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Analysing the Effect of Deep and Shallow Water Depth on the Motion of a Floating Offshore Pontoon

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Abstract: This research is intended to analyse the effect of seawater depth on sea seakeeping analyses. So it's crucial to understand ship motion on waves. As a result, precise hydrodynamic/motion force forecasts in constrained waterways is essential. The goal of this research is to look into how water depth affects ship heave motion. It is quite important to understand how floating offshore pontoon behave in deep and shallow water due to renewed interest of Nigeria Energy company in offshore exploration. Therefore accurate prediction of heave force will be analysed in this research. This study uses the linear wave theorem, Response Amplitude Operator, to estimate the hydrodynamic forces that occur in deep and shallow water. Bonny Island, Nigeria tidal wave using a depth of 500 and 5 meters. The results obtained in this research reveal a rapid decrease in heave response displacement from 0 to 0.2 wave frequency. According to the data, FOP operation is optimum at 500m seawater depth, where the effect of heave motion is less noticeable as shown in this research as at when compared to a 5m depth.

Keywords: Chromium, Nickel, Phytoremediation, Heavy metals, Maize, Soil, Nigeria.

1. Introduction

1.0 Introduction

The development of shallow and deepwater fields has piqued the interest of researchers in the offshore industry in recent years. In these situations, the Floating Offshore Pontoon (FOP) is a potential choice as most energy company in Nigeria favours offshore exploration. To maintain the platform in place, the FOP usually uses a system of mooring lines anchored to the bottom. The consequences of this dynamic behaviour due to external influences are generally minimal in shallow seas [1]. This system can be accurately predicted via computationally affordable quasi-static uncoupled analysis or full-scale model testing [2].

However, at this depths, the dynamic has a considerable impact on the system's behaviour. As a result, traditional and simplified methods for predicting shallow water systems may be impractical or erroneous [3]. For heave and pitch motions, as well as vertical and horizontal wave-induced stresses, comparisons with experimental data have shown a satisfactory consistency over time, however, the correctness of strip theories for horizontal motions (sway, yaw, roll) is significantly more unclear [4].

Various approaches for predicting wave-induced ship motions and loads have been developed during the last several decades, as outlined by the Committee on Loads of the International Ship and Offshore Structure Congress [5]. The impact of water depth on a floating platform and its mooring system is investigated further in this research. As an example, a pontoon-shaped storage facility is used. The fully coupled dynamic analysis method is used, with the effect of water depths being the main focus.

As a result, computer-assisted software is used for this research. This research looks into the FOP's motion behaviour with regards to its heave motion. The FOP model shown in fig 1 is used in this study and analysing how this FOP will react in deep and shallow water will be analysed. This study show how a FOP will behave in deep (500m) and shallow (5m) depth using gulf of Guinea wave characteristics.

Fig 1: Floating Offshore Pontoon [6]

2.0 Research Gap

Castiglione [3] studied the seakeeping behaviour of a catamaran. Papanikolaou [7] published a study that focused on the hydrodynamic module. Kukner and Sarioz [8] suggested a forward/inverse technique for seakeeping criteria to see if existing designs could be improved. Later on, Fonseca and Guedes [9] used a time-domain strip theory to ship hydrodynamics.

Analysing heave response amplitude operators (RAOs) and accelerations, as well as avoiding extreme effects like slamming and deck dampness, were among the objectives. In any case, given the benefits of strip theories in terms of low computational effort, making them ideal for optimization procedures, particularly during the early stages of design and within academic contexts, it appears clear that there is still room for improvement in terms of its use to predict the motion behaviour of FOP due to water depth.

3.0 Methodology

Equations 1 to 18 will be taken into account when analysing the heave response of the FOP and its accompanying structures. Heave stiffness, will be determined [10]. All values used for computational analyses are shown in matlab code section of this research. These should include forces acting horizontally against the pontoon owing to waves; forces acting vertically due to self-weight and hull structures carried by the buoyancy; and forces acting horizontally due to self-weight and hull structures carried by the buoyancy. The area, mass and density of water will be used to calculate heave stiffness as shown in equation 3.

