Journal of Engineering and Applied Sciences 2 (12): 1818-1822, 2007
ISSN: 1816-949X


# Interface Properties Between Lateritic Soils from Ife Region of Southwestern Nigeria and Some Foundation Materials

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**Abstract:** The interface properties between some lateritic soils within the Ife region in southwestern Nigeria and some common foundation materials (namely concrete, steel and wood) were investigated by the direct shear test method employing the shear box apparatus adapted specifically for that purpose. The values obtained were compared with the shear strength characteristics (cohesion and angle of internal friction) of the soils. The angles of interface frictions between the lateritic soils and concrete, steel and wood ranged from 24.6 and 41.2°, 17.5 and 34.0° and 12.0 and 16.0°, respectively, while the adhesion between the lateritic soils and concrete, steel and wood ranged from 15.8 and 30.2 kPa, 11.2 and 18.5 kPa and 7.5 and 10.8 kPa, respectively. The angles of internal friction and cohesion of the soils ranged between 29.1 and 40.7 ° and 23.7 and 32.3 kPa, respectively.

**Key words:** Interface properties, direct shear test, lateritic soils, foundation materials

## INTRODUCTION

The shear strength characteristics of a soil, namely the angle of internal friction $\varphi$ and the cohesion c, are parameters needed to estimate the shearing stresses within a soil mass. These characteristics determine the relationship between the shear stresses $\tau$ and normal stresses $\sigma$ on a given plane within the soil mass by the well-known Coulomb's equation:

$$\tau = c+\sigma \tan \varphi \quad (1)$$

Similarly, the determination of the shearing stresses generated between soils and foundation elements adjacent to them also require the knowledge of the interface properties of the soil and foundation material. These are the angle of interface friction $\delta$ and the adhesion $c_a$ between the soil and foundation materials. The expression is similar to Eq. 1.

$$\tau = c_a+\sigma \tan \delta \quad (2)$$

For partially- or fully-saturated conditions, the expression is valid for the effective stresses rather than the total stresses, with the principal actors now being the effective strength parameters $c_a'$ and $\delta'$.

For example, for retaining walls, knowledge of the angle of wall friction is essential in the determination of the magnitude and line of action of the wall reaction. Gravity and semi-gravity retaining walls may fail by sliding, by overturning, or by failure of the soil at the toe. For a wall prone to failure by sliding along its base, the interface properties determine the resistance to sliding T. In general,

$$T = c_a'.B+(W - U) \tan \delta' \quad (3)$$

Where, $c_a'$ is the effective adhesion between the foundation soil and foundation material, $\delta'$ is the effective angle of interface friction, B is the width of the wall base, W is the weight and U is the hydrostatic pressure at the base. For undrained loading, $\delta' = 0$ and $c_a = s_w$, where $s_w$ is the undrained shear strength between the soil and the base of the concrete wall. For drained loading, $c_a = 0$.

For pile foundations, the applied load on single piles is resisted by a force (base resistance) at the base and a force (shaft friction) along the pile shaft. Shaft friction is also responsible for resisting lateral loads and uplift forces in piles. The shaft friction is determined by the interface properties between the soil and pile material.

The interface properties between a soil and foundation material also find application in the determination of stresses induced on a basement wall by an adjacent soil mass subject to subsidence from internal stresses or settlement from superimposed loads. Also, in a soil that is settling adjacent to a pile or caisson, perhaps due to the weight of fill placed at the surface or due to groundwater lowering, the shaft friction will act downwards on the pile or caisson (causing negative shaft friction) and where the magnitude needs to be determined, the interface properties come into play.

In addition to all the above, in the design of reinforced earth structures, the soil- reinforcement interaction properties are fundamental design parameters.

It has been established that the angle of interface friction $\delta$ between a soil and foundation material cannot be greater than the angle of internal friction $\varphi$ of the soil (Smith, 1968). Also, the value of the angle of interface friction $\delta$ can be obtained from tests, but if tests are not available, then $\delta$ is usually assumed as 0.5-0.75 $\varphi$ (Smith, 1968). The values of $\delta$ and $c_a$ not only depend on the mode of loading (undrained or drained), they evidently also depend on the type of foundation material. For example, typically, piles are made from steel, concrete (plain, reinforced or prestressed) or timber. They may be driven or pushed into the soil or, for concrete piles, may be cast in situ by pouring concrete into a drilled hole (Atkinson, 1993).

