

Assessment of Soaked California Bearing Ratio Value Using Geotechnical Properties of Soils

Surendra Roy

Department of Civil Engineering, PSIT College of Engineering, Kanpur, Uttar Pradesh, India

Abstract California Bearing Ratio value is used for the evaluation of subgrade strengths during design of flexible pavements. To simulate worst moisture condition of the field, soaked California Bearing Ratio value is used in the design of pavements. But this test is an expansive and time consuming method. 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 analysed for different geotechnical properties like specific gravity, particle size, liquid limit, plastic limit, plasticity index, maximum dry density, optimum moisture content and soaked California Bearing Ratio. 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 on soaked California Bearing Ratio was studied. Stepwise regression procedure was carried out for the selection of most influencing variables. Incorporating selected variables, multiple regression model was developed for the prediction of soaked California Bearing Ratio. The performance of the multiple regression model was assessed in terms of correlation coefficient, F-statistics and residuals pattern. Using the developed model, soaked California Bearing Ratio can be computed for the study area.

Keywords California Bearing Ratio, Correlation, Significant, Multiple Regression Analysis, Geotechnical Properties

1. Introduction

Of all the methods of pavement design, the California bearing ratio (CBR) method has been found as the most reliable means for evaluating the strength of the subgrade (bearing capacity of the soil) and construction materials, and hence estimating the required thickness of pavement [1]. It is a penetration test meant for the evaluation of subgrade strength for roads and pavements. The results obtained by these tests are used with the empirical curves or charts to determine the thickness of pavement and of its component layers. This is the most widely used method for the design of flexible pavement [2]. The relevant tests for subgrade soil include moisture content determination, liquid and plastic limits, specific gravity and particle size analysis. Although provision of subsoil drains could likely reduce the effect of water on subgrade, fully soaked CBR is considered to be appropriate for pavement design purposes [3].

According to Patel and Desai [4], the CBR is affected by the type of soil and different soil properties. Its prediction using index properties of soils can be the alternate method for the time consuming test like CBR. As per Carter and Bentley [5], soil type, density, moisture content and method

of sample preparation play an important role in affecting CBR. Talukdar [6] explained that CBR depends on many factors like maximum dry density, optimum moisture content, liquid limit, plastic limit, plasticity index, type of soil, permeability of soil etc. Yildirm and Gunaydin [7] used statistical techniques for the evaluation of CBR from sieve analysis, Atterberg limits, maximum dry unit weight and optimum moisture content of soils.

To simulate worst moisture condition of the field, the specimens are tested in soaked conditions, for this, these are kept submerged in water for about 4 days before testing [8]. According to different researchers [9, 10], CBR test in laboratory requires a large soil sample and is laborious, expensive and time consuming. Furthermore, the results sometimes are not accurate due to poor quality of skill of the technicians testing the soil samples in the laboratory. All these problems may result in serious delay in the progress of the project and ultimately it may lead to escalation of the project cost. To overcome this situation, it is better to predict CBR value of subgrade soil with easily determinable parameters. Considering these, different geotechnical properties of soils were determined, its influence were assessed on the CBR and prediction models were developed using SPSS software for the computation of CBR.

2. Methodology

2.1. Sampling Locations

* Corresponding author:

surendraroydhn@yahoo.com (Surendra Roy)

Published online at <http://journal.sapub.org/re>

Copyright © 2016 Scientific & Academic Publishing. All Rights Reserved

Sirsa town is situated at latitude 29°32'0" north and longitude 75°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 for the evaluation of the CBR of the subgrade. Accordingly, 10 sampling locations in different area were selected for soil sampling. The details of the sampling locations are given in Table 1.

