The use of locally available sand in stabilization of Ugandan clayey soils: Case study of clayey soil from Busega area

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Abstract

Clayey soils need to be stabilized to improve their engineering properties and make them suitable for pavements and foundation engineering. Stabilization of pavements and foundation engineering soils in Uganda has traditionally relied on treatment with lime and cement and most designers (engineers) are hesitant to specify nontraditional stabilizers, like sand, without evidence of material effectiveness. This study aimed to use sand to improve the engineering properties of a typical Ugandan clayey soil. Sand was specifically selected because of its abundance locally. A series of laboratory experiments were implemented for specimens whose sand contents ranged between 20 - 80%. The results confirmed that sand blending diminishes shrinkage behavior of clayey soils. Additionally, plasticity index and shrinking potential decreases from 30.5% to non-plastic and from 9.3% to 1.8% respectively depending on the sand concentration in the composite. The MDD and OMC increased from 1867 to 2357 kg/m^3 and decreased from 16.5 to 8.5%, respectively, at sand blends of 20-100% while the unconfined compressive strength decreased from 787 to 95kPa at sand blends of 20-60%. The soil internal friction angle concerning shear strength parameters was enhanced from 26.6 to 42.1^o and soil cohesion decreased as well from 62 to 2kN/m^2 at sand blends of 20-80%. At sand blends 20-80%, consolidation settlement was lowered from 2.00 to 1.52.

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Keywords: clay-sand soil blends, shrinkage limit, modified compaction, unconfined compressive strength, shear strength, consolidation.

1. INTRODUCTION

Construction in problematic soils, such as clayey soils located in the low lying areas of the city traditionally not inhabited before the economic boom, is on the increase in Kampala and its suburbs due to the continued growth of the construction industry in Uganda at an average rate of 8.8% per annum since 1995/96. This growth is attributed to the country's rehabilitation efforts as well as new investments in real estate since 1986 (Construction and Building Industry Report, 2001). The problems in clays are due to its undesirable properties such as low strength, high swelling capacity, low bearing capacity and high levels of instability when unsupported (Jirathanathaworn et al, 2002). According to Jirathanathaworn et al (2002), in order to proceed with constructions under such soil conditions, some techniques are needed to improve their mechanical properties.

Lime has been used either in isolation or with other stabilizing agents to treat marginal soils like clay but it has been found to be expensive especially in third world countries like Uganda (Manella et al, 2004). Re-use of materials found on site is more sustainable and environmentally beneficial than the traditional method of "dig and dump". Soil stabilization is an economical and popular way to enable the re-use of these materials (Ground Engineering Magazine, 2009). According to Ameta et al (2007), it has been found that appropriate stabilization of clay by mixing with dry sand can improve undesirable characteristics of clayey soil.

Sand is one of the materials which are readily available and its constituents can easily be controlled (Construction and Building Industry Report, 2001). According to Adam and Agib (2001), in order to achieve higher quality and production costs reductions, proportions between soil, stabilizer and compaction pressure need to be optimized taking into consideration the specific characteristics of the soil. In spite of all this, little work has been done to obtain the requirements of sand for stabilizing clay in the vicinity of Kampala to obtain optimum results. Therefore, this study was aimed to use sand to improve such undesirable properties of clay as low strength, low bearing capacity and high levels of compressibility. The work concentrated on the characteristics of both clay and sand soil samples and the effect of stabilizing clay by mixing it with dry sand.

MATERIALS AND METHODS

1.1 Clayey soil

Bulk samples of clayey soil were obtained from Busega area, one of Kampala's latest and busiest suburbs in terms of real estate development. The samples were consistent, in terms of particle size grading, chemical composition and index properties compared to those found in many other low lying areas of Kampala making it suitable for repeatability of results. From *Figure 1,* the particle size distribution graph, it is illustrated that the soil specimen was a poorly-graded fine-grained soil. In general the soil sample was classified as sandy clay of intermediate plasticity. The characteristic properties of the soil specimen are summarized in *Table 1*, in which the sample had a plasticity index (PI) of 30.5% indicating it was venerable to swelling when wet.

2.2 Stabilizing sand

From *Figure 2*, it is illustrated that the stabilizing sand was a well-graded coarse-grained soil. This sand was specifically selected because of its availability locally from areas around Lake Victoria. The sample used in this study was obtained from Kazi scouts campsite along Busabala road. It was clean, consistent and easily controllable; that is identical samples could be reproduced if prepared the same way. Summary of the soil mechanical properties is presented in *Table 1.*

2.3 Sample preparations

The clay sample was collected disturbed in buckets and sacks. In the laboratory, the soil sample was air-dried for nearly 72 hours and then passed through sieve No.350 (0.045mm) to remove larger particles. Specimens with specified amounts of sand added to the clay sample were prepared by mixing the sand, passed through sieve No. 7 (2.36mm), with clay in the quantities of 0, 20, 40, 60, 80 and 100%. The mixing was done mechanically on a metal tray. For consistency, clay was mechanically blended before mixing with sand. The notations C_{00}, C_{20}, C_{40}, C_{60} and C_{80} denote the specimen samples containing concentration of 0%, 20%, 40%, 60% and 80% of stabilizing sand respectively. In order to examine the effect of sand on the properties of clayey soil, tests of physical properties of the different sand/clay blends were conducted. The tests included: liquid limit, plastic limit, specific gravity and shrinkage limit. Strength values for the compacted un-improved and improved clayey soil were investigated by UCS, shear box and consolidation tests. Due to the emergency of larger and heavier machines to increase the amount of compaction of the soil, the standard compaction test cannot reproduce the densities measured in the field hence the modified compaction test was used in the study.

