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Estimation of bulk density, moisture content, specific gravity, liquid and plastic limit of soil at Sirsa (Haryana)

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Abstract
A geotechnical site investigation is the process of collecting information and evaluating the conditions of the site for the purpose of designing and constructing the foundation for a structure, such as a building, plant or bridge. Shear strength property of soil plays a major role in controlling the stability of a soil mass under structural loads. Determination of shear strength parameters such as cohesion and angle of internal friction are needed for the evaluation of bearing capacity of foundations, the assessment of the stability of a slope, etc. Hence, it is always essential to measure this property before design of foundation of any structure. In this study, a detailed survey was carried out within a 5 km radius of Sirsa and 10 locations were identified for soil sampling. The soil samples were collected at 50 cm depth from ground surface and analyzed for different geotechnical properties like bulk density, dry density, natural moisture content, specific gravity, particle size, liquid limit, plastic limit, plasticity index and shear strength parameters (cohesion and angle of shearing resistance). With the help of particle size distribution curves, coefficient of uniformity and coefficient of curvature were evaluated to find out the gradation of particles. Influence of the geotechnical properties of soils on shear strength parameters was studied. Stepwise regression procedure was carried out for the selection of most influencing variables. Incorporating selected variables, multiple regression models were developed for the prediction of shear strength parameters. The performance of the multiple regression models were assessed in terms of correlation coefficient, F-statistics and residuals pattern. Using the developed models, shear strength parameters can be computed for the study area, which will be helpful for the determination of bearing capacity of soil.

Keywords: Shear strength, cohesion, angle of shearing resistance, multiple regressions, geotechnical properties, Sirsa.

1. Introduction
Soil supports different types of structures like buildings, roads, railway lines, pipelines, etc. Accurate investigations of geotechnical properties can enhance a good design of foundation to support the structure (Too, 2012) [43]. Therefore, the geotechnical properties of soils on which a superstructure is to be constructed must be well understood in order to avoid superstructure and foundation failures (Omotoso *et al*., 2011) [28]. One of the most important engineering properties of soil is its ability to resist sliding along internal surfaces within a mass. The stability of structures built on soil depends upon the shearing resistance offered by the soil along probable surfaces of slippage. The shear strength of geotechnical materials is generally represented by the Mohr–Coulomb theory. According to this theory, the shear strength of soils varies linearly with the applied stress through two shear strength components known as the cohesion intercept and angle of shearing resistance. The tangent to the Mohr–Coulomb failure envelopes is represented by its slope and intercept. The slope expressed in degrees is the angle of shearing resistance and the intercept is the cohesion (Arora, 1988; Murthy, 2008; Mollahasani *et al*., 2011) [2, 24, 22, 23]. The angle of shearing resistance represents the interlocking between the soils particles whereas cohesion is mainly due to the intermolecular bond between the adsorbed water surrounding each grain, especially in fine-grained soils

(Murthy 2008; El-Maksoud, 2006) [24, 6]. Cohesion has a major role in the design of different geotechnical structures such as foundations, slopes, underground chambers, and open excavations (Mollahasani *et al*. 2011) [22, 23] Soils with high plasticity have lower angle of shearing resistance and higher cohesion. Conversely, as the soil grain size increases, the soil internal friction angle increases and its cohesion decreases. Therefore, in a rational manner the main parameters which affect the soil strength parameters are the soil type, soil plasticity, and soil density (Mousavi *et al*., 2011) [23]. The angle of internal friction depends upon dry density, particle size distribution, shape of particles, surface texture, and water content whereas cohesion depends upon size of clayey particles, types of clay minerals, valence bond between particles, water content, and proportion of the clay (Jain *et al*., 2010) [17]. According to Lun (2011) [20], shear strength is affected by several factors such as grain size distribution, density, water content and few others.

Accurate determination of the soil shear strength parameters (cohesion and angle of shearing resistance) is a major concern in the design of different geotechnical structures. These key parameters can be determined either in the field or in the laboratory. The triaxial compression and direct shear tests are the most common tests for determining the cohesion and angle of shearing resistance values in the laboratory. However, experimental determination of the strength parameters is extensive, cumbersome and costly. Further, it is not always possible to conduct the tests on every new situation. In order to cope with such problems, numerical solutions have been developed to estimate shear strength parameters (Mousavi *et al*., 2011) [23]. As per Sorensen and Okkels (2013) [38], empirical correlations are widely used in geotechnical engineering practice as a tool to estimate the engineering properties of soils. Considering these, a study was conducted to generate data on geotechnical properties of soil of Sirsa area. This paper deals with correlation of geotechnical properties of soil with shear strength parameters, and to develop statistical models for its prediction.