Table 1. Details of sampling locations

Description of sampling locations	Reference number
Handi Khera Road	L1
HUDA Colony	L2
JCD Vidyapeeth	L3
Government Polytechnic	L4
Khatu Shyam Ji Mandir	L5
Parmarth Colony	L6
Near CDLU	L7
Near Air Force Station	L8
Nehru Park	L9
Near Delhi Pull	L10

2.2. Collection of Samples

Different researchers have collected the soil samples from different depth for the CBR test. The samples have been collected by digging a pit of about 1m x1m x1m but it is possible to get acceptable quality of soils within 60 cm depth from the ground level, which can be used in the subgrade and even in subbase/base courses [11]. Alhassan and Olaniyi [12] collected the soil samples from the depths between 40 cm and 150 cm after removing the topsoil whereas Riaz et al. [13] collected the samples from 91.4 cm depth. Jayakumar and Singh [14] collected the samples from the depth of 50 cm to 80 cm to assess the strength of subgrade soil. Considering these, the samples were collected from 50 cm depth from the ground surface. 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 labelled, sealed and brought to the laboratory for analysis.

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:

2.3.1. 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 °C. Particles passed through 4.75 mm IS sieve were used for determining specific gravity with the help of density

bottle [8]. The density bottle method is the most accurate and is suitable for all types of soils in the laboratory [15].

2.3.2. 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) [16, 17].

2.3.3. Consistency Limits

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 a 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 [18].

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 [17].

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 [19].

2.3.4. Compaction Test

3 kg of air-dried soil was sieved by 4.75 mm sieve. As the percentage of soil retained on the 4.75 mm sieve was less than 20%, therefore, 100 mm diameter mould was used. The capacity of the mould was 1000 ml and the weight of the rammer was 2.6 kg. The samples were mixed with water to about 4% in case of sandy soil and about 8% in the clayey soils. The moist samples were compacted into the mould in three layers with each layer of 25 blows from 310 mm drop height. The water content and dry density of the compacted soils were determined. Further, the water content was increased in the soil and compacted. Different values of water content and dry density were computed and graph was plotted to determine the maximum dry density (MDD) and optimum water content (OMC) [20].

2.3.5. California Bearing Ratio

The CBR is the measure of strength of subgrade soils (foundation soils) for construction of the pavements [21]. It has been found that moisture content is the most important factor in the case of clayey soils, which are most likely to suffer by water absorption. It is therefore, important to ascertain the wettest condition in a given case and the basis of design should be the strength of the subgrade in that condition. Testing the compacted soil for bearing strength at 100 percent saturation is essential for areas subject to water-logging and floods. As the governing factor is the bearing strength after full soaking, a soil which does not prove satisfactory after full soaking can be improved by suitable admixture of granular material. All clayey soils must be tested after full soaking whether or not the area is subjected to water-logging [1].

The CBR method combines a load penetration test performed in the laboratory or in-situ with the empirical design charts to determine the thickness of the pavement and of its constituent layers. It is a small scale penetration test in which a cylindrical plunger of 5 cm diameter is penetrated into a soil mass (subgrade material) at the rate of 1.25 mm/minute. The loads required for a penetration of 2.5 mm and 5.0 mm were determined. The greater of these values was taken for the design of pavement.

$$\text{CBR} = \frac{\text{Penetration load}}{\text{Standard load}} \times 100$$

About 5 kg soil was taken and mixed with exact quantity of water required for optimum water content. The sample was kept in the mould and compacted in 3 equal layers, each layer given 56 blows by 2.6 kg rammer with drop height of 310 mm and soaked into water for 96 hours for soaked test. Two weights each of 2.5 kg was put in CBR mould during testing. The load dial gauge and the displacement dial gauge were adjusted to zero. Load was applied on the plunger to keep the rate of penetration as 1.25 mm per minute. Load corresponding to penetration of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm were noted. Then load-penetration curve was plotted. The corrected loads corresponding to penetrations of 2.5 mm and 5.0 mm were found out [8, 20].

3. Results and Discussion

Different geotechnical properties like specific gravity, particle size, liquid limit, plastic limit, plasticity index, maximum dry density and optimum water content of soils, collected from the different locations of the Sirsa town were determined. The California bearing ratio was also assessed. At most of the locations, soils were cohesionless in nature. Only at few locations, soils were cohesive. Influence of individual and multiple geotechnical properties of soils on CBR were assessed.

