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EXPERIMENTAL DETERMINATION OF SOIL PROPERTIES RELATED TO TRACTION ON AN UNPAVED *ILE-APA* FARM ROAD

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ABSTRACT

Ile-Apa is a farming community in Kwara State, Nigeria. Loss of manhours resulting from loss of traction has been a major problem for farm vehicles travelling in and around *Ile-Apa*. This makes it difficult to convey farm inputs to the farm during certain periods of the year. Due to the heterogeneity of agricultural soils, it would be inappropriate to use soil data from different locations to design or select tractive devices for this community. It became necessary to determine soil parameters related to traction on the unpaved road in, and around the *Ile-Apa* community. Experimental methods were used to determine soil cohesion (C), internal angle of friction (ϕ), wet basis moisture content (Mc), void ratio (e), porosity (n) and bulk density (ρ). Results obtained showed that C, ϕ, Mc, e, n and ρ were 1.4 N/cm^2, 34.84°, 44.92%, 1.213, 0.548 and 1.768 g/cm^3 respectively. These indicated that the soil in the area lacked sufficient strength to support heavy vehicles during rainy periods. Appropriate tractive devices must therefore be carefully selected to avoid loss of manhour and damage to both soil and vehicle.

Keywords: Traction, Unpaved Road, void ratio, Porosity, Shear stress

1.0 INTRODUCTION

Traction is the force developed from the interaction between a tractive device and a tractive medium to facilitate motion required to move a load. This force is often less than tractive effort due to energy losses, especially from rolling resistance (Fenyvesi *et al*., 2002 Vedantu, 2023). Offroad tractions are common in the military, road construction, and agriculture. The tractive medium in these environments is the soil.
Soil trafficability is the ease with which a tractive device can trafficate a given tractive medium without damage to the device or the medium. Mueller *et al.* (2011) defined it as the capability of the soil to provide traffic support for agricultural machines without degrading the soil. Agricultural soils, however, lack sufficient strength to bear the weight of most traffic devices. When loaded, they deform plastically in shear, leading to wheel slip. Loading could be in pulling or pushing an implement or simply travelling over the soil. Abubakar *et al.* (2022) explained that wheel slip occurs when the horizontal force of the wheel overcomes the internal shear strength of soil in the wheel/soil contact planes, thereby displacing the soil in the opposite direction of travel of the wheel. Ajewole and Fayose (2022) reported that about 20% to 55% of the total energy available to the tractor is wasted at the interaction of the tractive device and soil. Reduction in wheel slip can lead to considerable savings in fuel consumption, tyre wear and machine maintenance, as well as increase in attractive efficiency (Abubakar *et al.,* 2022; Zoz and Grisso, 2003).

Agricultural soils are heterogeneous. Therefore, data from one location may not apply to another. Knowledge of the soil condition in a specific location is very important in the design or selection of the tractive device that may interact effectively in that location. Several attempts have been made to study tractor wheel slip to minimize traction losses resulting therefrom (Abubakar *et al.,* 2022). However, none of these attempts took into account the location of these studies. Abubakar *et al.* (2022) citing Ani *et al.* (2004) stated that soil condition is among the factors influencing tractor traction performance. Abubakar *et al.* (2022) further listed the soil conditions and included soil moisture content, bulk density, soil texture, and shear strength.

As a result of the heterogeneity of agricultural soils, design of tractive devices and their performance is often based on experimental approach rather than analytical, with soil material collected from the location of intended use. The purpose of this work, therefore, was to experimentally determine the parameters of soil related to traction around *Ile-Apa*, a farming community close to Ilorin, the Kwara State capital.

2. MATERIALS AND METHOD

2.1 Study Area

Ile-Apa is located in Ilorin-South Local Government Area of Kwara State, Nigeria, on latitude 8° 26′ 6″ North and longitude 4° 40′ 52″ East at an altitude of 397 m above sea level. The community has a rural setting with the majority of inhabitants farmers. The road selected for this work is among farm roads, one linking *Ile-Apa* to the University of Ilorin. Figure 1 is an aerial map of *Ile-Apa* showing the selected road. Soil properties determined were soil cohesion (C), angle of internal friction (ϕ), moisture content (Mc), void ratio (e), porosity (n), and bulk density (ρ).

Figure 1: Aerial Map of *Ile-Apa* showing research selected road
Source: Google Maps (2023).

