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PREDICTION OF SOAKED CBR USING INDEX PROPERTIES, DRY DENSITY AND UNSOAKED CBR OF LEAN CLAY

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Abstract: Load bearing capacity of subgrade soil is of great importance to the integrity of pavement. Soaked CBR of subgrade soil is used as a design parameter for determining the total thickness of a pavement for an estimated ESAL. However, determination of soaked CBR values for pavement design involves soaking a large number of representative soil samples for four days. This is both time consuming and economically discouraging. Establishment of mathematical models for determining soaked CBR values for different types of soils using their index properties, dry densities and unsoaked CBR values is likely to aid design more quickly. With this background in mind, in this study soil samples were collected from sub-grade of an existing flexible pavement in Savar Cantonment Area, Dhaka, Bangladesh. The soil samples were then tested and the index properties were determined. The tested soil samples were identified as Lean Clay and CBR test was performed both in soaked and unsoaked conditions at different densities. The test results of the sample soil have led to the formulation of three empirical equations for predicting soaked CBR values. Index properties of soil from grain size analysis, Atterberg limits test and compaction characteristics from CBR test are used in the first equation to predict soaked CBR value of this lean clay soil. The second equation relates dry density with soaked CBR whereas the third equation relates unsoaked CBR with soaked CBR values for a varying range of dry densities. These equations may be used to predict soaked CBR value where the sub-grade consists of Lean Clay.

Keywords: *Soaked CBR, equivalent single axle load, unsoaked CBR, sub-grade, lean clay.*

1.0 Introduction

Roads and highways are in the center of economic activities in countries where land based communication is dominant. The construction, operation and maintenance of the roadways play vital role in the economy. To get uninterrupted and sustainable service from the roadways, the first requirement is to construct the roads in such a way that these are able to withstand heavy traffic loads and weathering effects during the expected service life. The strength of soil on which the roads will be constructed is the basis of pavement design. So, predicting the strength of soil is of vital importance. California Bearing Ratio (CBR) test is developed to predict the strength of soil with reasonable accuracy under different site conditions, which helps to determine the required sub-grade thickness for the construction of a road (LGED, 2005). The present practice is to simulate the worst possible field condition for sub-grade soil in the laboratory by submerging the sample soil under water for four days and determine its strength. The samples are collected from different chainage along the centreline of a proposed road, the number of which is significantly large and takes a very long time to determine the strength. This affects the overall condition of the road construction project negatively. To overcome the negative effects of the elongated time requirement, it can be proposed that the strength of a particular type of sub-grade soil at worst field condition can be predicted by developing empirical relationships between standard laboratory strength of soil in four days soaked condition and properties of soil which are quickly and easily determinable through standard laboratory tests. This study is focused on the development of relationships through which soaked CBR can be predicted using the rather easily determinable index properties and unsoaked CBR value of a particular type of soil.

2.0 Available Prediction Models

The number of studies carried out to predict soaked CBR from easily identifiable properties of soil is minimal. Only a handful of models are proposed to predict four days soaked CBR of sub-grade soil. A model to predict CBR for plastic, fine-grained soils from percentage passing No. 200 U.S. sieve in decimal (w) and plasticity index (PI) was proposed in the Guide for Mechanistic and Empirical–Design for New and Rehabilitated Pavement Structures by NCHRP (2001). The R^2 value for this model is 0.67, which indicates that the validity of this model is not reliable. The equation is:

$$CBR=\frac{75}{1+.728wPI} \quad (1)$$

Satyanarayana Reddy and Pavani (2006) developed a model to predict soaked CBR value from percentage of fines (%F), liquid limit (LL) and maximum dry density of soil (MDD). This model is applicable only when the anticipated soaked CBR value lies within 12.8 to 56.8. When lower soaked CBR values are anticipated, this model cannot predict reliably. The model is:

$$CBR_S = - 0.388F - 0.064LL + 20.38MDD \quad (2)$$

Vinod and Reena (2008) proposed a model to predict soaked CBR value from fraction of soil coarser than 425 micron (%C) and liquid limit (LL). This model can predict soaked CBR value with desired accuracy only when the CBR value lies within the limit from 8.9 to 30.4. The model is expressed as:

