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RESEARCH ARTICLE

HORIZONTAL LOAD INDUCED DISPLACEMENT OF OFFSHORE FOUNDATION IN THE NIGER DELTA

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ABSTRACT

Horizontal displacement, u_{h1} of foundation on clay in the offshore Niger Delta has been attempted based on wave load simulation. Horizontal forces were evaluated from the impact of varying wave heights on circular piles of 1.0 to 2.0m diameter using available wave height records. Predictive lateral displacement under induced horizontal forces were analysed for varying Poisson ratio,μ foundation breadth, B and the ratio of horizontal force to breadth ratio(F/B). The results revealed that u_{h1} reduces with foundation breadth, Poisson ratio, and F/B ratio, while dimensionless plot of ratio of horizontal force to undrained shear strength, foundation breadth and lateral displacement versus Poisson ratio showed that at $\mu=0.5$, both methods of modified Bell and modified Gerrard and Harrison converge. Generally, higher lateral displacement occur using modified Gerrard and Harrison method at lower values of μ.

INTRODUCTION

The increasing level of oil and gas exploration and production activities in the Niger Delta offshore environment calls for further understanding on offshore foundation performance to gravity and environmental loading. Environmental loading are generally wave and wind induced generating horizontal forces and moments while gravity loads are due to self weight of the structure. These loads are subsequently transferred to the offshore foundation generating lateral (u_h), rotational (θ_m) and vertical (u_v) displacement. Evaluation of these displacements is very important in assessing the overall stability of the structure. Horizontal forces are evaluated for varying pile diameters and wave heights using Morrison equation, adopting the linear wave theory of Airy (1845). Horizontal displacement of offshore foundation on clay subjected to varying horizontal forces, foundation breadth and Poisson ratio were evaluated from horizontal wave forces impacting on circular piles of 1.0 to 2.0m diameters. This paper attempts to present predictive models on horizontal force-induced displacement of offshore foundation on clay in the Niger Delta.

MATERIALS AND METHODS

Wave Characteristics

The wave characteristics; wave height, wave period were deduced from relevant meteorological and oceanographic studies reported by Santala (2002), Cooper (2004) and Offshore Report (2005), while wave celerity, c, and wave length, L, were evaluated for conditions of shallow water waves (Sorenson, 2006).

Hydrodynamic Coefficients

Inertia coefficients, $C_{M,}$ and drag coefficient, $C_{D,}$ which depends on Reynold's number, Re, generally lie in the range of 0.8 to 2.0 [Haritos, 2007] and were obtained from standard charts. The dimensionless parameters for maximum drag force, $K_{DM,}$ and inertia force, K_{im}, maximum drag moment, $S_{DM,}$ and maximum inertia moment, $S_{im,}$ were also obtained from standard charts.

Hydrodynamic Forces

The total instantaneous hydrodynamic force, F, on a submerged structure per elemental length ds of the cylinder is obtained from;

$$F = \frac{C_d}{2}\rho D^2 + C_m\rho\left(\frac{\pi D^2}{4}\right)\frac{2\pi^2 H}{T^2}\left[\frac{\cosh k(d+z)}{\sinh kd}\right]\sin(kx - \omega t) \quad (1)$$

While the maximum horizontal force is obtained by summing both the drag force and inertia force as follows:

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$$F = \frac{C_d}{2}\gamma D H^2 K_{Dm} + C_m \gamma \pi \frac{D^2}{4} H K_{im} \quad (2)$$

where F= horizontal force, γ = unit weight of water, D= pile diameter and H = wave height. The horizontal forces were subsequently computed for varying pile diameters (1.0-2.0m) and wave heights.

Foundation displacement

Bell (1991) quoted works of Poulos and Davis (1974) and Bycroft (1956) regarding relationship between horizontal displacement and horizontal force given by the expression;

$$U_h = \left[\frac{7-8\mu}{32GR(1-\mu)}\right]F \quad (3)$$

while Gerrard and Harrison (1970) expression is given by;

$$U_h = \left[\frac{2-\mu}{8GR}\right]F \quad (4)$$

In this study, Equations (3) and (4) are modified with Shear modulus, G, substituted with the equivalent undrained shear strength, s_u, value while foundation radius, R, is substituted with equivalent foundation breadth, B. Substituting values of G = 39s_u (SNAME,1994), and $R = B/\sqrt{\pi}$ into Equation (3) gives the following;

$$U_{h1} = \left[\frac{(7-8\mu)\sqrt{\pi}}{1248 s_u B(1-\mu)}\right]F \quad (5)$$

Similarly, Equation (4) is modified to give;

$$U_{h1} = \left[\frac{(2-\mu)\sqrt{\pi}}{312 s_u B}\right]F \quad (6)$$

Here, values of hydrodynamic force, F, were generated from Equation (2), while horizontal displacement, u_{h1}, is obtained for varying horizontal force, F, foundation breadth, B, undrained shear strength, s_u, and μ varying from 0-0.5. Besides, s_u, values used reflects the foundation depth to breadth (D_f/B) ratio. Predictive relationship between u_{h1} versus μ, for varying F/B ratios and between μ versus F/s_uBu_{h1} was then investigated.

