GEOTECHNICAL INDEX PROPERTIES AND CORRELATION BETWEEN SOIL CLASSIFICATION SCHEMES: CASE STUDY OF TOMBIA AND ENVIRONS

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Abstract: In this study, laboratory testing of thirty disturbed soil samples obtained from eight boreholes in the project area was carried out to classify the soils and determine the correlation between the classification schemes. The Unified Soil Classification System (USCS), British Soil Classification System (BSCS), American Association of State Highway and Transportation Officials (AASHTO) and the United State Department of Agriculture (USDA) classification systems were used in the analysis. From the results, 6 samples each were of the Fat Clay (CH) and Lean Clay (CL) categories, 10 samples were classified as Clayey (SC) or Silty (SM) Sand, while 4 samples each were Poorly Graded Sand with Silt (SP-SM) and Poorly Graded Sand (SP) respectively based on USCS. The soil samples were also classified according to procedures stipulated by the other 3 classification schemes. Generally, the upper sections of the boreholes (< 10m depth) were dominated by fine (clay and silt) sediments, while the proportion of coarser (sand and gravel) geomaterials increased with depth. Correlation between the classification schemes was determined by analysing the consistency with which sample groups in the BSCS, AASHTO and USDA matched the corresponding sample group in the USCS. The analysis shows that 80% of samples that were classified as Fat Clay (CH) on the basis of USCS, classified as Clay of High Plasticity (CH) in BSCS, while 20% classified as Clay of Very High Plasticity (CV). The results also show that whereas 100% of the Lean Clay (CL) samples as per USCS, classified as Clay of Intermediate Plasticity (CI) in BSCS, 67% and 33% of the CL samples classified as A-7-5 and A-6 respectively in AASHTO. Comparison between USCS and USDA shows that while 10% each of CL samples as per USCS classified as Silty Clay (SIC) and Clay Loam (CL), the remaining 80% classified as Clay (C) based on USDA. Evidently, a better correlation exists between USCS and BSCS when compared to the correlation between USCS with either AASHTO or USDA. USCS can thus be interchangeably used with BSCS much more than it can be used with the AASHTO and USDA.

Keywords: Borehole, disturbed samples, correlation, plasticity, poorly graded, geomaterials

I. INTRODUCTION

Soil characteristics and properties are important to human daily living. A variety of disciplines (geology, agriculture, and engineering) require a systematic categorization of soil, detailing its physical properties. Due to different interests, numerous soil classification systems have been developed worldwide. According to Garcia-Gaines and Frankenstein (2015), soil classification systems can be divided into two main groups, one for engineering purposes and another for soil science. The purpose of soil classification is to group together soils with similar properties or attributes. Cline, (1949) stated that soil classification systems are used to help predict soil behaviour and provide information to geologists, engineers, builders, agricultural extension agents, community planners, and government agencies. Geoscientists and engineers use soil classification systems to characterize soils, determine potential behaviour, and understand the limitations of the soils encountered in construction projects. This knowledge is critical when designing airfields, roads, buildings, dams, bridges, and other infrastructure.

The first step in classifying a soil is to identify it. To be of practical value, a classification system should permit identification by either inspection or testing,

