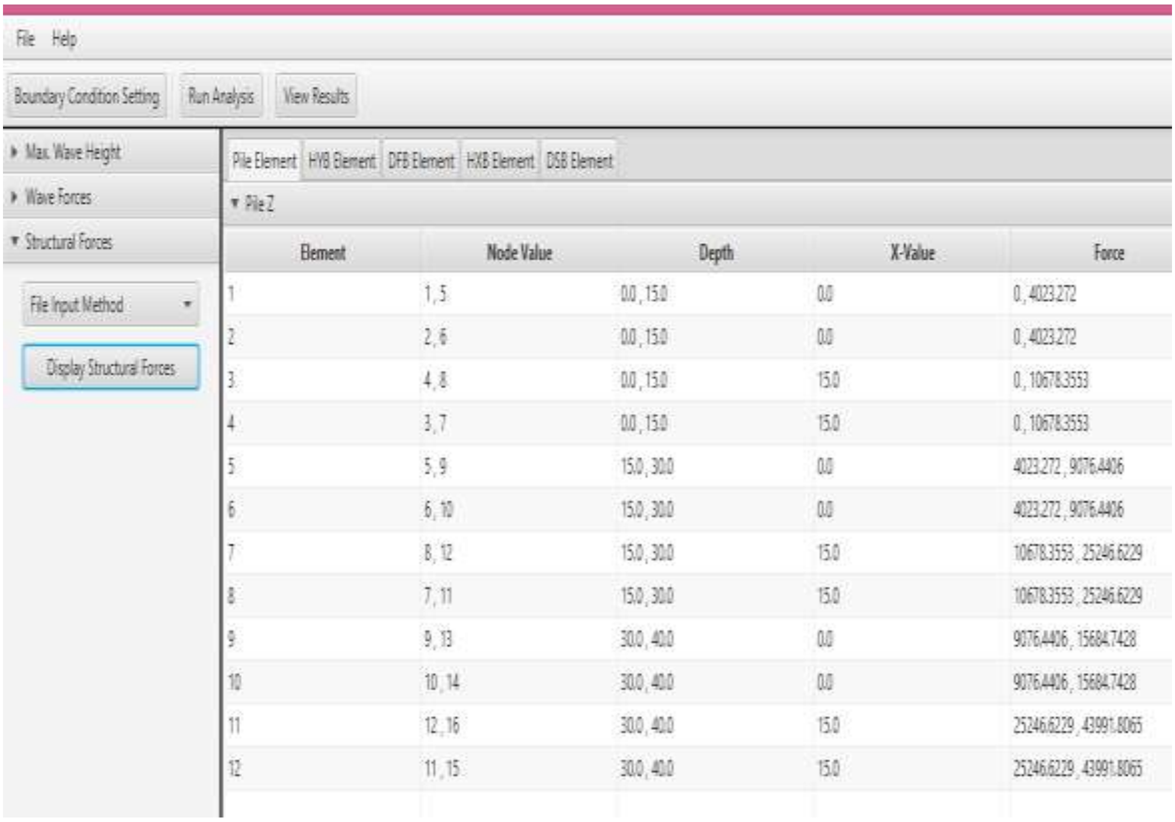

Figure 5: Pile Members Force Result from the Java Program

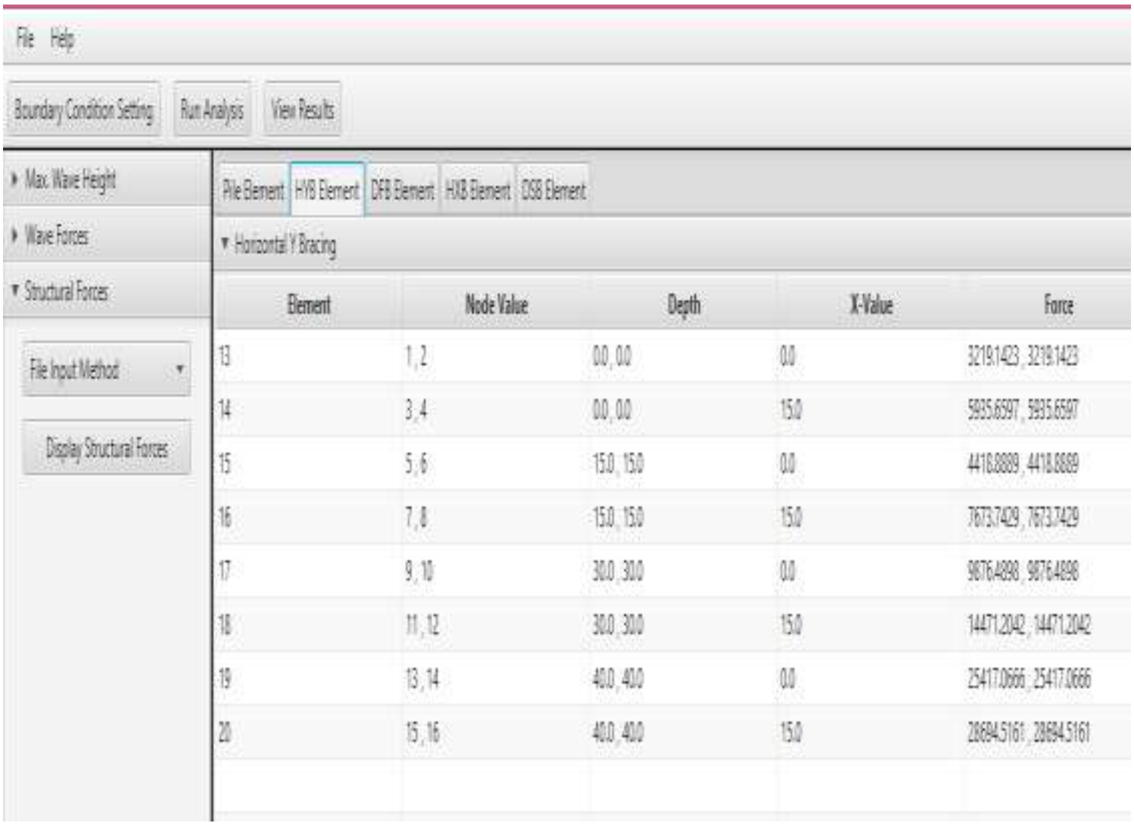

Figure 6: Horizontal ''y'' Members Bracing Force Result from the Java Program

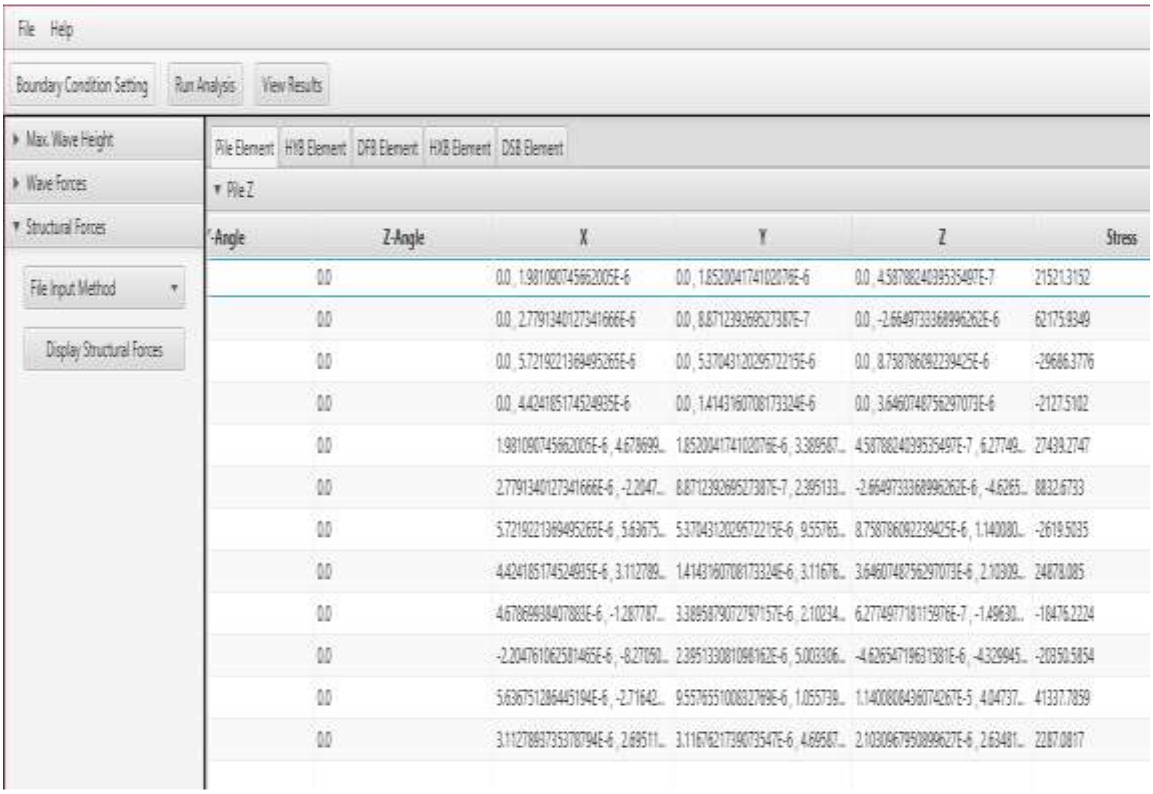

Figure 7: Pile Members Stress and Displacement from the Java Program

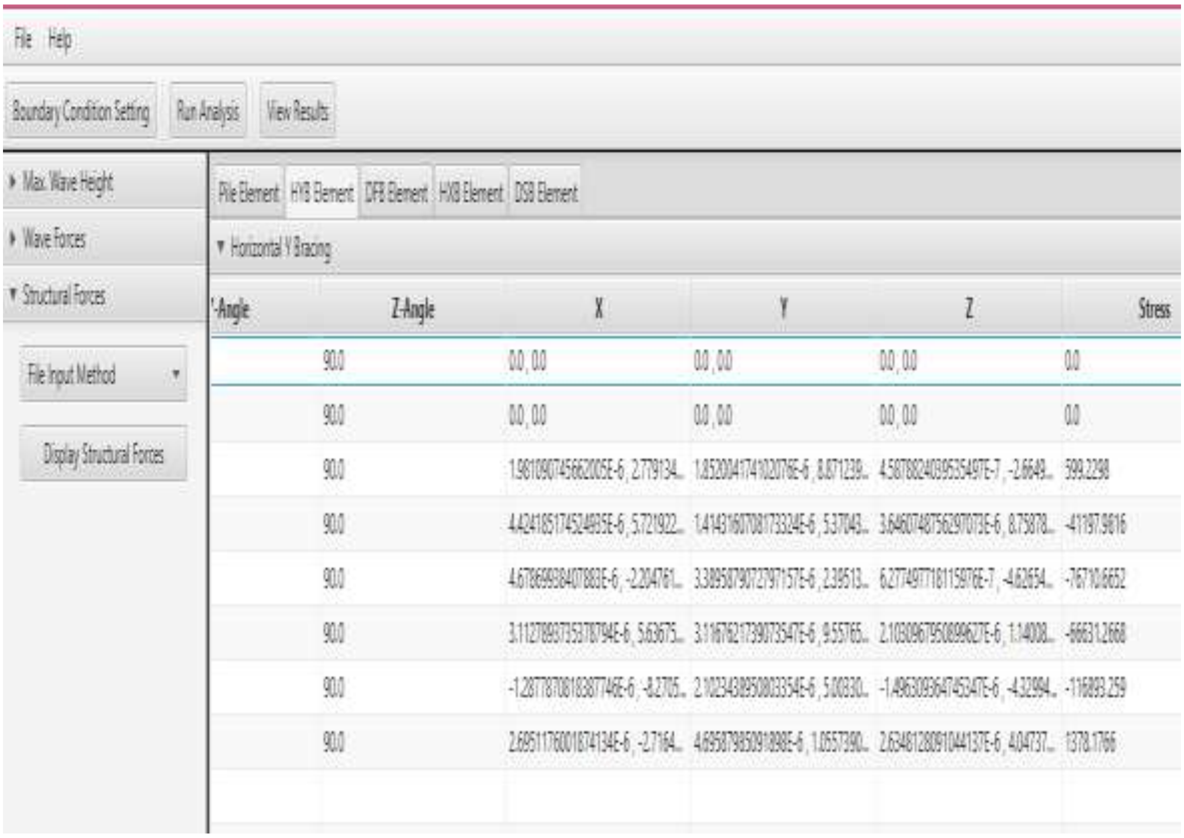

Figure 8: Horizontal ‘’y’’ Bracing Members Stress and Displacement from the Java Program

Figure 2 is graphs of inertia wave force against wave phase angle, while Figure 6 is the java program plot of the inertia wave force against wave phase angle, the graph start from the origin that is from zero to the maximum positive value of the inertia wave force at 90°, then move to zero again at 180° before it fall to maximum negative value of the inertia wave force at 270° and finally back to zero at 360°, this is line because the wave profile use for the inertia wave force contain $\sin\theta$ which when plot move from zero to positive maximum then to zero before it move to negative maximum then back to zero. Figure 3 is the java program plot of the drag wave force against wave