2.2 Determination of Soil Cohesion and Angle of Internal Friction

The translational (direct) shear box method was used to determine the apparent cohesion and angle of shearing resistance of the soil. Saturated soil samples for the test road were collected from random locations along the selected unpaved farm road, prepared into a cube, 0.061m^3, and placed in the box. A normal force (P) of 88.94N was exerted directly on the soil. A slow-running electric motor was used to apply a varying force tangential (F) on the upper half of the box at a constant rate. The force, F, was read directly from a proving ring while soil deformation (x) was simultaneously read from the dial gauge. Values of shear stress (τ) at each reading of F were determined by Equation 1.

$$\tau = \frac{F}{A} \qquad 1$$

where F is the A is the area of the shear plane = 3.721 x 10^{-3}m^2.

The procedure was repeated with different normal forces and shear stress at failure and recorded. The values of shear stress (τ) were then plotted against deformation (x) to determine the maximum shear load. The relationship between soil maximum shear strength (τ_f) and shear stress (σ′) is given by Sitkei (1986), Verruijt (2018) and Roy (2022) as:

$$\tau_f = C' + \sigma' tan\phi' \quad 2$$

Where C′ is soil cohesion and ϕ′ is angle of internal friction. Graphical method was adopted to estimate the values of C′ and ϕ′.

2.3 Determination of Soil Moisture Content, Void Ratio, Porosity, and Bulk Density

The oven method described by Tanam and Olaoye (2022) was used to determine the moisture content (Mc_{db}) (dry basis). Moisture content was determined using Equation 3:

$$Mc_{db} = \frac{m_1 - m_2}{m_2} \quad 3$$

Where m_1 is the mass of the saturated soil and m_2 is the mass of the oven-dry soil.

Since the soil was saturated, the volume of water removed was equal to the volume of void in the soil. Void ratio (e) was obtained by Equation (4).

$$e = \frac{V_v}{V_s} \quad 4$$

where V_v is volume of void and V_s is volume of solid soil particles.

The density of water (ρ_w) was taken as 1g/cm^3 and soil-specific gravity was taken as 2.7. Therefore, density soil solid (ρ_s) = 2.7ρ_w = 2.7gcm^{-2}. Dividing the mass of dry soil by ρ_s produced the volume of the dry soil.

Porosity (n) was determined from Equation 5.

$$n = \frac{V_v}{V} = \frac{e}{e+1} \quad 5$$

where V is the total volume of soil, m^3.

Bulk density was obtained as the ratio of the mass of the oven-dry soil to its total volume, expressed as Equation (6).

$$\rho = \frac{m_1 - m_2}{V} \quad 6$$

3. RESULTS AND DISCUSSION

3.1 Cohesion and Angle of Internal Friction

Figure 2 shows a graph of the series of shear stress and their corresponding deformation. Figure 2 showed that the first soil failed at a shear load of 17.5 kN with a normal load of 0.089 kN.

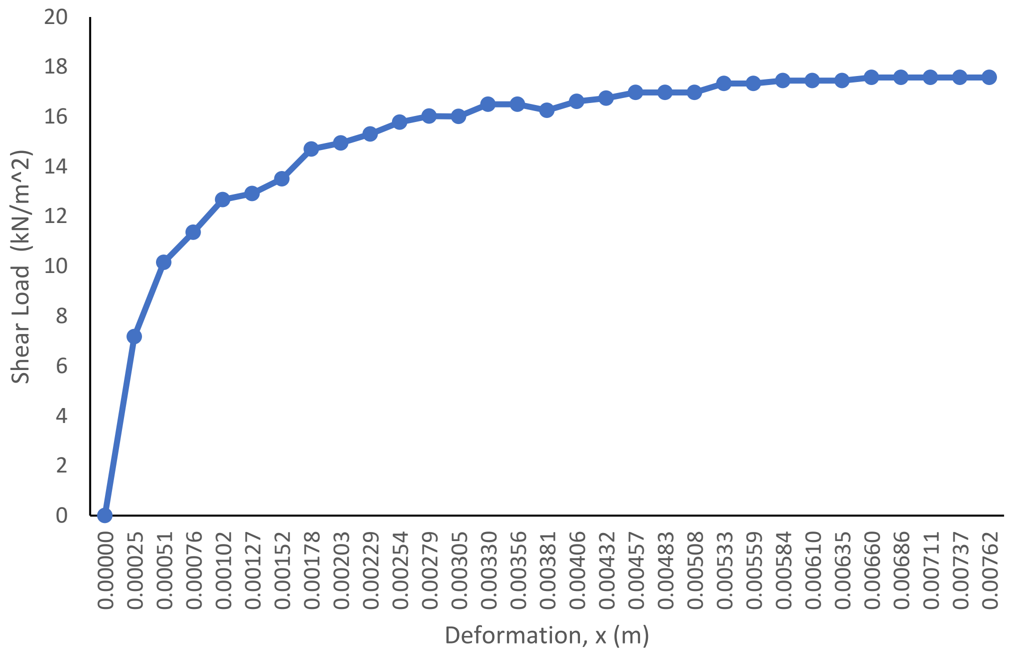

Figure 2: Graph of shear load against deformation.