Determination of the interface properties between native soils and foundation materials has usually been by direct shear tests, conducted with the adapted shear box apparatus. Many investigators have applied this method in the past. Examples are Acar *et al.* (1982), Gan *et al.* (1988), Tejchman and Wu (1995), Reddy *et al.* (2000), Miller and Hamid (2007) and others. In recent times, the Tilting Table method (Ling *et al.*, 2002) and the Pullout Box Method (Yuan and Chua, 1990) have also been used to determine soil-material interface properties. Though the Pullout Box method is more versatile than the direct shear test method in that it can be used to study wire meshes, strips, geogrids, geotextiles and other types of reinforcements in different soils (Yuan and Chua, 1990), it has been shown (Khire and Mohtar, 2003) that when testing some sands and planar geosynthetic products, the values of the interface friction angle obtained using the vertical pullout method lie within ±2° of the angle measured using the conventional direct shear apparatus. The direct shear test method can therefore be used with confidence in its reliability while exploiting its advantages of simplicity and familiarity. It was the method used in this study.

## NATURE OF LATERITES AND LATERITIC SOILS

Laterites and lateritic soils cover a large portion of the earth's surface. They are generally found in tropical and subtropical climates with high temperatures, abundant rainfall and seasonal, or at least some months of, marked dryness. Natural relief necessary to create drainage conditions is also associated.

Lateritic soils are products of weathering and contain principally oxides of iron, aluminium, titanium and magnesium. They are formed under conditions that permit leaching and facilitate the removal of silica, alkalis and alkaline earths. They are not uniquely associated with any particular parent rock, geologic age, method of formation, geographical region or climate per se. They are rock products resulting from a set of physico-chemical conditions which include an iron-containing parent rock, a well-drained terrain, abundant moisture for hydrolysis of the silica during weathering, relatively high oxidation potential and persistence of these conditions over thousands of years. These conditions enhancing laterization (i.e. the formation of laterites and lateritic soils) are prevalent and therefore these soils are found almost everywhere, in Nigeria, making them to be a useful source of building material. Clay minerals of the kaolinite group are typically associated with and are generally related to, lateritic soils. In his investigations on Nigerian lateritic soils, Ola (1983) has established that Nigerian lateritic soils are composed predominantly of kaolinite with some quartz. Significant is the absence of any swelling mineral type, e.g. vermiculite or montmorillonite. The significant proportion of free iron and aluminium oxides found in lateritic soils tend to cement the soil particles to form a coarse-grained weakly-bonded (aggregated) particulate material (Ola, 1983). This, coupled with the leaching out and removal of combined silica and bases from the soil profile, leads to an increase in porosity and drainage characteristics (permeability) of the soils. And because they are usually free draining, non-swelling and structurally stable (due to their granular structure), laterites and lateritic soils are used predominantly in backfills adjacent to retaining structures and other foundation structures, as well as fill material in road subgrades and base courses and where poor native soils have to be evacuated and replaced.

## PHYSICAL PROPERTIES OF THE SOILS INVESTIGATED

This study was conducted within the Ife region of Osun State in Southwestern Nigeria. The study area lies between latitudes 7°26'N and 7°34'N and longitudes 4°28'E and 4°36'E. Soil samples were collected at a depth of about 2.0 meters below the ground surface from four different locations within the study area, along different road axes from Ife town. Sample A was collected at km. 1+800 along the Ife-Ibadan Road, Sample B was collected at km. 4+150 along the Ife-Ifewara Road, Sample C was collected at km. 3+200 along the Ife-Ondo Road, while Sample D was collected at km. 3+700 along the Ife-Osu Road. After collection, the soil samples were spread out in the laboratory for two weeks for air-drying at room temperature, after which the clods were broken down and