2.4 Tests Conducted

2.4.1 Atterberg Limits test

The cone penetrometer method was used in this study to determine the liquid limit of the clay/sand mixtures. As the moisture content of the soil sample was increased by small amounts, the penetration of the cone was noted and plotted against the respective moisture content. From the same soil sample, a specimen was dried to near its plastic limit by air drying. It was then molded into a ball and rolled between the palms of the hand and glass plate to threads of nearly 3mm in diameter. The soil was now considered to be at the plastic limit and its moisture content determined.

2.4.2 Proctor test

The modified compaction test was used. The soil was compacted in five layers of equal thickness, into a metal mould of 105mm diameter and of one liter capacity. Each layer received blows from a 4.5kg mass falling freely through a height of 450mm, with 27blows in the one liter mould. The moisture content of the soil was adjusted, up or down, and the test was repeated to give at least five density values. The dry density of the soil was calculated and plotted versus moisture content.

2.4.3 Unconfined Compressive Strength test

UCS tests were conducted on the clay samples as well as on sand/clay blends. Cylindrical specimens used for the experiments were 105 mm diameter and 127 mm height. The samples used for the UCS tests were at their optimum moisture contents. Specified amounts of sand were added to screened clay soil and mixed well for homogeneity. The mixture was placed in five layers in a UCS steel mold having an inside diameter of 105mm and height of 127mm. All the different soil mixes were compacted as to the modified method (BS 1377: Part4: 1990), trimmed at both ends and wrapped in plastic bags. The UCS tests for the un-stabilized and stabilized clay samples were conducted on all extracted specimens using a strain rate of 1.27mm/min immediately after mixing. Corrections to the cross-sectional areas were applied prior to calculating the compressive stress on the specimen. Each specimen was loaded until peak stress was obtained.

2.4.4 Shear box test

Cylindrical specimens from the modified compaction test were extracted into rings of 60mm x 60mm x 20mm (three specimens extracted from each cylindrical specimen). Shear box testing was performed on all extracted specimens using a strain rate of 1.5095mm/min. Corrections to the sectional areas were performed prior to calculating the shear stress on the specimens. Three normal stresses of 75, 102 and 129kN/m^2 were applied and each specimen loaded horizontally until peak shear was attained. From the shear box test, the apparent cohesion and internal friction angle were obtained.

2.4.5 Consolidation test

Conventional 1-dimensional consolidation tests were performed on 75mm diameter and 20mm high soil specimens in the fixed-ring type odoemeter. The sides of the rings were smeared with silicone grease to reduce side friction. Samples of the soil blends were remolded at their respective optimum moisture contents using modified compaction. A load increment ratio (ratio of increase in pressure to the existing pressure) of 1 was adopted. The load was sustained sufficiently long to ensure completion of primary consolidation (24 hours).

3. RESULTS AND DISCUSSION

3.1 Physical properties of sand/clay blends

The cone penetrations for the different sand/clay blends were plotted against the corresponding moisture contents as shown in *Figure 3*. The resulting liquid limits and plastic limits were read off and plotted against the concentration of stabilizing sand as shown in *Figure 4*. The liquid limit and plastic limit of the resulting sand/clay blends all decreased as the concentration of the sand increased. The plasticity of the clay decreased from 30.5% to 22.7%, 22.7% to 15.25% and 15.2% to 10.6% with addition of 20%, 40% and 60% of sand, respectively. This conforms to what was expected as the increased addition of sand soils which are non-cohesive reduces the binding ability of the mixture and its ability to retain moisture. At 80% of sand, the clay-sand mixture was totally non-plastic. The decreasing plasticity would consequently result in decreasing swell-ability of the soil samples. All the resulting sand/clay mixes had liquid limits less than 50% evidence of lower plasticity. Such blends are suitable for both highways and foundation engineering. Materials having liquid limit greater than 50% are indicative of high plasticity soils. It is evident from *Table 2* that the addition of sand to the clay sample decreased its shrink-ability as was expected, evidence that the soil sample would be less susceptible to crack when dried. The addition of sand to the clay sample increased the specific gravity with increased addition of sand as expected since sand particles weigh more and occupy more volume per unit space than the clay particles, thus less dense.

3.2 Modified compaction characteristics

As seen from *Figure 5*, the MDD and OMC of the resulting soil blends increased and decreased respectively with higher sand concentration. This can be attributed to the variation in PI and SG. Reduction in PI results in lower binding and moisture retention abilities of the soil. Therefore, soil type is a major variable in establishing the moisture density relationships. Well-graded soils exhibit higher MDDs than poorly graded soils while finer soils exhibit higher OMCs and lower MDDs than coarser soils. Blending the soil specimen with the stabilizing sand improved the grading range of the composite making it coarser. The MDD was in the range of 1959 – 2357kg/m^3 at stabilizer contents of 20 to 100% inclusive while OMC in the range of 13.4 – 8.5% in the same range of stabilizer content. Usually soils with MDD greater than 2Mg/m^3 and OMC less than 15% are easier to compact. All blends having concentration of added sand between 20 and 100% satisfy these specifications and would therefore perform excellently in pavements and foundation engineering.