$$Aw = l * b \qquad (1)$$

Where
Aw= water plane area
l = length of the pontoon
b= beam of the pontoon

$$M = rho * l * b * d \qquad (2)$$

M= mass of the pontoon
rho = density of the sea water
d = draft of the pontoon

$$Ke = rho * g * Aw \qquad (3)$$

Ke = heave stiffness
g= acceleration due to gravity

3.1 Linear Wave Theory

This research will assume that our fluid has a uniform density, is perfect, and is incompressible. As a result, the continuity equation is straightforward. This, on the other hand, necessitates a response. The vorticity v is a property linked with the fluid constituents, as we recall from the theory of an ideal and homogeneous fluid. The fluid action propels it forward. This means that if a fluid element had zero vorticity at the start, it will continue to have zero vorticity. The ability of a wave to carry information, energy, and momentum across long distances without transporting matter is its most important property.

$$\nabla * v = 0 \qquad (4)$$

3.2 Deep water analysis

Concerning the wavelength, the FOP depicted in fig1 is stated to function in deep water when the water depth becomes considerable. As a result, the presence of a bottom influences the wave analysis of the deep depth can be calculated using equation 5. The wave analysis of the intermediate depth be calculated as stated in equation (6). As a result, compared to the general situation, the phrases describing the intermediate depth can be simplified.

$$w^2 = kg \qquad (5)$$

$$w^2 = k^2 gd \qquad (6)$$

Although the equation is only true for linear wave theory, it turns out that these reduced equations are excellent approximations when applied to other fields. In response, as a result, we can deduce that the depth of deep-sea waves is determined by the wave period and gravity acceleration [11]. It's worth noting that the uniform velocity and acceleration are both expressed in equation (6).

$$\frac{du}{dt} = \frac{2\Pi^2 H}{kT^2 d} e^{kz} \sin(kx - wt) \qquad (6)$$

3.2.1 Wave exciting force

The wave exiting force developed from the wave height and period can be analysed using (7) to (18)

$$\zeta^* = \zeta_a e^{-kD} \cos(\theta) \quad (7)$$

Where

ζ^* = Wave elevation

ζ_a (a) = Wave amplitude (1m)

K = Wave number (0.010)

D = Water depth (500)

3.2.2 Wave motion in heave

The motion effect of wave on the FOP in heave is shown in (8), this was used to analyse the wave effect as it affects the FOP at different water depth and wave position

$$F_{\omega 3} = (M + A_{33})\ddot{Z} + B_{33}\dot{Z} + C_{33}Z \quad (8)$$

Calculation of the heave added mass (A_{33})

$$A_{33} = C_a \left[\rho \frac{\pi}{2}\left(\frac{B}{2}\right)^2\right] L \quad (9)$$

Where

Ca= Constant

B = Vessel breadth

L = Length of the vessel

Calculation of the heave potential damping coefficient (B_{33})

$$B_{33} = 2\sqrt{C_{33}(M + A_{33})} \quad (10)$$

Calculation of the heave restoring coefficient (C_{33})

$$C_{33} = \rho g B L \quad (11)$$

Calculation of the mass of the vessel

$$M = \rho A_\omega L C_B \quad (12)$$

Where

A_ω = Vessel water plane area

D = Vessel draft

C_B = Block coefficient

Calculation of heave amplitude for consideration of a simple harmonic motion

$$Z_a = \frac{F_{a3}}{\sqrt{[C_{33} - M\omega^2]^2 + (B_{33})^2}} \quad (13)$$

Where

Z_a = Heave amplitude

Calculation of heave velocity ($\dot{Z}$)

$$\dot{Z} = -Z_a \omega \sin\theta \quad (14)$$

Calculation of heave acceleration

$$\ddot{Z} = -Z_a \omega^2 \cos\theta \quad (15)$$

3.2.3 Heave RAO and spectral

The heave RAO and its spectral on the FOP were analysed using (9) to (11), this enabled us to ascertain the response of the FOP

$$RAO_3 = \frac{Z_a}{\zeta_a} \quad (16)$$

Where

Z_a = Heave amplitude

ζ_a = Wave amplitude

Calculation of heave spectral response is analysed in equation (10)

$$\mathcal{S}_{(\omega)} = A\omega^{-p} e^{(-B\omega - q)} \quad (17)$$

Where

$\mathcal{S}_{(\omega)}$ = Wave spectral

$$A = \frac{124 H_s^2}{T_z^4}$$

$$B = \frac{496}{T_z^4}$$

H_s= Significant wave height (2m)

T_z= Wave zero up-crossing period (14.29s)

ω= Wave frequency

Calculation of heave spectrum $\mathcal{S}_{(\omega 3)}$

$$\mathcal{S}_{(\omega 3)} = \left|\frac{Z_a}{\zeta_a}(\omega)\right|^2 . \mathcal{S}_{(\omega)} \quad (18)$$

[12] [13] [14]

4.0 Results and Discussion

The influence of water depth on FOP motion is calculated using Matlab codes. The heave force exerted on the vessel at various water depths will be analysed. To assess heave response, spectrum analysis, heave response spectrum, and displacement, the phase shift was examined. Also calculated are the heave and hydrodynamic forces operating on the FOP. This research is intended to show if ocean depth will affect FOP.