It was observed the rate of deformation was lower at lower forces than at higher forces and increasing normal compressive load increased the maximum shear stress at failure. This observation is similar to that observed by Hu *et al*. (2020). The deformation was observed to be partially elastic with the possibility of returning to its original position when load is removed. However, at higher loads, the deformation became plastic and even brittle (Hu *et al*., 2020). For each soil sample tested, deformation continued even when no further force was applied beyond the maximum shear load. This showed that the soil had failed at that point. Deformation continued even when the tangential force was decreased. Table 1 is a summary of normal stress and shear stress for all soil samples.

Table 1: Summary of shear stress and normal stress from the translational shear test.

Normal Stress, σ (kN/m^2)	τ_{max} (kN/m^2)
23.91	17.57
29.83	19.84
41.92	28.87
47.84	33.47
53.75	37.54

Table 1 shows that the maximum shear stress was almost perfectly directly related to the normal stress with a positive correlation coefficient of 0.997. Increasing normal load led to an increase in shear stress at failure. Figure 3 is a graphical representation of the result. The intercept of the curve on the shear stress axis represents the soil cohesion (C) while the slope represents the angle of shearing resistance of the soil (ϕ).

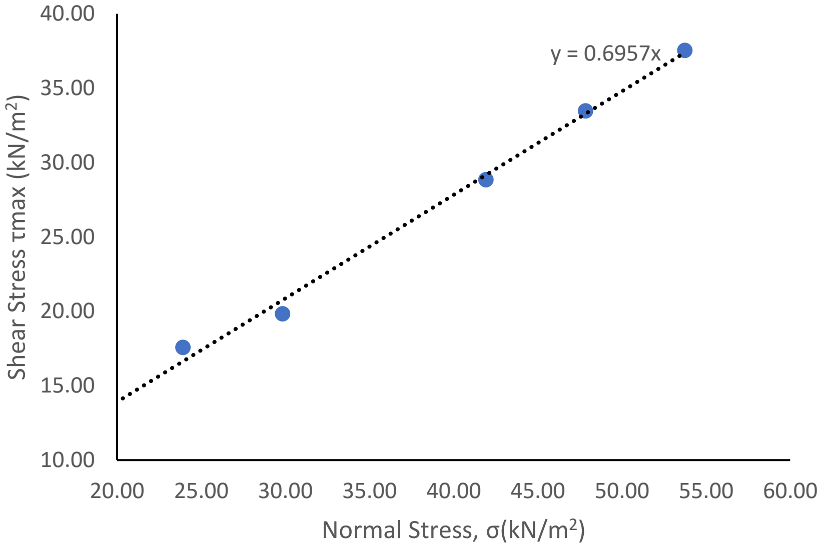

Figure 3: Graph of Shear stress against Normal stress showing the line of best fit.

From Figure 3, C was found to be 14.00 kN/m^2 or 1.4 N/cm^2 and the slope was obtained as 0.6957, giving an angle of internal friction of 34.84°. For the soil in *Ile-Apa* therefore, the relationship between the shear stress and normal stress may be expressed as Equation 7.

$$\therefore \tau = 1.4 + \sigma tan\, 34.84 \qquad 7$$

The low value of soil cohesion indicates that the soil is only slightly cohesive, representing a low clay content, whereas the observed high gradient is an indication that the soil is highly frictional, an indication of a high sand content. The soil along the unpaved *Ile-Apa* farm road may therefore be described as frictional-Cohesive and may be classified as sandy clay soil.

3.2 Moisture Content, Void Ratio, Porosity and Bulk Density

Equation 3 was used to determine the soil moisture content. Mass of the saturated soil was found to be 1526 g. Mass of the oven-dry soil was 1053 g. Moisture content (dry basis) was evaluated at 44.92%. With a moisture content of over 40%, trafficability is hampered by excessive wheel slip. This agrees with the findings of Abubakar *et al.* (2022), which showed that wheel slippage generally increased with increase in moisture. Abubakar *et al.* (2022) showed that a moisture content of 25% produced a wheel slippage of over 20% depending on the soil type.

