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Empirical correlations for characterization of black cotton soil in Kolhapur city

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ABSTRACT

Every civil engineering structure needs solid foundation, foundation needs suitable subsoil. Every soil has different properties hence react differently. Black cotton soil is one of the problematic soils for construction. In Kolhapur region, mostly black cotton soil is present. Samples of black cotton soil were collected at depth of 1.5m, from Kolhapur, district in State of Maharashtra, India. Different properties of soil were determined with change in various soil properties. Results obtained from field as well as laboratory tests were correlated. Total five equations were formed on the basis of output parameters of software. As **s**ampling is done on ten locations, equations provide form of correlation for certain properties of soil under observation. In this study, linear, logarithmic as well as polynomial regression analysis is used. This will be helpful for civil engineers and contractors as quick guide especially when unmarked area is to be utilized for development in Kolhapur city.

Keywords: black cotton soil; correlation coefficient; Kolhapur city.

1. INTRODUCTION

With rapid growth of population, fast urbanization and more construction of buildings and other structures has resulted in reduction of good quality available land. There is no choice, except to use soft and weak soils around for construction activities. Such soil possesses poor shear strength and high swelling & shrinkage. Soil is a complex material, composed of minerals, organic matter, gases, liquids, and countless organisms that together support life on the earth. The black cotton soil is a type of expansive soil with high plasticity and can retain moisture throughout the dry season and hence, valuable for growing crops. It exhibits low bearing capacity, low permeability and high volume change due to presence of montmorillonite in its mineralogical content(Berawala and Solanki2010). It either swells or shrinks based on the seasonal changes resulting in differential settlements, which result in additional moments to the structure. On account of its high volumetric changes, it is not suitable for construction of embankment and other engineering structures. Flexible pavement designed over this type of soil requires very high crust thickness, which makes it uneconomical. These soils are widely distributed all over the world and in India also, In India large surface deposits are covered by expansive soil. In Kolhapur region, mostly black cotton soil is present. Samples of black cotton soil were collected from Kolhapur, district in state of Maharashtra, India. Geographically, Kolhapur district can be divided into three broad soil zones: (a) the western part, with heavy rainfall (is mountainous and woody and is covered with lateritic soils); (b) the fertile central part, with brownish well-drained soils of neutral reaction; and (c) the dry eastern zone, with precarious rainfall and covered with black soil of varying depth deeper soils are more black in color and more clayey. Figure 1 shows distribution pattern of soils in Kolhapur district(Kolhapur District Gazetteer published by the Gazetteers Department, 1960).

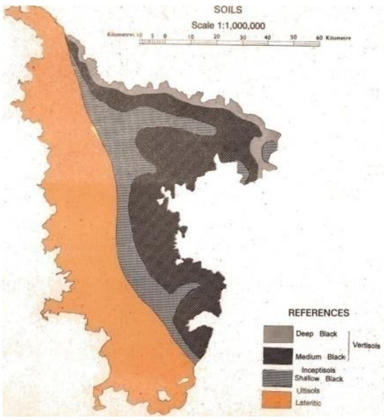

Fig.1. Distribution of soils in Kolhapur district

Though various empirical correlations are available to analyze the properties of black cotton soil, use of empirical correlations cannot be generalized for all places and all soils. Hence in the present study, number of samples of black cotton soil were taken from the different zones of Kolhapur district and identification and classification tests were conducted on the soil samples collected. The statistical analyses were carried out in order to obtain the most suitable relationships. New correlations were proposed in different combinations for black cotton soil of Kolhapur city in the Maharashtra State of India. These correlations will be very helpful for civil engineers and contractors as quick guide for designing and construction of foundations on black cotton soils in Kolhapur District.

2. LITERATURE REVIEW

Various researchers have focused and revealed potential of empirical correlation to predict important properties of black cotton soil for different regions. Various empirical relationship or phenomenological relationships between black cotton soil properties which are supported by experiment and observation are developed by many researchers in past some of them are listed in literature survey. Statistical tools were utilized by many of the researchers supported by software analysis. Especially regression analysis, both simple and multiple regression analysis is used for prediction of strength properties of Black cotton soil. Each researcher considered independent and dependent variables as per his interest and availability of experimental data. Many researcher used laboratory as well as field test results to develop equations.

Investigations are reported which aimed at developing an equation for quick prediction of swell pressures from easily determined soil properties. Bentonite-Kaolinite clay mixtures were prepared to obtain soils in a wide range of plasticity indices. A total of 80 constant volume swell tests in oedometers were performed on statically compacted specimens with varying properties. Swell pressure, plasticity index, water content, dry density interrelationships were evaluated. Swell pressure is correlated to the soil properties, namely, plasticity index, water content, liquidity index and dry density, using multiple regression analyses. The analyses have confirmed the existence of strong correlations between the swell pressure and the soil properties (Erzin 2004).