$$CBR_S = -0.889(W_{LM}) + 45.616 \quad (3)$$

Where, $W_{LM} = LL\,(1 - C/100)$

Patel and Desai (2010) proposed a multiple linear regression model to determine soaked CBR from plasticity index (Ip), maximum dry density (MDD) in g/cc unit and optimum moisture content (OMC). This model is reasonably accurate when CBR value is within 1.54 to 4.42. Higher soaked CBR values cannot be predicted reliably with this model. The model is:

$$CBR_S = 43.907 - 0.093Ip - 18.78MDD - 0.3081OMC \quad (4)$$

Yildirim and Gunaydin (2011) developed several models to predict soaked CBR from the following parameters namely percentage of gravel(%G), percentage of sand (%S), percentage of fines(%F), liquid limit(LL), plastic limit(PL), maximum dry density(MDD) in g/cc unit and optimum moisture content(OMC). Equation 5 and 6 are only applicable for particular type of soil. Equation 5 is applicable for coarse grained soil whereas equation 6 is applicable for fine grained soil. These two equations cannot predict CBR value of soil when it is contained with both fine and coarse particles. In equation number 7 and 8, MDD and OMC are determined from standard Proctor compaction test. In case of modified Proctor compaction test, use of these parameters becomes questionable. The proposed models are as follows:

$$CBR_S = 0.2353G + 3.0798 \quad (5)$$

$$CBR_S = -0.1805F + 18.508 \quad (6)$$

$$CBR_S = 0.22G + 0.045S + 4.739MDD + 0.122OMC \quad (7)$$

$$CBR_S = 0.62OMC + 58.9\,MDD + 0.11LL + 0.53PL - 126.18 \quad (8)$$

A general multiple linear regression analysis (MLRA) model to predict soaked CBR from index properties and compaction characteristics for all types of soil is proposed by Ramasubbarao and Siva Sankar (2013). However, the accuracy of prediction for coarse grained soils is not documented. The proposed model is:

$$CBR_S = 0.064(\%Fines) + 0.082\,(\%Sand) + 0.033\,(\%Gravel) - 0.069LL + 0.157PL - 1.810MDD - 0.061OMC \quad (9)$$

Here, %Fines is the sum of percentage of clay and silt from grain size analysis of soil as per unified soil classification system (ASTM D 1883, 2004).

Rakaraddi and Gomarsi (2015) proposed a multiple linear regression model to predict soaked CBR from liquid limit, plastic limit, % fines and specific gravity of soil. As the model ignores the percentage of sand and gravel, the accuracy of prediction is questionable for coarse grained soils. The model is as following:

$$CBR_S=0.275LL+0.118PL+0.033F+5.106G \quad (10)$$

Yadav *et al*. (2014) conducted investigation on different types of soil and proposed a multiple linear regression model to determine soaked CBR from liquid limit, plastic limit, optimum moisture content, maximum dry density and % fines. This model accuracy is questionable as it did not include particle size of soils. The model is as following:

$$CBR_S= -3.06 +188.64/LL-24.15/PL+ 38.06/OMC +0.225\ MDD + 0.018/ F \quad (11)$$

Sathawara and Patel (2013) experimented on CL type soil and established a correlation between 4-day soaked CBR and unsoaked CBR for the dry density achieved under different Proctor compaction efforts. However there predicted model's R^2 value is quite far from unity and indicates some extent of errors to a small scale. The developed model to relate unsoaked CBR with 4-Day soaked CBR is as following:

$$Y=0.936X^{0.819},\ [R^2 = 0.828] \quad (12)$$

Where, 'Y' stands for 4-day soaked CBR and 'X' stands for unsoaked CBR value.

