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Determination of the Bearing Capacities of Sandstone and Shale Lithologies from Shear Wave Velocity in the Niger Delta Sedimentary Basin, Nigeria

O.G. Emujakporue
Department of Physics, University of Port Harcourt, Rivers State, Nigeria

ABSTRACT

The bearing capacities and coefficient of subgrade reaction of sand and shale lithologies of Niger Delta sedimentary basin, Nigeria have been computed from shear wave velocities using a relatively simple formula. The shear velocities were obtained from five oil exploratory wells. The computed ultimate bearing capacities of the sand ranges from 3141.755 to 5593.447 kN m^{-3} with an average of 4367.601 kN m^{-3} while, that of the shale ranges between 2487.786 and 6335.588 kN m^{-3} with an average of 4411.687 kN m^{-3}. The computed allowable bearing capacity of the sand varies from 1047.252 to 1864.482 kN m^{-3} while that of the shale lithology is from 829.262 to 2111.863 kN m^{-3}. Furthermore, the estimated subgrade reaction for the sand varies between 41890.07 and 74579.29 kN m^{-3} while that of the shale is from 33170.48 to 84474.5 kN m^{-3}. The results show that the bearing capacities of the sand and shale lithologies are very high. This may be attributed to high consolidation and compaction of the formations in the subsurface and thereby resulting in the stability of most foundations in the area. Although, the shale lithology has a high bearing capacities and coefficient of subgrade reaction yet it is not advisable to put foundation on it whenever it is close to the earth surface because when it has the ability to swell/contract whenever it absorb or looses water it.

Key words: Bearing capacities, shear wave velocity, foundation, Niger Delta

INTRODUCTION

One of the main steps for the safe and economic design of foundation is based on the concept of "bearing capacity" which is the ability of a soil/rock to hold up a foundation and structure. The ultimate bearing capacity of a soil is the loading per unit area that will just cause a shear failure in the supporting soil. The allowable bearing capacity is the load per unit area that the rock is able to support without unsafe movement.

Geotechnical investigation is a crucial process of gathering information about rock deposits and the influence of construction or a structure performance of a building project. Traditionally, the investigation of the bearing capacity of rock is normally achieved by boring exploratory holes and carrying out soil and rock testing.

The use of geophysical methods in soil mechanics has been extensively deployed for the purpose of determining the properties of soils and rocks. The compressional and shear wave velocities of rocks in boreholes have been used for evaluating the mechanical properties of the subsurface rocks, especially the bearing capacities (Imai and Yoshimura, 1976; Abd EL-Rahman *et al.*, 1992; Keceli, 1990, 2000). Imai and Yoshimura (1976), proposed an empirical expression for the determination of bearing capacity which yields values unacceptably higher than the classical theory.

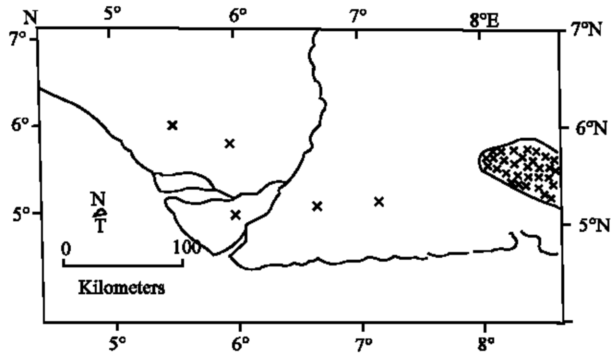

Fig. 1: Base map of the Niger Delta showing the location of wells used for the study

The study area is located within the Niger Delta sedimentary basin (Fig. 1). The Niger Delta is the youngest sedimentary basin within the Benue Trough system. Its development began after the Eocene tectonic phase. Up to 12 km of deltaic and shallow marine sediments have been accumulated in the basin. The Niger and Benue Rivers are the main supplier of sediments (Kulke, 1995; Reijers *et al.*, 1997)

Three lithostratigraphic units are distinguished in the Tertiary Niger Delta. The basal Akata Formation which is predominantly marine prodelta shale is overlain by the paralic sand/shale sequence of the Agbada Formation. The topmost section is the continental upper deltaic plain sands -the Benin Formation. Virtually all the hydrocarbon accumulations in the Niger Delta occur in the sands and sandstones of Agbada Formation where they are trapped by rollover anticlines related to growth fault development (Doust and Omatsola, 1990; Ekweozor and Daukoru, 1994).

