Soil Characterization for Spudcan punch-through Assessment: A Case Study Offshore Sangana, Nigeria

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ABSTRACT:

Jack-up rigs are widely used for deep drilling in offshore locations. Because of the heavy tonnage of the rig and accessories and the high cost of failure, it is required that the spudcan be driven to and supported by a competent bearing layer. Such competent layer must combine attributes of thickness and strength to maintain stability during drilling operations. This paper presents a case study offshore the coast of Sangana in the Niger delta.

INTRODUCTION

Large hydrocarbon reserves occur offshore and are being harnessed to provide energy to the world. Recent years have witnessed the intensification of offshore hydrocarbon exploration in Nigeria not only as a response to increased global energy demand but also as a strategy to escape the increasing community protestation to land degradation caused by crude oil pollution onshore the Niger delta (NDES 1999). Crude oil exploration and production in the offshore area involve deep drilling in the continental shelf characterized by dynamic marine conditions created by waves, currents and mobile seabed (De Mars and Nacci 1978). The drilling equipment commonly used is a 3-legged Jack-up rig. The stability of the jack-up rig during drilling is of major concern as this could determine the success and failure of the project.

According to Chaney and Demars (2001), the bearing capacity analysis of the Jack-up footing generally fulfils two functions. The first is to predict the penetration below the seabed in order to determine if the combined air gap, water depth and footing penetration are less or equal to the maximum available leg. The second purpose is to evaluate the risk of a foundation failure caused by a punch-through. On both counts, geotechnical data on the underlying soils are usually sought for the determination of a suitable bearing layer for the spud cans. The geotechnical investigations address three key concerns (Broadhead 1970; Ardus 1980), namely:

i. e stratigraphy of the sediments beneath the seabed to a depth of engineering significance.
ii. engineering characteristics of the deposits
iii. the determination of a suitable depth of embedment.

The engineering significance of these considerations to the analysis of footing penetration have been discussed by several previous workers (ASTM International (2003a and 2003b), ASTM International (2000), CEN European Committee for Standardization (2004, Kay, S, Geodemoed, S.S. and Vermeijden, C.A. (2005), and Society of Naval Architects and Marine Engineers (1997).

This paper describes a case study of a geotechnical assessment of an offshore location for spudding, preparatory to drilling.

Site Description and Geology

The site is within the shallow continental shelf, located south of Sangana River, Niger Delta. Analysis of the wave climate of the area indicate waves 3.2m high, originating from the direction 1750N and 2050N for approximately 95% of the time. Geologically, the site is underlain by marine sediments belonging to the Pleistocenic Formation (NDES 1999). The general geology of the area essentially reflects the interaction and influence of movements of rivers, (particularly the Sangana River) and ocean currents in the Niger delta and their search for lines of flow with consequent deposition of transported sediments. The shallow continental shelf exhibits a variety of slope (NEDECO 1961), (Fig. 1) which makes the sea floor become progressively shallower towards the east. The slope of the site of study was 1:100, while the water depth was 12m.

Methods of Investigation

A prefabricated base was welded to the side of the jack-up barge, forming a cantilever suitable for the installation of a percussion rig.

This was an improvisation, since there were no provisions for percussion drilling on the barge. The use of a percussion rig instead of a rotary rig is predicated on the latter's inability to accurately define lithostratigraphic boundaries, obtain undisturbed samples for strength determination and execute in-situ test such as SPT. The percussion boring method employed, utilized the light shell and auger technique in advancing the borehole. During the boring operations, disturbed samples were regularly collected at depths of 0.75m intervals and also when change of soil type was noticed. Undisturbed cohesive soil samples were retrieved from the boreholes with conventional open-tube sampler driven into the soil by a dynamic means using a drop hammer. All samples recovered from the boreholes were examined, identified and roughly classified in the field.

Laboratory classification tests were conducted in accordance with the British standards (BS 1377 of 1990) in order to verify and improve on the field identification and classification of the samples. These tests included natural moisture content, unit weight, specific gravity, liquid and plastic limit. Furthermore, laboratory vane shear tests were performed on the undisturbed samples recovered from the boreholes.

RESULTS

The stratigraphy of the site was evaluated based on data from soil borings and laboratory tests. Fig. 2 presents the stratigraphy within the depth of foundation engineering significance together with pertinent soil properties. The underlying strata consist essentially of alternating sequence of clay and sandy deposits beneath the site. The clay layers are mostly dark gray in colour and soft in consistency. Sandwiched between the clay deposits are thin bands of sandy layers. Within the clay sediment, there was an occasional occurrence of organic matter in the form of decomposed vegetal matter. The pertinent geotechnical properties of the sediments are summarized in tables 2 –5 and Fig.3.

This clay is predominantly of high plasticity according to the Unified Soil Classification System as indicated in Fig. 3. The first 8m of sediments below seabed consisted of supersaturated clay with liquidity index of 1.13. Laboratory miniature vane shear test gave undrained shear strength values that are comparable with quick undrained triaxial test as shown in tables 2 and 3.