and tests should be as simple as possible. According to Buol et al. (2011), in this respect, tests that require disturbed samples are preferable: not only do they dispense with the need for undisturbed sampling or field testing but, in addition, the properties they measure do not depend on the structure of the soil mass. Properties such as grain size, mineral composition, organic matter content and soil plasticity are therefore preferred as a basis for a classification system rather than properties such as moisture content, density and shear strength.
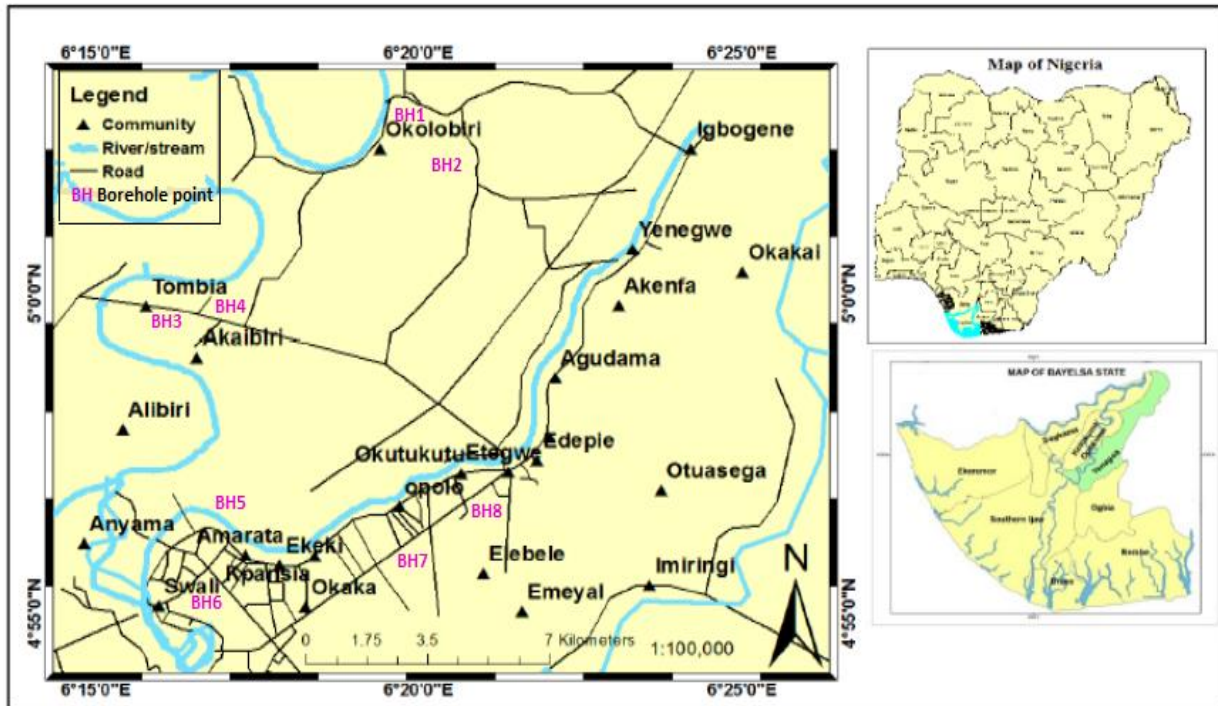

Figure 1: Map of study area showing sampling and sounding points

Implicit in the concept that soils with similar properties can be grouped together is the assumption that correlations exist between the various soil properties. However, since correlations are only approximate, classification systems can give only a rough guide to suitability and behaviour: a limitation which must be appreciated if classification systems are to be used sensibly. This is particularly important where a classification system based on the testing of disturbed samples is used to predict properties that depend on the state of the soil mass. For instance, since the shear strength of clay is heavily influenced by factors such as moisture content and field density, a classification system based on soil plasticity tests alone cannot be expected to predict bearing capacity to any great accuracy. Tingle et al. (2016) in their work, posited that even the best system of classification will never be able to give all of the information necessary for all practical purposes. It is therefore necessary to develop correlations between different soil classification systems and establish general guidance on critical material properties for all professional stakeholders. Providing a mapping tool to easily translate between soil classification systems will enhance communication during multidisciplinary or international efforts.

The objectives of this study is first and foremost to determine the geotechnical properties of the soils in the study area, secondly, classify them based on some of the widely used soil classification schemes and lastly establish possible interrelationships between the various classification schemes.

The sampled area of this investigation covers selected locations within yenagoa Local Government Area of Bayelsa State and is geographically located between latitudes 4^0 55'N and 5^0 51'N and longitudes 6^0 10'E and 6^0 25'E (Figure 1). The geology, hydrogeology and geotechnical characteristics of the area have been described by Doust, and Omatsola (1990), Etu-Efeotor and Akpokodje (1990) and Nwankwoala and Oborie (2014) respectively.

II. MATERIALS AND METHOD

Soil Sampling
Thirty disturbed soil samples were obtained from eight boreholes within the study area. Boring was performed using hand auger to a depth 6m in 4 borehole sites and manual percussion rig to a depth of 30m in 4 locations. The soil samples were secured in waterproof bags and brought to the laboratory for

sample preparation and testing. Atterberg limits and grain size distribution laboratory tests were carried out on the samples to determine their geotechnical index properties in accordance with ASTM (2010) D 4318 and ASTM (2007) D 422-63 standards respectively.

Grain size distribution test

The grain size distribution test of the soil samples were conducted using a set of sieves and hydrometer. Samples collected into the pan placed at the bottom of the set of sieves was used for the hydrometer test after mechanically shaking the assembly for the duration of about 10mins. Particle distribution curve was produced for each sample by plotting the percentage mass passing a particular sieve against the sieve mesh diameter.