RESULTS AND DISCUSSION

Wave Characteristics

The meteorological and oceanographic data from the offshore Niger Delta were analysed and a maximum directional wave height, H_{max} of approximately 7.0 m, mean wave period of 17 sec and average wind speed of 14.1m/s were obtained.

Hydrodynamic Coefficients

Hydrodynamic coefficients, C_D, and C_M, assume a constant value of 0.7 and 1.5 respectively for wave heights varying from 3.0 – 12.0m, pile diameter of 1.0 – 2.0m, wind speed, u of 12 m/s and kinematic viscosity, υ of 9.5×10^{-7} m^2/s. The dimensionless parameters of inertia and drag forces (K_{im} and K_{DM}) assume constant values for a given wave height on pile diameter range of 1.0 – 2.0m. These parameters also reduce with wave height. Generally, for a given wave height, K_{im} assumes lower values compared to K_{DM}. A similar trend is also observed between S_{im} and S_{DM}.

Foundation Displacement on Rough Base

Modified Bell's Method

Horizontal displacement, U_{h1} reduces with increasing Poisson ratio, μ for a given foundation breadth, B, but it reduces with increasing B when μ is constant. A typical variation of horizontal displacement versus Poisson ratio (Figure 1) with varying F/B ratio clearly demonstrates increase in U_{h1} as F/B ratio increases.

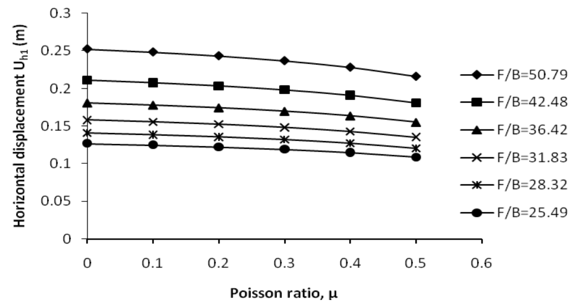

Fig. 1: Typical Horizontal force - horizontal displacement (modified Bell)

Modified Gerrard and Harrison Method

For a given horizontal force, wave height and foundation breadth B, U_{h1} reduce with increasing Poisson ratio, but it increases with increase in F/B ratio as shown in Figure 2. Generally, higher U_{h1} values are obtained as against those obtained in modified Bell's method.

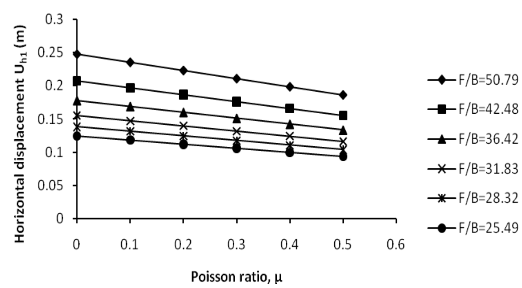

Fig. 2: Typical Horizontal force and Horizontal displacement (modified Gerrard and Harrison)

Comparison of modified Bell and modified Gerrard and Harrison Methods

This is shown (Figure 3) in the dimensionless plot of F/s_uBU_{h1} versus Poisson ratio, where at μ =0, F/s_uBU_{h1} values are approximately 88 and 100 for modified Gerrard and Harrison, and modified Bell's methods respectively. With increasing μ, both methods gradually converge at μ = 0.5, given a value of F/s_uBU_{h1} =117. Hence, the modified Gerrard and Harrison approach gives more conservative values of horizontal force as against those of modified Bell under the range of μ. The following predictive models are generated using either modified Bell or modified Gerrard and Harrison approaches respectively;

$F/s_uBU_{h1} = 90.01\mu^3 - 13.11\mu^2 + 17.57\mu + 100.5$ (7)

$F/s_uBU_{h1} = 33.58\mu^2 + 41.64\mu + 88.05$ (8)

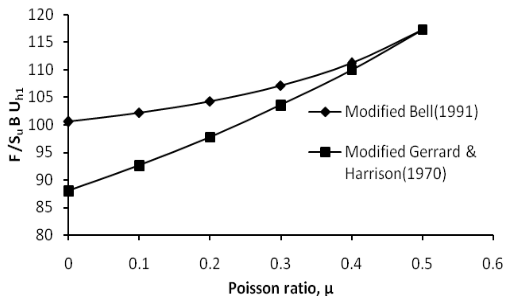

Fig. 3: Horizontal loading of Foundation

Conclusion

Based on this study, the following conclusions can be drawn;

i. Horizontal displacement, $U_{h1,}$ reduces with increasing Poisson ratio, but increases with increase in F/B ratio for a given horizontal force, wave height and foundation breadth.
ii. Generally, higher U_{h1} values are obtained in modified Gerrard and Harrison's method as against those obtained in modified Bell's method.
iii. For saturated clays, horizontal displacement attain same magnitude using either modified Bell or modified Gerrard and Harrison's method.
iv. The generated models can be used for preliminary design of horizontal load induced displacement of offshore foundation in the Niger Delta.

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