California Bearing Ratio (CBR) of some lateritic soil within Osogbo town of South Western Nigeria have been presented. For an appreciable conclusion to be established, lateritic soil samples were collected from eight (8) different borrow pits within the town and various laboratory tests including Atterberg limits, gradation analysis, California bearing ratio, compaction and specific gravity were performed on the soil samples. Various linear relationships between index properties and CBR of the samples were investigated and predictive equations estimating CBR from the experimental index values were developed. The findings indicate that good correlation exists between the two groups (i.e. Index properties and CBR values). It is recommended for future research that regression based models such as two ways ANOVA and computer based reliability analysis be carried out on a wider variety of soil samples so as to specify the range of applicability of the derived model as well as the input variables (Bello 2012).

Simple Linear Regression Analysis (SLRA) by using the function of Microsoft Excel software was utilized. SLRA was carried out by considering the soaked California Bearing Ratio (CBR) value as dependent variable and several soil properties like plasticity index, optimum moisture content and maximum dry density as independent variables. This has been carried out to develop the correlation between individual soil property and soaked CBR value. The empirical relationship was developed by using multiple regression analysis. It has been carried out by considering the soaked CBR value as the dependent variable and remaining soil properties such as maximum dry density (MDD), optimum moisture content (OMC) & plastic index (PI) as independent variables. The empirical relation obtained from multiple linear regression analysis (MLRA) shows good relation to predict CBR. Empirical equations, the correlation of CBR value with the two parameters that are OMC and MDD has the correlation coefficient (R^2) of 0.90. Correlation of CBR value with the three parameters that are PI, OMC and MDD has the correlation coefficient (R^2) of 0.99. It can be observed that as parameters increases, equations accuracy also increases (Agarwal et al., 2016).

An attempt has been made to establish the regression equations to predict the CBR value of Indian Black cotton soils based on their field strength properties as well with the index properties. For this purpose samples from 26 different locations representing Black cotton soils were collected and tested in the laboratory for various properties including test for CBR. Also Standard penetration tests (SPT) and dynamic cone penetration tests (DCPT) are conducted at the location of soil sample collection. Based on these laboratory and field test results attempts are made to develop regression equation using the statistical analysis (SPSS Software). The regression equations so developed indicated good correlation co-efficient (Srinivasa et al., 2016).

Six field soils were selected from Mysore District, Karnataka based on their index properties. Group 1 soils were sieved through 4.75mm sieves to have sand, silt and clay-fraction. Soils procured from source were also sieved through 425μm sieves to have fine-sand, silt and clay-fraction and named as Group 2 soils. For both Group 1 and 2 soils, compaction tests were carried out for varying energy levels like reduced standard proctor (RSP), standard proctor (SP), reduced modified proctor (RMP) and modified proctor (MP) and minimum of six trials were done with varying initial water content to get the compaction curve. In order to understand the soil characteristics, the physical tests were conducted on the soil samples as per Bureau of Indian Standards (BIS).

Different empirical equations were developed to predict maximum dry density (MDD) and optimum moisture contain (OMC) (Prasanna et al.2017).
Regression analysis was carried out to correlate standard penetration test (SPT) and pressure meter test (PMT) values and the R^2 values were calculated to determine the accuracy of the relation. Standard penetration tests were carried out in the 17 boreholes following ASTM D1586. Tests were carried out at 1.5 m intervals. The pressure meter test was also carried out at the same depth interval following the ASTM D4719. The pressure meter tests were executed using the Prebored, G type Menard pressure meter (Anwar, 2018).

3. PROBLEMS ASSOCIATED WITH BLACK COTTON SOIL

Due to their peculiar nature black cotton soils are challenge for engineers everywhere in the world, and more so in tropical countries like India because of wide variation in temperature and because of distinct dry and wet seasons, leading to wide variations in moisture content of soil. Black cotton soils are highly plastic and compressible, when they are saturated. Footings resting on such soil undergo consolidation settlement of high magnitude due to its high compressibility. A structure built in a dry season, when the natural water content is low shows differential movement of soils as result during subsequent wet season. This causes structures supported by such swelling soils to lift up and crack. A structure built at the end of the wet season when the natural water content is high, shows settlement and shrinkage cracks during subsequent dry season(Mishra 2015).