MATERIALS AND METHODS

The basic data used for this study is the shear wave velocity of sandstone and shale lithologies obtained from five exploratory oil wells in the Niger Delta Sedimentary Basin, drilled and acquired by Shell Petroleum Development Company. In this study, the dynamic empirical formula of Tezcan and Ozdemir. (2011) which was modified from Keceli (1990) will be used. This formula has been calibrated and improved with the soil data of 550 construction sites. The modified formula between the bearing capacity and the shear wave velocity is given as:

$$Q_{ult} = 0.10YV_s \quad (1)$$

And:

$$Qa = \frac{0.1YVs}{n} \quad (2)$$

Where:

Q_{ult} = Ultimate bearing capacity
V_s = Shear wave velocity
Y = Unit weight
n = Factor of safety
Q_a = Allowable bearing capacity

According to Tezcan and Ozdemir (2011) and Keceli (1990) the unit weight (Y) can be estimated using the empirical formula:

$$Y = 4.3V_s^{0.25} \quad (3)$$

The factor of safety, n can be obtained as follows:

- n = 1.4 (for Vs ≥4000 m sec^{-1})
- n = 4.0 (for Vs ≤750 m sec^{-1})

For other intermediate values of shear wave velocity, linear interpolation is recommended. The factor of safety equals three for cohesive soils was used for this work.

The shear wave velocity was also used for the determination of the coefficient of the sub grade-reaction of the soil layer just beneath the foundation base by making use of the expression:

$$K_s = 40Q_a \quad (4)$$

Where:
K_s = Subgrade reaction of the rock
Q_a = Allowable bearing capacity

The coefficient of subgrade reaction which is similar to the spring constant in engineering mechanics, is the necessary vertical pressure needed to produce a unit vertical displacement. In the above methodology, an isotropic and homogenous medium was assumed.

RESULTS AND DISCUSSION

The calculated bearing capacities and the subgrade reaction of the sandstone and shale lithologies are shown in Table 1. The ultimate bearing capacity of the sand ranges from 3141.755 to 5593.447 kN m^{-3} with an average of 4367.601 kN m^{-3} while that of the shale ranges between 2487.786 and 6335.588 kN m^{-3} with an average of 4411.687 kN m^{-3}. The computed allowable bearing capacity of the sand varies from 1047.252 and 1864.482 kN m^{-3} while that of the shale lithology is from 829.262 to 2111.863 kN m^{-3}. Furthermore the estimated subgrade reaction for the sand vary between 41890.07 and 74579.29 kN m^{-3} while that of the shale is from 33170.48 to 84474.5 kN m^{-3}.

Table 1: Calculated bearing capacities of sand and shale lithologies in the Niger delta

Well	Shear velocity (m sec^{-1})	Lithology	Ultimate bearing capacity ($Q_{ult.}$)	Allowable bearing capacity (Q_a)	Coefficient of subgrade reaction (K)
1	1233-1515	Sand	3141.755-4064.286	1047.252-1354.762	41890.07-54190.48
1	1023-1412	Shale	2487.786-3721.875	829.262-1240.625	33170.48-49625
2	1894-1956	Sand	5372.71-5593.447	1790.903-1864.482	71636.14-74579.29
2	1734-2161	Shale	4811.493-6335.588	1603.831-2111.863	64153.23-84474.5
3	1499-1668	Sand	4010.703-4583.672	1336.901-1527.891	53476.04-61115.62
3	1388-1510	Shale	3642.967-4047.526	1214.322-1349.175	48572.9-53967.01
4	1577-1644	Sand	4273.248-4501.38	1424.416-1500.46	56976.64-60018.41
4	1478-1582	Shale	3940.592-4290.19	1313.531-1430.063	52541.23-57202.54
5	13399-1630	Sand	3679.092-4453.515	1226.364-1484.505	49054.55-59380.21
5	1364-1649	Shale	3564.4-4518.5	1188.133-1506.167	47525.33-60246.67

The results of the study show that the sand and shale lithologies of the Niger Delta have high ultimate and allowable bearing capacities. This may be attributed to the consolidation of the sedimentary rock in the subsurface. Though, the shale has a high bearing capacity but due to its clayish structure, it will be prone to mass movements when a foundation is placed on it. Similarly, when the clay absorbed water it will swell and heave thereby leading to the instability the structure build on it.

The Benin Formation (topmost) of the Niger Delta is made up of sand and since the bearing capacity of the sand is very high, this might be the reason while structures in the area are very stable. The coefficient of the subgrade reaction which vertical pressure needed to produce a unit vertical displacement in the subsurface is also very high.

CONCLUSION

The bearing capacities and the coefficient of the subgrade reaction of sand and shale lithologies in the Niger Delta have been computed using shear wave velocities. The shear and compressional- wave velocities of rocks/soil are important geophysical parameters that can be used rapidly and economically for the determination of the allowable bearing pressure, the coefficient of subgrade reaction, various other elasticity parameters, as well as the approximate values of the unit weight, using relatively simple empirical expressions. The results show that the bearing capacities and the coefficient of subgrade reaction of the sand and shale lithologies of the area are very high. These high values may be attributed to the consolidation and compaction of the formation in the subsurface and thus resulting in the stability of foundations in the area.

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