2. Methodology

2.1. Sampling locations

Sirsa town is situated at latitude 29 ^{0}32'0" north and longitude 75 ^{0}1'0" east in Haryana, India. It is at distance of 260 km by rail from Delhi. As the Sirsa Township is developing in different directions, therefore, a detailed survey was conducted within a 5 km radius of Sirsa to identify locations being used for construction purposes. Accordingly, 10 sampling locations in different area were selected for soil sampling. The sampling locations, and other surface structures are depicted in Figure 1.

2.2. Collection of samples

IS: 1904 – 1978 specifies that all foundations should extend to a depth of at least 50 cm below the natural ground surface (Arora, 1988) [22], therefore, samples from different locations of the area were collected from this depth. The tools like trowel, spade, auger, etc were used for samples collection. Sampling tubes made up of steel were used for the collection of bulk density samples. The collected samples kept into thick quality polythene bags were labeled, sealed and brought to the laboratory for analysis.

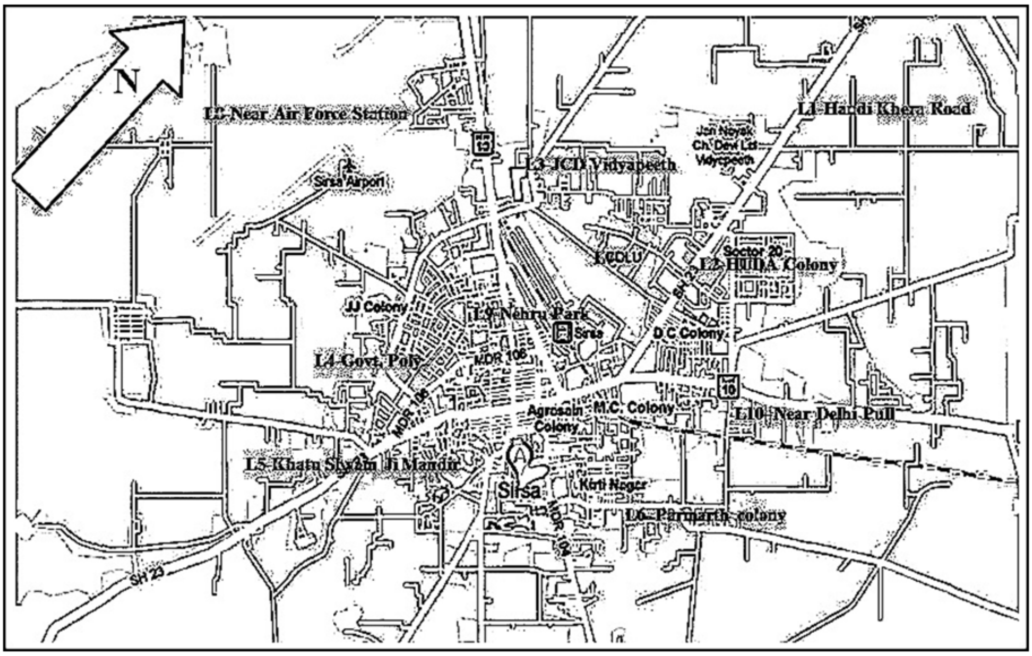


Fig 1: Sampling locations and other surface structures at Sirsa.

2.3. Testing of geotechnical properties of soil

The geotechnical properties of soils were determined in the Geotechnical Laboratory of Civil Engineering Department, Jan Nayak Ch. Devi Lal Memorial College of Engineering, Sirsa. The methods adopted for testing of different parameters are as under: *Bulk density and dry density*: Bulk density is the ratio of the weight of soil to the total volume of soil including water and air both whereas dry density is the ratio of the dry solids to the total volume (Apparao and Rao, 1995) [3]. The density was determined using the core cutter method (IS: 2720-Part XXIX, 1975; Raj, 1995) [15, 34].

Water content: Moisture content is the ratio of the weight of water to the weight of dry materials. It is expressed in percentage. It was determined by oven drying method (IS: 2720-Part II, 1973) [14]. The natural moisture content gives an idea about the state of soil in the field (Apparao and Rao, 1995) [3]. *Specific gravity*: It is the ratio of the weight in air of a given volume of dry soil solids to the weight of equal volume of distilled water at 4^{0}C. Particles passed through 4.75 mm IS sieve were used for determining specific gravity with the help of density bottle (Punmia *et al*., 2005) [33].

Grain size analysis: For grain size analysis, air dried soil sample of 500 gm was sieved through a set of sieves ranged from 4.75 mm to 75 µm. The entire set of sieves was kept on electric sieve shaker machine and operated for 10 minutes. Percent finer for different sizes of the particles retained on different sieves were calculated. The percentage finer (summation passing) was plotted as ordinate (on arithmetic scale) and the particle size (aperture size) as abscissa (on log scale) (IS:2720-Part IV, 1975; Raj, 1995) [34].