3.3 Unconfined compressive strength of soil blends.

The addition of sand to the clay sample decreased the unconfined compressive as shown in *Figure 7*. There was a very sharp decrease of 40% from 787kPa to 479kPa of the unconfined compressive strength with the addition of 20% of the sand to the clay sample. At 80% of the concentration of stabilizer, the cylindrical specimens could not be extruded from the moulds without collapse. From *Figure 8*, at the level of this mixture the cohesion was nearly zero. Hence, the UCS test could not be conducted at this concentration and above. It can be seen from *Figure 6* that the axial stress for each soil blend first increased, reached a maximum and then decreased with increasing strain. The maximum value of the axial stress is the UCS value for each soil blend at the attained strain value. The variation in the unconfined compressive strength, as seen in *Figure 7*, can be attributed to the reduction in the silt and clay content of the soil samples (Leonards, 1962), which reduces the cohesion and the binding ability of the samples.

3.4 Cohesion and Internal friction angle of soil blends

From *Figure 8* and *Table 3*, the coefficient of cohesion decreased with increased concentration of the stabilizer while the angle of friction increased as expected. The presence of the well graded particles coupled with an intermediate plasticity index leads to a high apparent cohesion. This is evidently shown by the clay sample with no sand added which had the highest apparent cohesion. Plasticity is an indication of the binding ability of the soil particles and the higher the plasticity, the higher the binding ability of the soil particles.

The coefficient of cohesion and angle of friction values were read off from the plots of peak shear stress versus normal load. These were then plotted against plasticity index of the different blends as shown in *Figure 9*. It is evident from the figure that apparent cohesion increased while friction angle decreased with increasing plasticity. Higher plasticity results into the soil particles to slip easily resulting to lower friction.

From the respective cohesion coefficient and friction angle values, the ultimate bearing capacity was computed using the equation below *(Table 5).* The computation assumed square pad foundations of 1.0 m x 1.0 m, since these are the least dimensions commonly used in Uganda for pad footings to a depth of 1.0 m.

$$Q_{ult} = CN_c + \gamma D(N_q - 1) + 0.5\gamma BN_\gamma,$$

where Q_{ult} = ultimate bearing capacity
C = coefficient of cohesion
D = depth of the footing
B = breadth of the footing
γ = unit weight of the soil
N_c, N_q, N_γ = bearing capacity factors

It can be seen from *Figure 10* that the bearing capacity of the sand/clay mixtures increased with increased concentration of the stabilizing sand peaking at 60%. The obtained values indicated bearing capacity values at a depth of 1.0 m ranging from 2081.5kN/m^2 for C_{00} to 7685kN/m^2 for C_{60}. The low bearing capacity for C_{80} was due to the low bonding between the soil particles, (Leonards, 1962). All the soil blends had high bearing capacities, hence being favorable for foundation and highway use.

3.6 Compressibility of soil blends

The voids ratio of the different sand/clay mixtures was plotted against the logarithm of the applied pressure at each stage as shown in *Figure 12.*

The curves corresponding to all the resulting blend mixtures are similar but their void ratios at any given pressure decreases with increased concentration of added sand. Voids ratio, e, depends on the shape of the grains, the uniformity of grain size and the conditions of sedimentation. Voids increases with increased uniformity of grain size. The voids ratio for the different mixture blends decreased with increased addition of sand due the reduction in the uniformity of the grains' size.

The compressibility of clays is influenced by both mechanical and physicochemical effects (Olson and Mesri, 1970), depending upon the type of mineral, saturating cation and pore fluid. The term "mechanical" is used to denote short-range particle interactions controlled by the physical properties of the mineral particles, that is, by their strength and flexibility and by surface friction. The term "physicochemical" signifies comparatively long-range interactions between particles, especially through diffuse double layers. The virgin compressibility of kaolinite and illite, even in the case of polar pore fluids, is primarily controlled by mechanical effects, where as physicochemical effects control the compressibility of montmorillonite (Olson and Mesri, 1970).

From *Figure 12*, the compressibility index decreased with increasing concentration of sand. This was due to the increase in the strength and friction of the soil particles and also the breakdown of the double layer of the clay particles due to the introduction of the sand particles. The correlation coefficient value of 0.885, greater than 0.81, represents a statistically significant relationship between coefficient of compressibility and the concentration of stabilizing sand (Johnson, 1984). The slope of the line of best-fit of 0.008 indicates a low a rate of decrease of the coefficient of compressibility with increasing concentration of stabilizing sand.

3.7 Practical Implication

Kyasanku (2000), investigated the engineering properties (natural moisture content gradation, Atterberg limits, specific gravity, maximum dry density, optimum moisture content, cohesion, angle of internal friction and California bearing ratio) of murram deposits around Kampala (Namasuba hill, Mutundwe hill, Makerere hill, Mbuya hill and Kireka hill). *Table 6* below gives the summary of his findings.