3.1. Specific Gravity

Specific gravity is an important index property of soils that is closely linked with mineralogy or chemical composition [22] and also reflects the history of weathering [23].

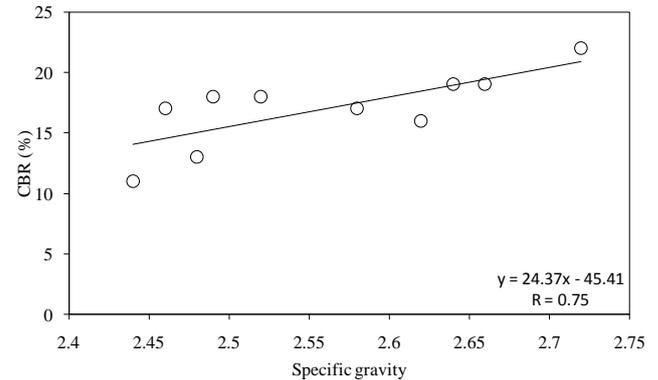


Figure 1. Correlation of CBR with specific gravity

The plot of specific gravity with CBR shows that increase in specific gravity increases the CBR values (Figure 1). Correlations are statistically significant at 1% level of significance indicating influence of specific gravity on CBR. 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 [24].

3.2. Particle Size Analysis

The particle size distribution curve (gradation curve) represents the distribution of particles of different sizes in the soil mass [25]. The subgrade soil strength depends on type of subgrade soil, internal structure of the soil and the type and mode of stress application. The shearing resistance in soil represents the subgrade soil strength [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 [27]. Soil containing particles with high angularity tend to resist displacement and hence possess higher shearing strength compared to those with less angular particles [28].

The particle size distribution curves are shown in Figure 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 coefficient of uniformity (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, C_u must be greater than 4 for gravels and greater than 6 for sands. If both these requirements are not met, the soil is termed as poorly graded [28, 29]. 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 as poorly graded.