Liquid limit and plastic limit tests

The moisture content at the Liquid limit boundary is arbitrarily defined as the water content at which two halves of a soil cake will flow together for a distance of 12.7 mm along the bottom of a groove of standard dimensions separating the two halves when the cup of a standard liquid limit apparatus is dropped 25 times from a height of 10 mm at the rate of two drops/second. The moisture content at the plastic limit boundary is arbitrarily defined as the water content at which a soil will just begin to crumble

when rolled into a thread 3 mm in diameter using a ground glass plate or other acceptable surfaces. The numerical difference between the liquid limit and plastic limit of a soil is referred to as plasticity index.

Soil Classification schemes

Four soil classification schemes were used in this study and the results were compared to evaluate interrelationships between the classification systems. The schemes include (1) Unified Soil Classification System (USCS) based on ASTM D2487-11, (2) British Soil Classification System (BSCS) following guidelines stipulated in BS 5930:1981 (3) American Association of State Highway and Transportation Officials (AASHTO) in line with AASHTO (2013) and modified by Das and Soban (2014), and (4) United State Department of Agriculture (USDA) based on USDA (1987).

III. RESULTS AND DISCUSSION

Representative results of grain size distribution and liquid limit laboratory tests of some selected soil samples are presented in Figures 2 and 3 respectively. The particle size distribution curve shows that the soil samples were predominantly composed of fine soils, fine-medium sands, with a lesser proportion of coarse sand and gravel fractions.
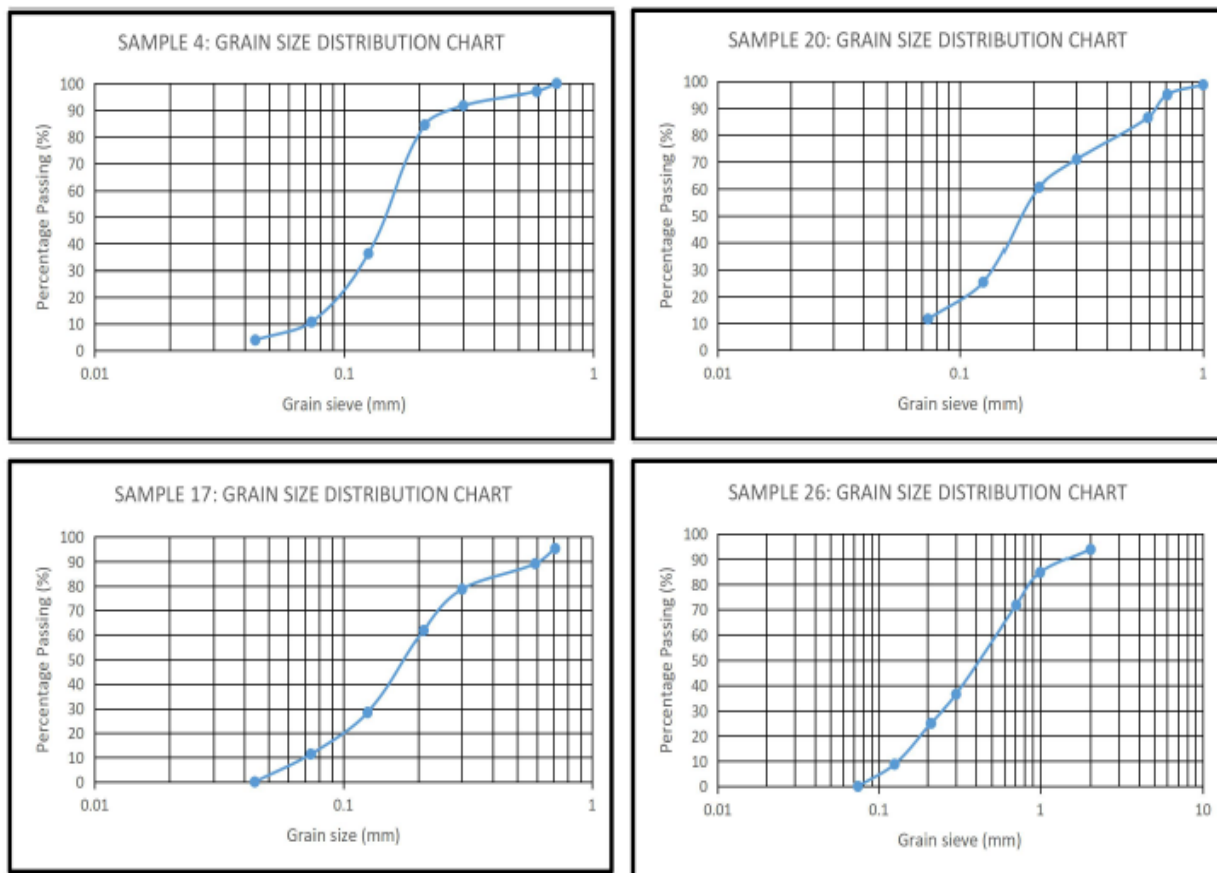

