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Spatially Distributed Sub-Soil Information Model of Guwahati City on Regional Scale

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***Abstract:** An attempt is made to develop a spatially distributed shear strength based sub-soil information model of Guwahati city on a regional scale. The study involves undisturbed sampling up to a depth of 15.0m from E.G.L. and laboratory testing on 2500 soil samples collected from 520 numbers of boreholes across Guwahati city. The shear strength parameters are obtained by performing consolidated drained triaxial test, direct shear test and unconfined compression tests under laboratory controlled test conditions. Guwahati sub-soil is found to be predominantly alluvial, and excluding the hilly areas, it is found that 80% of the soil are find grained CL or CI type i.e. inorganic clays with low or intermediate compressibility. These soil types exhibit a wide range of unit cohesion, 'C' with small values of angle of internal friction 'φ' and significant contribution to the shear strength comes from unit cohesion component only. Various interactive maps showing range of unit cohesion at different depths of the Guwahati city are presented. Correlations between cohesion, C and angle of internal friction, φ, for the fine grained C-φ soil, are also proposed depth wise, appropriate to Guwahati sub-soil. The sub-surface shear strength based geotechnical information, presented in this paper, would help rapid estimation of shear strength parameters of soils at various locations across Guwahati and at various depths for preliminary design of sub-structures of proposed infrastructure viz. water supply network, sewage network, oil pipe line installation, city road and metro rail network or even large housing projects. The results presented will reduce the precious project planning time in preparation of detailed project report for infrastructure projects in the city.*
Keywords: **Cohesion, correlation, Guwahati, maps, sub-soil**

I. INTRODUCTION

The foundation system forms the basis of a structure. A safe and economical design of any structure demands a site specific thorough geotechnical investigation of the sub-soil involved for proper evaluation of the shear strength parameters, i.e., cohesion, C and angle of internal friction, φ. However, for preparation of a preliminary detailed project report, site specific estimation of these properties is highly essential and due to budget limitation and time constraints, conducting site specific experiments for obtaining C and φ becomes a challenging issue. In this study, shear strength parameters of the sub-soil of Guwahati are determined by drilling 520 numbers of exploratory boreholes, spatially distributed across Guwahati and 2500 numbers of undisturbed sampling from various depths from these boreholes.

Hill areas of Guwahati are excluded from this study, as in general, the lateritic hill soil possess much higher shear strength as compared to that of the plain areas Guwahati. Laboratory test data from all these samples show that 80 per cent of the soil are fine grained soil of CL or CI type, indicating inorganic clay with low or intermediate compressibility, having a wide range of unit cohesion 'C' and very low value of angle of internal friction 'φ'. Soil shear strength parameters at different depths namely C and φ are estimated from consolidated drained triaxial test, direct shear test and unconfined compression test under laboratory controlled test conditions. It is observed that unit cohesion contributes significantly to the shear strength of Guwahati soil and because of low values of angle of internal friction; its contribution to the shear strength may often be neglected. Based on the laboratory test data on 2500 samples, representative maps, showing spatial distribution of soil with various values of cohesion are prepared and presented. Additionally, correlations between C and φ are established for Guwahati soil.

II. STUDY AREA

The study area comprises of city of Guwahati, lying across the banks of the river Brahmaputra, situated in Assam, located in the northeastern part of India. The extent of the area under study is situated between latitude 2605'N and 26015'N and between longitude 91038'E and 91050'E.

Guwahati, being a developing city, is constantly undergoing with construction of numerous infrastructure development projects. For the preliminary assessment of these projects, in order to obtain the geotechnical information, conducting in-situ tests and laboratory experiments become quite time consuming. Hence, representative maps of the city showing sub-soil information proves to be helpful for the engineers.

Endowed with hills and hillocks, and the mighty Brahmaputra river, Guwahati city is mostly occupied by valleys and low lands which are filled with alluvial soil, silty clays, clayey silts and sandy soils [1]. Due to the varied nature of the soil of the region, it is important to study the relationship between the strength parameters, C and φ, for quick reference by the geotechnical engineers of this region. In this study, field and laboratory data from 520 numbers of boreholes across Guwahati region were collated. Fig. 1 shows the distribution of these boreholes over the city area as red-coloured dots on the map generated in QGIS.

