GEOTECHNICAL CHARACTERIZATION OF HILL SLOPE SOILS OF GUWAHATI REGION

Chiranjib Prasad Sarma[1]
A. Murali Krishna[2]
Arindam Dey[3]
[1]Research Scholar, [2]Assoc. Prof., [3]Asst. Prof., Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati – 781039.
[1]s.chiranjib@iitg.ernet.in, [2]amurali@iitg.ernet.in, [3]arindam.dey@iitg.ernet.in

ABSTRACT: Hill slopes within the city of Guwahati consist of geological stratification, that characterize progressive stages of residual weathering, which can be categorized as basal rock, decomposed granitic rock and corestones, saprolitic and lateritic residual overburden. Saprolite formation is the layer of residual soil derived from isovolumetric weathering of the bedrock. Undisturbed saprolite formation looks very compact and retains much of the parent rock structure and fabric, but actually is extremely porous due to washing out of the finer particles. Such soils are very friable and once disturbed are exceedingly susceptible to landslides. Several rainfall induced landslide occurrences have been reported in the hillslopes of Guwahati region. Characterization of these soils is important for proper analysis of hill slope stability of this region. Laboratory test have been performed on disturbed and undisturbed soil samples to assess the geotechnical characteristics. Test to determine grain size distribution, specific gravity, Atterberg's limits, in-situ dry density, shear strength parameters and permeability were conducted. Hill slopes within Guwahati region consist of residual soils in unsaturated condition. The Soil Water Characteristic Curve, which is an important characteristic of unsaturated soil, is determined and compared with that obtained from empirical methods using grain size distribution and Atterberg's limits provided in literature. Unconsolidated undrained triaxial test were conducted on statically compacted samples remoulded to in-situ density at different water content to understand the effect of degree of saturation and moisture content on the shear strength of the soil. Such detailed characterization would provide the requisite understanding for an efficient analysis of the rainfall induced natural hill slope failure in this region.

Keywords: Geotechnical characterization, Soil Water Characteristic Curve, laterite, saprolite, landslides.

1 INTRODUCTION

Numerous geotechnical slope stability models are developed which are exceedingly capable of providing detailed description of potential instability taking into account the changing environmental and climatic conditions and thus establish threshold values of the triggering rainfall. However, before being able to conduct such an analysis proper characterization of the behaviour of the unsaturated residual soils is essential. A proper understanding of the geology and the geotechnical characterization is absolutely necessary to develop a meaningful model for analysis of the phenomena.

The residual soils of the hills within the Guwahati municipality region are derived through physical and chemical weathering process on the parent rock vis., granite, gneiss and porphyritic granite, which form the constituent basal stratum of the hills of this region (Maswood, 1981). The influence of rainfall in initiating landslides in this soil slopes are widely documented. Infiltration of rainwater increases the water content and thus decreases the matric suction, thereby raising the unit weight and reducing the shear strength of the natural hillslope soils. To assess the propensity to rainfall-induced landslide a comprehensive understanding of changes in water content and matric suction in response to rainfall infiltration is essential (Selby, 1993; Wesley, 2010). In this context, severe limitations are observed as far as literature pertaining to characterizing the unsaturated soil behaviour of this region is concerned. Hill slopes within the city of Guwahati consist of residual soils, in unsaturated condition (Das and Saikia, 2010; 2011), therefore characterizing the unsaturated soil parameters is essential for thoroughly assessing the stability of the natural hill slopes. The study attempts to provide a detailed geotechnical characterization that would provide the requisite understanding for an efficient analysis of the rainfall induced natural hill slope failure in this region.

2 Hill Slope Soil Characterization

Laboratory test have been performed on disturbed and undisturbed soil samples to assess the geotechnical characteristics. Test to determine grain size distribution, specific gravity, Atterberg's limits, in-situ dry density, shear strength parameters and permeability were conducted. Figure 1 gives the images of the cut slope from where the samples have been collected. Two distinct layers of soil can easily identified from the images. Irregular zones of contrasting weathering, weathered corestones, etc. can be observed from Figure1. Figure 2 gives the cross-section of the undisturbed soil samples collected at different sites.