From Kyasanku's work (2000), murram from Mbuya hill had the highest plasticity index of 21.25% and from this research, only clay samples with 40%, 60% and 80% had plasticity lower than this. But, the higher the plasticity index of a soil, the higher the swelling ability of the soil samples when wet, the higher the binding ability of the soil particles, the higher the cohesiveness and the higher the ability to retain moisture and shrinkage ability when loosing it. In regard to plasticity, murram from the different sites would be preferred to the different sand/clay blends with different concentrations of additional sand.

Murram from Makerere hill had the highest maximum dry density of 2.19Mg/m^3 and only clay samples containing 60% and 80% percentage of additional sand had maximum dry density greater than this. The higher the maximum dry density the higher the compressive strength and usually, soils with MDD greater than 2Mg/m^3 and OMC less than 15% are easily compacted and these samples would perform excellently in pavements and foundation engineering. In regard to maximum dry density, all the murram samples from the different sites would meet the required specifications therefore preferred.

From *Table 6*, Mbuya attained the highest coefficient of cohesion of 26.10kN/m^2 with internal friction angle of 41.3^o while Namasuba hill attained the highest internal angle of friction of 42.8^o with cohesion of 23.9kN/m^2. From Table 3, blend with 0% of added sand attained the highest cohesion of 62kN/m^2 with 26.6^o of internal friction angle while blend with 80% of added sand attained the highest internal friction angle of 42.1^o with cohesion of 2kN/m^2. The lower the coefficient of cohesion the higher the internal friction angle and bearing capacity. In regard to bearing capacity, the sand/clay blends would be preferred to the different murram samples.

4. CONCLUSIONS

From the results of the laboratory-scale experiments, the following may be concluded concerning the use of dry-sand mixing in improving the engineering properties of a typical Ugandan clayey soil:

- The clay sample was classified as fine-grained sandy clay of intermediate plasticity while the sand sample was classified as coarse-grained and well-graded.
- From the modified proctor compaction test, various optimum moisture contents with their maximum dry densities were obtained when different concentrations of sand were added.
- The highest unconfined compressive strength achieved was 787kPa with un-stabilized clay sample and it was found that the higher the concentration of added sand, the lower the value of the unconfined compressive strength that can be obtained.

- The highest bearing capacity achieved was 2561.66kPa, which is 3.7 times higher than that of the untreated clay soil sample and it was found that the higher the concentration of added sand, the higher the value of the bearing capacity that can be obtained up to 60% concentration of added sand.
- The clay sample with 60% concentration of added sand had the lowest coefficient of compressibility of 0.52×10^{-5}, which is 3.8 times lower than that of the untreated clay soil sample.

The different clay-sand combinations can be used for different engineering applications as recommended:

- The clay sample was well-graded therefore suitable for use as a backfill in foundations.
- The clay sample with 80% concentration of added sand had the lowest plasticity and shrinkage limit, thus, it can be used as a backfill in retaining walls although it had a high specific gravity hence high horizontal pressures.
- Soils for use as backfills in foundations have to be of low shrinkage, low coefficient of compressibility, high specific gravity and maximum dry density hence high bearing capacity. The clay sample with 60% concentration of added sand satisfies these conditions.
- Clay samples with 40%, 60% and 80% concentrations of added sand satisfy the conditions for use as pavement layers in road construction, although the one with 60% concentration is recommended for use because of low shrinkage and high maximum dry density and specific gravity hence high bearing capacity.

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Table 1: Physical properties of soils used

Physical property		Clay	Sand
Coarse fraction (Sand, %)	BS1377: Part2: 1990	30.2	100
Fine fraction (Clay, %)	BS1377: Part2: 1990	52.8	0
Shrinkage potential (%)	BS1377: Part2: 1990	9.3	0
Liquid limit (%)	BS1377: Part2: 1990	49.4	0
Plasticity index, PI, (%)	BS1377: Part2: 1990	30.5	0
Specific gravity, SG	BS1377: Part2: 1990	1.63	2.56
Natural moisture content, NMC, (%)	BS1377: Part2: 1990: 3.2	20.76	-
Maximum dry density, MDD, (Mg/m^3)	BS1377: Part4: 1990	1.87	2.4
Optimum moisture content, OMC, (%)	BS1377: Part4: 1990	16.5	8.5
Unconfined compressive strength, UCS, (kPa)	BS1377: Part4: 1990	625.20 – 898.08	-
Apparent cohesion (kPa)	BS1377: Part7: 1990: 4	62	0
Internal angle of friction (^{o})	BS1377: Part7: 1990: 4	26.6	42.8
Coefficient of compressibility	BS1377: Part5: 1990	2	-

Table 2: Physical properties of soil mixes

Specimen reference	**Unified soil classification of soil blends**	**Linear shrinkage (%)**	**Specific gravity**
Clay	Sandy clay of intermediate plasticity	9.3	1.63
Clay + 20% sand	Sandy clay of intermediate plasticity	6.8	2.26
Clay + 40% sand	Sandy clay of low plasticity	5.7	2.32
Clay + 60% sand	Sandy clay of low plasticity	4.3	2.46
Clay + 80% sand	Sandy silt of low plasticity	1.8	2.55

