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A correlative study of different geotechnical parameters of local soil of West Bengal with varying percentage of sand

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ABSTRACT

Coarse fraction of soil plays an important role on the geotechnical properties of soil whereas soils having more fines are the most unpredictable and problematic engineering materials for construction of civil structures over it. Therefore, there arises a need for proper prediction of the geotechnical properties of soils where there is limited facility for laboratory experiments. In the present study, soil parameters like particle size distribution, liquid limit (LL), plastic limit (PL), optimum moisture content (OMC), maximum dry density (MDD), CBR value, compression index (C_c), cohesion (c) and angle of internal friction (φ) are determined by carrying out various laboratory tests, as per I.S specifications, on a local soil (CL-ML) and the samples obtained by varying the sand (SP) content in it. The primary objective of this work is to study the aforementioned soil properties and establish a correlation between them, which will be useful to the civil engineers for quick determination of strength parameters for subgrade soil or embankment fill. Attempts are made to develop linear empirical relationships for LL, CBR, C_c and φ, respectively, as a function of % sand content whereas a polynomial equation is developed between MDD and % sand content. Attempts are also made to develop empirical relationships of soaked CBR and φ value respectively as a function of both % sand content and MDD by performing multi variable regression analysis. These empirical correlations may be beneficial for predicting the desirable geotechnical properties if only grain-size analysis data and/or other few geotechnical properties of soil are available.

Keywords: % sand content, Geotechnical Properties, Correlation

1. INTRODUCTION

Various geotechnical parameters are being used in the design of several civil engineering structures. For example, soil parameters like Atterberg's limits and particle size distribution are used in classification of soil samples. Shear strength is an important property which controls the stability of soil mass under various loading condition. It also governs the bearing capacity of soil, stability of slopes, earth pressure against retraining structures etc. Several tests have been conducted by researchers to study the effect of particle shape and size on the shear strength parameters. California bearing ratio is helpful for the design of flexible pavement whereas sub grade modulus (k –value) is required for the design of rigid pavement and raft foundation. Therefore, a detailed study of the various geotechnical parameters is must for safe and economical solution of various geotechnical problems. In the present study, soil parameters like particle size distribution, liquid limit (LL), plastic limit (PL), optimum moisture content (OMC), maximum dry density (MDD), CBR value, compression index (C_c), cohesion (c) and angle of internal friction (φ) are determined by carrying out various laboratory tests, as per I.S specifications, on a local soil (CL-ML) and the samples obtained by varying the sand (SP) content in it. The primary objective of this work is to study the aforementioned soil properties and establish correlations between them, which will be very useful to the civil engineers for quick determination of strength parameters for sub grade soil or embankment fill.

2. LITERATURE REVIEW

Danistan & Vipulanandan (2010) have studied the correlation between CBR and soil parameters. In their study, laboratory and field compacted soil sample (CL, CH & SC) were characterized using the CBR test and the relationship between CBR and undrained shear strength was studied which was found to be nonlinear. Patel & Desai (2010) evolved a correlation between CBR values with index properties like plasticity index, optimum moisture content and dry density of alluvial soil of Surat region by carrying out statistical analysis using the SPSS software. Laskar & Pal (2012) studied the geotechnical properties of two different soils; one of them obtained from NIT Agartala campus and the other from river bank of Howrah and found that as clay content increases in the soil, the plasticity index (PI) increases and angle of internal friction (Φ) decreases. It was also found that the optimum moisture content (OMC) of the soil increases with the increase of plasticity index, compression index (C_c) increases as liquid limit (LL) increases and with the increase of OMC, C_c also increases. Patel & Patel (2012) derived some correlation of CBR, PBT, and UCS with DCP, for various soils in soaked condition. Reddy (2013) studied the correlation between CBR and shear strength of some artificially prepared soil samples with varying plasticity index. The soil sample was red moorum and the fraction passing 425 micron was replaced by sand powder and medium plastic clay in various percentages. A nonlinear correlation was obtained between soaked CBR and undrained shear strength which is validated with test results and the variation was found to be within 1.5%. Adunoye (2014) carried out an experimental study to find out the correlation between fines content and angle of internal friction of a lateritic soil. A nonlinear relationship was found out between the fines content and the angle of internal friction of the soil sample. Shah Nawaz & Gupta (2014) gave a correlation between different geotechnical parameters of soil obtained from five sites of Nagar district (Kashipur, Bajpur, Rudrapur, Pantnagar and Kiccha). In continuation of the above literature review, a study of local soil (CL-ML) procured from Mogra, West Bengal, which was mixed with sand in varying percentages is being done for the establishment of a relationship among the different soil parameters.