Figure 1: IITG Cut Slope Site depicting two layers of soil and weathered corestones. (Top layer is referred as SOIL 1 while the bottom layer as SOIL 2

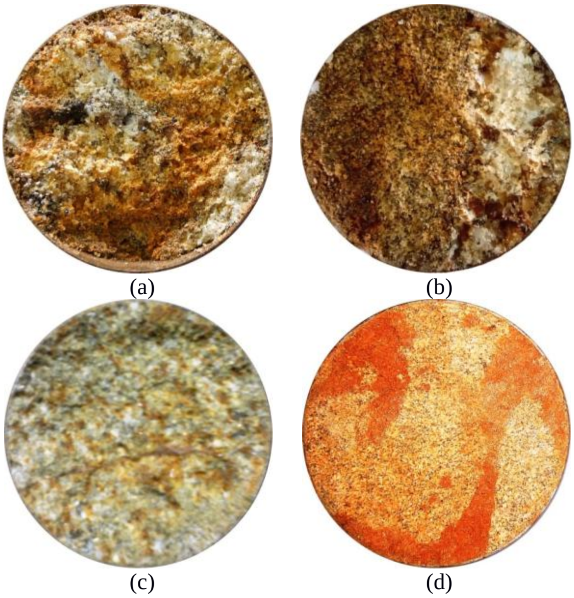

Figure 2: Cross-section of the undisturbed soil samples

Variations in soil structure at the material scale can be easily observed in the samples. Weathering decreases with depth; the uppermost layers (0~2 m) of the soil can be considered as true or mature residual soils i.e., lateritic soils. Underlying the lateritic soils is the saprolitic formation. This soil layer retains much of the parent rock structure and fabric but with a much lower density. The saprolite formation is very porous and friable in nature and can easily crumble from the slightest disturbance. In equatorial climates of heavy rainfall, saprolitic soil formation can reach depths of tens of meters (Shelby, 1993). Table 1 gives the test results for Index properties and Atterberg's Limits for the two different types of soils.

Table 1: Index properties and Atterberg's Limits for the two different types of soils.

Soil Characteristics	Experimental Results – SOIL 1	Experimental Results – SOIL 2
Referred as	RSC_EXP1	PGSS_EXP2
Specific Gravity	2.68	2.68
In-situ dry density (gcm^{-3})	1.50	1.57
Liquid Limit (%)	47	35
Plastic Limit (%)	27	Non – Plastic
Co-eff. of Uniformity	18	12.12
Co-eff. of Curvature	2.1	2.546
Fines Content (%)	77.8	36.75
Porosity	0.44	0.41
In-situ degree of Saturation (%)	95	47.79
Saturated Permeability	10^{-7} ms^{-1}	10^{-5} ms^{-1}

Concluding from field investigation, two types of commonly found overburden residual soils constituting the hill slopes around Guwahati can be reported. A top laterite formation of reddish silty clay varying in thickness from few centimetres to few meters, underlain by a saprolite formation of pale yellowish poorly graded silty sand. Hill slopes within the city of Guwahati consist of geological stratification, that characterize progressive stages of residual weathering, typical of tropical and sub–tropical climatic conditions with very high amount of annual precipitation and excessive fluctuation of the ground water table, which can be categorized as basal rock, decomposed granitic rock and corestones, saprolitic and lateritic residual overburden.

2.1 Determination of shear strength parameters

Triaxial Tests were conducted on undisturbed samples as well as remoulded samples, compacted to in-situ dry density for evaluating the shear strength characteristics of the hill slope soils. The tests were conducted at effective confining stress of 50 kPa, 100 kPa and 200 kPa. Strain rate of 20%/hr i.e., 0.4667 mm/min was found sufficiently low to prevent any excess pore pressure generation in the consolidated drained test and hence was adopted for all further test.

Figure 3 gives the p'-q plot for the consolidated drained triaxial test, whereas Figure 4 gives the p'-q plot for the consolidated undrained triaxial test. From Figure 4 it can be observed that the soil behaved as normally consolidated even at low confining stress of 50 kPa. Similar results were observed for all the other samples.