3.0 Methodology and Results

3.1 Soil Sample Collection

Three soil samples were collected from three different chainage of the sub-grade of an existing flexible pavement in Savar Cantonment, Dhaka. Then following laboratory tests were carried out on the collected samples at the Geotechnical Engineering Laboratory of Bangladesh University of Engineering and Technology (BUET):

- Atterberg Limits Test
- Grain Size Analysis
- Proctor Compaction Test at different energies
- Soaked and Unsoaked CBR Test

3.2 Identification of Soil Sample

The soil sample was identified according to Unified Soil Classification System (ASTM D 4318, 2004; ASTM D 2487, 2004) and BNBC (1993) guideline as Lean Clay with group symbol CL. The results are summarized in Table 1.

Table 1: Index Properties of the Collected Soil Sample

Chainage	Liquid limit (LL)%	Plastic Limit (PL)%	Plasticity Index (PI)%	Sand (%)	Silt (%)	Clay (%)	USCS Classification
300 m	38	14	24	4	50	46	Lean Clay(CL)
600 m	40	14	26	3	51	47	Lean Clay(CL)
800 m	38	13	25	6	50	44	Lean Clay(CL)

3.3 Proctor Compaction Test Results

Proctor compaction test with different compactive efforts was performed to determine optimum moisture contents for subsequent soaked and unsoaked CBR tests. The energy used in compaction test is presented in Table 2 and the results of Proctor compaction test is presented in Table 3.

Table 2: Energy used for Proctor Compaction

Compaction Method	Energy ($kN\text{-}m/m^3$)
½ of standard	309
Standard	594
Intermediate	1,620
Modified	2,700

Table 3: Optimum Moisture Content from Proctor Compaction

Chainage	Maximum Dry Density (kN/m^3)	Optimum Moisture Content(%)
300 m	18.51	13.43
600 m	18.97	13.66
800 m	18.71	13.59

3.4 Unsoaked CBR and Soaked CBR Test Results

Optimum moisture contents determined from Proctor compaction test were used as reference moisture content to perform both soaked and unsoaked CBR tests. The compactive energies used for CBR tests were slightly less than that for Proctor compaction test. The purpose of using reduced energy is to ensure that approximately 95% of maximum dry density is achieved in CBR test to properly resemble the field condition. The summary of the soaked and unsoaked CBR test results are listed in Table 4 and Table 5.

Table 4: Soaked CBR Results

Chainage	Target Moisture Content (%)	Energy Used (kN-m/m^3)	Obtained Moisture Content (%)	Achieved Dry Density (kN/m^3)	Soaked CBR value
300 m	13.43	297	13.37	13.37	1.62
		591	13.12	14.13	1.90
		1,613	13.43	16.08	2.57
		2,688	13.80	17.56	3.62
600 m	13.66	297	13.57	14.10	1.43
		591	13.50	15.83	2.09
		1,613	13.48	17.02	2.85
		2,688	13.50	18.31	3.42
800 m	13.59	297	13.57	13.65	1.43
		591	13.50	14.83	1.90
		1,613	13.48	17.02	2.66
		2,688	13.50	18.09	3.62

Table 5: Unsoaked CBR Results

Chainage	Target Moisture Content (%)	Energy Used (kN-m/m^3)	Obtained Moisture Content (%)	Achieved Dry Density (kN/m^3)	Unsoaked CBR value
300 m	13.43	297	13.42	14.82	2.79
		591	13.35	16.58	3.57
		1,613	13.41	17.68	4.74
		2,688	13.32	18.40	5.13
600 m	13.66	297	13.56	14.23	2.01
		591	14.49	16.36	3.18
		1,613	13.54	17.45	4.35
		2,688	13.18	18.50	4.93
800 m	13.59	297	13.53	14.10	2.11
		591	13.56	15.83	4.15
		1,613	12.06	17.02	4.93
		2,688	13.60	18.31	5.71

4.0 Analysis and Discussion

4.1 Multiple Linear Regression Analysis (MLRA) Model

Using the index properties, moisture content and maximum dry density of soaked CBR test as independent variable, a multiple linear regression model is prepared using statistical data analysis tool to predict soaked CBR. From the experimental data presented in Table 6, the following model is prepared:

$$CBR_S = - 0.163*(Sand\ \%) + 0.166*(Silt\ \%) + 0.001*(Clay\ \%) - 0.402LL - 0.001PL + 0.222MC + 0.462MDD \quad (13)$$

