IJET International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 8, August, 2012

Prediction of Offshore Foundation Performance under Combined Horizontal-Moment loading in the Niger Delta of Nigeria

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ABSTRACT

The performance of offshore foundation with varying area, A, on clay in the Niger Delta subjected to combined horizontal – moment load has been studied. Undrained shear strength, s_u, of soil were evaluated from triaxial test results of offshore soil samples. Horizontal forces were evaluated from the impact of varying wave heights on circular piles from which moment loads, M, were subsequently evaluated. Under pure moment loading, the maximum moment , M_u, ranged from M of 0.997M_u to 1.00M_u ,but under combined loading, the maximum moment, M of 1.085M_u coincided with a horizontal load ,H, of 0.56As_u for ratio of foundation depth to breadth less than one (D_f /B<1). For cases of D_f/B>1.0, it is noticed that at zero horizontal load, the ratio of moment to maximum moment is equal to one ((M/M_u=1) irrespective of the foundation size. Under combined loading, the maximum moment capacity occurred at M of 1.0886 M_u and it coincided with a horizontal load, H, of 0.492As_u.

Keywords: *Wave height. Circular piles. Undrained shear strength.*

1. INTRODUCTION

The oil exploration and exploitation activities are carried out on offshore structures whose foundations are impacted upon by gravity and environmental loads. Gravity loads are due to the self weight of the structure while environmental loads are wave induced, giving rise to vertical, horizontal and moment loading that are subsequently transferred to the foundation. The foundation response to these loads may be assessed under the impact of single loading; vertical, horizontal or moment but generally, offshore structures are being impacted upon by varying degree of combined loading. Several studies on foundations subjected to combined loading have been reported by scholars including Bell (1991), Martin (1994), Tran (1996), Taiebat (1999), Zhang (2008). In the offshore Niger Delta, recent studies on offshore foundations performance due to wave loads simulation have been reported (Akpila, 2011; Akpila and Ejezie, 2011a; Akpila and Ejezie, 2011b; Ejezie and Akpila 2011; and Akpila, 2012). The increasing level of exploration and production activities in the Niger Delta offshore environment calls for further understanding on offshore foundation performance to gravity and environmental loading. These loads are transferred to the offshore foundation generating lateral (u_h), rotational (θ_m) and vertical (u_v) displacement.

This paper attempts to present the performance of offshore foundation on clay subjected to combined horizontal-moment load in the Niger Delta region of Nigeria.

2. MATERIALS AND METHODS

2.1 Meteorological and Oceanographic Data

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

2.2 Hydrodynamic Coefficients

Inertia coefficients, $C_{m,}$ and drag coefficient, $C_{d,}$ 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, $K_{Dm,}$ inertia force, K_{im}, maximum drag moment, $S_{Dm,}$ and maximum inertia moment, $S_{im,}$ were also evaluated from standard charts. In the offshore Niger Delta, Akpila and Ejezie (2011) reported that C_m and C_d values were 1.5 and 0.7 respectively for piles of 1.0m to 2.0m diameters.

2.3 Hydrodynamic Forces and Moments

The total instantaneous hydrodynamic force, F, on a submerged structure per elemental length ds of the cylinder (Sorenson, 2006) can be obtained from:

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

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

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

where F is horizontal force, γ_w is unit weight of water, D is pile diameter, T is wave period, K is wave number, ω is wave angular frequency and H is wave height. Horizontal forces were computed for varying pile diameters and wave heights using Morrison equation, adopting the linear wave theory of Airy (1845). A study on the variation of hydrodynamic forces on piles in the offshore Niger Delta has been reported by Akpila and Ejezie (2011).

The maximum moment at mud line is then evaluated from the expression;

$$M = c_m \gamma_w \left(\frac{\pi D^2}{4}\right) H K_{im} dS_{im} + \frac{C_d}{2}\gamma_w D H^2 K_{Dm} dS_{Dm} \quad (3)$$

where d is water depth below still water level and γ_w is unit weight of water. Ejezie and Akpila (2011) have also reported on moment induced displacement of offshore piles in the Niger Delta.

2.4 Horizontal and Moment Load (V=0)

Horizontal forces used in this analysis ranged from 23-938kN, while foundation area ranged between 98-314m^2. The evaluated subsea undrained shear strength of 2kN/m^2 and 21kN/m^2 were used for footing embedment of $D_f/B<1.0$ and $D_f/B>1.0$ respectively. Studies of numerical analysis on foundation subjected to horizontal and moment loading, with zero vertical loads have been reported by Taiebat (1999). He gave a maximum moment capacity, M, of 0.894ADs$_u$ which conceded with a horizontal load, H, of 0.71As$_u$ from which the following approximate equation given for H-M loading is used;

$$\frac{M}{M_u} = 0.6\sqrt{1-\left(\frac{H}{H_u}\right)^2} + \frac{0.4\cos\left(\frac{H}{H_u}\right)}{1-0.8\sin\left(\frac{H}{H_u}\right)} \quad (4)$$

where M = applied moment, $M_u = ADc_u$; is maximum moment, H = applied force, $H_u = Ac_u$; is maximum horizontal force, A = footing area and D = pile diameter.