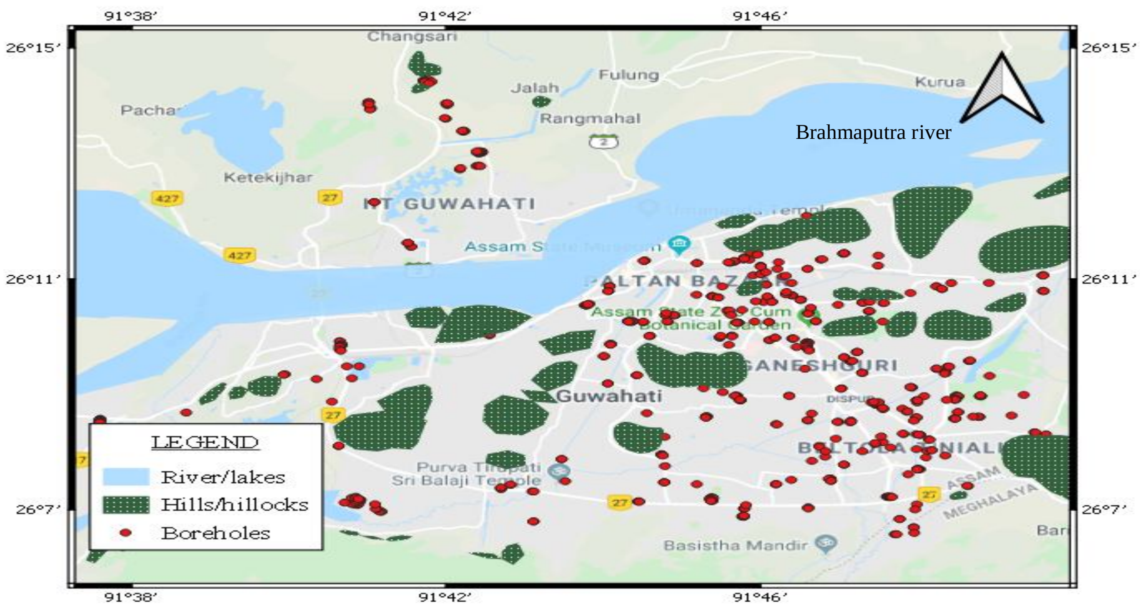

Fig. 1. Distribution of the 520 boreholes across Guwahati

III. METHODOLOGY

Geotechnical investigations are carried out at 520 boreholes across Guwahati city. Exploratory drill holes in the hilly areas are not included in the present study, since, in these areas, construction of buildings or dwelling of human habitat is not permitted by the Guwahati Metropolitan Development Authority. Undisturbed sampling is done at every 3 m, upto 15 m depth in each borehole and laboratory tests such as grain size distribution, Atterberg limits, shear strength properties etc. are determined for 2500 undisturbed samples from 520 boreholes. The grain size distribution of the soil samples is determined by sieve analysis of soil as per the provisions set by IS 2720 (Part IV)-1985. For determination of liquid limit and plastic limit of the soil, laboratory tests were performed as per the provisions set by IS 2720 (Part V)-1985. For determination of the strength parameters, unconfined compression test, consolidated drained triaxial test and direct shear test are conducted, under laboratory controlled test conditions. While the unconfined compression tests are performed as per the provisions set by IS 2720 (Part X)-1991, the consolidated drained triaxial test and direct shear test are conducted in accordance with the provisions set by IS 2720 (Part XIII)-1986. After determination of the grain size distribution, liquid limit, plastic limit, cohesion and angle of internal friction of the soil samples obtained from the boreholes, the fine grained C-φ soil is then classified on the basis of the plasticity chart according to IS 1498-1970. Also, the cohesion obtained from the laboratory results are then plotted corresponding to the boreholes, on the Guwahati map, and then interpolated spatially at different depths in the QGIS platform to get an overview of the distribution of cohesion across Guwahati region.

IV. ANALYSIS OF TEST RESULTS

The subsoil, in general consists of silty clay, clayey silt and sandy clay. At these locations, the soil encountered is predominantly C-φ soil. The Ground Water Table (GWT) is found to be located at depths varying from 1 m to 4 m, as recorded during geotechnical investigations.

Out of the 2500 soil samples, the average clay content is found to be 58 per cent, that of silt is 30 per cent and average sand content is observed to be 12 per cent. 20 per cent of the soil has been found to be cohesionless soil. 80 per cent of the soil is fine grained C-φ soil consisting of predominantly silty clay having cohesion ranging from 5 kN/m^2 to 80 kN/m^2 and angle of internal friction varying from 2^0 to 5^0. Fig. 2 demonstrates the classification of the fine grained C-φ soil of Guwahati, based on the Indian Standard plasticity chart. It is revealed that around 30 per cent are CL soil, i.e., inorganic clayey soil having intermediate compressibility and 70 per cent of the soil is CI type, which is inorganic clay with low compressibility. In this paper, the study is confined to CI and CL soil only.