Liquid limit: Soil sample passing through 425 µm sieve, weighing 120 gm was mixed with distilled water to form a uniform paste. A portion of the paste was taken in the cup of the liquid limit device. In the paste, a groove was formed and then device was operated at the rate of two revolutions per second until the two parts of the soil came in contact at the bottom of the groove along a distance of 12 mm. After that the numbers of drops were recorded. Finally, moisture content corresponding to 25 numbers of blows was taken as the liquid limit (IS:2720-Part V, 1970) [12].

Plastic limit: For the determination of plastic limit, 20 gm of soil passing through 425 µm sieve was taken and mixed thoroughly with distilled water so that it could become plastic enough. Then out of 20 gm wet soil, 8 gm of soil was taken to form a ball. The ball was rolled on the glass plate with the palm of the hand to form a thread of 3 mm uniform diameter throughout its length. The rolling process was continued till the thread just crumbles at 3 mm diameter. Then moisture content of the crumbled thread was determined as plastic limit (Raj, 1995) [34]. *Plasticity index*: The numerical difference between liquid limit and plastic limit is known as plasticity index. It indicates the degree of plasticity of a soil. Greater the difference between liquid and plastic limits greater is the plasticity of the soil. A cohesionless soil has zero plasticity index. Hence it is called non-plastic (Murthy, 2002) [24].

Shear strength parameters: The direct shear test is a very popular test for determining shear strength of soils (Moayed *et al*., 2012). In many engineering problems such as design of foundation, retaining walls, slab bridges, pipes, sheet piling, the value of angle of shearing resistance and cohesion of the soil involved are required for the design. Direct shear test is used to predict these parameters quickly (Apparao and Rao, 1995) [3]. This test was conducted to determine the undrained shear strength parameters of soil. Tests were performed in accordance to IS: 2720 Part-XIII (1972) [11]. The samples were sieved from 4.75 mm sieve and compacted in a square shear box of 60 mm x 60 mm x 50 mm. The samples were prepared at water content and dry density same as in the field conditions, without respect to the fact, that the conditions in the future might not remain the same (Kristyna et al., 2013) [18]. Based on the experiment, the graph between normal stress and shear stress was plotted to determine the cohesion and angle of shearing resistance.

3. Results and discussion

Different geotechnical properties like bulk density, dry density, natural moisture content, specific gravity, particle size, liquid limit, plastic limit and plasticity index of soils, collected in and around of Sirsa town were determined. The shear strength *parameters* like cohesion and angle of shearing resistance was also assessed. At most of the locations, soils were cohesionless in nature. Only at few locations, soils were cohesive. Correlation of individual property with shear strength parameters and statistical models for its prediction were developed.

3.1. Bulk density and dry density

Bulk density shows an appreciable effect on the shear strength of soil. Tight packing of soils to generate large bulk densities is a common engineering practice to provide added soil strength. When foundations, footings or roadbeds are built upon soil, the strengthening of the underlying strata helps to prevent soil shifting or settling after the structure is built (Traffic and Soil Mechanics, 2013) [38, 41].

The correlation of cohesion and angle of shearing resistance with bulk density and dry density were determined (Table 1). Using SPSS software version 13.0, the significant level of correlation coefficients was checked and found (Table 1) indicating that density influences the shear strength parameters. Positive correlation shows that increase in soil density results in a linear increase in shear strength for both cohesive and granular soils. That is, higher density soils show higher strength for all textures and water contents as compared to soils that are more loosely packed (Traffic and Soil Mechanics, 2013) [38, 41]. According to Garcia *et al*. (2012) [9], shear strength increases with increasing dry bulk density indicating that the reduction in pore volume caused soil resistance. An increase in bulk density with corresponding increase in undrained shear strength was also observed by Ojuri (2013) [30].

Table 1: Individual correlation of shear strength parameters with geotechnical properties of soils

Geotechnical properties	Cohesion (kg/cm^2)	Level of significance (%)	Angle of shearing resistance (degree)	Level of significance (%)
Bulk density (gm/cm^3)	0.84	1	0.99	1
Dry density (gm/cm^3)	0.76	5	0.86	1
Natural moisture content (%)	0.65	5	0.83	1
Specific gravity	0.96	1	0.84	1
Coefficient of uniformity (C_u)	0.60	Not significant	0.48	Not significant
Coefficient of curvature (C_c)	0.56	Not significant	0.59	Not significant
Liquid limit (%)	0.86	1	0.83	1
Plastic limit (%)	0.80	1	0.77	1
Plasticity index (%)	0.68	5	0.69	5