The transition between forward – tilted scoop failure to surface sliding failure of foundation under H-M loading has been reported by Zhang (2008).

3. RESULTS AND DISCUSSIONS

3.1 Wave Characteristics

The offshore Niger Delta meteorological and oceanographic data 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.

3.2 Hydrodynamic Coefficients

Both the drag and inertia coefficients assumed 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 9.5x10^{-7} m^2/s were The dimensionless parameters of inertia and drag forces had constant values for a given wave height. These parameters also reduced with wave height and generally, K_{im} assumes lower values compared to K_{Dm}. A similar trend is also observed between S_{im} and S_{Dm}.

3.3 Horizontal-moment Loading for D_f/B<1.0

Typical failure envelopes of horizontal and moment loading are presented in Figures 1 and 2. It can be deduced from the failure envelopes that a maximum moment capacity, M, of 0.997M_u to 1.00M_u is obtained under pure moment loading (H/As$_u$=0), but under combined loading, a maximum moment, M of 1.085M_u which coincides with a maximum horizontal load, H, of 0.56As$_u$ is observed. In the various analysis, it is noticed that M/M_u increases with increase in H/H_u up to the maximum value of moment, M = 1.085M_u. The failure envelope beyond maximum M/M_u and H/H_u values is similar to the transition between forward – tilted scoop failure to surface sliding failure reported by Zhang (2008). Although sliding failure mode was not experienced within the range of horizontal loading used in this study, it is evident from the trend that sliding failure will commence at $M/M_u=0$

3.4 Horizontal-moment Loading for $D_f/B>1.0$

The failure envelopes of the various H-M loading under consideration (Figures 3 and 4) show that at $H/H_u = 0$, the ratio of $M/M_u=1.0$ irrespective of the foundation size. As H/H_u increases, a progressive increase in M/M_u occurs but the performance trend do not yield a maximum value of M/M_u under the horizontal loads applied, except for the case with footing area $A=78m^2$ shown in Figure 3. Here, maximum moment capacity occurred at $M = 1.0886M_u$ and it coincides with a horizontal load, $H = 0.492As_u$. In other cases where footing area exceeded $78m^2$, the maximum moment was not attained under the range of horizontal loads applied. The horizontal – moment load case for $D_f/B>1.0$ for footing with area greater than $78m^2$ gave the following average predictive model;

$$\frac{M}{M_u} = -0.261\left(\frac{H}{H_u}\right)^2 + 0.322\frac{H}{H_u} + 0.999 \qquad (4)$$

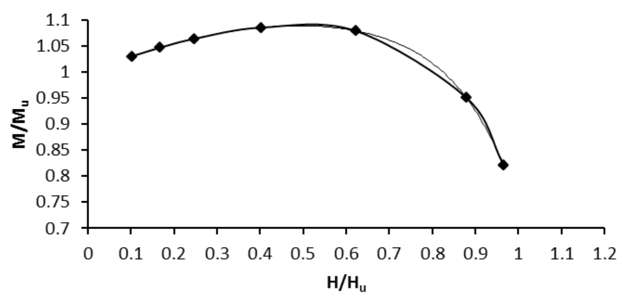

Figure 1: Horizontal-Moment loading on footing ($D_f/B<1$, Area=113m^2)

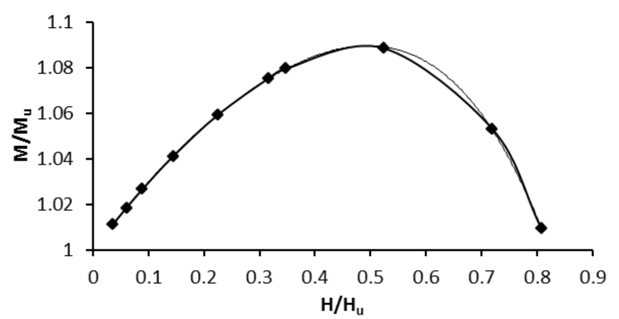

Figure 2: Horizontal-Moment loading on footing ($D_f/B<1$, Area=314m^2)

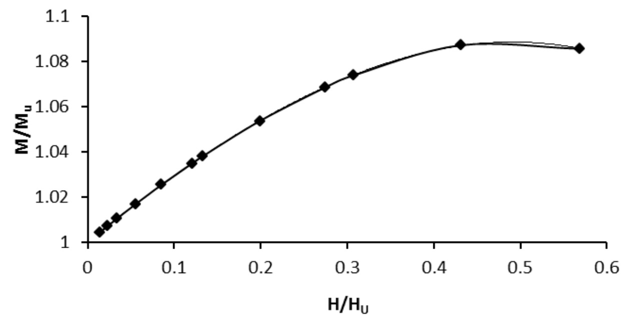

Figure 3: Horizontal- Moment loading on footing ($D_f/B>1$, Area =78m^2)