Table 6: Data used to Derive MLRA Model

Chainage	Liquid limit (LL)%	Plastic Limit (PL)%	Sand (%)	Silt (%)	Clay (%)	Moisture Content (%)	Dry Density (KN/m^3)	Soaked CBR
300 m	38	14	4	50	46	13.37	13.37	1.62
	38	14	4	50	46	13.12	14.13	1.9
	38	14	4	50	46	13.43	16.08	2.57
	38	14	4	50	46	13.8	17.56	3.62
600 m	40	14	3	51	47	13.57	14.1	1.43
	40	14	3	51	47	13.5	15.83	2.09
	40	14	3	51	47	13.48	17.02	2.85
	40	14	3	51	47	13.5	18.31	3.42
800 m	38	13	6	50	44	13.57	13.65	1.43
	38	13	6	50	44	13.5	14.83	1.9
	38	13	6	50	44	13.48	17.02	2.66
	38	13	6	50	44	13.5	18.09	3.62

4.1.1 Validity of the Proposed MLRA Model

The validity of the proposed MLRA model is checked by performing Analysis of Variance (ANOVA). The outcome of the analysis is shown in Table 7.

Table 7: ANOVA for Testing Significance of Proposed MLRA Model

	Degree of Freedom (d.o.f)	*Sum of Squares (SS)*	*Mean Square (MS)*	$F = MS_R/MS_E$
Regression	7	77.8053	MS_R=77.8053/7=11.1150	530.7987
Residual	7	0.2052	$MS_{E=}$ 0.2052/7=0.0293	
Total	14	78.0105		

A F-test is performed with degree of freedom (d.o.f) df_1=7 and df_2=7 at 95% confidence level. The critical region will include values exceeding 3.79 for the above mentioned criteria. If the calculated value of F exceeds the tabulated F value, then the developed model can be considered valid. In this particular case, the calculated value, F=530.7987 is larger than tabulated value of F=3.79. So, the proposed model can be accepted as valid.

4.1.2 Prediction of Soaked CBR using Index Properties

A comparison is made between the soaked CBR predicted using the proposed MLRA model and observed soaked CBR for the tested soil samples. This is shown in Table 8.

Table 8: Comparison between Observed and Predicted Soaked CBR

Chainage	Observed Soaked CBR	Predicted Soaked CBR using Proposed MLRA Model	Ratio Between Predicted and Observed Soaked CBR	% Difference
300 m	1.62	1.55	0.96	4.38
	1.9	1.84	0.97	2.91
	2.57	2.81	1.10	-9.51
	3.62	3.58	0.99	1.10
600 m	1.43	1.46	1.02	-1.87
	2.09	2.24	1.07	-7.20
	2.85	2.79	0.98	2.25
	3.42	3.39	0.99	0.99
800 m	1.43	1.40	0.98	2.39
	1.9	1.93	1.01	-1.34
	2.66	2.93	1.10	-10.26
	3.62	3.43	0.95	5.20

A graphical representation of the outcome from proposed MLRA model presented in equation No. (13) is shown in Figure 1.