3.2. Natural moisture content

Water exerts controlling influence on most of the physical, chemical and biological processes that occur in soil. Water in soil acts both as a lubricant and as a binding agent among the soil particulate materials, thereby influencing the structural stability and strength of soil and geologic materials (Kristyna *et al*., 2013) [18]. The correlation of the natural moisture content with cohesion and angle of shearing resistance showed increase in shear strength parameters with an increase of moisture content. The correlations were statistically significant (Table 1). Cohesive and cohesionless properties of soils might cause variation in moisture content in the soils and hence variation in shear strength parameters. According to Dafalla (2013) [5], increase or decrease in cohesion and angle of shearing resistance depends on the presence of clay and moisture content in the soils. Obasi and Anyaegbunam (2005)

[31] explained that partially saturated soils have undrained shear strength, which depends on its moisture content. Kumari (2009) [19], stated that the cohesion and angle of shearing resistance increases or decreases depending on the variation in water content.

3.3. Specific gravity

Specific gravity is an important index property of soils that is closely linked with mineralogy or chemical composition (Oyediran and Durojaiye, 2011) [29]. And also reflects the history of weathering (Tuncer and Lohnes, 1977) [44]. It gives an idea about the suitability of the soil as a construction material; higher value of specific gravity gives more strength for roads and foundations (Prakash and Jain, 2002) [32]. Correlations were statistically significant at 1% level (Table 1) of significance indicating influence of specific gravity on shear strength parameters.

3.4. Particle size analysis

The particle size distribution curve (gradation curve) represents the distribution of particles of different sizes in the soil mass (Mallo and Umbugadu, 2012) [26]. The shear strength parameters of a granular soil are directly correlated to the maximum particle size, the coefficient of uniformity, the density, the applied normal stress, and the gravel and fines content of the sample. It can be said that the shear strength parameters are a result of the frictional forces of the particles, as they slide and interlock during shearing (Yagiz, 2001) [45]. Soil containing particles with high angularity tend to resist displacement and hence possess higher shearing strength compared to those with less angular particles (Ranjan and Rao, 1991) [35].

The particle size distribution curves are shown in Fig. 2. The curve is used to define the grading of soil in terms of effective size, the uniformity coefficient and the coefficient of curvature. The uniformity coefficient (C_u) and the coefficient of curvature (C_c) are defined as

$$C_u = D_{60}/D_{10}$$

$$C_c = (D_{30})^2/(D_{60} \times D_{10})$$

Where, D_{10}=particle diameter at 10% finer, D_{30}=particle diameter at 30% finer, D_{60}=particle diameter at 60% finer.

The coefficient of curvature, C_c is a measure of the symmetry and shape of the gradation curve. For a soil to be well graded C_c must lie between 1 and 3 and in addition to this, C_u must be greater than 6 for sands. If both these requirements are not met, the soil is termed as poorly graded (Singh, 1992; Ranjan and Rao, 1991) [35]. From Table 2, it is observed that coefficient of uniformity and coefficient of curvature obtained from the Figure 2 does not meet the criteria hence soils might be considered poorly graded.

Table 2: Coefficient of uniformity and coefficient of curvature for the soils at different locations.

Locations	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
C_u	2.10	1.75	1.72	1.62	4.49	8.45	1.81	4.37	1.74	1.80
C_c	1.00	0.92	0.91	1.08	0.38	0.34	0.87	0.37	0.77	0.95

The coefficient of uniformity and coefficient of curvature did not show significant correlation with shear strength parameters, which might be due to poor gradation of soils. The sand shape whether it is rounded, subrounded, or angular affects the shearing strength. Angular grains provide more interlock and increased shear resistance. The gradation and size of the sand affect the shear resistance. Well-graded materials provide more grain to grain area contact than poorly graded materials. The particle size distribution is a good measure of the soil grading. Well-graded soil samples are expected to achieve shear strength higher than poorly graded material. Poorly graded materials involve more voids and less particle-to-particle contact (Dafalla, 2013) [5].

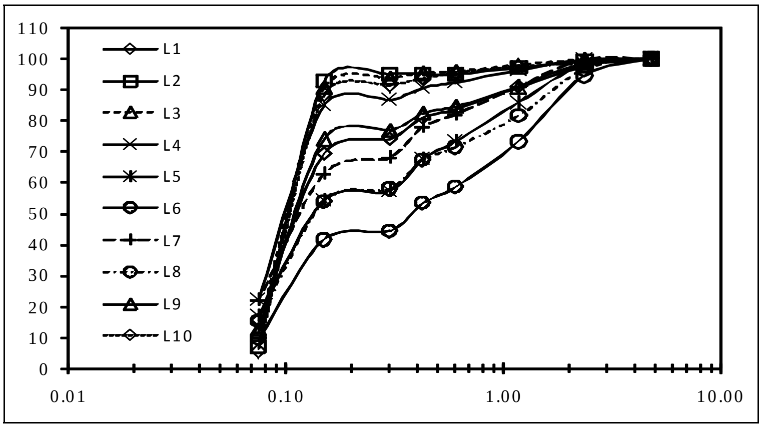


Fig 2: Particle size distribution curves.