The volume of the dry soil was found to be 390 cm^3. Applying this to Equation 4, void ratio (e) was calculated to be 1.213. This value is above average for typical soil which varies from 0.3 – 2.0 (Hillel, 2003). The implication is that soil compressibility is high. Therefore, when a heavy wheel load traverses the study road, there is a high chance of wheel sinkage, causing adjacent soil displacement. Trafficability is therefore impaired. Equation 5 showed that porosity (n) was 0.548, while Equation 6 returned a bulk density (ρ) of 1.768 g/cm^3. Again, the high value of porosity is an indication of possible soil compaction when a heavy vehicle travels over it, thereby causing damage to the soil and the vehicle, with heavy loss of manhours. *Ile-Apa* should therefore be avoided at the peak of rainy seasons when the soil is saturated.

4 CONCLUSIONS

Experimental values for the soil parameters related to traction showed that the *Ile-Apa* road lacks sufficient strength to support heavy loads when wet. Soil cohesion was found to be 1.4 N/cm^2 with a coefficient of internal friction of 34.84°. Moisture content, void ratio, porosity and bulk density were 44.92%, 1.213, 0.548 and 1.768 g/cm^3 respectively. A low load-bearing capacity would cause damage to the soil as the failure rate is quite high. There would be heavy loss of energy and manhours due to loss of traction. This road must therefore be avoided when rains are high, else, the road should be improved or appropriate tractive devices should be employed. Since this road may not avoided completely as farmer must continue with farming operations, it would be necessary to determine the optimum levels of these parameters with a view of advising offroad vehicle owner on the best period to engage the road.

REFERENCES

Abubakar, M.S., Sabo, A. A., Haruna, S.A. and Geidam, A. K. (2022). Determination of a wheel slippage of mf 375e tractor during ploughing and harrowing operations at the Agricultural and Environmental Engineering Departmental Farm of Bayero University, Kano Nigeria Proceedings of the Nigerian Institution of Agricultural Engineers. 84-94

Ajewole, P. O. and Fayose, F. (2012). Decision support system approach to farm machinery management in Nigeria. Proceedings of PASAE/NIAE International Conference. 169-177.

Ani, A. O., Akubuo, C. O., Odigbo, E. U. (2004). Tractability Conditions for Disc Ploughing on a Loamy Sand soil in the Ilorin Agro-Ecological Zone. Proceedings of the 5th International Conference of the Nigerian Institution of Institution of Agricultural Engineers (NIAE). Pp. 33-39.

Fenyvesi, L., Jóri, I. and Borsa, B. (2002). Reduction of the Energy Requirement by New Soil Cultivation Tools. ASAE/CIGR Paper No. 021140, Proceeding of ASAE/CIGR Annual International Meeting. Chicago July

Google Maps (2023) https://www.google.com/maps/@8.4943643,4.6942606,737m/data=!3m1!1e3?entry=ttu

Hillel, D. (2003). Soil Physics. In Encyclopedia of Physical Science and Technology 3rd Ed. Academic Press. 77-97

Hu, T., Liu, D., and Chang, J. (2020). Experimental study on strain rate effect of strength characteristics of unsaturated silty clay. Case Studies in Construction Materials 12 (2020) e00332 www.elsevier.com/locate/cscm

Roy, S (2022). Shear Strength Behaviour of Different Soils. Journal of Geotechnical Engineering. 9(1): 1-5

Mueller, L., Lipiec, J. Kornecki, T. S. and Gebhardt S (2011). Trafficability and Workability of Soils. In book: Encyclopedia of Agrophysics. 912-924

Sitkei, G Y (1986): Mechanics of Agricultural Material. *Developments in Agricultural Engineering*. Vol 8 1st Ed. *Elsevier Ebooks* https://www.elsevier.com accessed May 2011.

Tanam, U. I. and Olaoye, J. O. (2022). Determination of Crop and Machine Parameters Relevant to the Harvesting and Postharvest Handling of Acha Journal of Agricultural Engineering and Technology. 27(1). 52-61

Vedantu (2023: What is Tractive Force. https: https://www.vedantu.com/question-answer/what-is-tractive-force-class-11-physics-cbse-60c7576abb5f1a2d8304df29

Verruijt, A. (2018). An Introduction to Soil Mechanics. Springer International Publishing AG 163-186

Zoz, F. M. and Grisso, R. D. (2003). Traction and Tractor Performance: ASAE Distinguished Lecture No. 27, Agricultural Equipment Technology Conference, 9-11 February 2003, Louisville, Kentucky USA. ASAE Publication Number 913C0403.