BULK DENSITY, CONE INDEX AND WATER CONTENT RELATIONS FOR SOME GHANAIAN SOILS

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Abstract

Correlations were established between water content (θ), bulk density (ρ) and cone index (Δ) for 4 Ghanaian soils, namely, *Kumasi*, *Akroso*, *Nta* and *Offin* series. The relationship between Δ and θ is in the form $\Delta = a\theta^2 + b\theta + c$, where the correlation coefficients (r^2) for the various soils were found to be very high. Similarly, Δ - ρ relationships were linear but the correlations got weaker with increasing sand content of the soil, as expected. Soil sample sizes and compaction procedures did not conform to standard procedures, yet the results did not deviate from what pertains when standard procedures are used.

Keywords: water content, bulk density, cone index, soils, Ghana.

1. Introduction

The soil does not only serve as a medium for plant growth but also for engineering construction purposes. It is very weak in tension, very strong in compression and fails only by shearing. The behaviour of the soil under any form of loading and the interactions of the earth materials during and after any engineering construction work has a major influence on the success, economy and the safety of the work (Mitchell, 1976). Moreover, the soil also serves as a sink and recycling factory for numerous waste products which might otherwise accumulate and poison the environment. Soils and their management have therefore become a broad social concern. A limitless variety of soil materials are encountered in both agronomy and engineering problems, varying from hard, dense, large pieces of rock through gravel, sand, silt and clay to organic deposits of soft compressible peat. All these materials may occur over a range of physical properties, such as water contents, texture, bulk density and strength of soils. Therefore, to deal properly with soils and soil materials in any case requires knowledge and understanding of these physical properties.

The water content of the soil is an important property that controls its behaviour. As a quantitative measure of wetness of a soil mass, water content affects the level of compaction of soil, which is indicated by its bulk density. Soil bulk density is an indicator of the degree of compaction in engineering construction works. The desired value of bulk density varies with the degree of stability required in construction. Bulk density is also used as an indicator of problems of root penetration, soil aeration and also water infiltration. The cone index of a soil which is the degree of its strength has been shown to be affected by its water content and bulk density. This strength of soil has been widely used to predict the tractive capabilities of off-road vehicles, the draught forces in tillage operations and the compaction related to vehicle traffic. This property is also used in foundation engineering problems.

While not conforming to standard test procedures, this work attempts to add to the basic information on such important soil parameters as water content, bulk density and cone index for 4 Ghanaian soils namely, *Kumasi*, *Akroso*, *Nta* and *Offin* series.

2. **Materials and Methods**

2.1 **Brief description of the test soils**

The test soils are briefly described in Table 1 below:

Table 1. Brief description of the test soils

Ghana Classification	FAO-UNESCO Classification	Soil Texture	Soil Depth (cm)	Soil Colour	Slope (%)	Drainage
Kumasi	Orthic-Ferric Acrisol	Gravelly and gritty/sandy clay loam and clay	Up to 70 cm	Very dark greyish brown to dark brown soil, underlain by reddish brown or red coarse sandy clay loam or clay	3-12	Well drained
Akroso	Dystric-Haplic Nitisol	Coarse sandy clay loam	Up to 90 cm	Dark brown to brown coarse sandy loam to coarse sandy clay, underlain by brownish yellow or yellowish red coarse sandy clay loam	2-5	Moderately to imperfectly drained, moderately slow permeability
Nta	Gleyic Arenosol	Coarse sand or loamy coarse sand	Up to 150 cm	Pale brown or yellowish brown loamy coarse sand, underlain by yellowish brown coarse sandy loam	2-5	Imperfectly drained, rapid permeability
Offin	Stagnic-Dystric Gleysol	Stratified sands and clays	> 30 cm to a few meters thick	Dark grey to dark brown loamy sand and sandy loam humus stained topsoil, underlain by grey to brownish grey coarse sand	Relatively flat	Slow internal drainage, rapid permeability

Source: Adapted and Modified from Adu (1992)

2.2 Experimental methods

Soils belonging to the various groups described in Table 1 were collected, air-dried and sieved with the 2 mm sieve. Texture classes were determined by the hydrometer method. Using core samplers (5 cm diameter x 5 cm length), moist soils were compacted into the cores at different levels of compaction. Both ends of the soil cores were trimmed and one end covered while exposing the other. This is to allow for progressive drying of the core under room conditions. Using a pocket penetrometer, cone indexes were determined progressively as the soils in the cores dried up. The core samplers plus the moist soils were weighed each day as the soil dries up progressively. These took between 10 to 14 days to complete each set of data reading. At the last set of data reading, the samples were oven dried and the water contents and the wet bulk densities calculated. Dry bulk densities were also determined for each core sample. Correlations were established between water content, bulk density and cone index for the data generated.

3. Results and Discussions

3.1 Results

3.1.1 Textural class

The textural classes of the soils used were determined as shown in Table 2.