3. MATERIALS AND METHODOLOGY

Local soil (CL-ML) was procured from Mogra, West Bengal. The soil was excavated from a depth of 1.5 m from the natural ground level. The obtained soil was air dried, pulverized and the soil fraction passing through 425 μ I.S. sieve was used. Apart from the local soil sample (sample-I), five other soil samples were obtained by varying the sand (SP) content in the percentages of 12.5 %, 25.0 %, 50.0 %, 75.0 % and 87.5 % in the locally procured soil which are designated as sample-II to sample-VI respectively. The physical and geotechnical properties of the local soil and the prepared soil samples (sample-I to sample-VI) used in this investigation are given in Table 1. Soil parameters like particle size distribution, liquid limit (LL), plastic limit (PL), optimum moisture content (OMC), maximum dry density (MDD), CBR value, compression index (C_c), cohesion (c) and angle of internal friction (φ) are determined by carrying out various laboratory tests, as per I.S specifications.

Table 1 Results of laboratory tests of soil samples

Properties	Sample-I	Sample-II	Sample-III	Sample-IV	Sample-V	Sample-VI
LL (%)	28	25	23	20	NP	NP
PL (%)	16.5	14.2	12	8		
PI (%)	11.5	10.8	11	12		
C (kg/cm²)	0.3	0.9	0.4	0.2	0.15	0
Φ in degree	22	23	28	34	38	36
CBRsoaked(%)	3.02	4.82	5.5	7.67	10.2	12.3
OMC (%)	17	17	15.5	16	14	15.3
MDD (gm/cc)	1.655	1.75	1.76	1.87	1.905	1.88
Cc	0.099	0.182	0.149	0.075	0.05	0.066

4. DISCUSSIONS AND CORRELATIONS

Based on test results as presented above, the effects of percentage (%) of sand content in soil samples on liquid limit (LL), California bearing ratio (CBR), coefficient of compressibility (C_c), angle of internal friction (Φ), maximum dry density (MDD) and optimum moisture content (OMC) are discussed in this section. Also, linear regression technique is used to analyze data of test results and establish relations between different variables. Attempts have been made for development of relationship between two variables by fitting a linear or nonlinear equation on observed data. Multi variable regression analysis to establish the relationships between different geotechnical parameters have been also tried.

4.1. Effect of Sand Content on Liquid Limit

The liquid limit value decreases with the increase of percentage sand content present in the soil. With the increase of % sand content, the plasticity of the material decreases and tends to be non plastic. It may be due to decrease of inter molecular attraction force. Due to decrease of attraction force liquid limit of the soil decreases. Hence, the LL value decreases with the increase of sand content in the soil. The following equation of the trend line has been achieved by 1st order linear regression analysis between LL and % sand content (Fig 1a).

LL = 28.36 - 0.164 x % sand content -------------------- (1)

4.2. Effect of Sand Content on CBR

The CBR value depends on the sand percentage and it increases proportionally with the increase of percentage sand content present in the soil. With the increase of % sand content, the plasticity of the material decrease due to decrease of inter molecular attraction force. At the same time, as the finer percentage of the soil decreases the soil loses its water retention capacity inside the void space. Thereby, the soil sample does not become softer when submerged in comparison with the soil having more amounts of finer particles. Hence, soaked CBR value increases with the increase of sand content in the soil. Figure 1b shows the linear trend line depicting the good correlation between the percentage sand content in the soil sample with CBR value. The following equation of the trend line has been achieved by 1st order linear regression analysis between CBR value and % sand content.

Soaked CBR = 2.456 + 0.107 x % sand content -------------------- (2)

4.3. Effect of Sand Content on Compression Index

From the test results, it is observed that initially the C_c value increases and then decreases consistently with the increase of percentage sand content present in the soil. Except the 1st value, the other test results show a particular trend which is decreasing in nature with the increase of sand content in the soil. This nature of the soil can be explained from the point of view of amount of finer materials presents in the soil. Finer particles present in soil give greater plasticity and by virtue of which soil can undergo large amount of deformation. Therefore, the soil having greater fine percentages shows greater compressible characteristics. Figure 1c shows the linear trend line which shows good correlation between the percentage sand content in the soil sample with C_c value discarding the 1st test result. The following equation of the trend line has been achieved by 1^{st} order linear regression analysis between C_c value and % sand content.

C_c = 0.2022 - 0.00186 x % sand content -------------------- (3)

4.4. Effect of Sand Content on Angle of Internal Friction

Soil strength is the resistance to mass deformation. It depends on a) interlocking of particles, b) frictional resistance between the soil grains, and c) adhesion or cohesion between soil particles. This friction and cohesion of soil depends upon the percentages of finer (silt and clay) or coarser (sand) particles present in the soil. With the increase of coarser content in soil, frictional resistance between soil grains increases during shearing and hence the value of φ increases. Figure 1d shows the linear trend line which shows good correlation between the percentage sand content in the soil sample with φ value. The following equation of the trend line has been achieved by 1^{st} order linear regression analysis between φ value and % sand content.