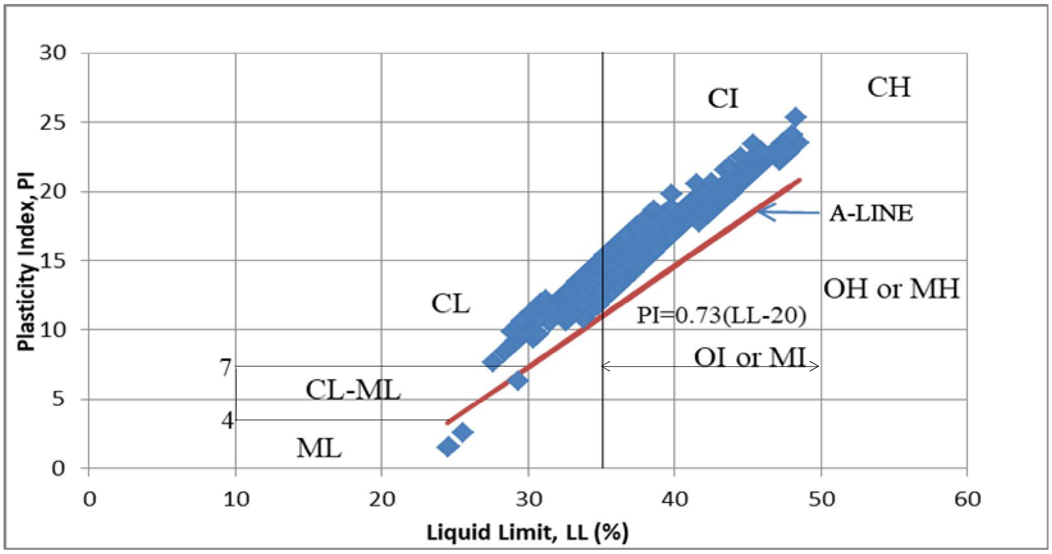

Fig. 2. Plasticity chart showing soil classification as per IS 1498-1970

V. SPATIAL DISTRIBUTION OF COHESION OF GUWAHATI SOIL

Laboratory test results of the predominant component of the shear strength parameter, viz., the unit cohesion in kN/m2, obtained from various boreholes at depths of 3m, 6m, 9m,12m and 15m, are plotted on the map of Guwahati and interpolated in QGIS to get spatial distribution of the unit cohesion across Guwahati city. Fig. 3 through Fig. 7 presents the distribution maps of unit cohesion at depths of 3m, 6m, 9m, 12m and 15m, respectively. It is observed from Fig. 3 that, at a depth of 3m below ground level (GL), around 50 per cent of Guwahati soil possess a unit cohesion ranging from 20-30 kN/m^2 and another 33 per cent of the soil has unit cohesion of 30-40 kN/m^2. Similarly, from Fig 4, it can be seen that at a depth of 6m below GL, around 60 per cent of the soil exhibits unit cohesion of 30-40 kN/m^2 and another 30 per cent have unit cohesion of 20-30 kN/m^2. At 9m depth below the GL, 60 per cent of the fine grained soil has unit cohesion ranging between 30-40 kN/m^2. At 12m below GL, around 35 per cent of the soil possess unit cohesion in the range of 40-50 kN/m^2 and at 15 m depth, around 50 per cent of the soil has unit cohesion of 30-40 kN/m^2 and 30 per cent have cohesion more than 40 kN/m^2.