4.1 Heave Response displacement

Fig 2 and 3 show the heave motion response displacement at various wave frequencies using a depth of 500 and 5m as a case study for deep and shallow water. As the wave frequency rises from 0 to 0.2, the heave response displacement decreases. It was also observed that the heave response in shallow water was higher 0.0006m. The difference between the two responses is quite minimal as shown by this result. The results shows a similar trend from frequency 0.4 to 2. With minimal heave response as shown in this result. The FOP will operate optimally in both conditions as the heave response is quite low. Higher heave response if observed will cause sea sickness and obstruct vessel operations.

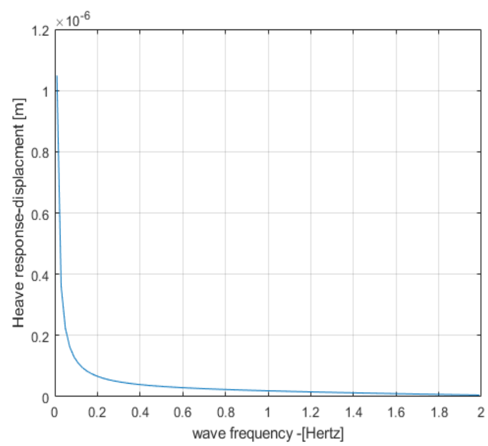

Fig 2: Heave Response Displacement of the FOP at Deep Water

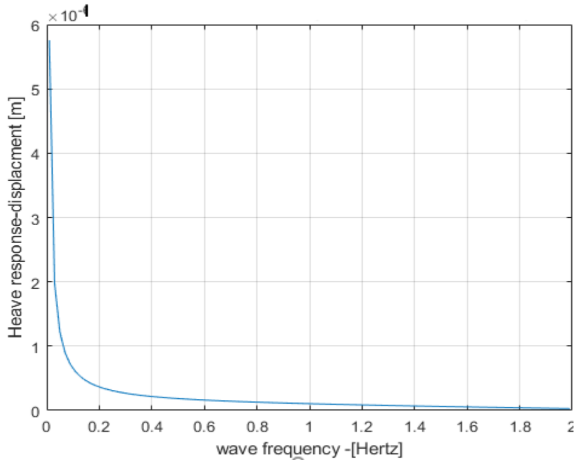

Fig 3: Heave Response Displacement of the FOP at shallow Water

4.2 Heave Spectrum

The heave response spectrum of the deep and shallow water increases rapidly from 0.4 to 0.6 wave frequency, as illustrated in fig 4 and 5. From 0 to 0.4 of the wave frequency, the heave response displacement tends to zero. From 0.6 to 2 of the wave frequency, the heave response also tends to zero. The shallow water heave spectrum observed in fig 5 is greater when compared to that of the deep water. This result shown has been able to show how a FOP will behave in shallow and deep water.