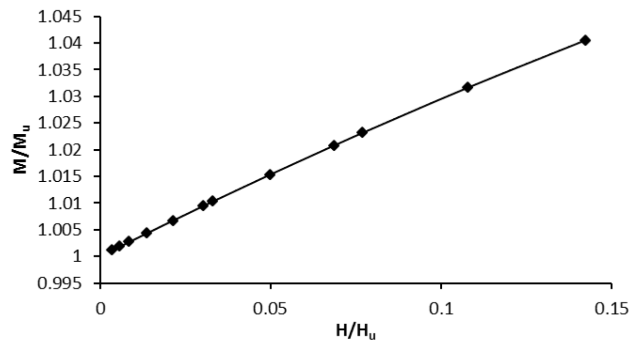

Figure 4: Horizontal- Moment loading on footing ($D_f/B>1$, Area=314m^2)

4. CONCLUSION

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

a. A maximum capacity of $M = 0.997M_u$ to $M = 1.00M_u$ is obtained under pure moment loading ($H/As_u=0$), but under combined loading, a maximum moment of $M = 1.085M_u$ is obtained and it coincides with a horizontal load of $H = 0.56As_u$ for cases of $D_f/B<1.0$.

b. For cases of $D_f/B>1.0$, it is noticed that at $H/H_o = 0$, the ratio of $M/M_u=1.0$ irrespective of the foundation size. As H/H_o increases, a progressive increase in M/M_u occurs but the performance trend do not yield a maximum value of M/M_u under the horizontal loads applied, except for the case with footing area $A=78m^2$. Here, maximum moment capacity occurred at $M = 1.0886M_u$ and it coincides with a horizontal load, $H = 0.492As_u$.

REFERENCES

[1] Airy, G.B. (1845): Tides and Waves Encyclopadia Metropolitian, Vol 5, Art. 192, pp. 241-396.

[2] Akpila, S.B., and Ejezie, S.U.(2011). "Variation of hydrodynamic forces and Moments on offshore piles in the Niger Delta," Proc. of 15th African Regional Conference on Soil Mechanics and Geotechnical Engineering, Maputo, pp 152-157.

[3] Ejezie, S.U. and Akpila, S.B. (2011). "Moments induced displacement of offshore foundation in the Niger Delta," Proc. of 15th African Regional Conference on Soil Mechanics and Geotechnical Engineering, Maputo, pp 133-138.

[4] Akpila, S.B. (2011). "Offshore foundation performance under vertical load induced displacement in the Niger Delta," International Journal of Current Research, Vol.3, Issue 9, pp 107-109.

[5] Akpila, S. B. and S.U. Ejezie (2011)," Horizontal load induced Displacement of offshore Foundations in the Niger Delta," International Journal of Current Research, Vol. 3, Issue10, pp 087-091.

[6] Akpila, S. B. (2012)," Comparison of Offshore Foundation Performance under Combined Horizontal- Vertical Loading in the Niger Delta of Nigeria," European Journal of Applied Engineering and Scientific Research," 1(2): 43-49.

[7] Bell, R.W. (1991): The analysis of offshore foundations subjected to combined loading, M.Sc thesis, University of Oxford, U.K.

[8] Cooper (2004): Met Ocean and Hydrodynamic Criteria for Shallow fixed Structures and Pipelines off W.Africa; Revision 11.

[9] Santala, M.J (2002): Eastern Nigerian Shallow Water Metocean Criteria: Version 1.2.

[10] Haritos, N. (2007), "Introduction to the analysis and design of offshore structures – An overview", EJSE, Special Issue: Loading in Structures pp.55-65.

[11] Martin, C.M. (1994): Physical and Numerical modeling of offshore foundations under combined loads, Ph.D Thesis, the University, of Oxford.

[12] Ngo Tran, C.C (1996) "The Analysis of Offshore Foundations subjected to Combined loading" D.Phil. Thesis, Oxford University.

[13] Offshore Report (2005): Adanga Field Development Metocean Study, Report, No. L21208/NDE/RS.

[14] Qi-yi Zhang (2008), "Failure mode of foundation under combined loadings," EJGE, vol. 13,Bund. K. pp. 1-10.

[15] Sorenson, R.M. (2006): Basic Coastal Engineering, 3th Edition, Spring Science and Business media, New York.

[16] Taiebat, H.A. (1999): 3-Dimensional liquefaction Analysis of offshore foundations, PhD thesis, University of Sydney.