Table 1: Physical properties of soil samples

| Physical property | | Sample A | Sample B | Sample C | Sample D |
|---|---|---|---|---|---|
| Description | | Dark-brown well-graded sand | Red-brown well-graded sand | Light-brown clayey sand | Light-brown well-graded sand |
| Grain size distribution (percentage passing sieve sizes): | 4.75 mm | 91.1 | 85.2 | 96.9 | 96.5 |
| | 2.36 mm | 75.5 | 73.6 | 93.4 | 85.8 |
| | 1.18 mm | 51.3 | 56.7 | 84.3 | 74.2 |
| | 0.600 mm | 34.5 | 39.8 | 63.0 | 49.0 |
| | 0.300 mm | 18.0 | 24.0 | 40.2 | 21.8 |
| | 0.212 mm | 11.0 | 17.8 | 31.4 | 14.6 |
| | 0.150 mm | 5.4 | 12.0 | 20.1 | 7.9 |
| | 0.075 mm | 2.4 | 7.2 | 12.3 | 4.5 |
| Specific gravity | | 2.70 | 2.86 | 2.88 | 2.76 |
| Natural moisture content, % | | 18.8 | 20.0 | 15.9 | 19.5 |
| Liquid limit, % | | 50.0 | 48.9 | 49.2 | 52.3 |
| Plastic limit, % | | 32.8 | 32.2 | 29.9 | 32.8 |
| Plasticity index, % | | 17.2 | 16.7 | 19.3 | 19.5 |
| Optimum moisture content (Standard proctor), % | | 17.3 | 19.7 | 20.1 | 15.9 |
| Maximum dry density (Standard proctor), kg $m^{-3}$ | | 1798 | 1717 | 1738 | 1814 |
| AASHTO classification | | A-2-7 | A-2-7 | A-2-7 | A-2-7 |
| Group index | | 0 | 0 | 0 | 0 |
| Universal soil classification | | SP | SP-SM | SM | SP |

the samples well pulverized. Thereafter, employing standard procedures, the samples were tested for their classification and index properties, their consistency properties and their compaction and strength characteristics. The results are shown in Table 1.

In most systems of soil classification, the silt and clay grain sizes comprise the fraction passing the 0.075 mm sieve size, while the sand fraction comprises grains passing the 2.36 mm sieve size and retained on the 0.075 mm sieve size. It is evident therefore, that the sand fraction is predominant in the particle size distribution of all the soils sampled in this study. The clay fraction is minimal (less than 10% except in Sample C). All the samples plot below the A-line in the Casagrande plasticity chart.

## RESULTS AND DISCUSSION

Further, the soils were investigated for their shear strength parameters and their interface properties with different common foundation materials (namely concrete, wood and steel) through the direct shear method. The compaction for each test specimen was conducted at the soil's optimum moisture content and taken to the respective maximum dry density. As earlier stated, the lateritic soils are free draining (even classified as sandy soils as in Table 1), therefore it was the consolidated-drained type of tests that were performed on them and the obtained parameters were the total stress parameters. The shearing stresses were determined at normal stresses of 100, 200 and 300 kPa. Since the Mohr-Coulomb failure envelopes are represented by Eq. 1 and 2 which are linear relationships between the shear and normal stresses, straight-line graphs were fitted for each test over the data points by first order least squares regression analysis to obtain the intercept on the shear stress axis and the angle the line makes with the normal stress axis. The intercept of the lines on the shear stress axis is the cohesion c and adhesion $c_a$ respectively while the angle the lines make with the normal stress axis is the angle of internal friction $\varphi$ and angle of interface friction $\delta$, respectively.

It was discovered that, for the soils sampled, the cohesion and angle of internal friction ranged between 23.7 and 32.3 kPa and 29.1 and 40.7°, respectively shows in Table 2. The adhesion and angle of interface friction between the lateritic soil samples and concrete ranged between 15.8 and 30.2 kPa and 24.6 and 41.2°, respectively shows in Table 3. The adhesion and angle of interface friction between the lateritic soil samples and wood ranged between 11.2 and 18.5 kPa and 17.5 and 34.0°, respectively shows in Table 4. The adhesion and angle of interface friction between the lateritic soil samples and steel ranged between 7.5 and 10.8 kPa and 12.0 and 16.0°, respectively represent in Table 5. The values for the interface properties (both the adhesion and angle of interface friction) were highest for concrete and lowest for steel.

It was also observed that the angle of interface friction between all the soil samples and all the foundation materials in their various combinations were less than the cohesion and angle of internal friction of the soil samples. This is in agreement with the statement by Smith (1968) that the angle of interface friction $\delta$ between a soil and foundation material cannot be greater than the angle of internal friction $\varphi$ of the soil. It was also observed that the difference between the angle of interface friction