phase angle, it was seen that the graph start from the maximum positive value of the drag wave force at 0°, then move to zero at 90° before it fall to maximum negative value of the drag wave force at 180°, the move to zero at 270°, before it finally rise to maximum positive value of the drag wave force at 360°,this is line because the wave profile use for the drag wave force contain $\cos\theta$ which when plot start from positive maximum to zero then it move to negative maximum then back to zero before it final rise to the positive maximum again. Figure 4 is the java program plot of the total wave force against wave phase angle, it was seen that the graph start from the origin with the value of the total wave force equal that of the drag wave force at $0^\circ$to the maximum positive value of the total wave force at 90°, then move to zero at 180° before it fall to maximum negative value of the total wave force at 270° and finally back to the positive value equal that of drag wave force at 360°, this is in line because the wave profile use for the total wave force contain $\sin\theta$and $\cos\theta$which when plot move from positive value to positive maximum value then to zero before it move to negative maximum value then back to positive value.

In other to get each member force, stress and the displacement at each nodal point of the structure an excel file input is created for pile members and other classes with the first column showing each member length with the exception of the diagonal front bracing members and the diagonal side bracing members that the length cannot be known except during calculation and the value of the length is replace by zero in both case while the second column show each member outer diameter follow by the third column which show each member inner diameter, then the fourth column which show each member angle with respect to x-axis co-ordinate while the fifth column show each member angle with respect to y-axis co-ordinate then follow by the sixth column which show each member angle in respect to z-axis co-ordinate also the seventh column show the first nodal point value number as name on the structure while the eight column show the second nodal point value number as name on the structure then the ninth column show the first water depth relative to the first node point of each members while the tenth column show the second water depth relative to the second node point of each members, then the eleventh column show the first value of x magnitude in relative to the first node point of each members while the twelfth column show the second value of x magnitude in relative to the second node point of each members.

By successful importing all the excel files created above, then each of members force is calculated by the java program and the result shown is classes, Figure 5 show pile members force from the java program with the force result on the fifth column, Figure 6 show horizontal y bracing members force from the java program with the force result on the fifth column. The stress on each member and the displacement is calculated as show in Figure 7 and Figure 8 from the java program, the displacement is based on the nodal value of each member and the degree of freedom that is each member has six displacement since it has two node value and at each of the node value has three degree of freedom, the degree of freedom simple imply direction which is x, y, and z in this case.