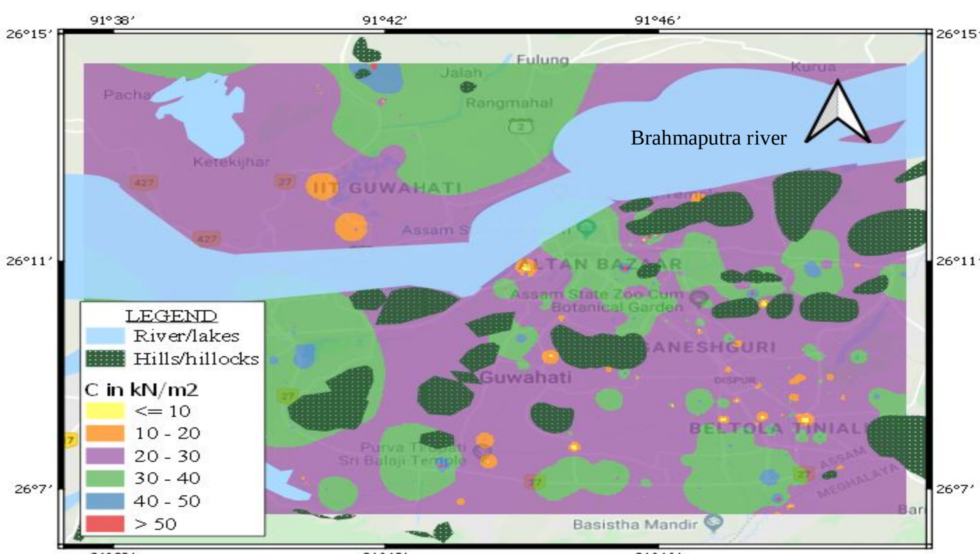

Fig. 3. Distribution of cohesion at 3m depth below GL

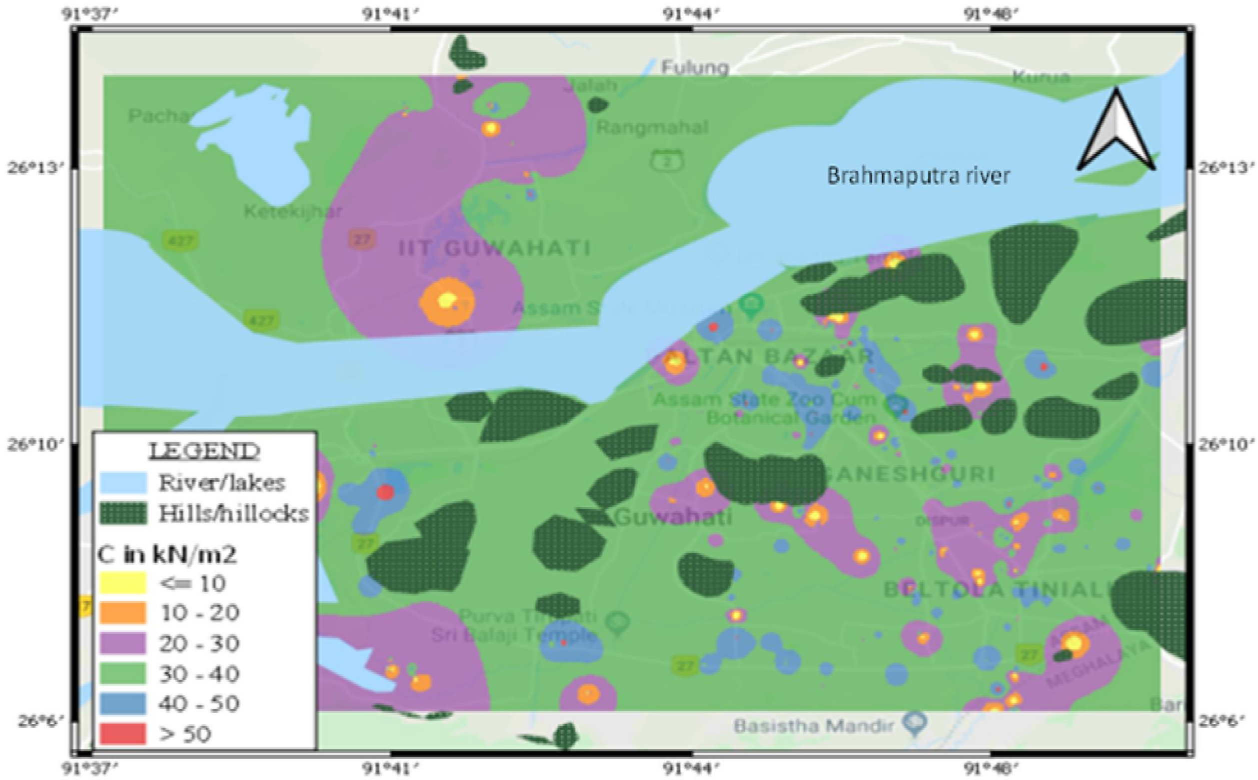

Fig. 4. Distribution of cohesion at 6m depth below GL

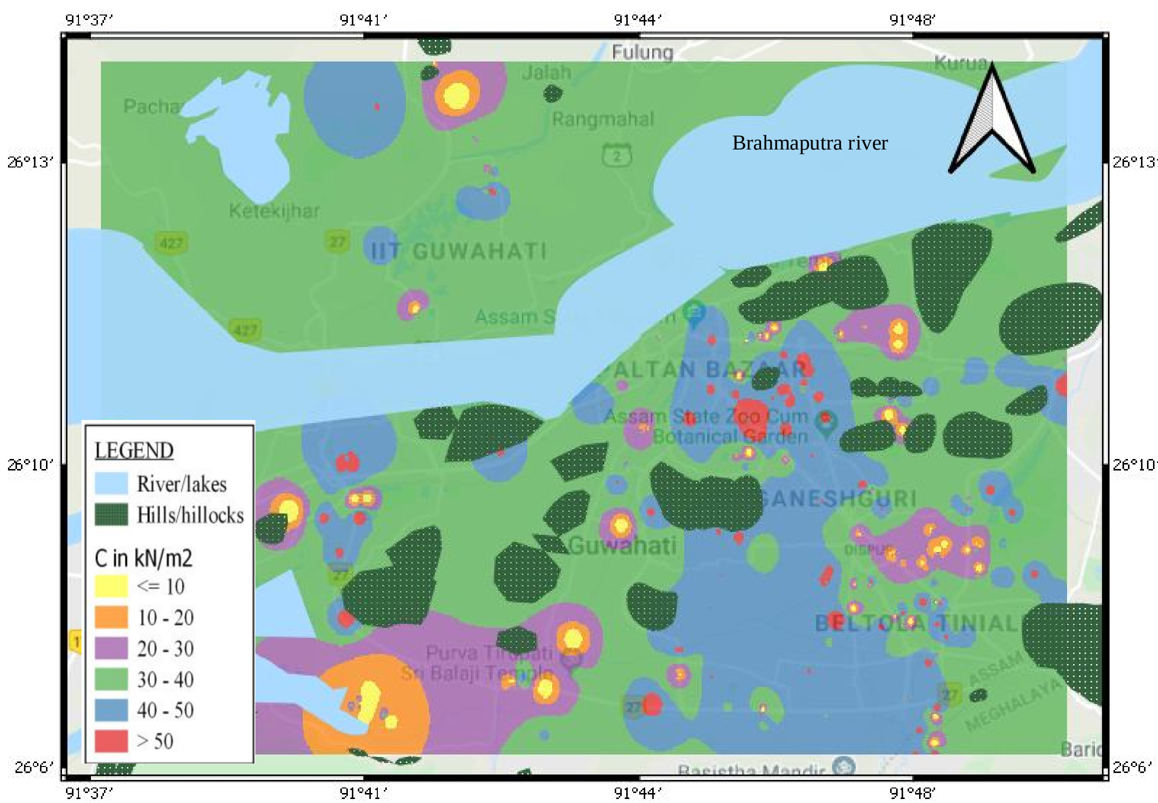

Fig. 5. Distribution of cohesion at 9m depth below GL