Because of difficulties with sample retrieval, estimates of undrained strength by empirical formula using plasticity index and effective overburden pressure was employed to populate the strength profile. This method which was proposed by Skempton (1957) assumes that the sediments are normally consolidated and calculates the undrained shear strength using the formula:

$$Cu/\sigma^{1} = 0.11 + 0.0037\,(PI)$$

Where σ^{1} is effective overburden pressure and PI the plasticity index.

The sand layers are loose to medium dense in relative density and occur between 8 and 9m and 22 and 23m below seabed with a maximum thickness of 1m. The laboratory results indicated an average angle of shearing resistance of 30^{0} and bulk unit weight of $19.5kN/m^{3}$ for each of these sand deposits.

DISCUSSIONS

The risk of a foundation failure caused by a punch through can be assessed using bearing capacity analysis for an individual footing. Several procedures are available for computing the bearing capacity of a foundation in cohesive soils provided the shear strength is fairly constant. A general form of these procedures is given by Young et al (1984.

$$Q = AN_cS_u + \gamma_b V$$

Where Q = footing capacity

A = Cross-sectional area of embedded footing

N_c = Dimension bearing capacity function

S_u = Undrained Shear Strength

γ_b = Buoyant unit weight of soil displaced by footing

V = Embedded volume of footing

The footing capacity values estimated from this relationship are usually conservative in comparison to the method of SNAME (1997) in which footing capacity in cohesive soils is evaluated by:

$$Fv = (Su_o\, N_c + \sigma_{\cdot\gamma o})A + \sigma' v'$$

Where $\sigma' v_o'$ = In-situ vertical effective stress

Young et al (1984) have shown that for layered soils, Hanna and Meyerhoff's equation for circular footing give the closest fit between model test results and predicted capacities.

$$Q = A\left(\sigma\, S_u B + 2\cdot\gamma_b H^2 \left(\frac{1 + 2D}{H}\right) Ks \frac{\tan\phi}{B}\right) + \gamma_b v$$

Where H = thickness of upper layer in a two layer system

D = Depth of widest cross-sectional area

Ks = Coefficient of punching shear

ϕ = Angle of internal friction of granular stratum

γ_b = Buoyant unit of granular stratum

Where a relatively competent layer occurs, its suitability for embedment of the spudcan was assessed by a combination of the strength and the thickness. The bearing capacity in this case could be defined as the load or pressure developed under the foundation without introducing damaging movements of the jack-up platform. Damaging movements may result from foundation failure or excessive settlement. These two criteria were therefore used in the ultimate selection of a depth of embedment.

Since the rate of spudding is relatively fast in comparison to the permeability, undrained conditions were deemed to apply. Consequently, the undrained strength parameters are applicable and allowed the design to be based on undrained shear strength tests. According to Young et al (1984), the accurate prediction of footing penetration is more dependent upon the selection of undrained shear strength than on the analytical method.

A factor of safety of 1.8 was applied to the undrained strength as recommended by Eurocode such that $C_{ub} = \frac{Cu}{Fs = 1.5 - 1.8)}$

The variation of the soil resistance with depth of the penetration of spudcan computed from the undrained strength values determined from various methods is graphically presented (Fig. 4).

The results indicated that the minimum soil resistance per leg to ensure stability of the jack-up was met only at the sandy horizons occurring between 8 and 9m and 22 and 23m below seabed. However, these sandy horizons were only 1m in thickness, thereby creating concern for a possible punch-through by the spudcan. By considering the shearing resistance mobilized across a sand thickness of 1m in comparison to the proportion of load transmitted through a jack-up leg, it was found that such concerns may be justified. Furthermore, such fears would have been adequately addressed, if substantial data were obtained just below the sandy horizon through the collection of undisturbed samples at closer intervals. In the circumstance, the consolidation settlement that would be induced by the placement of the spudcan on the sandy layer was assessed using the limited data available. This assessment indicated that the total settlement to be expected would be less than the thickness of the sandy layer, thus implying a condition of stability. Furthermore, the undrained strength-depth profile derived from triaxial tests appears to indicate that the clay sediments from 15m below seabed were normally consolidated, suggesting the existence of improved bearing characteristics from this depth. Above 15m, there are indications from the liquidity indices that the clay layer could easily be remolded following penetration of the spudcan.

The results also indicate that only a marginal stability would have existed if no sandy layer had occurred. The results further show that if a factor of safety were not applied to the undrained strength, prior to the computation of the end bearing capacity of the spudcan, the required minimum capacity for embedment would be met earlier than 15m below seabed. However, following successful completion of spudding and drilling, it is conclusive that the application of a factor of safety to the undrained strength resulted in unduly conservative estimates of the carrying capacity of the subsoil. It is therefore recommended that only the global factor of safety to the ultimate carrying capacity should apply in order to derive the allowable carrying capacity.

Conclusions:

Based on this study, it is concluded that the thickness and properties of sandy layers (where they occur) must be carefully evaluated. The prospects offered by such sandy layers must be assessed in conjunction with the consolidation characteristics of the underlying cohesive sediments. Furthermore, the application a factor of safety to the undrained strength resulted in conservative estimates of the carrying capacity of the subsoil. This investigation confirms that the accurate prediction of footing penetration is greatly dependent upon the selection of undrained shear strength than on the analytical method.

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