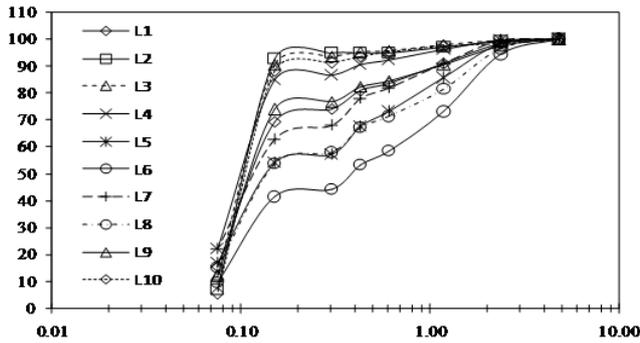


Figure 2. Particle size distribution curves

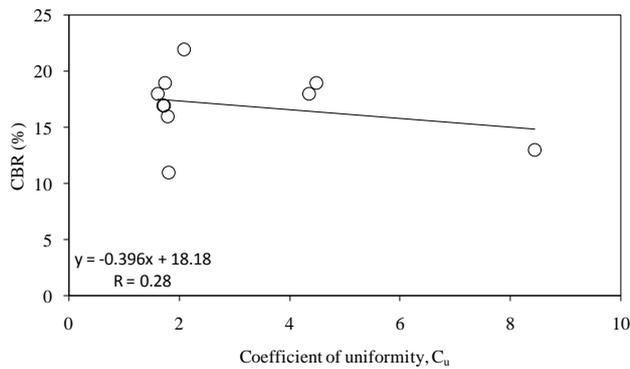


Figure 3. Correlation of CBR with coefficient of uniformity

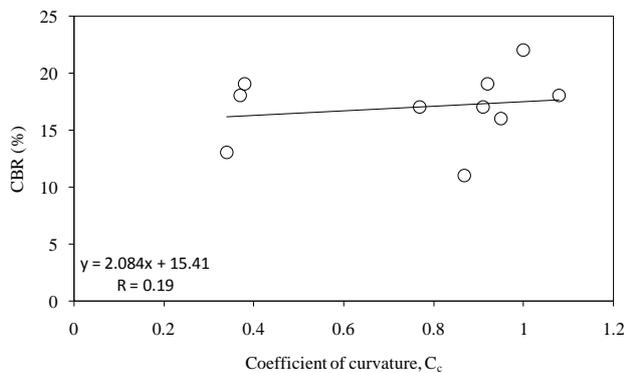


Figure 4. Correlation of CBR with coefficient of curvature

The coefficient of uniformity and coefficient of curvature was plotted with CBR (Figure 3 and 4). CBR did not show significant correlation with these parameters, which might be due to poor gradation of soils.

3.3. Consistency Limits

Consistency limits and the plasticity index vary for different soil types and therefore, these properties are generally used in the identification and classification of soils. Soils having high values of liquid limit and plasticity index are poor as engineering materials. Both liquid limit and plastic limit depend on the type and amount of clay in soils. The plasticity index generally depends only on the amount of clay present; giving an indication of clay content in soil [26].

The liquid limit of a soil is defined as the moisture content above which the soil behaves as a liquid [30]. The correlation between liquid limit and CBR is insignificant (Figure 5) whereas negative trend line indicates that as the liquid limit increases CBR decreases. In the study area, most of the locations have cohesionless soils, which might be the reasons of poor correlations. The negative insignificant correlation between liquid limit and CBR was also observed by Talukdar [6] and Saklecha et al. [21].

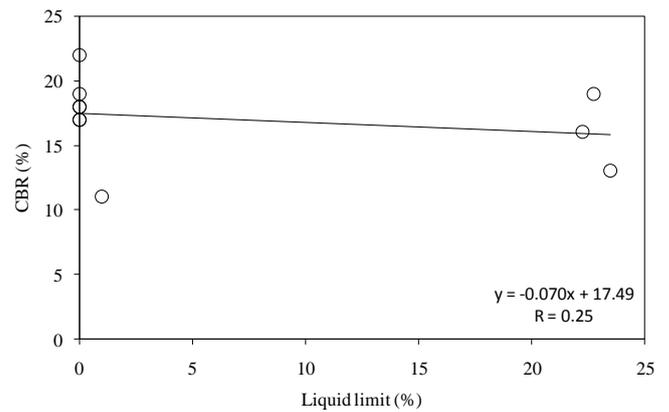


Figure 5. Correlation of CBR with liquid limit

Plastic limit is the moisture content above which the soil behaves plastically [30]. The plastic limit values obtained from experiments for different locations were plotted with CBR (Figure 6). Correlation was not significant. The negative trend line showed as the plastic limit increased CBR decreased. The soils at most of the locations are cohesionless in nature, which might be the reasons for insignificant correlations. Talukdar [6] and Saklecha et al. [21] also observed insignificant correlations.

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

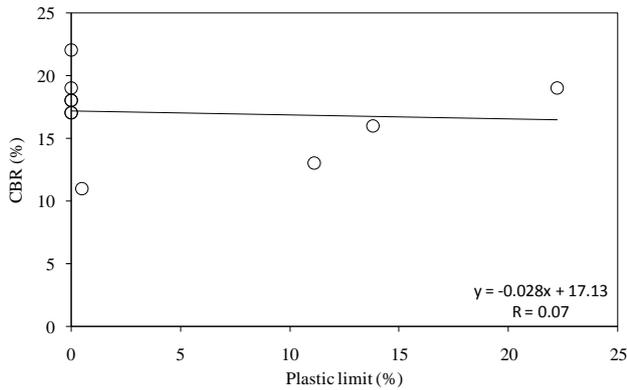


Figure 6. Correlation of CBR with plastic limit

The numerical difference between the liquid limit and plastic limit is termed as plasticity index [30]. The values of plasticity index were plotted with CBR (Figure 7). No correlations were observed between plasticity index and CBR but negative trend line shows that as the plasticity index increases CBR decreases. The study areas mainly consist of cohesionless soils, which might be the reasons for insignificant correlations. Saklecha et al. [21] did not find significant correlations between these two parameters. Talukdar [6] observed negative correlations between plasticity index and CBR. If the clay content is high or low, it directly affects the CBR value [4].