Figure 2: Grain size distribution chart of some soil samples in the study area

Casagrande chart (Figure 4) which essentially shows the relationship between plasticity index and liquid limit, also display domains into which the fine-grained soils and fine-grained fractions of coarse-grained soils are plotted or located in the classification. From the chart, it can be seen that most of the samples are sandwiched between the A-LINE and U-LINE and fall within the CL section.

It is noteworthy that, the USCS, BSCS and AASHTO schemes rely upon both particle size gradation and Atterberg limits for their classification, while USDA is based only on grain size analysis of the soil samples. A comprehensive summary of the laboratory analytical results which include grain type (size), liquid limit (LL), plasticity index (PI) and the four classification scheme results is presented in Table 1. Liquid limit values determined from the analysis ranged between 22%-73%, the plastic limit

(PL) was 16%-36%, and plasticity index ranged between 6%-41%.

USCS
The basic criteria for determination of the USCS classification for soil samples include: (a) % passing through 0.075mm sieve, (b) % retained in 0.075mm sieve (c) the value of LL (d) the section in which PI against LL of sample plots with respect to the A-line on the Casagrande plasticity chart, and (e) gradation of the sample. From the results, classification of the thirty soil samples was such that, 6 samples each were of Fat Clay (CH) and Lean Clay categories respectively, 10 samples were classified as Clayey Sand (SC) or Silty Sand (SM), while 4 samples each were Poorly Graded Sand with Silt (SP-SM) and Poorly Graded Sand (SP) respectively. Generally, the upper sections (< 10m depth) were dominated by fine (clay and silt) sediments, while the proportion of coarse (sand and gravel) increased with depth.
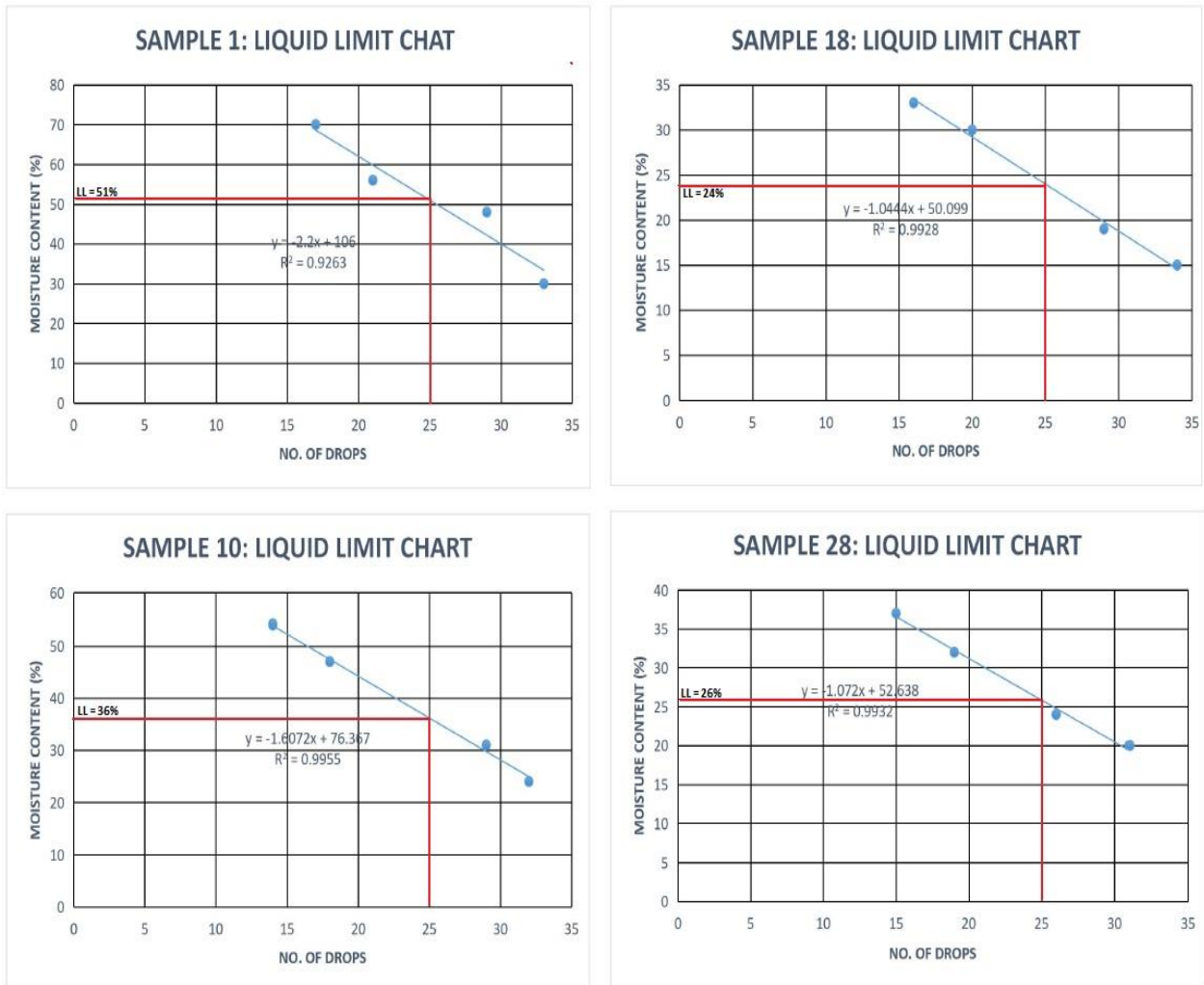