3.5. Liquid limit

The liquid limit of a soil is defined as the moisture content above which the soil behaves as a liquid (Rogers, 2009) [36]. The correlation coefficient is statistically significant at 1% level of significance indicating influence of liquid limit on shear strength parameters. The positive correlation indicates that as the liquid limit increases shear strength parameters increases. Variation in properties of soils (cohesionless and cohesive) at different locations might be the reasons for these results. The maximum liquid limit in experimental samples was observed 25%. According to Mousavi *et al.* (2011) [23], cohesion increases due to increasing liquid limit. They observed angle of shearing resistance positively correlated up to 35% of liquid limit and thereafter the correlation became negative.

3.6. Plastic limit
Plastic limit is the moisture content above which the soil behaves plastically (Rogers, 2009) [36]. The plastic limit values obtained from experiments for different locations showed (Table 1) correlation at 1% level of significance indicating the influence of plastic limit on shear strength parameters.

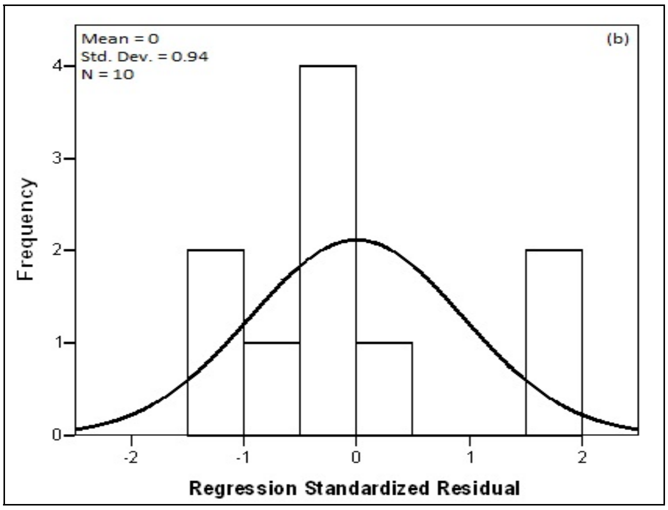
3.7. Plasticity index
The numerical difference between the liquid limit and plastic limit is termed as plasticity index (Rogers, 2009) [36]. Liquid and plastic limits tests determine the plasticity of fines particles and thereby allow them to be defined as either silts or clays soils (Guidelines, 2010) [10]. Clays and silts react with the water and thus change sizes and have varying shear strengths. Thus, these tests are used widely in the preliminary stages of building any structure to insure that the soil will have the correct amount of shear strength and not too much change in volume as it expands and shrinks with different moisture contents (Seed, 1976) [40].
The correlation of plasticity index with shear strength parameters is statistically significant at 5% level of significance (Table 1). The positive correlation shows that shear strength parameters increased as the plasticity index increased. The presence of cohesionless and cohesive soils at different locations might be the reasons for this type of variation. As per Akayuli (2013) [1], the plasticity index of the soils increases linearly with the amount of clay occurring in the soil. Clay content also increases the cohesion and decreases the friction angle. This is due to the fact that plasticity is offered only by the clay fraction with the sand acting as inert filler that does not have any physio-chemical interaction with the clay to affect its plasticity.

3.8. Multiple linear regression analysis of data
In preceding sections, it was observed that individual correlation of geotechnical properties with shear strength parameters varied differently. To determine the most influencing parameters as well as to develop a multiple linear regression model for the assessment of cohesion and angle of shearing strength from the sets of data generated, SPSS software version 13.0 was used. Stepwise regression algorithm was followed for the selection of variables. According to different researchers (Grivas and Chaloulakou, 2006) [7], stepwise multiple regression procedure is commonly used to produce a parsimonious model that maximizes accuracy with an optionally reduced number of predictor variables.
For the developed model (Table 3), the derived regression coefficients are neither zero nor less than the standard error. For a model, adjusted R^2 increases if the addition of the variable reduces the residual mean square. In addition to this, it is not good to retain negligible variables, that is, variables with zero coefficients or the coefficients less than their corresponding standard errors (Montgomery *et al*., 2003) [27]. Variance inflation factor (VIF) for the input variables is lower than 10 indicating that there is no multicollinearity. According to Montgomery *et al*. (2003) [27], VIF lower than 10 do not imply problems with multicollinearity whereas higher values cause poor prediction equations. Therefore, regression coefficients for the predictors of models were used to derive the equation for shear strength parameters, which are as under:

$$\textit{Cohesion} = -0.525 + \textit{0.}\ 0.241 * \textit{Specific gravity} \quad (1)$$

$$\textit{Angle of shearing resistance} = -29.604 + 34.220 * \textit{Bulk density (gm/cm}^3\textit{)} \quad (2)$$

