Malaysian Journal of Civil Engineering 28(2):172-182 (2016)

EVALUATION OF SOAKED AND UNSOAKED CBR VALUES OF SOIL BASED ON THE COMPACTION CHARACTERISTICS

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Abstract: Subgrade of a pavement should be strong enough to give adequate support to the pavement and for supporting and distributing the wheel loads. The design and behaviour of a flexible pavement depends mainly on the stability of the subgrade soil, which can be increased by compacting the soil at optimum moisture content (OMC) thus achieving maximum dry density (MDD). In this study, Modified Proctor Compaction Test (MPCT) was conducted by giving 5 different number of blows per layer so as to establish a relationship of compaction energy with OMC & MDD. Also, OMC and MDD are one of the most important parameters influencing California Bearing Ratio (CBR) test. CBR is a penetration test used for evaluating the mechanical strength of subgrade soil and for determining the thickness of the pavement required. Determination of soaked and unsoaked CBR value for a soil is time consuming and a laborious process. Hence in this paper an attempt has been made to arrive at regression equations to correlate soaked and unsoaked CBR values for the silty clay (CL) soil with the compaction characteristics, so that based on OMC and MDD, CBR value of soil can be predicted thus avoiding the time consuming process of conducting CBR tests. The soil sample used in this project was a disturbed sample collected from Thiruporur District in Chennai.

Keywords: *Subgrade soil, optimum moisture content, maximum dry density, soaked CBR, unsoaked CBR, compaction energy.*

1.0 Introduction

Economic development of a country can be assessed by the connectivity of its different places by means of roads and railways. Thus, construction of roads/pavements is one of the important civil engineering works undertaken for interconnecting the different places in a country. Pavements are of two types, namely rigid pavements and flexible pavements. Most of the highways constructed in India are flexible pavements consisting of different layers namely, subgrade, subbase, base course and surface course. The design, behavior and thickness of these flexible pavements depend on the strength of the natural soil present at the site (Ramasubbarao and Siva Sankar, 2013). The foundation soil supporting the pavement is called the subgrade. If the subgrade consists of weak soil then it is first replaced by stable material before the commencement of pavement construction. The main function of the subgrade is to give adequate support to the pavement and for this the subgrade should possess sufficient strength under adverse climatic and loading conditions. To achieve this, soil should be well stabilized by means of controlled compaction.

Compaction removes entrapped air from the voids thus rearranging the soil grains to achieve a dense compact layer. Soil compaction improves the physical and mechanical properties of soil thus causing an increase in its shear strength & bearing capacity, decrease in future settlement of soil & decrease in its permeability (Cheng and Jack, 1981). These three changes in soil characteristics results in a high quality subgrade. Thus the strength of the subgrade soil can be improved by compacting the soil well at OMC to achieve MDD. This OMC & MDD values for a soil can be found in the laboratory from Proctor Compaction Test and are not unique for various types of soils but vary with the type of soil and the compaction energy (Mehrab Jesmani *et al*., 2008). Thus compaction is a function of four variables – dry density, moisture content, compaction effort and type of soil (Naveen *et al*., 2014). Anjaneyappa and Amarnath (2012) found that, increase in dry density was 14.3 % for soil compacted at modified compaction energy compared to samples compacted at standard compaction energy. In this paper, the effect of five different compaction energy levels on OMC and MDD for CL soil has been studied.

There are different methods available for design of a flexible pavement, of which CBR test is the most commonly used empirical method for design (Dilip Kumar, 2014). During floods pavement may be submerged under water for at least 3 to 4 days. Thus soaked CBR is usually determined, as it reflects the soil strength at the worst likely condition during the life of a pavement (Deepak *et al*., 2014). Anjaneyappa and Amarnath (2012) found that, increase in CBR was 2.8 times for samples compacted at modified Proctor compaction energy compared to standard Proctor energy level. In this paper, remolded soil specimen for CBR test was prepared by heavy compaction at predetermined OMC obtained from Modified Proctor Compaction Test (MPCT) for different compaction energy levels.

To determine the soaked CBR value, soil sample needs to be soaked in water for at least 4 days prior to the test. Thus to complete a soaked CBR test it requires at least 5 days which is time consuming and tedious process. In a road construction project, to determine the strength of the subgrade soil, soaked CBR values needs to be found out at regular intervals throughout the length of the project. This increases the construction time and causes delay in the execution of the project which in turn leads to increase in construction cost (Datta and Chottopadhyay, 2011). This delay in obtaining the soaked CBR value of soil in laboratory can be avoided if we can suggest an empirical relation between soaked CBR and any of the easily determinable index properties of soil (Deepak *et al*., 2014).