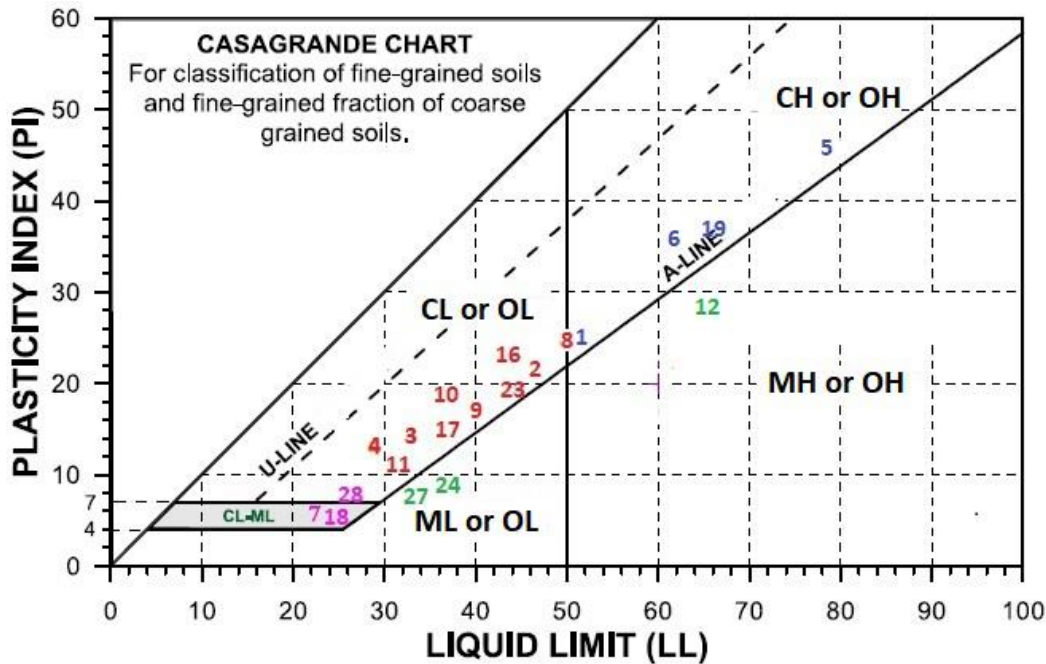Figure 3: Liquid limit determination plot of selected soil samples