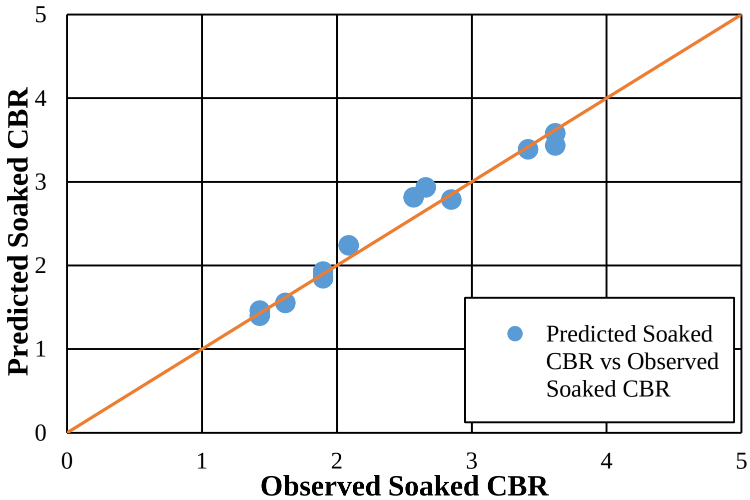

Figure 1: Result from the Proposed MLRA Model

4.2 Power Based Regression Model

4.2.1 Power Based Model using Dry Density

A model is developed to predict soaked CBR from dry density of soil subjected to different compactive efforts. The data used to develop the model is summarized in Table 9. Graphical representation of the model is shown in Figure 2. This model has R^2 value 0.921 which is close to unity and thus can be used with good certainty for predicting soaked CBR value. The proposed model is:

$$CBR_S=0.0007(\text{Dry Density})^{2.9181}, \quad [R^2=0.921] \qquad (14)$$

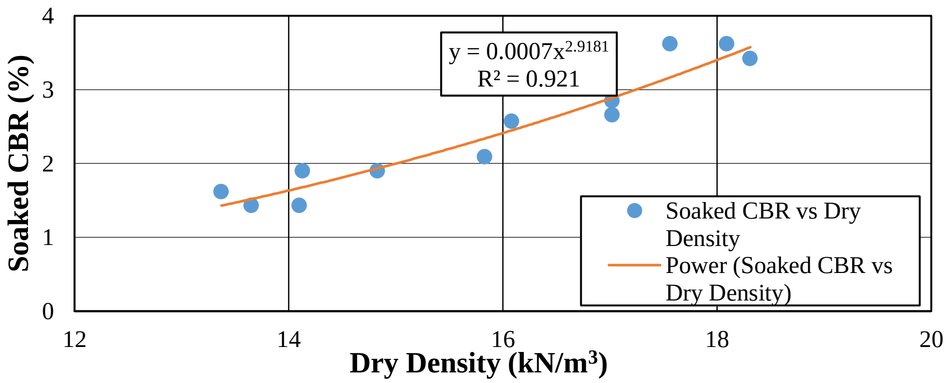

Figure 2: Proposed Model Relating with Dry Density

Table 9: Data table for Relating Dry Density with Soaked CBR values

Chainage	Energy Used (kN-m/m^3)	Achieved Dry Density (kN/m^3)	Soaked CBR value
300 m	297	13.37	1.62
	591	14.13	1.90
	1,613	16.08	2.57
	2,688	17.56	3.62
600 m	297	14.10	1.43
	591	15.83	2.09
	1,613	17.02	2.85
	2,688	18.31	3.42
800 m	297	13.65	1.43
	591	14.83	1.90
	1,613	17.02	2.66
	2,688	18.09	3.62

4.2.2 Power Based Model using Unsoaked CBR Values

Three regression equations relating dry density with Soaked CBR and three regression equations relating dry density with Unsoaked CBR were formed to calculate the CBR values at soaked and unsoaked conditions for a specified range of dry density. The format of the six equations is like:

$$Y=AX^B \tag{15}$$

Where, Y = CBR value at Soaked/Unsoaked Condition
X= Dry Density in kN/m^3
A, B = Constants

The range of dry density was selected based on the observed maximum and minimum dry densities in CBR tests at different compactive energies. The obtained results are presented in Table 10.

Table 10: Unsoaked and Soaked CBR from Experimental Regression Equations

	Chainage 300 m		Chainage 600 m		Chainage 800 m	
Dry Density (kN/m^3)	Unsoaked CBR	Soaked CBR	Unsoaked CBR	Soaked CBR	Unsoaked CBR	Soaked CBR
13.5	2.16	1.68	1.94	1.47	2.08	1.35
14.0	2.40	1.86	2.21	1.66	2.36	1.52
14.5	2.66	2.06	2.50	1.87	2.65	1.69
15.0	2.94	2.27	2.82	2.10	2.98	1.88
15.5	3.23	2.49	3.16	2.35	3.33	2.09
16.0	3.55	2.72	3.54	2.62	3.71	2.30
16.5	3.88	2.97	3.94	2.91	4.12	2.53
17.0	4.23	3.24	4.38	3.23	4.56	2.78
17.5	4.61	3.52	4.85	3.56	5.03	3.05
18.0	5.00	3.81	5.36	3.92	5.54	3.33
18.5	5.41	4.12	5.90	4.31	6.08	3.62