Table 2: Direct shear test results for shear strength parameters of lateritic soils

| | Normal stress $\sigma_1$, kPa | Shear stress $\tau_1$, kPa | Normal stress $\sigma_2$, kPa | Shear stress $\tau_2$, kPa | Normal stress $\sigma_3$, kPa | Shear stress $\tau_3$, kPa | Cohesion $c$, kPa | Angle of internal friction $\varphi$, ° |
|---|---|---|---|---|---|---|---|---|
| Sample A | 100 | 110.5 | 200 | 202.5 | 300 | 282.5 | 26.5 | 40.7 |
| Sample B | 100 | 98.5 | 200 | 168.5 | 300 | 242.5 | 25.8 | 35.8 |
| Sample C | 100 | 85.5 | 200 | 149.0 | 300 | 197.0 | 32.3 | 29.1 |
| Sample D | 100 | 83.5 | 200 | 136.0 | 300 | 199.5 | 23.7 | 30.1 |

Table 3: Direct shear test results for lateritic soils and concrete interface

| | Normal stress $\sigma_1$, kPa | Shear stress $\tau_1$, kPa | Normal stress $\sigma_2$, kPa | Shear stress $\tau_2$, kPa | Normal stress $\sigma_3$, kPa | Shear stress $\tau_3$, kPa | Cohesion $c$, kPa | Angle of internal friction $\varphi$, ° |
|---|---|---|---|---|---|---|---|---|
| Sample A | 100 | 107.5 | 200 | 192.5 | 300 | 282.5 | 19.2 | 41.2 |
| Sample B | 100 | 84.0 | 200 | 149.5 | 300 | 212.5 | 20.2 | 32.7 |
| Sample C | 100 | 72.5 | 200 | 127.5 | 300 | 185.0 | 15.8 | 29.4 |
| Sample D | 100 | 77.5 | 200 | 122.5 | 300 | 167.0 | 30.2 | 24.6 |

Table 4: Direct shear test results for lateritic soils and wood interface

| | Normal stress $\sigma_1$, kPa | Shear stress $\tau_1$, kPa | Normal stress $\sigma_2$, kPa | Shear stress $\tau_2$, kPa | Normal stress $\sigma_3$, kPa | Shear stress $\tau_3$, kPa | Cohesion $c$, kPa | Angle of internal friction $\varphi$, ° |
|---|---|---|---|---|---|---|---|---|
| Sample A | 100 | 80.0 | 200 | 148.5 | 300 | 275.0 | 12.8 | 34.0 |
| Sample B | 100 | 58.0 | 200 | 102.5 | 300 | 150.0 | 11.5 | 24.7 |
| Sample C | 100 | 64.0 | 200 | 112.5 | 300 | 167.5 | 11.2 | 27.4 |
| Sample D | 100 | 49.5 | 200 | 82.5 | 300 | 112.5 | 18.5 | 17.5 |

Table 5: Direct shear test results for lateritic soils and steel interface

| | Normal stress $\sigma_1$, kPa | Shear stress $\tau_1$, kPa | Normal stress $\sigma_2$, kPa | Shear stress $\tau_2$, kPa | Normal stress $\sigma_3$, kPa | Shear stress $\tau_3$, kPa | Cohesion $c$, kPa | Angle of internal friction $\varphi$, ° |
|---|---|---|---|---|---|---|---|---|
| Sample A | 100 | 37.5 | 200 | 65.0 | 300 | 95.0 | 8.3 | 16.0 |
| Sample B | 100 | 30.0 | 200 | 50.0 | 300 | 72.5 | 8.3 | 12.0 |
| Sample C | 100 | 32.5 | 200 | 57.5 | 300 | 82.5 | 7.5 | 14.0 |
| Sample D | 100 | 35.0 | 200 | 57.5 | 300 | 82.5 | 10.8 | 13.4 |

between the various soils and concrete is very near to and just slightly lower than the angle of internal friction of the soils. This is in agreement with the statement by Bowles (1982) that an alternative method of estimating the value of the angle of interface friction between a soil and concrete is to approximate it to the soil's angle of internal friction.

General values obtained in the literature for the interface properties between silty sand (close in texture to the lateritic soil samples being investigated) and the various foundation materials show that the angle of interface friction between silty sand and mass concrete, wood and steel lie in the range 24-35°, 14-26° for wood and 15-16°, respectively. A comparison of the values obtained in this study with these values shows that the values obtained in the study fall within the appropriate ranges.

## CONCLUSION

The lateritic soils within the Ife region in southwestern Nigeria were investigated for their shear strength and interface properties with common foundation materials, namely concrete, wood and steel. The obtained values of these properties will be useful in the design of foundations and earth-retaining structures.

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