φ = 21.124 + 0.2024 x % sand content -------------------- (4)

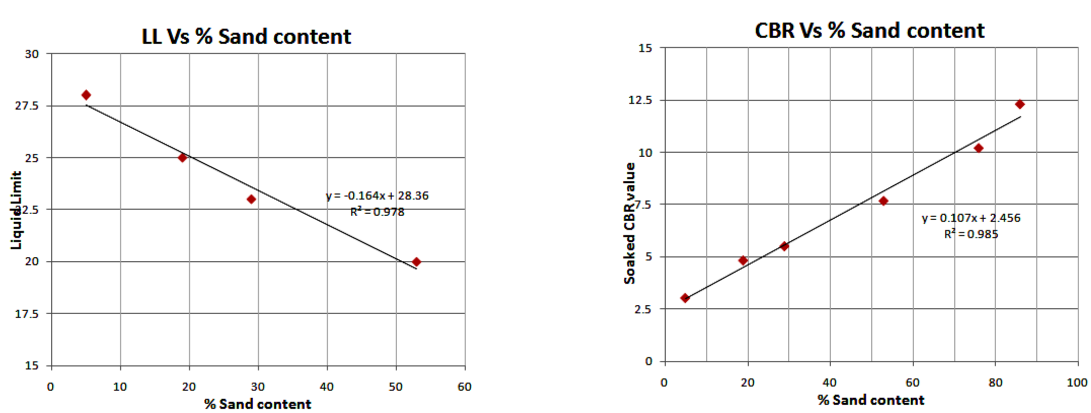
4.5. Effect of Sand Content on Maximum Dry Density

The MDD value increases with the increase of percentage sand content present in the soil up to a certain % and then it decreases. Generally, the densification stages of a particular soil are represented by its compaction curve. Very low water content in soil creates a capillarity effect that produces tension stress and grouping of the solid particles that result in a high friction resistance that opposes the compaction stresses. With the increase of water content, lubrication effect between soil grains increases and hence, better rearrangement between soil grains can be achieved. It continues up to certain moisture content (OMC) where the maximum dry density (MDD) is reached. With the increase of % sand content, by the application of external energy a better rearrangement of the soil particles is achieved, thus, MDD increases but at very high value of sand content, the MDD value decreases probably due to the fact of the poor grading of the sand which is used in this test. Figure 1e shows the trend line which depicts a non-linear correlation between the percentage sand content in the soil sample with MDD value. The following equation of the trend line has been achieved from Excel chart option and a 2^{nd} degree polynomial equation is chosen which give the highest value of R^2 i.e. the coefficient of determination.

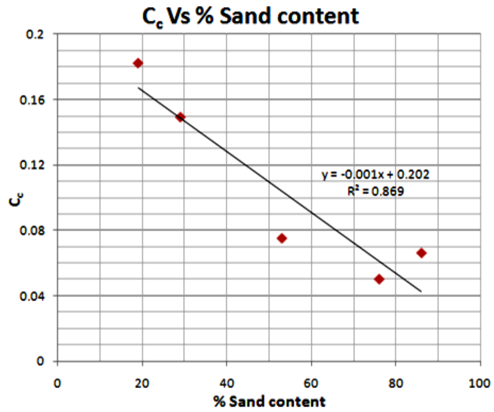
MDD (gm/cc) = -4×10^{-5} x (% of sand)^2 + 0.0066 x (% sand content) + 1.620 --------- (5)

4.6. Effect of Sand Content on Optimum Moisture Content

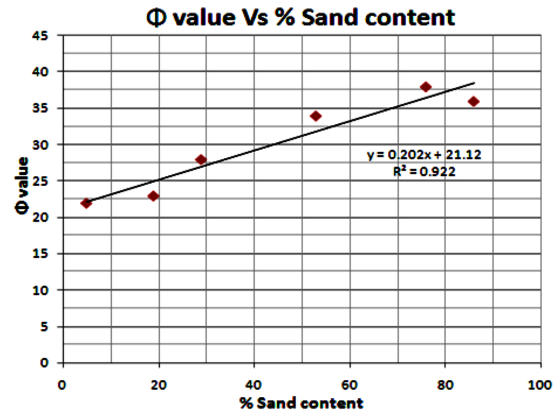
The OMC is decreasing with the increase of sand percentage in the soil. As the percentage of coarser soil particles increase, specific surface area of the soil mass decreases and less amount of water is required to lubricate the soil grain surfaces. Hence, to achieve maximum density by reorienting the soil grain inside the soil mass by external effort, less amount of water is required and thus resulting in lesser OMC value.