Using the data mentioned in Table 10, a power-based equation was developed to relate unsoaked CBR with soaked CBR. Graphical representation of the equation is shown in Figure 3. With this equation, soaked CBR value can be predicted from the unsoaked CBR value for CL type soil. The equation is as following:

$$CBR_S=0.767(CBR_{US})^{0.9362}, [R^2=0.9174] \quad (16)$$

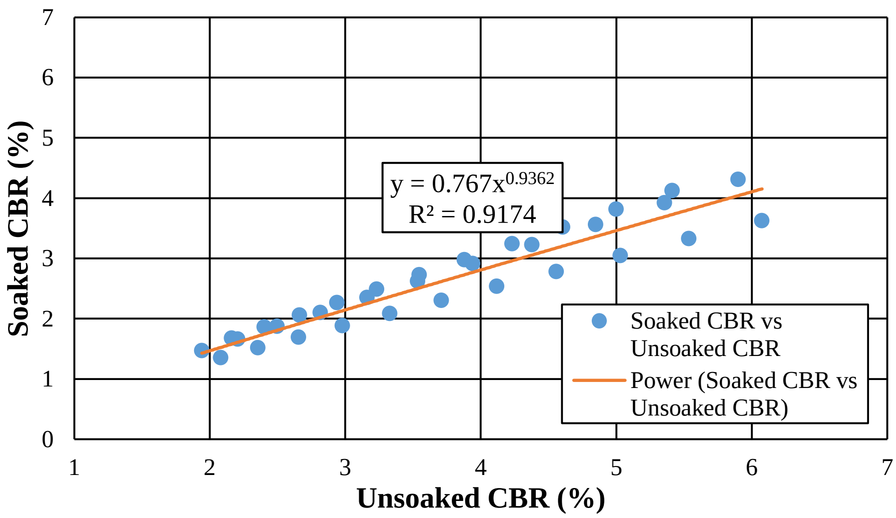

Figure 3: Soaked CBR versus Unsoaked CBR

The variation between predicted soaked CBR values using the proposed model and the model suggested by Sathawara and Patel (2013) is graphically represented in Figure 4.

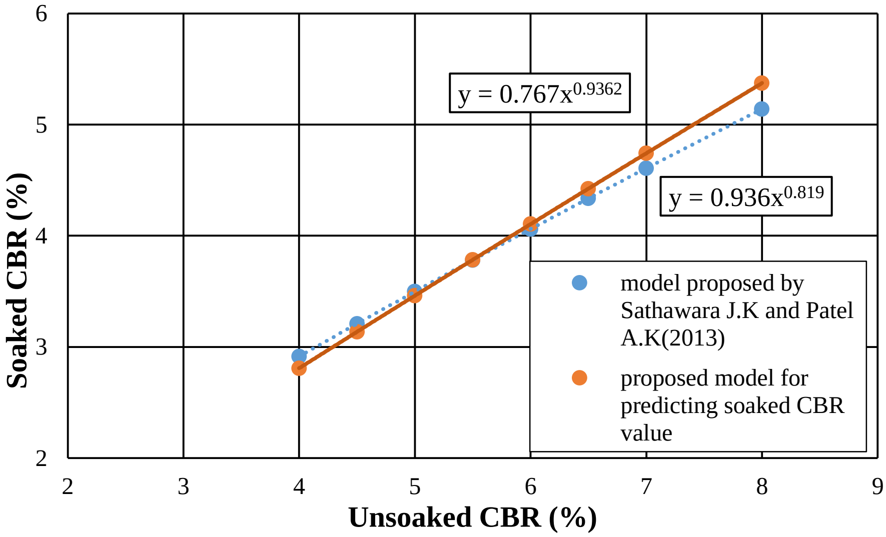

Figure 4: Comparison of Soaked CBR between proposed model and Sathawara and Patel (2013)