Analysis of variance (ANOVA) for the models indicated that observed value of F was 105.66 for cohesion and 442.748 for angle of shearing resistance whereas critical value of $F_{0.01,1,8}$ for these were 11.26. It reveals that observed value is many times higher than critical value. For the regression model, to be useful as a predictor, observed F ratio (Box and Wetz, 1973) must be at least four or five times greater than critical value of F as reported in Montgomery *et al*. (2003) [27].
The study of residuals (or error) is very important in deciding the adequacy of the statistical model. If the error shows any kind of pattern, then it is considered that the model is not taking care for all the systematic information. For the best performance of the model, residuals should be random i.e. they should follow the normal distribution with zero mean and constant variance (Goyal *et al*., 2006; Montgomery *et al*., 2003) [8, 27]. Grivas and Chaloulakou (2006) [7]. Used correlation coefficient (R) between measured and predicted values for the evaluation of model performance. All these methods were also used by Roy *et al*. (2011) [37]. For checking the model adequacy.



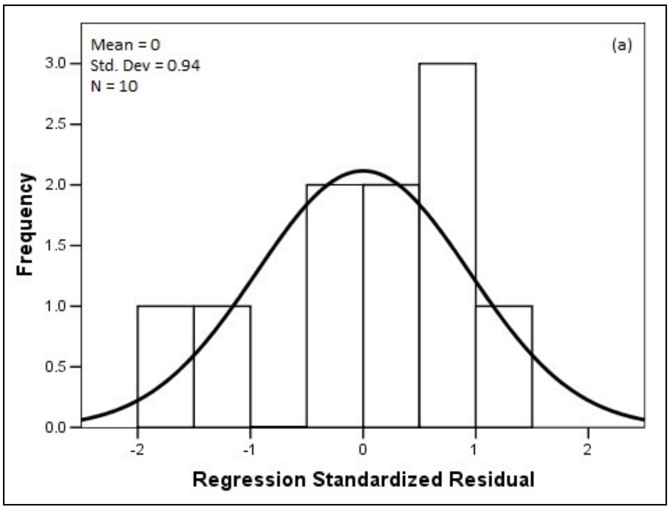


Fig 3: Standardized residual analysis of (a) Cohesion and (b) Angle of shearing resistance.

Figure 3 indicates histograms of the residuals of shear strength parameters. The residuals analysis shows that the residuals are distributed normally with zero mean and constant variance. The R^2 for equation (1) and (2) is 0.93 and 0.98 respectively, which are significant in statistical sense at 1% level of significance. All the regression coefficients of predictors are also statistically significant (Table 2). Figure 4 shows the plots of predicted and measured values of shear strength parameters. Considering the adequacy of the model, equations 1 and 2 can be used to estimate the shear strength parameters of the study area.

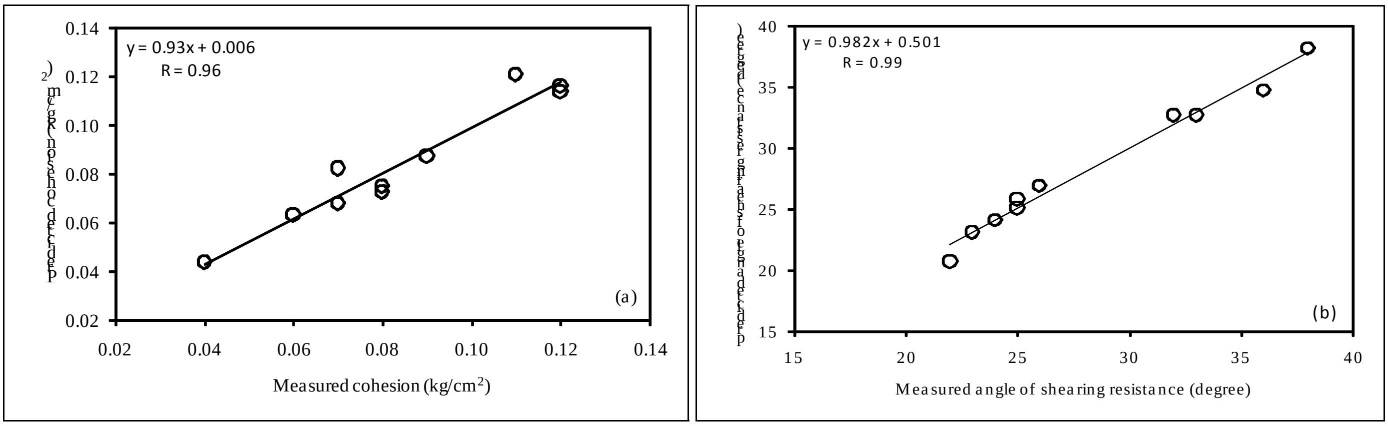


Fig 4: Correlations between predicted and measured values of (a) cohesion and (b) angle of shearing resistance.