4. METHODOLOGY

Kolhapur is a city on the banks of the Panchaganga river, in the State of Maharashtra. Kolhapur is governed by Kolhapur Municipal Corporation (KMC). The city is divided into five wards, named with the letters A to E. To develop empirical correlations huge data set is required as input, to achieve better accuracy. Correlations should be always supported by experimental analysis as well as extensive sampling of soil. Generally, samples are collected from the study area after appropriate identification of soil pattern of the certain area through reconnaissance survey. For this study, sampling locations were identified from various wards of Kolhapur city where black cotton soil is present, through reconnaissance survey. Sampling was done at ten different locations. Samples were collected from 1.5m depths below ground level at every location by various methods such as, core cutter, test pits and bore holes**.** The main aim of this study is to develop empirical correlation of black cotton soil properties for Kolhapur city.
Soil samples were collected from ten different places i.e. Karandemala, Tarabai Park, Sugar Mill, Bawada, Biranje Panand, Chabukhadi, Fulewadi, Vathar, Gokulshirgaon, Rankala lake area and Kandalgaon, which were tested for all index properties. The main aim of this study is to identify correlation between index properties of soil.
Various index properties of soil were determined i.e. grain size analysis (IS–2720: Part 4 -1985),specific gravity of soil (IS-2720: Part3-1980), field density by core cutter method (IS-27270: Part 29-1975), plastic limit and liquid limit test of soil using Casagrande's apparatus (IS-2720: Part 5-1985). Changes in various soil properties were analyzed. Results obtained from field as well as laboratory tests were correlated to form an equation of correlation on the basis of output parameters of software. Linear, logarithmic as well as polynomial analyses were carried out by using MS-Excel.
For development of empirical correlations data set is generally analyzed with the help of appropriate statistical tool. In this study, regression analysis was used as statistical tool for development of co-relationships between black cotton soil properties. In statistical modeling, regression analysis is a set of statistical processes for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. Regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed.

It is used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships. In restricted circumstances, regression analysis can be used to infer causal relationships between the independent and dependent variables.
In this study, linear, logarithmic as well as polynomial regression analysis is used.

4. RESULTS AND DISCUSSIONS

Samples were collected from ten locations, basically soil was black cotton soil which generally under cultivation of sugarcane, but due to expansion of the city and rapid demand of land, the same will be utilized for construction purpose. Many projects already completed, at each location three sets of samples were collected for accuracy, and tested in lab for different properties. On the basis of lab and field test results, properties are correlated by using Microsoft Excel to form appropriate equation of correlation. Different correlations were cheeked for significance level as P- value and for regression coefficient of correlation (R^2). Some significant correlations are listed below.

Specific gravity was correlated with field density; it indicates significant relationship with $R^2 = 0.957$ as shown in Eq. (1).

$$G = 5.4 - 2.434\rho_d \qquad (1)$$

Maximum dry density by Standard Proctor test was correlated with field dry density with R^2= 0.986 as shown in Eq. (2).

$$MDD = -1.816(\rho)^6 + 18041(\rho)^5 - 74411(\rho)^4 + 16311(\rho)^3 - 20044(\rho)^2 + 13092(\rho) - 35511. \qquad (2)$$

Optimum moisture contain (OMC) was correlated with California bearing ratio value with R^2= 0.9139 as shown in Eq. (3).

$$CBR = 19.453\ln(OMC) - 50.174 \qquad (3)$$

Free swell index (FSI) was correlated with specific gravity (G) with R^2= 0.9644 as shown in Eq. (4).

$$FSI = 3643.8G^3 - 24774G^2 + 56162G - 42397 \qquad (4)$$

Plastic limit was correlated with Specific gravity with R^2= 0.679 as shown in Eq. (5).

$$PL = 9.674(G) - 0.564 \qquad (5)$$

Where, G = specific gravity, γ_d = field density, ρ = field bulk density by core cutter method, OMC = optimum moisture contain by standard proctor test, CBR= California bearing ratio value, FSI= free swell index and PL = plastic limit.

Different correlations were developed by using different soil properties. Some correlations were proposed here on the basis of correlation coefficient.