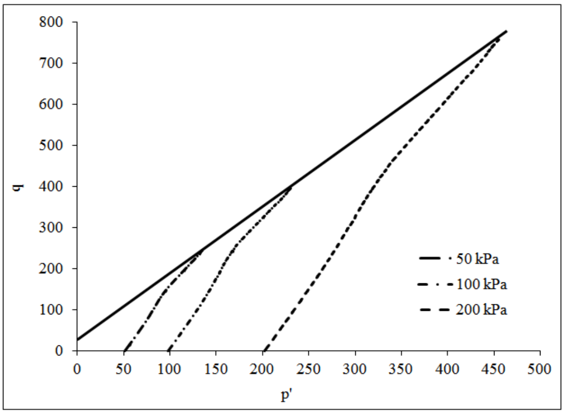

Figure 3: p'-q plot of Consolidated Drained triaxial test of IITG Cut Slope Site sample

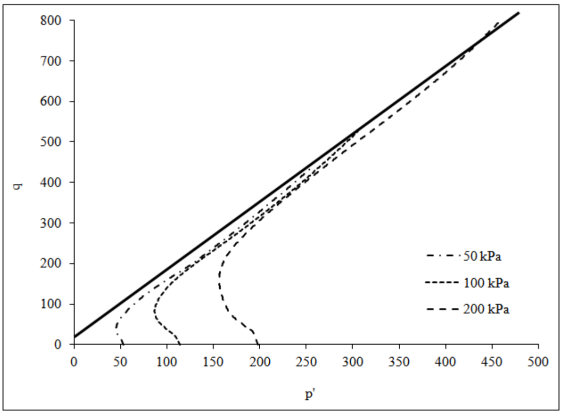

Figure 4: p'-q plot of Consolidated Undrained triaxial test of IITG Cut Slope Site sample

Table 2 gives the summary of the test procedure conducted and the corresponding cohesion and angle of internal friction evaluated from the test results.

2.2 Soil Water Characteristics (SWCC)

Soil Water Characteristic Curve is the relationship between the water content and matric suction. SWCC can be applied for quantifying unsaturated shear strength and derivation of unsaturated hydraulic conductivity. The SWCC for the soil was determined using Dielectric Water Potential Sensor, (MPS–1) combined with volumetric water content sensor (EC–5). The experimentally obtained SWCC was then compared with the SWCC estimated using the modified Kovac's method (Aubertin *et al.*, 2003) from the grain size distribution and liquid limit of the soil.

Table 2: Triaxial test procedure and Cohesion and angle of Internal Friction

Sample No.:/Site	Triaxial Test	*c* (kPa)	ϕ'(°)
IITG Cut Slope Site 1	Consolidated Drained	16.73	30.38
IITG Cut Slope Site 1	Consolidated Undrained	11.87	30.9
IITG Cut Slope Site 2	Consolidated Undrained	14.53	30.63
IITG Lothia Gate Cut Slope	Consolidated Undrained	15.31	31.24
IITG Cut Slope Site 1 (Remoulded to In-Situ Density)	Consolidated Undrained	10.42	30.4

Figure 5 gives the SWCC for silty sand (PGSS_EXP2) along with that estimated using grain size distribution and liquid limit data. It can be observed from Figure 5 that the estimation procedure falls short of properly predicting the SWCC for this type of soil.

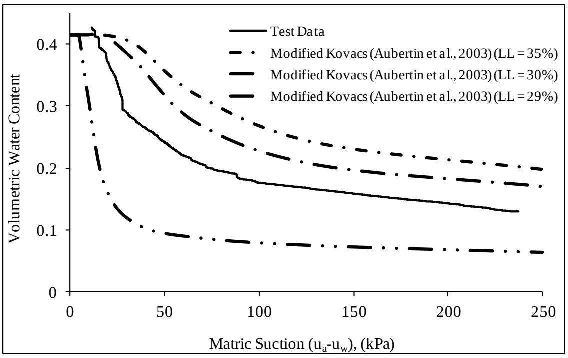

Figure 5: Soil Water Characteristic Curves for the saprolitic soil (PGSS_EXP2)

2.3 Influence of moisture content on the shear strength

The test procedure consists of determining the shear strength of statically compacted partially saturated soil specimens. Soil samples were mixed with water in proper weight ratio so that after compacting the soil samples attain the required degree of saturation and dry density. The soil samples are so prepared such that the dry density of the soil specimen turns out to be approximately 1.57 gcm^{-3} while the water content is varied so that the specimens attain the desired Degree of Saturation (equal to 40%, 50%, 60% and so on up to 90%). The samples were then kept properly packed in airtight plastic pouches and left in desiccators for 48 hours to attain equilibrium distribution of water content. The soil samples were then statically compacted to specimens of 38 mm diameter and 76 mm length using constant volume mould. The specimens were again kept in dessicator for 24 hours. The samples were then setup in the triaxial test equipment. Conventional unconsolidated undrained triaxial test procedures were followed to shear the soil specimens. The samples were sheared at minimal cell pressure of 25 kPa. The stress-strain behaviour is presented in Figure 6. The peak deviatoric stresses are then plotted in Figure 7 against the degree of saturation. It can be observed from Figure 6 and 7 that with decrease in water content the peak deviatoric stress increases. With decrease in the water content the stiffness of the soil also increases.