CBR value of soil depends on many factors like MDD, OMC, liquid limit (LL), plastic limit (PL), plasticity index (PI), type of soil, permeability of soil and also on soaked and unsoaked conditions of soil (Dilip Kumar, 2014). Many researchers have suggested different empirical relations to correlate CBR with different index properties of soil. Ramasubbarao and Siva Sankar (2013) suggested a correlation for soaked CBR value of fine-grained soils with % Gravel, % Sand, % Fines, Plasticity Characteristics and Compaction Characteristics (MDD and OMC). Dr. Dilip Kumar (2014) suggested a correlation for soaked CBR value with MDD, OMC, LL, PL and PI for inorganic silts of low and medium plasticity. Patel and Desai (2010) proposed a correlation between CBR and PI, MDD, OMC for alluvial soil. Agarwal and Ghanekar (1970) found an equation that correlates soaked CBR with OMC and LL based on their research on 48 samples of fine grained soil. Other researchers like Venkatasubramanian and Dhinakaran (2011); Naveen *et al.* (2014); Deepak *et al*. (2014); Roy *et al*. (2009); correlated CBR values of soil with the LL, PL, PI, shrinkage limit, fine content, OMC, MDD and unconfined compression test values of soil. In this paper, an attempt has been made to predict the soaked and unsoaked CBR values of CL soil from OMC and MDD obtained from MPCT which is less time consuming and less tedious compared to CBR tests.

2.0 Experimental Work

Disturbed soil sample collected from Thiruporur District in Chennai was used in the experimental work. Series of test like sieve analysis, sedimentation analysis, specific gravity test, Atterberg's limit test and free swell index test were conducted in the laboratory to determine the index properties of the soil. Soil was classified as per Indian Standard Soil Classification System (ISCS) based on the index properties of the soil.

MPCT was conducted on the soil sample (IS 2720, 1983) by varying the number of blows per layer to determine the OMC and MDD at different compaction energy levels. 5 MPCT were carried on the soil sample by varying the number of blows per layer as 10, 25, 35, 45 and 55. Based on the experimental results, relation of OMC and MDD with respect to compaction energy was studied.

CBR test was conducted on the soil sample in soaked and unsoaked condition (IS 2720, 1987) at 5 different OMC and corresponding MDD which were obtained from MPCT corresponding to varying number of blows per layer. Remolded soil specimen was prepared at 97 % relative compaction for carrying out 5 soaked CBR and unsoaked CBR tests to determine the CBR values of soil in soaked and unsoaked condition corresponding to different OMC and MDD. Based on the experimental results, variation of soaked CBR value and unsoaked CBR value with respect to varying OMC & MDD was studied and regression equations were also obtained.

3.0 Results and Discussion

3.1 Soil Classification

Results of the tests conducted in the laboratory to determine the index properties of soil are presented in Table 1. Soil sample was classified as per ISCS based on the index properties of the soil.

Table 1: Soil classification as per ISCS

Sr. No.	Name of the test	Result
1.	Specific Gravity test	G = 2.053
2.	Atterberg's Limit test Liquid Limit (w_L) Plastic Limit (w_P) Plasticity Index (I_p) Shrinkage Limit (w_s)	 w_L = 27 % w_P = 13.04 % I_p = 13.96 % w_s = 7.66 %
3.	Sieve Analysis	Percentage of Gravel = 3 % Percentage of Sand = 42.5 % Percentage of Silt and Clay = 54.5 %
4.	Sedimentation Analysis	Percentage of Silt = 39.2 % Percentage of Clay = 15.3 %
5.	Free Swell Index test	Free Swell Index = 22.22 %
As per ISCS, soil was classified as CL – Silty Clay of low plasticity		

3.2 Modified Proctor Compaction Test

Moisture content (w) and dry density (ρ_d) values obtained from MPCT, conducted by varying the number of blows per layer as 10, 25, 35, 45 and 55 is given in Table 2. Figure 1 shows the graph of moisture content v/s dry density for 10, 25, 35, 45 and 55 number of blows per layer.