Table 3: Summary of the shear box test results

Specimen reference	Cohesion (C)	Angle of friction (θ)
Clay	62	26.6
Clay + 20% sand	60	28.1
Clay + 40% sand	50	29.4
Clay + 60% sand	24	40.9
Clay + 80% sand	2	42.1

Table 4: Summary of unconfined compression test results

Specimen reference	DD (kg/m^3)	MC (%)	Compressive strength	
			Individual (kPa)	Average (kPa)
Clay	1936.59	17.00	625.20	
Clay	1986.50	17.00	837.63	787.0
Clay	2001.48	17.00	898.08	
Clay + 20% sand	2035.68	13.90	583.75	
Clay + 20% sand	2020.30	13.90	414.50	479.0
Clay + 20% sand	2107.47	13.90	438.68	
Clay + 40% sand	2014.40	12.50	307.42	
Clay + 40% sand	2076.70	12.50	222.79	236.0
Clay + 40% sand	2128.62	12.50	177.89	
Clay + 60% sand	2020.47	11.30	84.63	
Clay + 60% sand	2020.47	11.30	86.35	95.0
Clay + 60% sand	2235.64	11.30	113.99	
Clay + 80% sand	1888.74	10.10	0.00	
Clay + 80% sand	1904.65	10.10	0.00	0.0
Clay + 80% sand	1894.04	10.10	0.00	

Table 5: Ultimate bearing capacity

Specimen reference	C (kN/m^2)	Ø^{0}C	γ *(Mg/m^3)*	N_c	N_q	N_γ	Q_{ult}
Clay	62	26.55	24.72	25	12	10	2081.5
Clay + 20% sand	60	28.09	24.03	31	28	18	4023.1
Clay + 40% sand	50	29.41	25.51	32	29	19	3984.8
Clay + 60% sand	24	40.94	25.31	65	65	100	7685.0
Clay + 80% sand	2	42.1	26.29	65	65	100	6492.4

Table 6: Summary of the engineering properties of murram deposits around Kampala (Kyasanku, 2000)

Property	Borrow pit location	Units	Makerere Hill	Namasuba Hill	Mutundwe Hill	Kireka Hill	Mbuya Hill
	Extraction depth	m	1.5	2.5	2.0	2.5	3.0
Grading			Well graded	Well graded	Well graded	Well graded	Well graded
Soil Classification			Coarse Gravelly Sandy Clay	Coarse Gravelly Sandy Clay	Coarse Gravelly Sandy Clay	Coarse Gravelly Sandy Clay	Coarse Sandy Clay
Atterberg Limits	Liquid limit	%	42.89	47.70	44.70	46.30	54.10
	Plastic limit	%	28.21	28.05	27.13	31.72	32.85
	Plasticity	%	14.68	19.65	17.57	14.58	21.25
NMC	w	%	12.50	17.00	16.50	11.50	18.00
SG	G_s		2.70	2.60	2.64	2.71	2.75
Proctor	MDD	g/cm^3	2.07	2.06	2.08	2.12	1.96
	OMC	%	11.90	13.60	13.55	11.00	14.80
Shear strength	ǿ	^{o}	39.50	42.80	40.20	39.20	41.30
	C	kN/m^2	22.80	23.90	23.40	21.90	26.10