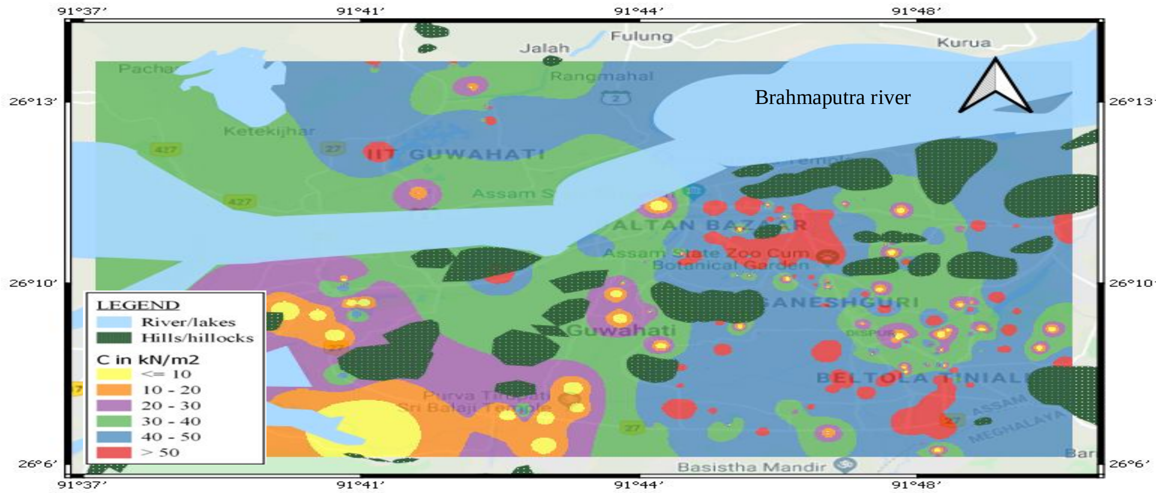

Fig. 6. Distribution of cohesion at 12m depth below GL

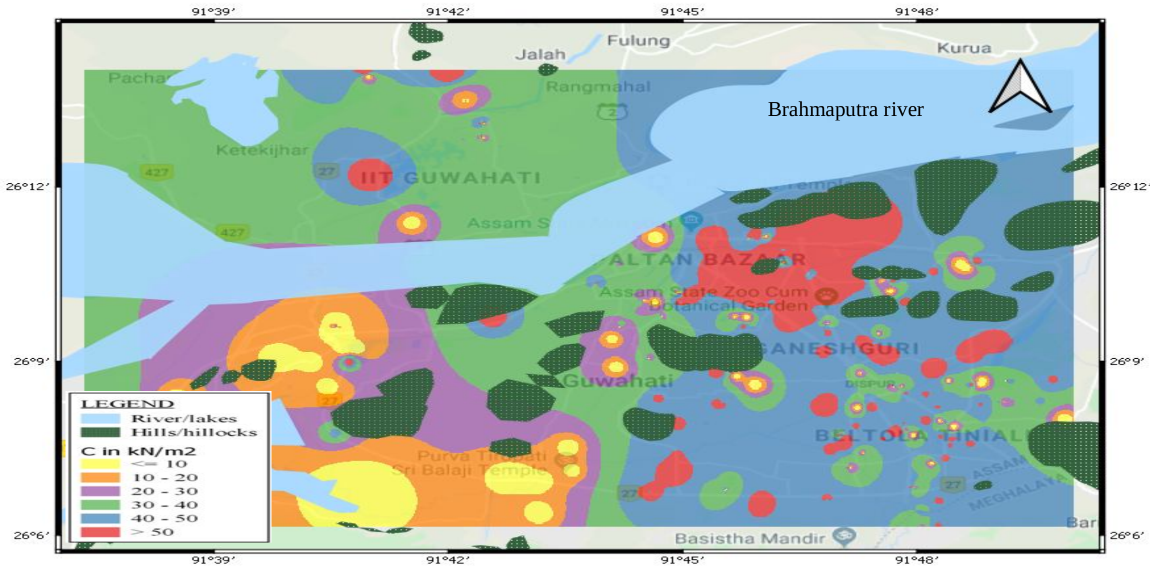

Fig. 7. Distribution of cohesion at 15m depth below GL

VI. CORRELATION BETWEEN COHESION AND ANGLE OF INTERNAL FRICTION

On the basis of the experimental results of the 2500 samples of Guwahati soil from various depths, regression model is created between $\sqrt{(C+\varphi)}$ along the ordinate (y-axis) and C in kN/m^2 along the abscissa (x-axis), depth wise i.e. at depths of 3m, 6m, 9m, 12m and 15m each, as shown in Fig. 8 through Fig. 12, respectively.