Table 2: Moisture content - Dry Density values at varying number of blows per layer

Number of blows per layer (Compaction Energy kJ/m^3)									
10 blows (1082 kJ/m^3)		25 blows (2704 kJ/m^3)		35 blows (3785 kJ/m^3)		45 blows (4867 kJ/m^3)		55 blows (5949 kJ/m^3)	
w (%)	ρ_d gm/cm^3	w (%)	ρ_d gm/cm^3	w (%)	ρ_d gm/cm^3	w (%)	ρ_d gm/cm^3	w (%)	ρ_d gm/cm^3
2.4	1.50	2.51	1.627	2.5	1.607	2.8	1.65	2.64	1.693
4.5	1.604	4.8	1.698	4.7	1.733	4.6	1.77	4.34	2.045
6.5	1.667	7.5	1.751	6.8	1.78	6.6	1.81	6.41	2.11
8.5	1.723	8.125	1.744	8.4	1.766	8.7	1.77	8.28	2.045
10.4	1.672	10.375	1.649	10.5	1.677	10.7	1.64	10.42	1.926

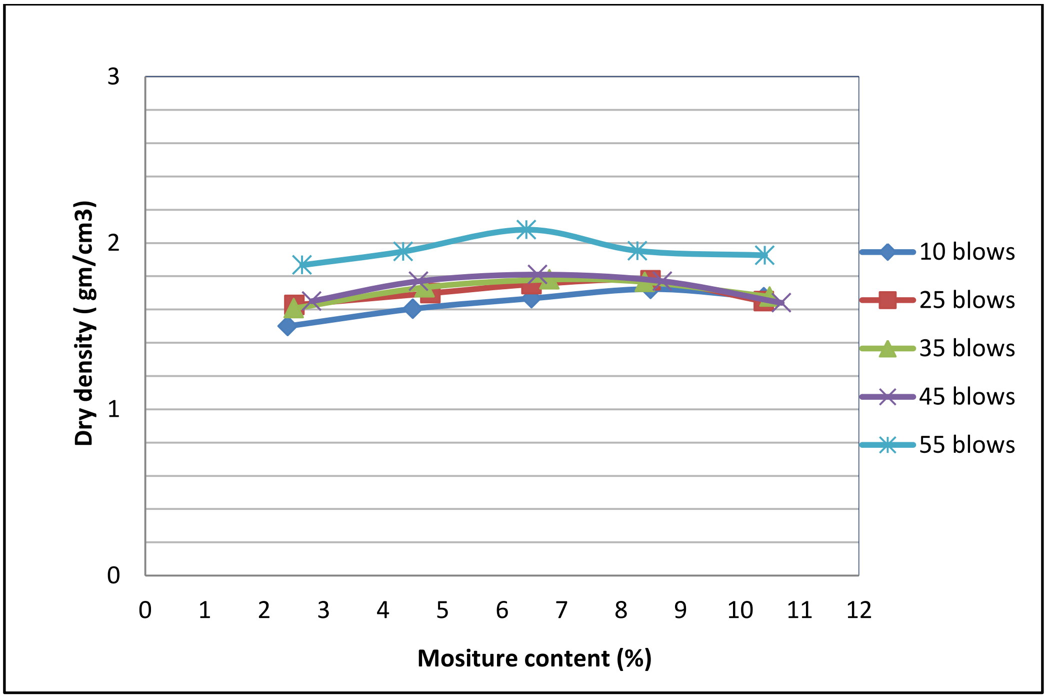

Figure 1: Graph of Moisture content v/s Dry Density at varying number of blows per layer

OMC and MDD obtained from MPCT, conducted at varying compaction energies are given in Table 3. Figure 2 shows the graph of Compaction Energy (i.e. number of blows per layer) v/s percentage increase in MDD w.r.t. 10 blows per layer.

Table 3: OMC and MDD of soil at varying Compaction Energy

Sr. No.	No of Blows per layer	Compaction Energy (kJ/m^3)	OMC (%)	MDD (gm/cm^3)	% Increase in MDD w.r.t. 10 blows per layer
1.	10	1082	8.5	1.723	-
2.	25	2704	7.5	1.751	1.63
3.	35	3785	6.8	1.78	3.31
4.	45	4867	6.6	1.81	5.05
5.	55	5949	6.41	2.11	22.46