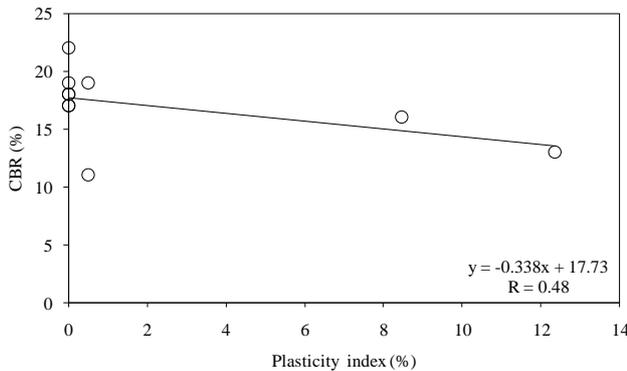


Figure 7. Correlation of CBR with plasticity index

3.4. Compaction

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 [31]. The correlation between CBR and maximum dry density was found significant (Figure 8) indicating that density influences the CBR. According to Raj [17], CBR values are higher when the compacted densities are high and when the clay content, liquid limit and plasticity index are low. Figure 9 shows influence of optimum moisture content on CBR. The correlation was statistically significant indicating that as the OMC increases CBR decreases.

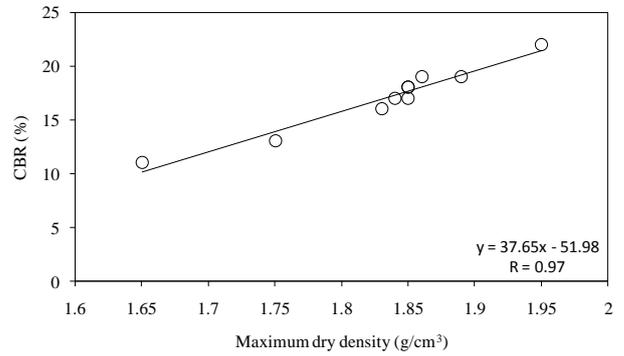


Figure 8. Correlation of CBR with maximum dry density

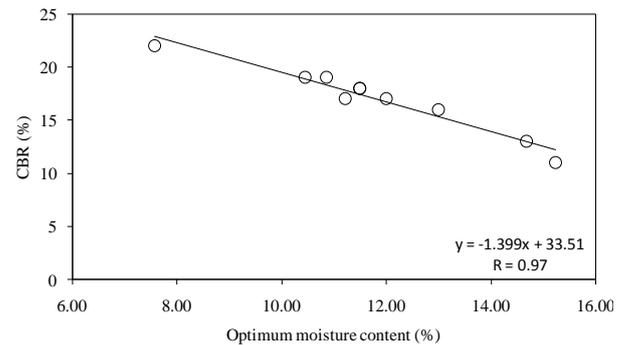


Figure 9. Correlation of CBR with optimum moisture content

3.5. Multiple Linear Regression Analysis of Data

In preceding sections, it was observed that individual correlation of geotechnical properties with CBR varied differently. To determine the most influencing parameters as well as to develop a multiple linear regression model for the assessment of CBR 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 [32-34], stepwise multiple regression procedure is commonly used to produce a parsimonious model that maximizes accuracy with an optionally reduced number of predictor variables.

Table 3 shows the model summary of CBR. The adjusted R² value is the highest and the residual mean square is the lowest for model 2. The derived regression coefficients are neither zero nor less than the standard error. For a model, adjusted R² 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 [35]. Variance inflation factor (VIF) for the input variables is lower than 10 indicating that there is no multicollinearity. According to Montgomery et al. [35], VIF lower than 10 do not imply problems with multicollinearity whereas higher values cause poor prediction equations. Therefore, regression coefficients for the predictors of model 2 were used to derive the equation for CBR, which is as under:

$$CBR = -10.888 + 19.810 * MDD (g/cm^3) - 0.712 * OMC (%) \tag{1}$$

Analysis of variance (ANOVA) for the models indicated that observed value of F was 189.905 for CBR whereas critical value of $F_{0.01,2,7}$ was 9.55. 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 [36] must be at least four or five times greater than critical value of F as reported in Montgomery et al. [35].