IV. CONCLUSIONS

From this research work I can conclude that the wave force result curves on the entire structure that is figure1, figure 2 and figure 3 produced by the software are in line with what is obtainable in practice for a regular wave, also since the force on each member from the software (java program) has the same results as Deo, M.C. text when the same structure was considered, it can be said that the software (java program) developed are in agreement with world standard practice when wave force on jack up members is been considered and regular wave is been adopted, lastly since all the member stress gotten from the software (java program) is far less than that of the global known stress limit for an iron material which is 90Mpa, it can be said that even with factor of safety the software (java program) developed is within agreement for practical purpose, while discussing the reason for java preferable over other programming language, mathematical model for jack up structure were given and the software was developed and ran to give impressive results.

ACKNOWLEDGEMENT

The Author would want to appreciate the assistance of the staff of the software laboratory of the Marine Engineering Department of Rivers State University.

REFERENCES

[1]. Veldman, .H & Lager, G. (1997). Offshore foundation for offshore studies Deift, Netherland.

[2]. Stiff, J. J., Sharples, B.P.M and Bowie, R.D. (1997). ‘’Jack-up classification past, present and future’’, proc6th international conference on jack-up platform design, construction and operation, City university, London.

[3]. Bennett, W.T. &Sharples, B.P.M. (1987). Jack-up legs to stand on mobileOffshore structures, Elsevier, London, page 1-32

[4]. Baerheim, M., Manschot, D. &Nortvedt, T. (1997). Proc of 6th international Conference jack-up platform design, construction and operation, City University London.

[5]. Morrison, J.R., O’Brien, M.P., Johnson, J.W. &Schaaf, S.A. (1950). Force exerted by surface waves on piles,petroleum transactions, AIME Volume 189, Page 149-157.

[6]. Verley, R.L.P. (1982). Simple model of vortex induced forces in waves and Oscillating currents.

[7]. Sarpkaya, T. &Issacson, M. (1981). Mechanics of wave induced forces on offshoreStructure, Van Nostrand Reinhold.

[8]. Almar-Naess, A. (1985). Fatigue handbook: offshore steel structures, Trondheim

[9]. Dover, W.D. &MadhavaRao, A.G. (1996). Fatigue in offshore structures Volume 1.Balkema, Rotterdam/Brookfield.

[10]. Etube, L.S., Brennan, F.F. & Dover, W.D. (1999). Modeling of jack-upResponse for fatigue under simulated service conditions. Marine Structures, Page 327-348.

[11]. Ramachandra, M. D.S., Madhava, R. A.G. &Santhakumar, A.R. (1994). Corrosion fatigue of stiffened offshore steel tubular joints journal of StructuralEngineering, page 1991-2080.

[12]. Gandhi, .P, Raghava&Ramachandra Murthy, D.S. (2000). Fatigue behaviour of internallyring-stiffened welded steel tubular joints, Journal of Structural Engineering, page 809-815.

[13]. Vugts, J.H. (2005). ‘’Damage assessments and the influence of wave directionality’’, Applied ocean research, page 173-185.

[14]. Shunfeng, G Yong He &Weiliang Jin, (2007). Fatigue life reliability Analysis of dynamic response spectrum for offshore platform, Structures Journal of Zhejiang University.page 12-17.

[15]. Ditlevsen, O. (1979) Narrow reliability bounds for structural system, journals of Structural mechanic page 42-61.

[16]. Zienkiewicz, O.C. & Taylor, R.L. (2000). Finite element method solid mechanics, Vol. 2 Butter worth-Heinemann, oxford.

[17]. Deo, M.C. (2013), Wave and Structure Civil Engineering Indian Institute ofTechnology Bombay Powai Mumbai.

Olusegun Samuel Dare" Wave Forces, Displacements and Stresses on Offshore Structures (Using Africa Waters)" American Journal of Engineering Research (AJER), vol.8, no.02, 2019, pp.271-282