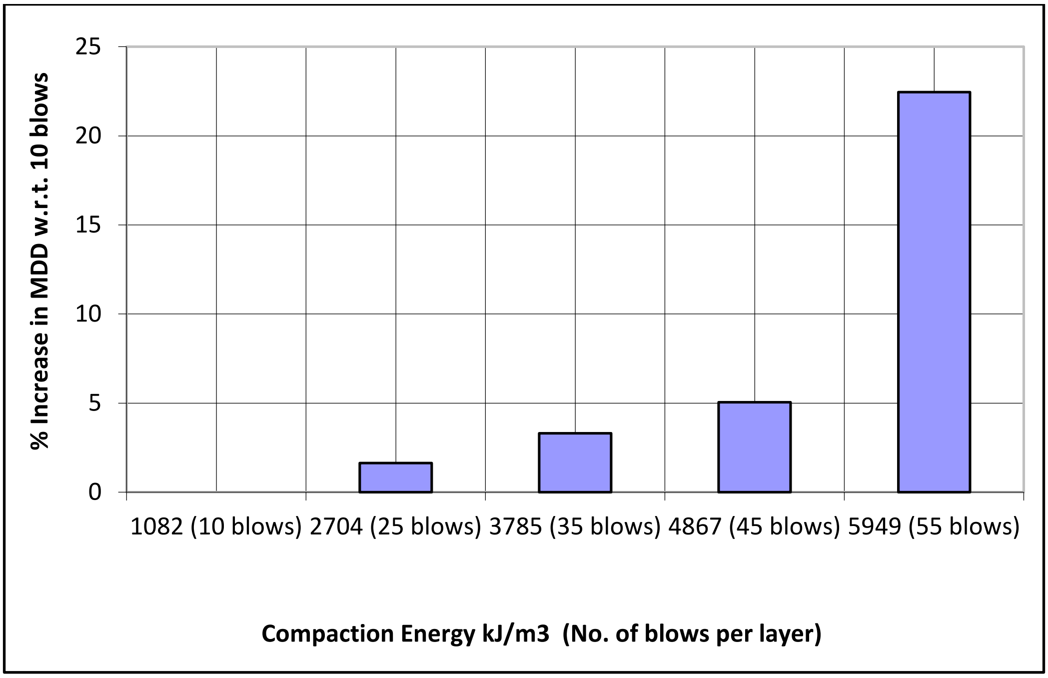

Figure 2: Graph of Compaction Energy (kJ/m^3) v/s Percentage Increase in MDD

From the results it can be observed that as the compaction energy increased OMC decreased and MDD increased. OMC decreased from 8.5 % to 6.41 % and MDD increased from 1.723 gm/cm^3 to 2.11 gm/cm^3 when compaction energy increased from 1082 kJ/m^3 to 5949 kJ/m^3. Percentage decrease in OMC was found to be 24.59 % and percentage increase in MDD was found to be 22.46 %. MDD increased gradually from 10 blows per layer to 45 blows per layer (i.e. from 1.723 gm/cm^3 to 1.81 gm/cm^3) but drastic increase in MDD was observed at 55 blows per layer (i.e. 2.11 gm/cm^3) as indicated in Figure 2. Thus it can be inferred that maximum amount of dry density for

CL soil can be achieved at compaction energy of 5949 kJ/m^3 or more (i.e. for 55 or more no. of blows per layer).

3.3 Soaked and Unsoaked CBR Test

Soaked and Unsoaked CBR values for the soil specimen prepared at 97 % relative compaction, compacted at 5 different OMC and corresponding MDD predetermined from MPCT corresponding to varying number of blows per layer is given in Table 4.

Table 4: Soaked and Unsoaked CBR values of soil at varying OMC and corresponding MDD

Sr. No.	OMC (%)	MDD (gm/cm^3)	Unsoaked CBR value (%)	Soaked CBR value (%)	% decrease in soaked CBR w.r.t unsoaked CBR
1.	8.5 % (w.r.t. 10 blows per layer)	1.723	3.130	0.29	90.73
2.	7.5 % (w.r.t. 25 blows per layer)	1.751	11.429	0.51	95.54
3.	6.8 % (w.r.t. 35 blows per layer)	1.78	14.92	1.019	93.17
4.	6.6 % (w.r.t. 45 blows per layer)	1.81	18.2	1.221	93.29
5.	6.41 % (w.r.t. 55 blows per layer)	2.11	20.4	2.84	86.08

From the results it can be observed that soaked and unsoaked CBR values of soil were found to increase as the OMC decreased and MDD increased due to the presence of lesser voids with increasing compactness of soil. Percentage decrease in soaked CBR w.r.t. unsoaked CBR was found to be minimum (86.08 %) at higher density of soil (2.11 gm/cm^3), indicating that at higher densities the void ratio reduces thus decreasing the permeability of soil and therefore the soil specimen gets less affected by water in soaked condition compared to the soil specimen prepared at lesser densities. Percentage decrease in soaked CBR w.r.t. unsoaked CBR for the above considered values of OMC and their corresponding MDD was found to lie between 86% and 96%. Thus an average value of 91 % can be considered as the percentage decrease in soaked CBR w.r.t. unsoaked CBR for CL soil. It will be useful in predicting the soaked CBR value of soil from unsoaked CBR test which is less time consuming compared to soaked CBR test (Sathawara and Patel, 2013).