Table 2 Texture class of test soils

Soil Series	**Percentage Soil Fraction**			**Soil Texture**
	Sand	Silt	Clay	
Kumasi	63.6	9.8	26.6	Sandy clay loam
Akroso	71.6	11.8	16.6	Sandy loam
Nta	75.6	9.8	14.6	Loamy sand
Offin	83.6	9.8	6.6	Sand

3.1.2 Water content, bulk density and cone index

The data plotted for water content (θ) and cone index (Δ) generated polynomial equations of the form:

$$\Delta = a\theta^2 + b\theta + c; \qquad r^2 < 1.00 \qquad (1)$$

where, a, b and c are soil constants.

Straight line relationships were obtained between dry bulk density (ρ) and cone index as:

$$\Delta = m\rho + n; \qquad r^2 < 1.00 \qquad (2)$$

where, m and n are soil constants.

Detailed results are presented in Table 3.

Table 3. Water content, bulk density and cone index relationship

$\Delta = a\theta^2 + b\theta + c$					$\Delta = m\rho + n$
ρ	a	b	c	r^2	
Kumasi Series					
1.010	0.0048	-0.2519	3.4960	0.9611	m = 2.7909 n = -2.3545 r^2 = 0.8970
1.098	0.0038	-0.2110	3.1203	0.9946	
1.112	0.0029	-0.1614	2.4918	0.9963	
1.140	0.0029	-0.1664	2.6407	0.9944	
1.162	0.0032	-0.1799	2.7703	0.9815	
1.170	0.0041	-0.2394	3.6932	0.9918	
Akroso Series					
1.478	0.0155	-0.7087	8.3599	0.9824	m = 1.7793 n = -2.3820 r^2 = 0.7943
1.542	0.0241	-1.0500	11.811	0.9900	
1.641	0.0165	-0.7728	9.3165	0.9491	
1.645	0.0520	-2.0248	20.3130	0.9851	
1.649	0.0629	-2.3866	23.2490	0.9157	
1.700	0.0108	-0.5827	7.8100	0.9245	
Nta Series					
1.330	0.0037	-0.1743	2.2811	0.9319	m = 2.0891 n = -2.4764 r^2 = 0.8719
1.364	0.0036	-0.1737	2.3336	0.8963	
1.367	0.0034	-0.1625	2.1869	0.9347	
1.414	0.0098	-0.4044	4.3829	0.8480	
1.420	0.0067	-0.3026	3.6499	0.9440	
1.432	0.0073	-0.3216	3.7969	0.9224	
Offin Series					
1.257	0.0062	-0.3036	3.9371	0.7049	m = 1.9466 n = -2.0434 r^2 = 0.3727
1.278	0.0025	-0.1189	1.6875	0.9477	
1.313	0.0051	-0.2430	3.1615	0.9795	
1.347	0.0021	-0.1073	1.6234	0.9638	
1.354	0.0014	-0.0904	1.6834	0.9712	
1.372	0.0037	-0.1744	2.3475	0.9537	

3.2 **Discussion**

Being a sandy clay loam, *Kumasi* series has a clay content of 26.6 % and a sand content of 63.6 %. Its clay content is highest among the test soils and sand content, the least in the group. This suggests that it has the highest water holding capacity and at the same time the least dry bulk density values. Consequently, it recorded the least soil strength values at the same applied compactive efforts and as expected. For the *Kumasi* series, the cone index - water content relationships obtained at different dry bulk densities showed some trend. The soil constants a, b and c for the *Kumasi* series increase with increasing dry bulk densities to a maximum and then begin to fall as the bulk densities continue to increase. No definite trends were observed for the *Akroso*, *Nta* and *Offin* series as shown in Table 3. As expected, dry bulk density increased linearly with increasing soil strength for all the soils. However, dry bulk density has smaller effect than water content for determining soil strength, partly due to cementation changes that occur with soil wetting and drying.

It must be noted that the samples used for the tests were small, that is, equivalent to the volume of the small core sampler. Even though the standard proctor test procedure was not used in soil compaction, the results obtained suggest that the procedure adopted in this study has produced results that conform to the standard test procedures. The hand penetrometer used is an improvement on the thumb-fingernail technique for estimating the engineering consistency of cohesive soils and designed to penetrate the soil up to .0.6 cm only and to give a direct reading of unconfined compressive strength.

4. **Conclusion**

The procedures used for determining relationships between water content, bulk density and cone index did not conform to standard test procedures. But results obtained did not deviate from what could have been obtained using the standard procedures. The data generated for the 4 Ghanaian soils could at best serve as a useful guide for basic soil data generation for development planning. This work is continuing to confirm the test procedures.

References

1. Adu, S. V. (1992): *Soils of Kumasi, Ashanti Region, Ghana*. Soil Research Institute, Kumasi
2. Mitchell, J. K. (1976): *Fundamental of soil behaviour*. Macmillan Press.

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