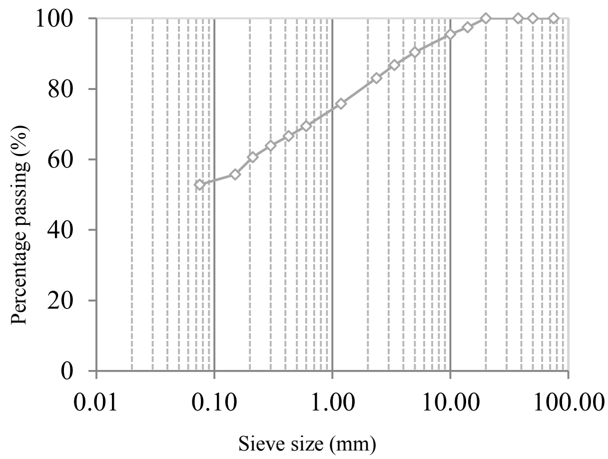

Figure 13: Soil specimen particle size grading

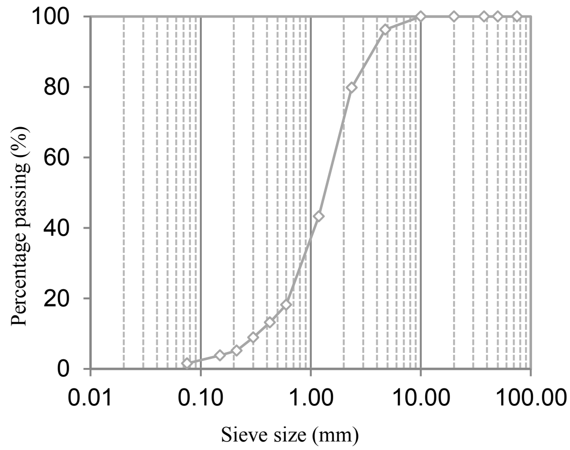

Figure 14 : Stabilizing sand particle size grading

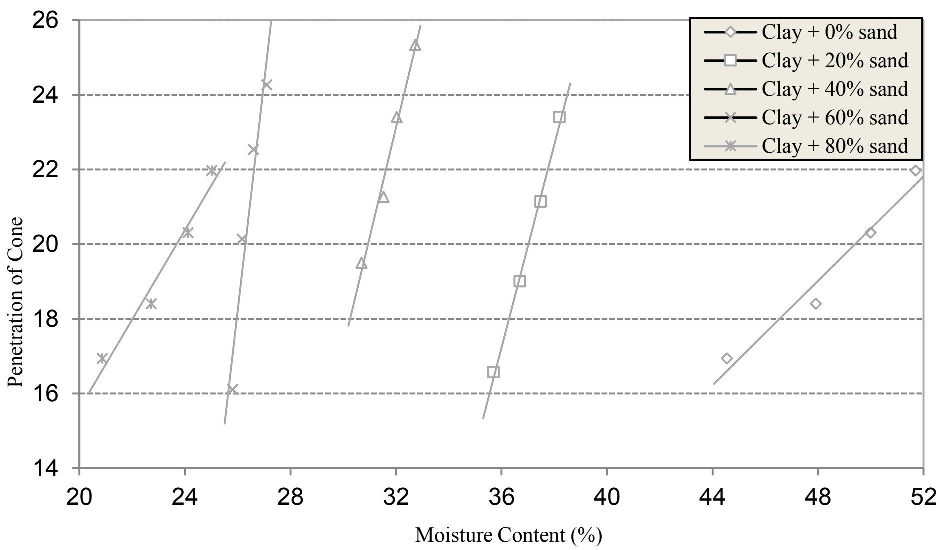

Figure 15: Penetration of cone versus moisture content

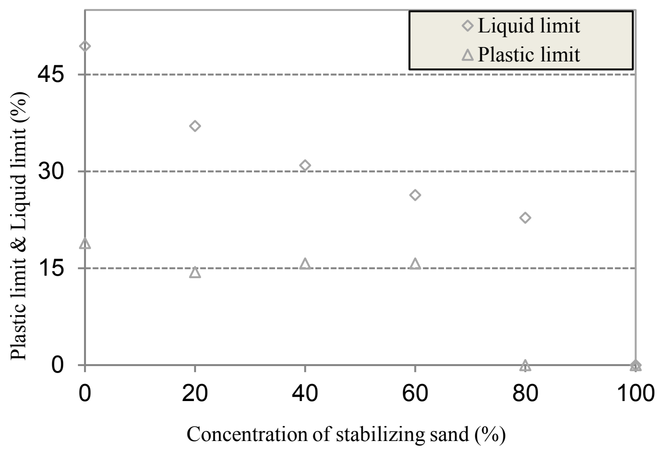

Figure 16: PL & LL versus Concentration of sand