Figure 4: Casagrande plasticity chart

Table 1**:** Geotechnical index parameters and classifications of soil samples

Sample no.	% Gravel	% Coarse Sand	% Medium Sand	% Fine Sand	% Silt	% Clay	LL	PI	USCS	BSCS	AASHTO	USDA
1	-	-	-	-	9	91	51	22	CH	CH	A-7-6	C
2	-	-	-	-	25	75	45	21	CL	CI	A-7-5	SIC
3	-	-	8	48	15	29	32	14	SC	SCL	A-6	SL
4	-	-	12	57	8	23	28	12	SC	SCL	A-6	SCL
5	-	-	-	-	16	84	73	41	CH	CV	A-7-6	C
6	-	-	-	-	22	78	61	34	CH	CH	A-7-6	C
7	-	-	15	51	23	11	22	6	SM	SML	A-2-4	SL
8	-	-	-	-	25	75	50	22	CH	CH	A-7-5	C
9	-	-	-	27	17	56	40	16	CL	CI	A-6	C
10	-	4	15	20	24	37	36	18	CL	CI	A-6	CL
11	-	7	17	42	21	13	30	11	SC	SCL	A-2-6	SL
12	-	-	-	-	14	86	65	29	MH	MH	A-7-5	C
13	-	-	-	18	23	59	49	26	CL	CI	A-7-5	C
14	-	-	11	46	16	27	34	13	SC	CLS	A-6	SCL
15	-	5	19	42	13	21	27	9	SC	SCL	A-2-4	SL
16	-	-	-	-	22	78	46	22	CL	CI	A-7-5	C
17	-	4.1	30.1	45.9	9.6	10.3	36	16	SC	SCI	A-2-4	SL
18	-	-	16.4	38.6	18.3	26.7	24	6	SC-SM	SCH	A-2-4	SCL
19	-	-	-	-	8	92	62	34	CH	CH	A-7-6	C
20		4.9	34.4	51.1	9.6	-	-	-	SP-SM	SPC	A-3	S
21	-	17.8	60.5	16.5	5.2	-	-	-	SP-SM	SPM	A-3	S
22	12.4	43.1	37.7	6.8	-	-	-	-	SP	SP	A-1-b	S
23	-	-	-	-	19	81	48	20	CL	CI	A-7-5	C
24	-	3.3	38.3	47.8	10.6	-	33	9	SP-SM	SPM	A-2-4	S
25		5.2	52.7	35.6	6.5	-	-	-	SP-SM	SPM	A-2-4	S
26	5.8	22.9	46.2	25.1	-	-	-	-	SP	SP	A-1-b	S
27		3.1	33.9	46.3	12.5	4.2	32	9	SM	SPM	A-2-4	LS
28		1.8	28.5	49.6	11.4	8.7	26	6	SC-SM	SPM	A-2-4	LS
29		17.2	52.5	28.1	2.2	-	-	-	SP	SP	A-3	S
30	1.6	21.8	40.2	36.4	-	-	-	-	SP	SP	A-3	S

BSCS
Results of the soil classification according to BSCS shows that 4 samples were Clay of High Plasticity (CH), 1 sample each was classified as Silt of High Plasticity (MH) and Clay of very High Plasticity (CV) respectively. Clay of Intermediate Plasticity (CI) were 6, while 8 samples were categorised as

Very Clayey or Silty Sand (SCL or SML). Six (6) of the samples were classified as Poorly Graded Silty or Clayey Sand while the number of Poorly Graded Sand samples were 4. The criteria for sampling in BSCS is similar to that of USCS, a basic difference however is that whereas the interface between coarse and fine soil is hinged on 50% of the sample passing

through or retained on 0.075mm sieve in USCS, it is determined by 35% passing through or retained on 0.06mm sieve in BSCS. Another difference is that the subdivisions of fine soils or fine soil fraction of coarse soils in BSCS classification are based only on the liquid of limit of the sample while for USCS it is based on both the plasticity index and liquid limit.