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 [35, 37]. Grivas and Chaloulakou [34] and Papanastasiou et al. [38] 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. [39] for checking the model adequacy.

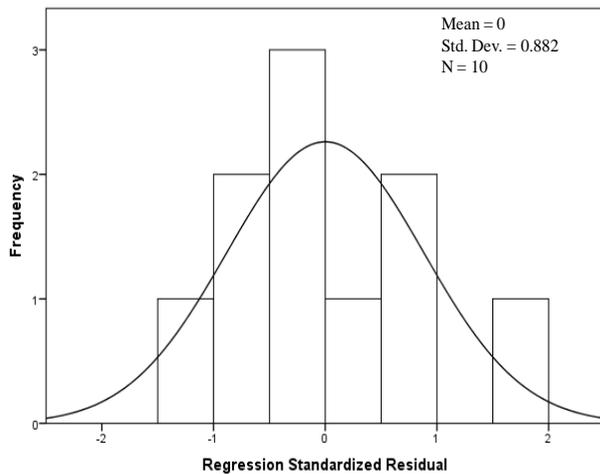


Figure 10. Standardized residual analysis of CBR

Figure 10 indicates histograms of the residuals of CBR. The residuals analysis shows that the residuals are distributed normally with zero mean and constant variance. The R^2 for equation (1) is 0.98, which is significant in statistical sense at 1% level of significance. All the regression coefficients of predictors are also statistically

significant (Table 3). Figure 11 shows the plots of predicted and measured values of CBR. Considering the adequacy of the model, equations 1 can be used to estimate the CBR of the study area.

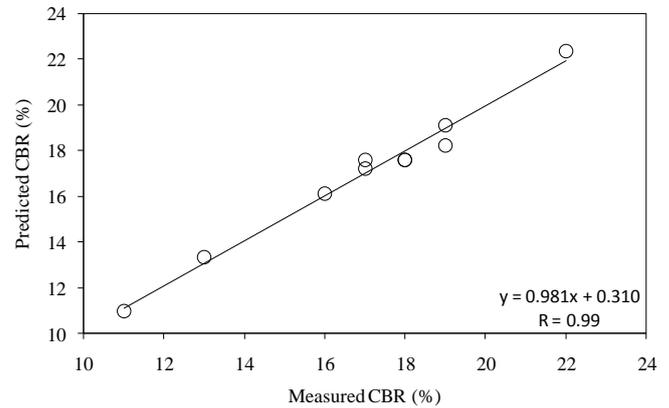


Figure 11. Correlations between predicted and measured values of CBR

4. Conclusions

Coefficient of uniformity and coefficient of curvature determined with the help of particle size distribution curves showed poor gradation of particles.

CBR was significantly correlated with specific gravity, MDD and OMC whereas it was insignificantly correlated with liquid limit, plastic limit and plasticity index. The soils at most of the locations are cohesionless in nature, which might be the reasons for insignificant correlations with these properties. Poor gradation of particle sizes indicated insignificant correlations with coefficient of uniformity and coefficient of curvature.

Based on stepwise regression procedures, MDD and OMC were selected as the most influencing parameters for the CBR. Model adequacy checked by various statistical methods showed that developed multiple regression models can be used for prediction of CBR of the study area. Hence, the model developed does not need to go for sophisticated and time consuming laboratory tests for the soaked CBR.

The models will be useful not only for individuals but also for the government agencies, who are involved in road constructions in the study area. The cost and time required for soaked CBR test will be saved.