5.0 Conclusion

Soaked CBR of the soil is an important parameter in designing a pavement. Thereby a quick and correct measure of soaked CBR value plays a vital part. In this study efforts have been made to develop a correlation between soaked CBR and unsoaked CBR for lean clay. The findings of the investigation are as follows:

a) A multiple linear regression equation has been developed to determine soaked CBR from index properties, particle size distribution, liquid limit, plastic limit, maximum dry density and moisture content. The equation is as following:

$$CBR_S = -0.163*(Sand\ \%) + 0.166*(Silt\ \%) + 0.001*(Clay\ \%) - 0.402LL - 0.001PL + 0.222MC + 0.462MDD$$

b) A regression equation has been developed to relate soaked CBR values from available dry density data. The equation is as follows:

$$CBR_S = 0.0007(Dry\ Density)^{2.9181},\ [R^2=0.921]$$

c) A regression equation has been developed to relate soaked CBR with unsoaked CBR for lean clay based on the laboratory test results. The equation is as follows:

$$CBR_S=0.767(CBR_{US})^{0.9362}, [R^2=0.9174]$$

d) Comparison has been made with similar equation developed by Sathawara and Patel (2013) and the results from this investigation closely resemble their findings. Additional number of soil samples can be tested for further refinement of developed model. The same procedure of the investigation can be used for other types of soils to develop a correlation of soaked and unsoaked CBR values which can be used in the practical works with great convenience.

References

ASTM D 4318 (2004). Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils, ASTM International, West Conshohocken, PA.

ASTM D 2487 (2004). Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM International, West Conshohocken, PA.

ASTM D 1883 (2004). Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils, ASTM International, West Conshohocken, PA.

BNBC (1993). Bangladesh National Building Code Housing and Building Research Institute, Dhaka, Bangladesh.

LGED (2005). Road Design Standards Local Government Engineering Department(LGED), Dhaka, Bangladesh.

NCHRP. (2001). National Cooperative Highway Research Program Guide for Mechanistic and Empirical–Design for New and Rehabilitated Pavement Structures, Final Document, Appendix CC-1: Correlation of CBR Values with Soil Index Properties, West University Avenue Champaign, Illinois, USA.

Patel, R.S. and Desai, M.D. (2010). CBR predicted by index properties for alluvial soils of South Gujarat. *Proceedings of the Indian Geotechnical conference*. Mumbai, India, 79-82.

Rakaraddi, P.G. and Gomarsi, V. (2015). Establishing Relationship Between CBR with Different Soil Properties. International Journal of Research in Engineering and Technology, 4(2), pp.182-188.

Ramasubbarao, G.V. and Siva Sankar, G. (2013). Predicting Soaked CBR value of fine grained soils using index and compaction characteristics. *Jordan Journal of Civil Engineering*, 7(3): 354-360.

Sathawara J.K. and Patel A.K. (2013). Comparison between Soaked and Unsoaked CBR. *International Journal of Advanced Engineering Research and Studies*, 2 (1): 132-135.

Satyanarayana Reddy, C.N.V. and Pavani, K. (2006). Mechanically Stabilised Soils-Regression Equation for CBR Evaluation, *Proceedings of the Indian Geotechnical Conference*, Chennai, India, 731-734.

Vinod, P. and Reena, C. (2008). Prediction of CBR Value of Lateritic Soils Using Liquid Limit and Gradation Characteristics Data. *Highway Research Journal, IRC*, 1 (1): 89-98.

Yadav, D., Jain P.K. and Kumar, R. (2014) Prediction of Soaked CBR of Fine Grained Soils from Classification and Compaction Parameters. *International Journal of Advanced Engineering Research and Studies,* 3 (4): 119-121.

Yildirim, B., and Gunaydin, O. (2011). Estimation of California bearing ratio by using soft computing systems. *Expert Systems with Applications*, 38(5), 6381-6391.