AASHTO
Based on AASHTO, 2 samples, 1 each from BH6 and BH7 belong to the A-1-b category, 4 samples with 2 each from BH6 and BH8 were of the A-3 soil type, while 8 samples were classified as A-2-4 type with at least one sample in all the boreholes except for BH1, BH3 and BH6. Only one sample was identified as A-2-6 sample, whereas 5 samples with 2 each from BH1 and BH3 were classified in Group A-6. A total of 10 samples were classified as either A-7-5 and A-7-6 with at least one sample of this category found in all the boreholes except for BH8. The results show that with regard to performance as sub-grade materials, poor to fair soil samples dominates soils collected from BH1-BH4, whereas good to excellent sub-grade geomaterials are dominant in samples recovered from BH5-BH8. This occurrence and distribution can be attributed to the depth at which samples were collected. Note that samples collected from BH1 to BH4 were generally obtained at relatively shallow depths ($\leq$ 6m), while the total drill depth for BH5-BH8 was 30m.
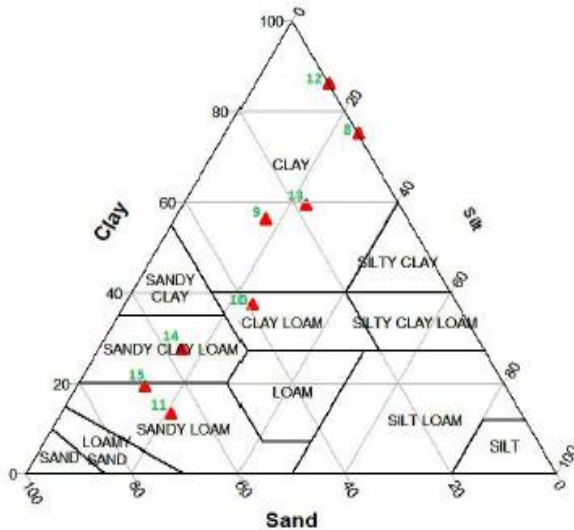
USDA
Figure 5 is a ternary diagram which shows sections in which the various soil samples were domiciled based on USDA classification. Analysis of the USDA classification scheme shows that 10 samples plotted in the clay (C) section, 8 samples plotted in the sand (S) section, 5 in the sandy loam (SL) section, 3 in the sandy clay loam (SCL) section, 2 in the loamy sand (LS) section and 1 sample each in the clay loam (CL) and silty clay (SIC) sections.
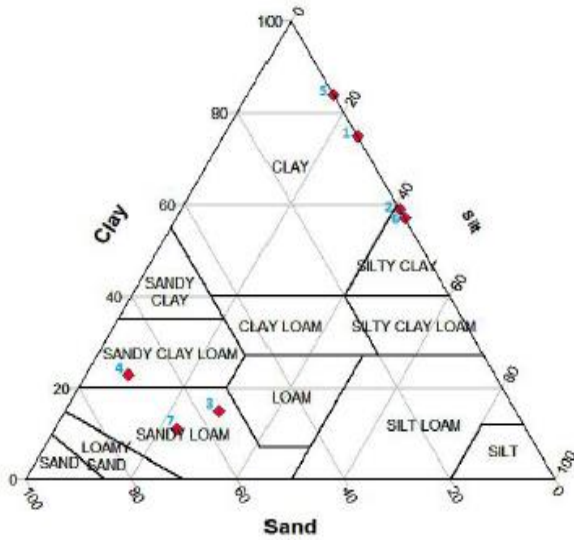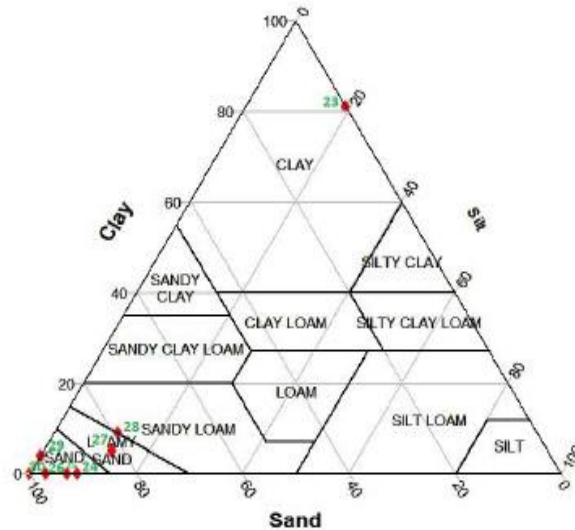
USDA classification (sample 1-7) BH 1 & 2
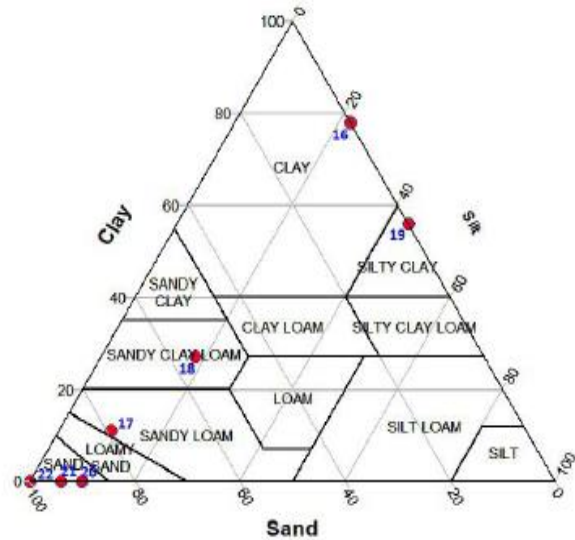
USDA classification (sample 16-22) BH 5 & 6