Table 3. Model summary of CBR

Model	Predictors	R square	Adjusted R square	Residual mean square	Regression coefficients		Significance	Variance Inflation Factor (VIF)
					Coefficient	Standard error		
1	Constant	0.950	0.944	0.551	-51.980	5.607	0.000	1.000
	MDD				37.653	3.058		
2	Constant	0.982	0.977	0.228	-10.888	12.217	0.402	7.659
	MDD				19.810	5.436	0.008	
	OMC				-0.712	0.202	0.010	

REFERENCES

- [1] P.N. Khanna, Indian Practical Civil Engineers' Handbook, Engineers' Publishers, New Delhi, p. 18/134, 1994.
- [2] K.V.S. Apparao and V.C.S. Rao, Soil Testing Laboratory Manual and Question Bank, Universal Science Press, New Delhi, p. 6, 1995.
- [3] Guidance Notes, Soil Test for Pavement Design, Research & Development Division, Highways Department, Publication No. RD/GN/012, August, 1990. http://www.hyd.gov.hk/en/publications_and_publicity/publications/technical_document/guidance_notes/pdf/gn012.pdf.
- [4] Patel, R.S. and Desai, M.D., 2010, CBR predicted by index properties for alluvial soils of South Gujarat, Indian Geotechnical Conference – 2010, GEO Trend, December 16–18, IGS Mumbai Chapter & IIT Bombay, pp. 79-82.
- [5] Carter, M. And Bentley, S.P., Correlations of Soil Properties, Pentech Press Ltd., London, 1991.
- [6] Talukdar, D.K., 2014, A Study of correlation between California bearing ratio (CBR) value with other properties of soil., IJETAE, 4 (1), 559-562.
- [7] Yildirm, B. and Gunaydin, O., 2011, Estimation of California bearing ratio by using soft computing systems., Expert Syst Appl., 38, 6381-6391.
- [8] B.C. Punmia, A.K. Jain and A.K. Jain, Soil Mechanics and Foundations, Sixteenth Edition, Laxmi Publications (P) Ltd., New Delhi, 2005.
- [9] Roy, T.K., Chattapadhyay, B.C. and Roy, S.K., 2010, California bearing ratio, evaluation and estimation: A study of comparisons. Indian Geotechnical Conference-2010, GEO Trend, December 16-18, 2010, IGS Mumbai Chapter & IIT Bombay, pp. 19-22.
- [10] Ramasubbarao, G.V. and Siva, S.G., 2013, Predicting soaked CBR value of fine grained soils using index and compaction characteristics., Jordan J. Civ. Eng., 7 (3), 354-360.
- [11] Pradhan Mantri Gram Sadak Yojana (PMGSY), National Rural Roads Development Agency, Operations Manual for Rural Roads, Annexure 5.1, 2005, website: <http://pmgsy.nic.in/opmn3.htm>
- [12] Alhassan, H.M. and Olaniyi, L.F., 2013, Effect of 'Ionic Soil Stabilizer 2500' on the properties of black cotton soil., Br J Appl Sci Technol., 3(3), 406-416.
- [13] Riaz, S., Aadil, N. and Waseem, U., 2014, Stabilization of subgrade soils using cement and lime: a case study of Kala Shah Kaku, Lahore., Pakistan, Pak. j. sci., 66 (1), 39-44.
- [14] Jayakumar, M. and Singh, L.C., 2012, Experimental studies on treated sub-base soil with fly ash and cement for sustainable design recommendations., World Acad Sci Eng Technol., 6 (8), 760-763.
- [15] S.P. Bindra, A Course in Highway Engineering, Fourth Edition, Dhanpat Rai & Sons, Delhi, 1986.
- [16] IS:2720-Part IV, 1975, Grain Size Analysis, BIS, New Delhi.
- [17] P.P. Raj, Geotechnical Engineering, Tata McGraw-Hill Publishing Company Limited, New Delhi, p. 327, 2012.
- [18] IS:2720-Part V, 1970, Determination of Liquid and Plastic Limits, BIS, New Delhi.
- [19] V.N.S. Murthy, Principles of Soil Mechanics and Foundation Engineering, UBS Publishers' Distributors Ltd., New Delhi, 2002.