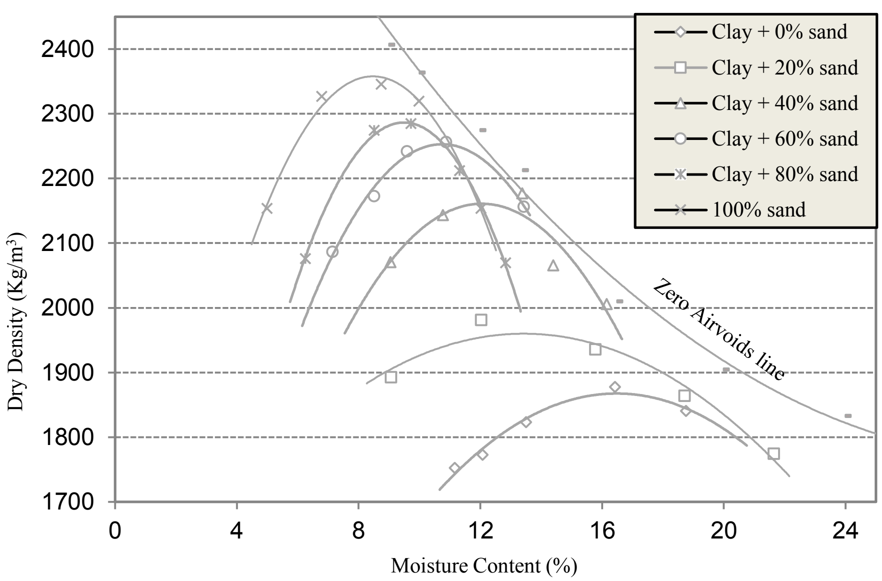

Figure 17: Dry density versus moisture content

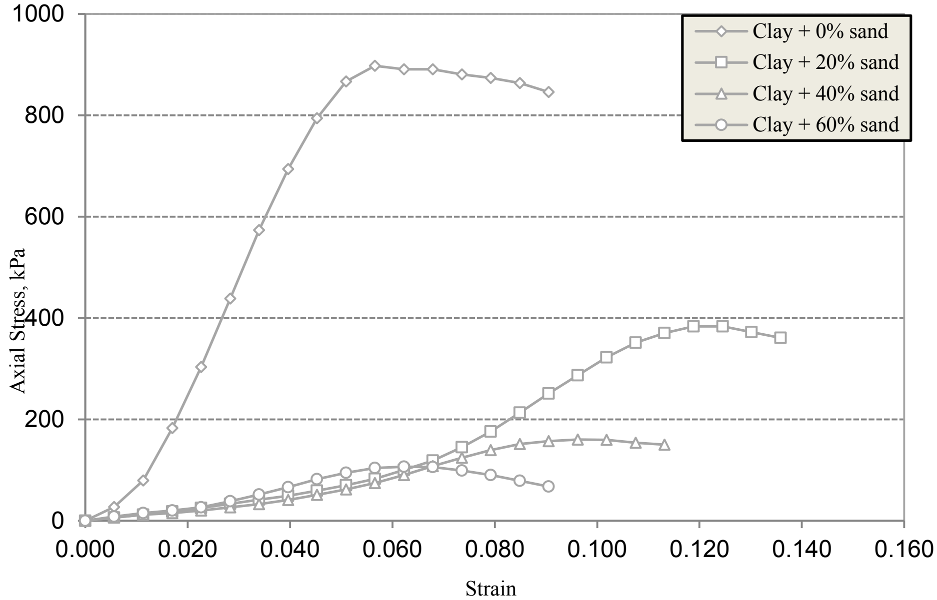

Figure 18: Axial stress versus strain

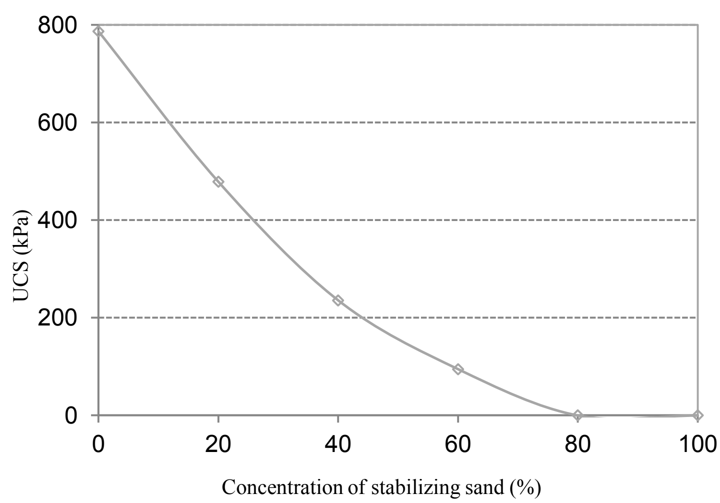

Figure 19: UCS versus Concentration of sand

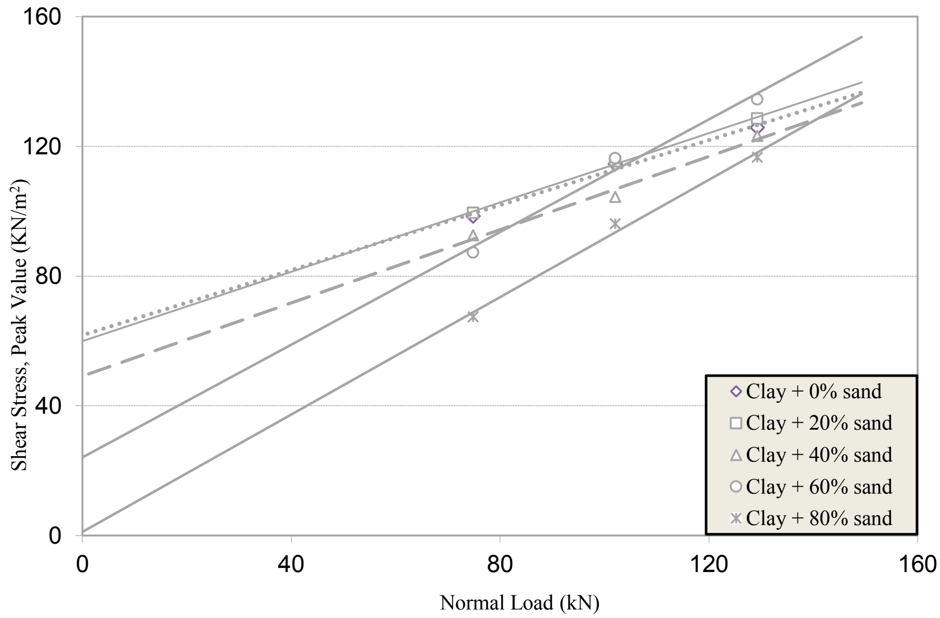

Figure 20: Shear stress versus normal load

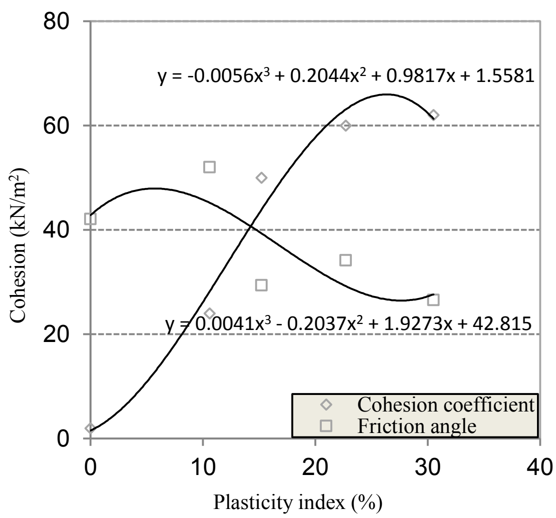