Table 3: Model summary of shear strength parameters

Predictors	R square	Adjusted R square	Residual mean square	Regression coefficients: Coefficient	Regression coefficients: Standard error	Significance	Variance Inflation Factor (VIF)
Cohesion							
Constant Specific gravity	0.930	0.921	0.000	-0.525 0.241	0.059 0.023	0.000 0.000	1.000
Angle of shearing resistance							
Constant Bulk density	0.982	0.980	0.671	-29.604 34.220	2.769 1.626	0.000 0.000	1.000

4. Conclusions

- Coefficient of uniformity and coefficient of curvature determined with the help of particle size distribution curves showed poor gradation of particles.
- Shear strength parameters were significantly correlated with bulk density, dry density, natural moisture content, specific gravity, liquid limit, plastic limit, plasticity index whereas they were not significantly correlated with coefficient of uniformity and coefficient of curvature, which might be due to poor gradation of particle sizes.
- Based on stepwise regression procedures, specific gravity was selected as the most influencing parameter for cohesion and bulk density for angle of shearing resistance. Models adequacy checked by various statistical methods showed that developed multiple regression models can be used for prediction of shear strength parameters of the study area. Hence the models developed do not need to go for sophisticated and time consuming laboratory tests.
- The models will be useful not only for individuals but also for the government agencies, who are involved in building construction and other structures in the study area. The cost and time required for shear strength test will be saved and bearing capacity of soils can be assessed required for the foundation design of structures.

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References

1. Akayuli C, Ofosu B, Nyako SO, Opuni KO. The Influence of Observed Clay Content on Shear Strength and Compressibility of Residual Sandy Soils, International Journal of Engineering Research and Applications (IJERA). 2013; 3(4):2538-2542.
2. Arora KR. Introductory Soil Engineering: Text Book, Nem Chand Jane (Prop), Standard Publishers Distributors, Nai Sarak, Delhi, 1988.
3. Apparao KVS, Rao VCS. Soil Testing Laboratory Manual and Question Bank, Universal Science Press, New Delhi, 1995, 6.
4. Box GEP, Wetz JM. Criteria for judging the adequacy of estimation by an approximating response polynomial, Technical report Department of Statistics, University of Wisconsin, Madison, 1973, 9.
5. Dafalla MA. Effects of clay and moisture content on direct shear tests for clay-sand mixtures, Advances in Materials Science and Engineering, 2013, 1-8. http://dx.doi.org/10.1155/2013/562726,
6. El-Maksoud MAF. Laboratory determining of soil strength parameters in calcareous soils and their effect on chiseling draft prediction, In: Proceedings of Energy Efficiency and Agricultural Engineering International Conference, Rousse, Bulgaria, 2006.
7. Grivas G, Chaloulakou A. Artificial neural network models for prediction of PM_{10} hourly concentrations, in the Greater area of Athens, Greece, Atmospheric Environment 2006; 40(7):1216-1229.
8. Goyal P, Chan AT, Jaiswal N. Statistical models for the prediction of respirable suspended particulate matter in urban cities, Atmospheric Environment 2006; 40(11):2068-2077.
9. Garcia AJH, Jaime YNM, Contreras AMZ, Bastardo LDS, Llovera FAS. Savanna soil water content effect on its shear strength-compaction relationship, Revista Científica UDO Agrícola 2012; 12(2):324-337.
10. Guidelines. Geotechnical Site Investigation Guidelines for Building Foundations in Permafrost January, I. Holubec Consulting Inc., 2010. *www. pws. gov. nt.*