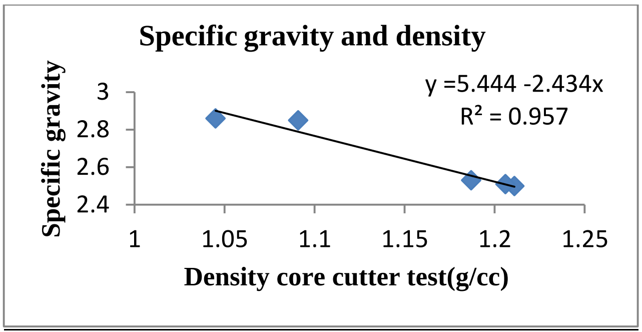

Fig.2. Relation between G and Field Density

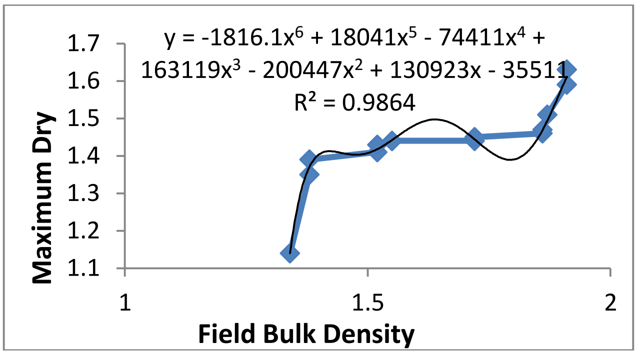

Fig.3. Relation between MDD and field bulk Density

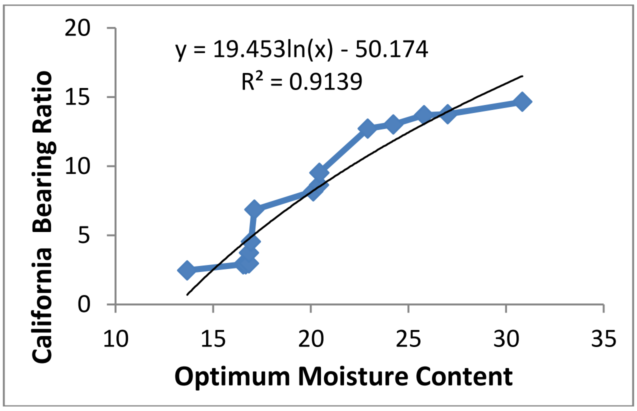

Fig.4. Relation between OMC and CBR

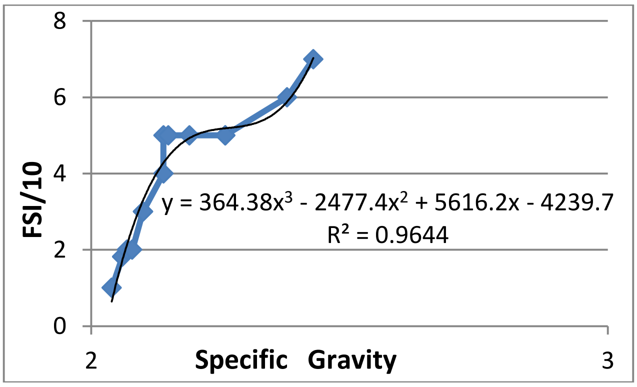

Fig.5. Relation between FSI and G

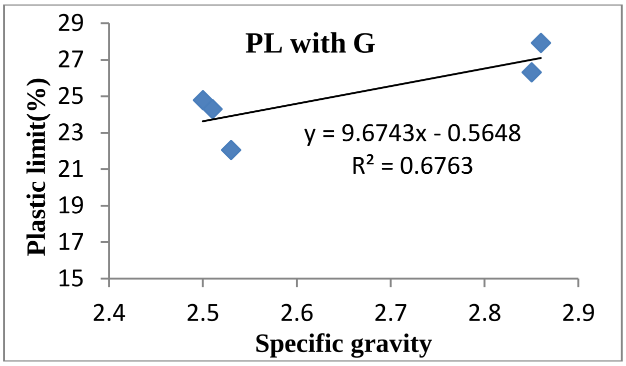

Fig.6. Relation between FSI and G

5. CONCLUSION

Based on results of laboratory and field test conducted on soil samples collected from ten locations from Kolhapur city, various equations of correlation were established. Most significant of them, based on R^2 values are considered as co-relation equations for specific parameters in between analysis was carried out. Every equation is useful for prediction certain variable such as, specific gravity, CBR value, MDD, OMC, FSI and density. Specific gravity was strongly correlated with field density with R^2= 96%. Also, maximum dry density by Standard Proctor test was correlated with field dry density with R^2= 99%. Significant correlation was also obtained between OMC and CBR with R^2 = 97%. FSI was correlated with G with R^2= 0.98% as shown in Figure 5. Plastic limit was also correlated with specific gravity with R^2= 68%. This will be helpful for civil engineers and contractors as quick guide especially when unmarked area is to be utilized for development in Kolhapur city.

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