- [20] K.R. Arora, Soil Mechanics and Foundation Engineering (Geotechnical Engineering), Seventh Edition, Standard Publishers Distributors, Nai Sarak, Delhi, 2008.
- [21] Saklecha, P.P., Kedar, R.S. and Saklecha, P.K., 2013, Correlation of CBR with mechanical properties of foundation soil, Proc. of Indian Geotechnical Conference December 22-24, Roorkee, pp. 1-8, 2013.
- [22] Oyediran, A. and Durojaiye, H.F., 2011, Variability in the geotechnical properties of some residual clay soils from south-western Nigeria., IJSER, 2 (9), 1-6.
- [23] Tuncer, E.R. and Lohnes, R.A., 1977, An engineering classification for basalt-derived lateritic soils., Eng. Geol., 4, 319– 339.
- [24] S. Prakash and P.K. Jain, Engineering Soil Testing, Nem Chand & Bros, Roorkee, India, p. 26, 2002.
- [25] Mallo, S.J. and Umbugadu, A.A., 2012, Geotechnical study of the properties of soils: a case study of Nassarawa – Eggon town and Environs, Northern Nigeria., C J Earth Sci., 7 (1), 40 – 47.
- [26] S.K. Khanna and C.E.G. Justo, Highway Engineering, Ninth Edition, Nem Chand & Bros, Roorkee, India, 2011.
- [27] Yagiz, S., 2001, Brief note on the influence of shape and percentage of gravel on the shear strength of sand and gravel mixture., Bull. Eng. Geol. Environ., 60(4), 321-323.
- [28] G. Ranjan and A.S.R. Rao, Basic and Applied Soil Mechanics, New Age International (P) Ltd., Publishers, New Delhi, 1991.
- [29] A. Singh, Basic Soil Mechanics and Foundations, CBS Publishers & Distributors, New Delhi. 1992.
- [30] J.D. Rogers, GE 441 - Engineering Geology and Geotechnics, Expansive Soils, Correlations Between Soil Plasticity and Strength Parameters, 2014, web.mst.edu/~rogersda/umrcourses/ge441/.
- [31] Kristyna, B., Lenka, S. and Pavla, P., 2013, 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, LXI, No. 6, pp. 1583–1588.
- [32] Comrie, A.C., 1997, Comparing neural networks and regression models for Ozone forecasting., J Air Waste Manag Assoc., 47, 653-663.
- [33] Chaloulakou, A., Grivas, G. and Spyrellis, N., 2003, Neural network and multiple regression models for PM10 prediction in Athens: A comparative assessment., J Air Waste Manag Assoc., 53, 1183-1190.
- [34] Grivas, G. and Chaloulakou, A., 2006, Artificial neural network models for prediction of PM₁₀ hourly concentrations, in the Greater area of Athens, Greece., Atmos. Environ., 40, 1216-1229.

- [35] D.C., Montgomery, E.A. Peck and G.G. Vining, Introduction to Linear Regression analysis, John Wiley & Sons, Inc., New York, 2003.
- [36] G.E.P. Box and J.M. Wetz, Criteria for judging the adequacy of estimation by an approximating response polynomial, Technical report No.9, Department of Statistics, University of Wisconsin, Madison, 1973.
- [37] Goyal, P., Chan, A.T. and Jaiswal, N., 2006, Statistical models for the prediction of respirable suspended particulate matter in urban cities., *Atmos. Environ.*, 40, 2068-2077.
- [38] Papanastasiou, D.K., Melas, D. and Kioutsioukis, I., 2007, Development and assessment of neural network and multiple regression models in order to predict PM_{10} levels in a medium-sized Mediterranean city., *Water Air Soil Pollut.*, 182, 325-334.
- [39] Roy, S., Adhikari, G.R., Renaldy T.A. and Jha, A.K., 2011, Development of multiple regression and neural network models for assessment of blasting dust at a large surface coal mine., *J. Environ. Sci. Technol.*, 4 (3), 284-301.