ca/pdf/publications/GeotechnicalGuidelines.pdf
11. IS: 2720 Part-XIII Direct Shear Test, BIS, New Delhi, 1972.
12. IS: 2720-Part V Determination of Liquid and Plastic Limits, BIS, New Delhi, 1970.
13. IS: 2720-Part IV Grain Size Analysis, BIS, New Delhi, 1975.
14. IS: 2720-Part II Determination of Water Content, BIS, New Delhi, 1973.
15. IS: 2720- Part XXIX Determination of Dry Density of Soils, in place, by the Core Cutter Method, BIS, New Delhi, 1975.
16. IS: 1904-1978 COP for Structural Safety of Buildings Shallow Foundations (second revision) BIS, New Delhi.
17. Jain R, Jain PK, Bhadauria SS. Computational approach to predict soil shear strength, International Journal of Engineering Science and Technology. 2010; 2(8):3874-3885.
18. Kristyna B, Lenka S, Pavla P. Influence of water content on the shear strength parameters of clayey soil in relation to stability analysis of a hillside in Brno region, Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 2013; LXI(6):1583-1588.
19. Kumari D. A study on the effect of moisture on strength characteristics of river sand, UG Dissertation, NIT Rourkela, India, 2009.
20. Lun ACY. Influence of grain size distribution on shear strength of sand, UG Thesis, Universiti Teknologi, Malaysia, 2011.
21. Murthy S. Geotechnical Engineering: Principles and Practices of Soil Mechanics, 2nd edn, Taylor & Francis, CRC Press, UK, 2008.
22. Mollahasani A, Alavi AH, Gandomi AH, Rashed A. Nonlinear neural-based modeling of soil cohesion intercept, KSCE Journal of Civil Engineering. 2011; 15(5):831-840.
23. Mousavi SM, Alavi AH, Gandomi AH, Mollahasani A. Nonlinear genetic-based simulation of soil shear strength parameters, Journal of Earth System Science. December. 2011; 120(6):1001-1022.
24. Murthy VNS. Principles of Soil Mechanics and Foundation Engineering, UBS Publishers’ Distributors Ltd., New Delhi, 2002.
25. Moayed RZ, Tamassoki S, Izadi E. Numerical modeling of direct shear tests on sandy clay, World Academy of Science, Engineering and Technology 2012; 61:1093-1097.
26. Mallo SJ, Umbugadu AA. Geotechnical study of the properties of soils: a case study of Nassarawa – Eggon town and Environs, Northern Nigeria, Continental Journal of Earth Sciences. 2012; 7(1):40-47.
27. Montgomery DC, Peck EA, Vining GG. Introduction to Linear Regression analysis, John Wiley & Sons, Inc., New York, 2003.
28. Omotoso OA, Mamodu MO, Ojo OJ. Evaluation of geotechnical properties of laterite soils in Asa-dam area, Ilorin, south western Nigeria, World Journal of Applied Science and Technology. 2011; 3(2):1-9.
29. Oyediran A, Durojaiye HF. Variability in the geotechnical properties of some residual clay soils from southwestern Nigeria, International Journal of Scientific & Engineering Research. 2011; 2(9):1-6.
30. Ojuri OO. Predictive shear strength models for tropical lateritic soils, Journal of Engineering. 2013; 2013:1-8. Article ID 595626, http://dx.doi.org/10.1155/2013/595626,
31. Obasi NL, Anyaegbunam AJ. Correlation of the undrained shear strength and plasticity index of tropical clays, Nigerian Journal of Technology 2005; 24(2):1-11.
32. Prakash S, Jain PK. Engineering Soil Testing, Nem Chand & Bros, Roorkee, 2002, 26.
33. Punmia BC, Jain AK, Jain AK. Soil Mechanics and Foundations, 16th Edition, Laxmi Publications (P) Ltd., New Delhi, 2005.
34. Raj PP. Geotechnical Engineering, Tata McGraw-Hill Publishing Company Limited, New Delhi, 1995, 327.
35. Ranjan G, Rao ASR. Basic and Applied Soil Mechanics, New Age International (P) Ltd., Publishers, New Delhi, 1991.
36. Rogers JD. GE 441 - Engineering Geology and Geotechnics, Correlations between Soil Plasticity and Strength Parameters, 2009. web.mst.edu/~rogersda/umrcourses/ge441/
37. Roy S, Adhikari GR, Renaldy TA, Jha AK. Development of multiple regression and neural network models for assessment of blasting dust at a large surface coal mine, Journal of Environmental Science and Technology. 2011; 4(3):284-301.
38. Sorensen KK, Okkels N. Correlation between drained shear strength and plasticity index of undisturbed overconsolidated clays, Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, 2013, 1-6.
39. Singh A. Basic Soil Mechanics and Foundations, CBS Publishers & Distributers, New Delhi, 1992.
40. Seed HB. Evaluation of soil liquefaction effects on level ground during earthquakes, Liquefaction Problems in Geotechnical Engineering, ASCE National Convention, Philadelphia, PA Preprint 2725, 1976, 1-104.
41. Traffic and Soil Mechanics Ohio Agricultural Research, 2013, 3.
42. www.oardc.ohio-state.edu/ss540/chapters/SWSGCch3.pdf
43. Too VK. 3D Modelling for geotechnical investigation, M.S. Thesis, Department of Environmental and Biosystems Engineering, School of Engineering, University of Nairobi, 2012.
44. Tuncer ER, Lohnes RA. An engineering classification for basalt-derived lateritic soils. Engineering Geology 1977; 4:319-339.
45. Yagiz S. Brief note on the influence of shape and percentage of gravel on the shear strength of sand and gravel mixture, Bulletin of Engineering Geology and the Environment 2001; 60(4):321-323.