Figure 21: Cohesion versus plasticity index

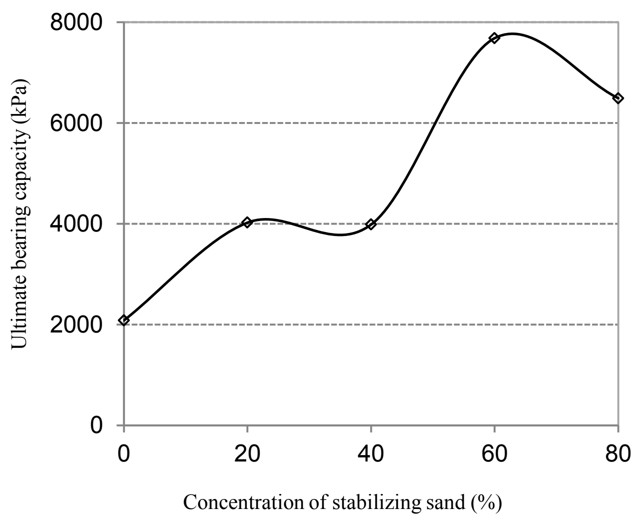

Figure 22: Ultimate bearing capacity versus Concentration of sand

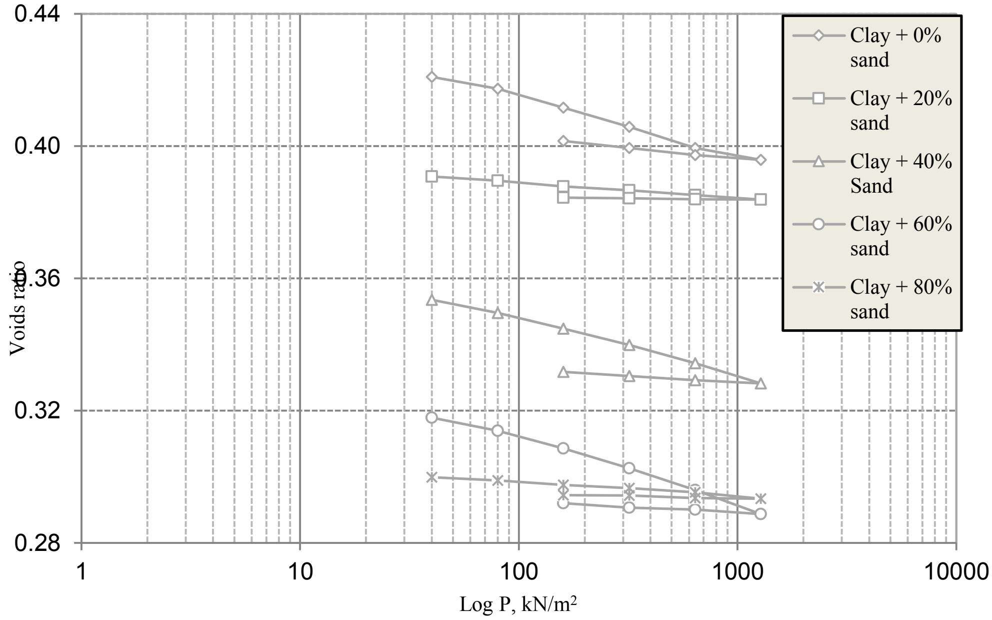

Figure 23: Voids ratio versus Log pressure

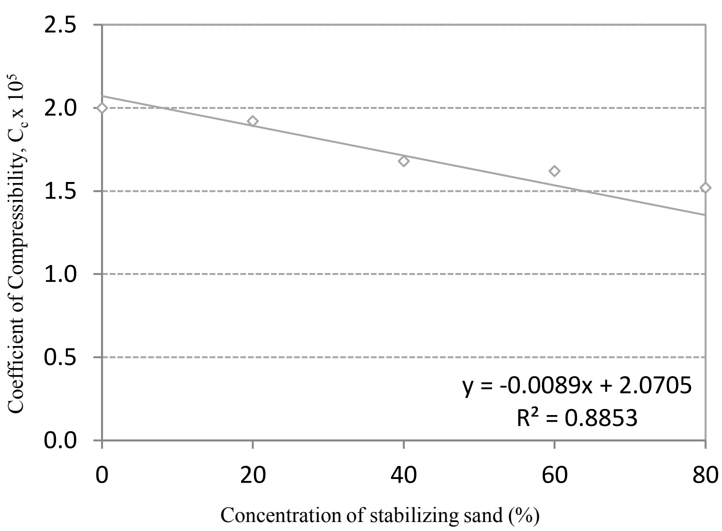

Figure 24: Coefficient of Compressibility versus Concentration of sand