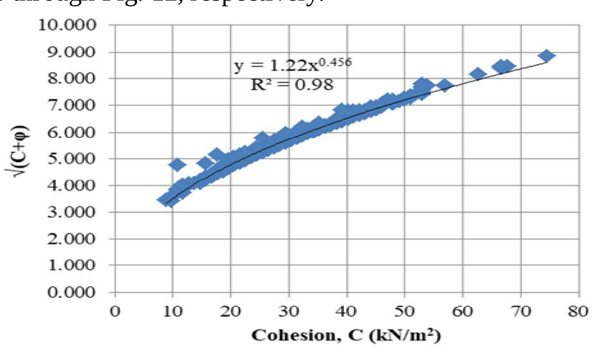

Fig. 8. $\sqrt{(C+\varphi)}$ vs C plot at 3m depth below GL

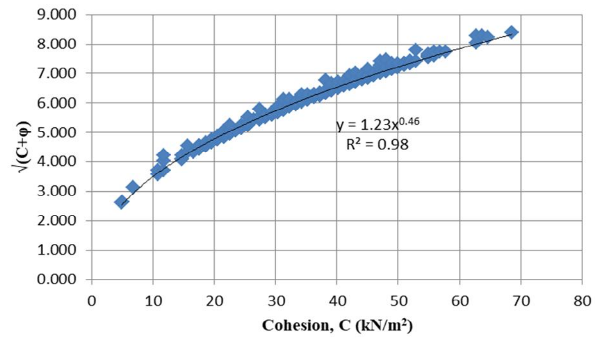

Fig. 9. √(C+φ) vs C plot at 6m depth below GL

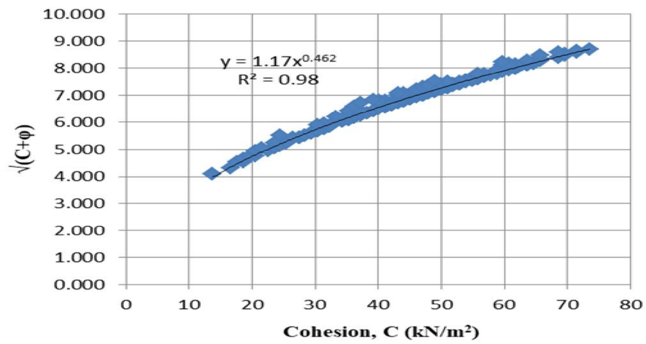

Fig. 10. √(C+φ) vs C plot at 9m depth below GL

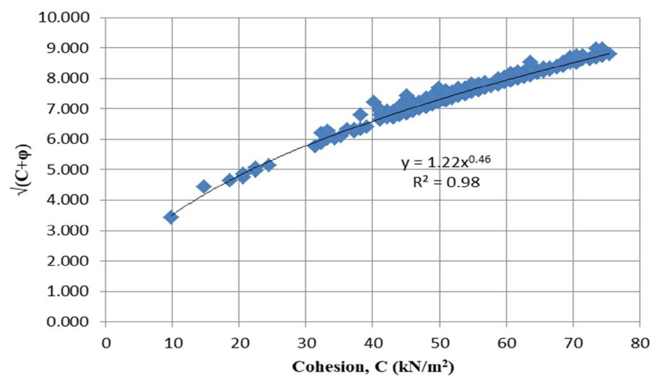

Fig -11:√(C+φ) vs C plot at 12m depth below GL

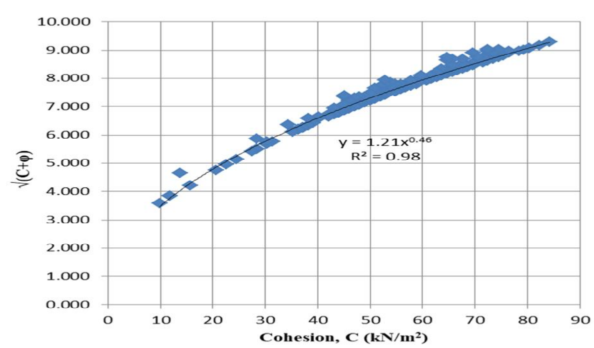

Fig. 12. √(C+φ) vs C plot at 15m depth below GL

Fig. 8 through Fig. 12 shows the regression analysis, and the best fit curve with correlation coefficient $R^2 = 0.98$, is approximately represented by the following equation :

$$y = 1.2x^{0.46} \quad (1)$$

Placing y = √(C+φ) and x=φ in the above equation,

$$\sqrt{(C+\varphi)} = 1.2C^{0.46} \quad (2)$$

Squaring both sides,

$$\Rightarrow C+\varphi = 1.44C^{0.92} \quad (3)$$

$$\Rightarrow \varphi = \left(1.44C^{0.92}\right) - C \quad (4)$$

Eq. 4, gives an approximate estimation of internal friction angle, φ in degrees, when, cohesion, C in kN/m^2 is known parameter. Unit cohesion 'C', at any given location and at any depth can be read from Fig. 3 through Fig. 7. Exactly similarly, angle of internal friction, 'φ' can be found, at depths of 3 m through 15 m from Fig. 8 through Fig. 12 respectively.

VII. RESULTS AND DISCUSSIONS

An exhaustive geotechnical investigation program was taken up by drilling 520 boreholes across Guwahati city, excluding its hill areas, and laboratory tests were performed on the 2500 soil samples collected from these boreholes in order to obtain their grain size distribution, liquid limit, plastic limit, C and φ. On the basis of the results from the laboratory tests, it is found that, around 80 per cent of the sub-soil of Guwahati consists primarily of inorganic clayey soils with intermediate and low compressibility. It is also observed that the predominant shear strength parameters, contributing to the shear strength for these soils are unit cohesion and not the angle of internal friction. Based on these experimental results, illustrative maps portraying distribution of values of unit cohesion in kN/m^2 at various depths from ground level are presented in Fig. 3 through Fig. 7. From the maps, it can be inferred that most of the subsoil from 3m depth or more, unit cohesion is found to vary between 30-50 kN/m^2. Relationships, developed from this present study, between C and φ, is believed to be very helpful in assessing the angle of internal friction also at various depth across Guwahati.

VIII. CONCLUSION

Guwahati city, with its natural terrain consisting of a bowl-shaped valley with several hills and wetlands interspersed along its landscape, has a varied soil profile. Hence, it becomes important to study the soil type and their shear strength properties. In this study, geotechnical investigations in the form boreholes were conducted across the city. Undisturbed soil samplings at different depths, from these boreholes were then undergone laboratory tests to obtain soil classification and shear strength properties. Illustrative maps of Guwahati city depicting spatial distribution of unit cohesion at different depths from the GL have been presented. Correlations between C and φ, for various depths, appropriate to Guwahati fine grained soil have also been proposed. Cohesion and angle of internal friction are important parameters for determining the shear strength of soil and is useful in foundation design. The shear strength information of the sub-soil strata, presented in this paper, would help prompt estimation of shear strength properties of soils at various locations across Guwahati and at various depths for preliminary design of foundation of the various upcoming infrastructure development projects proposed in the city. This would help in saving time and capital required for obtaining the geotechnical information while preparing the detailed project report of the proposed construction projects. Hence, the developed maps and the proposed correlation can be highly useful in planning and execution of construction projects in Guwahati city.