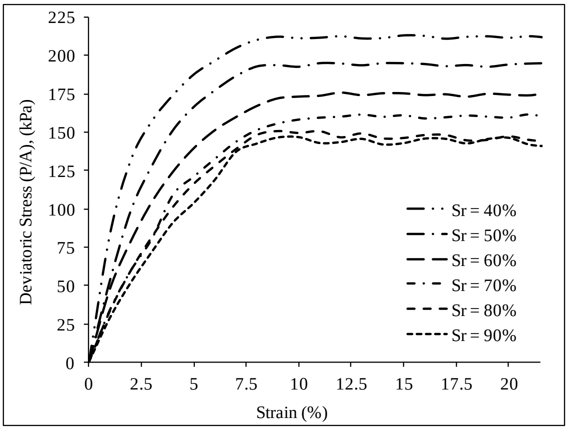

Figure 6: Deviatoric Stress vs. Strain (%) for partially saturated soil sample.

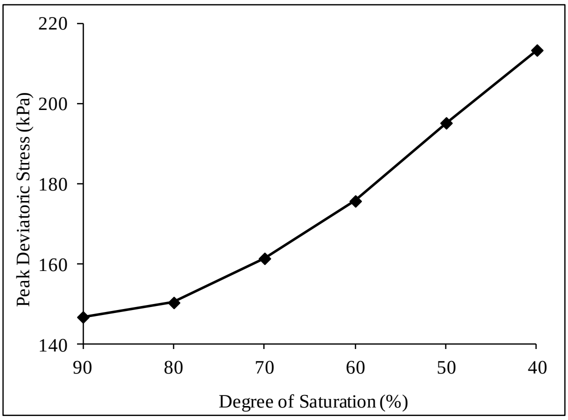

Figure 7: Increase in Peak Deviatoric Stress with decrease in Degree of Saturation (%)

3 Conclusions

Two types of soil can be identified in the hillslopes of this region. The uppermost layers, lateritic in nature, varying in thickness from few centimetres to few (1~2) meters can be considered as mature residual soils and is characterized by high plasticity index, higher percentage content of clay size particles and low permeability values. Underlying the lateritic soils are the saprolitic soils which can be classified as poorly graded silty sand.

Saprolite formation is isovolumetrically weathered from rocks and retains much of the parent rock structure and fabric but with lower density. Such soils are very porous and friable in nature and can easily disintegrate from the slightest disturbance. However in in-situ conditions, such soils appear to very stiff giving a feeling of stability, which actually is not existent. In equatorial climates of heavy rainfall, saprolitic soil formation can reach depths of tens of meters.

Though considerable differences are observed at material scale of the soil samples, however, variations in the shear strength was not very significant. The angle of internal friction was around 30°~31°, while the cohesion was varying from ~ 10 to 17 kPa.

The SWCC of the soil could not be estimated applying the modified Kovac's method from the grain size distribution and liquid limit. Thus for analysis purpose experimentally obtained SWCC should be used as far as possible.

Moisture content had a significant effect on the shear strength of the soil. With degree of saturation decreasing, increase in the peak deviatoric stress was observed. The stiffness of the soil also increased with decrease in the water content.

References

Aubertin, M., Mbonimpa, M., Bussière, B. and Chapuis, R.P. (2003), A model to predict the water retention curve from basic geotechnical properties, *Canadian Geotechnical Journal*, 40(6): 1104-1122

Das, U.K. and Saikia, B.D. (2010), Shear Strength of Unsaturated Residual Soils of the Hills in Guwahati, *Proceedings of Indian Geotechnical Conference, GEOtrendz*, 679-682

Das, U.K. and Saikia, B.D. (2011), Evaluation of a Prediction Model for Shear Strength of Unsaturated Soils, *Proceedings of Indian Geotechnical Conference*, Kochi, 643-646

Maswood, Md. (1981), Granite Gneisses around Guwahati, Assam, *Journal of Geological & Mineralogical Society of India*, 53(3, 4), 115–124.

Selby, M. J. (1993), *Hillslope Materials and Processes*, Oxford University Press Inc., New York.

Wesley, L. D. (2010), *Geotechnical Engineering in Residual Soils*, John Wiley & Sons Inc.