USDA classification (sample 8-15) BH 3 & 4

USDA classification (sample 23-30) BH 7 & 8

Figure 5: Results of USDA classification showing borehole and sample numbers

Correlation Between USCS and other Classification Systems

The interrelationship between USCS and the other classification schemes was evaluated by analysing the consistency with which particular category of samples was classified in the schemes been compared. For instance, 80% of samples that were classified as Fat Clay (CH) on the basis of USCS classified as Clay of High Plasticity (CH) in BSCS, while 20% classified as Clay of Very High Plasticity (CV). This implies that a CH sample based on USCS picked randomly from a set of samples will most probably classify as CH and less probably as CV in BSCS. Another example from the analytical results shows that whereas 100% of the Lean Clay (CL) samples as per USCS classified as Clay of

Intermediate Plasticity (CI) in BSCS, 67% and 33% of the CL samples classified as A-7-5 and A-6 respectively in AASHTO. A comparison between results of USCS and USDA classification shows that while 10% each of CL samples as per USCS classified as Silty Clay (SIC) and Clay Loam (CL), the remaining 80% classified as clay (C) based on USDA. Tables 6, 7 and 8 show the soil group or classification in USCS and comparable soil group in BSCS, AASHTO and USDA. The likelihood that a given soil sample will be classified in a comparable soil group with respect to USCS is designated "most probable" if the occurrence between the two schemes is 61-100%, "probable" if it is 30-60%, "possible" if its 11-30% and "improbable but possible" if it is 1-10%.

Table 2: Correlation between USCS and BSCS

Soil group in USCS	No. of samples	Comparable soil group in BSCS system and % occurrence			
		(61-100%)	(31-60%)	(11-30%)	(1-10%)
CH	5	CH	-	CV	-
CL	6	CI	-	-	-
SC,SM, SC-SM	10	SCL	-	SPM	SCI, SML
MH	1	MH	-	-	-
SP-SM	4	SPM	-	SPC	-
SP	4	SP	-	-	-

Table 3: Correlation between USCS and AASHTO

Soil group in USCS	No. of samples	Comparable soil group in AASHTO system and % occurrence			
		(61-100%)	(31-60%)	(11-30%)	(1-10%)
CH	5	A-7-6	-	A-7-5	-
CL	6	A-7-5	A-6	-	-
SC,SM, SC-SM	10	A-2-4	A-2-6	-	-
MH	1	A-7-5	-	-	-
SP-SM	4	-	A-2-4, A-3	-	-
SP	4	-	A-1-B, A-3	-	-

Table 4: Correlation between USCS and USDA

Soil group in USCS	No. of samples	Comparable soil group in USDA system and % occurrence			
		(61-100%)	(31-60%)	(11-30%)	(1-10%)
CH	5	C	-	-	-
CL	6	C	-	CL, SIC	-
SC,SM, SC-SM	10	-	SL	SCL, LS	-
MH	1	C	-	-	-
SP-SM	4	S	-	-	-
SP	4	S	-	-	-

IV. CONCLUSION

Soil classification systems provide a common language to concisely express the general characteristics of soils and can be used to predict soil behaviour and provide information for professionals, community planners, and government agencies. Whereas it may be desirable for an analyst to use most of the available soil classification schemes in characterising soils for a particular project, the cost implication and time constrain may deter him from doing so. The alternative is to rely on established correlations between soil classification schemes, noting that every classification scheme has its strengths and weaknesses.

This work has highlighted some useful correlations between the USCS, BSCS, AASHTO and USDA for soil samples analysed in the study area. The USDA classification scheme, however, has limited application in site characterization for civil engineering projects because unlike the others it based only on grain size distribution with no reference to the Atterberg limits of the soil. From the results, a greater correlation exists between USCS and BSCS, while the least correlation was seen between the USCS and USDA.

V. ACKNOWLEDGEMENT

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