IX. ACKNOWLEDGMENT

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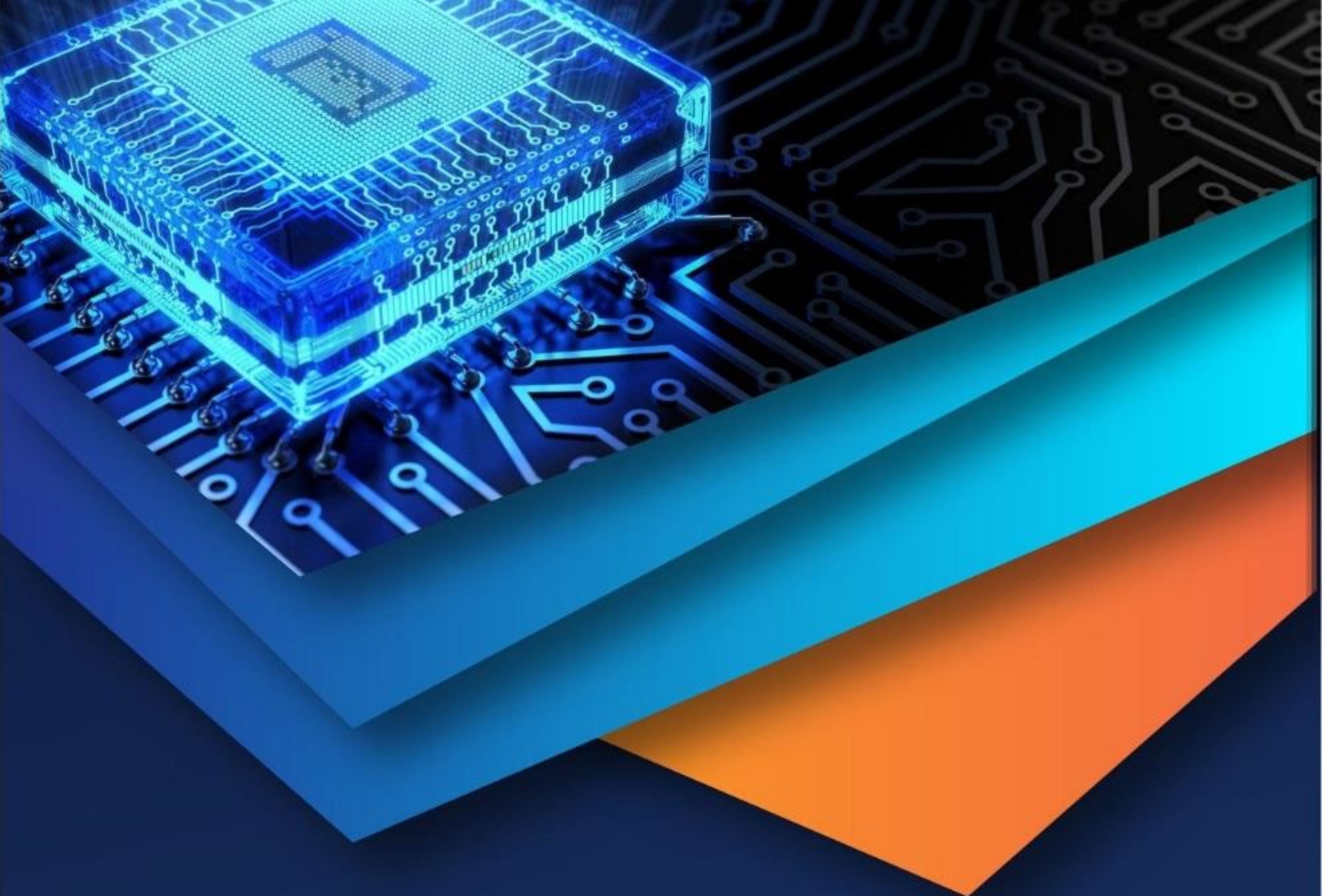
[1] B. Sharma and S.K. Rahman, "Use of GIS Based Maps for Preliminary Assessment of Subsoil of Guwahati City", *Journal of Geoscience and Environment Protection*, 4, pp. 106-116, 2016.



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