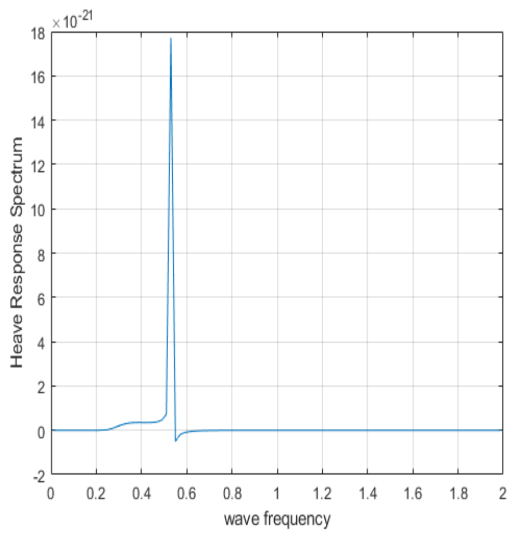

Fig 4: Heave Response Spectrum of the FOP in Deep Water

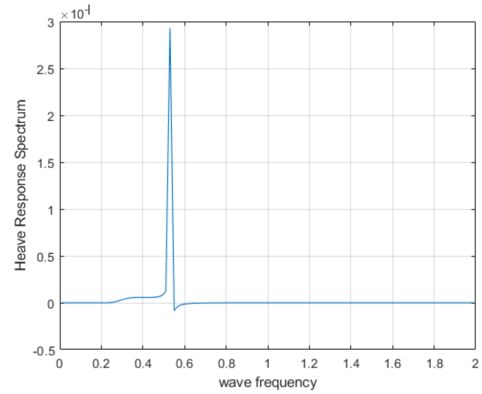

Fig 5: Heave Response Spectrum of the FOP in Shallow Water

As shown in figs 6 and 7, the encounter spectrum in heave motion was analysed at different wave frequencies (0 to 2) and at sea depths of 500 and 5m. The heave response rises quickly from 0.5 to 0.65 of the encounter frequency of the result. It can be shown that the encounter spectrum in deep and shallow water is the same. According to the findings, FOP will be fully operational in both deep and shallow water with regards to the encounter spectrum shown in this research.

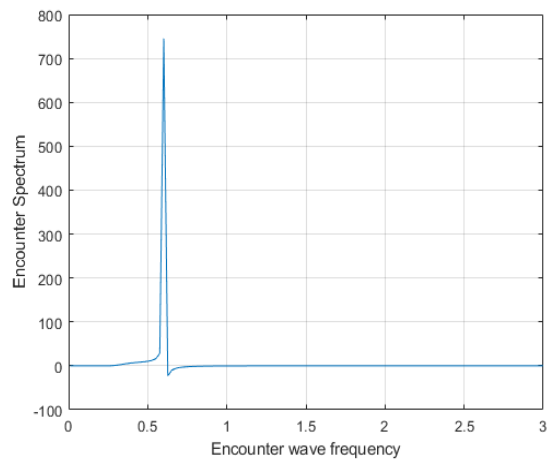

Fig 6: Encounter Spectrum of the FOP in Deep Water

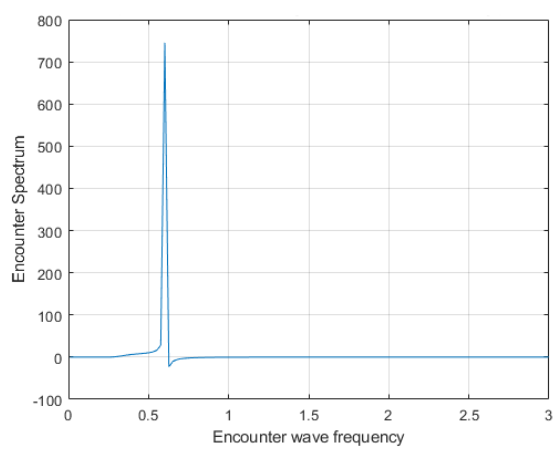

Fig 7: Encounter Spectrum of the FOP in Shallow Water

5.0 Conclusion

The comfort of the crew members on board FOP, as well as the seaworthiness of the vessel throughout its operational life cycle, is critical not only to the vessel owner, but also to the environment and the facility's safe performance. This study examines the simulations of water depths in heave motion, creating mathematical model equations, and analysing the effects of deep and shallow water when applied to a FOP and its design parameters. As a result, the FOP will operate optimally in deep and shallow waters as shown in results presented in this research. Heave motion experienced by the FOP will be relatively easy to manage due to low encounter spectrum experienced. The deep and shallow water analysis revealed that the FOP will operate optimally in both region. However, the difference isn't significant, and the FOP can be effective in both deep and shallow water environments.

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MATLAB CODE INPUTS

```
rho = 1025; % density of the sea water
g= 9.81; % acceleration due to gravity
l =40;% length of the pontoon
b= 4.56; % beam of the pontoon
d = 1.45;% depth of the pontoon
```

computation of wave kinematics

```
wave_amp =1.123; % wave amplitude
d = 5, 500M ;% shallow and deep water depth
w = 0.01:0.02:2; % [0,2] wave frequency
for i=1:length(w)
```

```
t = 12; % time
v =5;% velocity of the pontoon
    mu =120 ;% wave heading,120 is a qaurtering wave,0 following wave,180 head wave
    T = 12; % wave period p=5;
    q=4;
```