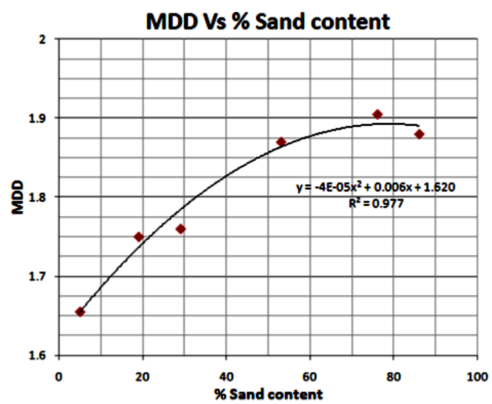
(a) (b)



(c)



(d)



(e)

Figure 1 Correlation between (a) LL (b) CBR (c) C_C (d) φ (e) MDD with % Sand Content

4.7. Prediction of CBR Value from MDD and Percent Sand Content

A relation between CBR, % sand content and MDD is determined from experimental data by multiple variable regression analysis and is expressed by Equation 6.

CBR = 16.5235 + 0.1314 x (% of sand) – 8.3923 MDD (gm/cc) -------------------- (6)

A plot between actual and predicted CBR values is shown in Figure 2.

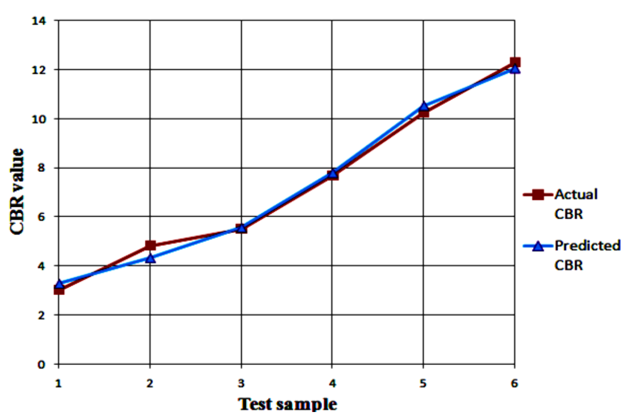


Figure 2 Plot between actual and predicted value CBR Values

4.8. Prediction of Φ Value from MDD and Percent Sand Content

A relation between φ value, % sand content and MDD is determined from experimental data by multiple variable regression analysis and is expressed by Equation 7.

$$\varphi = -36.1479 + 0.1057\,(\%\text{ of sand}) + 34.1562\,\text{MDD} \qquad \text{-------------------- (7)}$$

A plot between actual and predicted CBR values is shown in Figure 3.

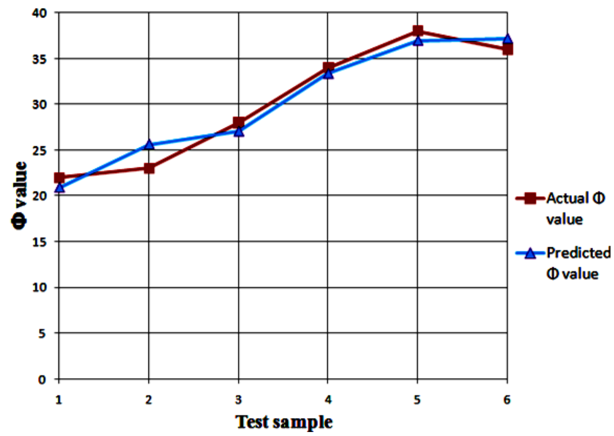


Figure 3 Plot between actual and predicted value Φ Values

5. CONCLUSIONS

Based on the above test results, discussions and correlations, it is found that as sand content increases in the soil, plasticity, liquid limit, optimum moisture content and compression index decreases, whereas CBR, angle of internal friction, and maximum dry density value increases. The correlations for liquid limit, CBR, compression index and φ, respectively with varying % sand content, that are developed by means of regression analysis from the test data are found to be in agreement with the predicted data. The empirical relationships developed for LL, CBR, C_c and φ, respectively, as a function of % sand content show a form of a linear equation whereas the empirical relationship developed for MDD as a function of % sand content is in the form of a polynomial equation. Empirical relationships of soaked CBR and φ value respectively as a function of both % sand content and MDD developed by performing multi variable regression analysis from the test data are also found to be in agreement with the predicted data. The values of coefficient of determination (R^2) for all the relationships established are found to be close to one. These empirical correlations may be beneficial for predicting the desirable geotechnical properties if only grain-size analysis data and/or other few geotechnical properties of soil are available.

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