Figure 3 shows the variation of soaked and unsoaked CBR values with respect to predetermined OMC whereas Figure 4 shows the variation of soaked and unsoaked CBR values with respect to predetermined MDD which were obtained from MPCT for varying compaction energies.

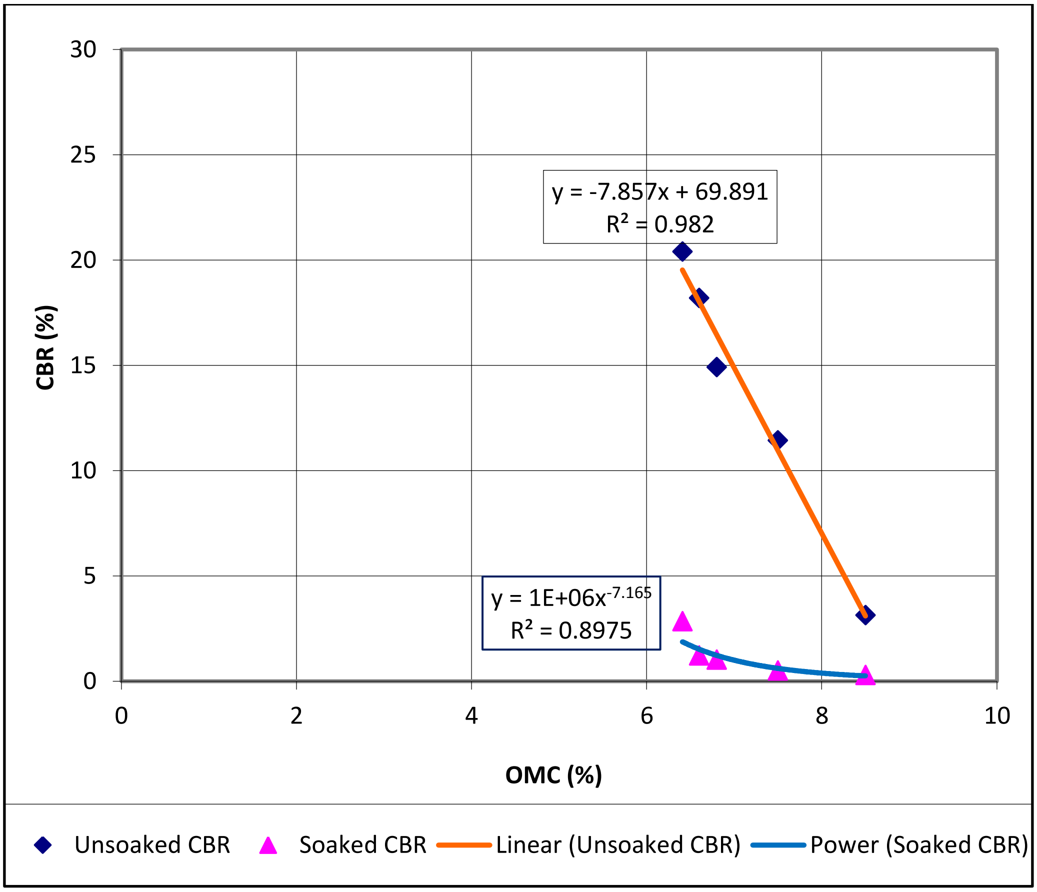

Figure 3: Graph of Soaked and Unsoaked CBR v/s OMC

From Figure 3, regression equations for soaked and unsoaked CBR values corresponding to various OMC are obtained and given below

- Linear Regression equation for Unsoaked CBR
  CBR(unsoaked) = -7.857(OMC) + 69.891; $R^2 = 0.982$

- Power Regression equation for Soaked CBR
  $CBR(soaked) = 1E{+}06(OMC)^{-7.16}$ $R^2 = 0.897$

The above mentioned regression equations can be used to predict the soaked and unsoaked CBR values for the CL soil based on the OMC obtained from MPCT thus avoiding the laborious work and saving the time involved in conducting CBR tests.

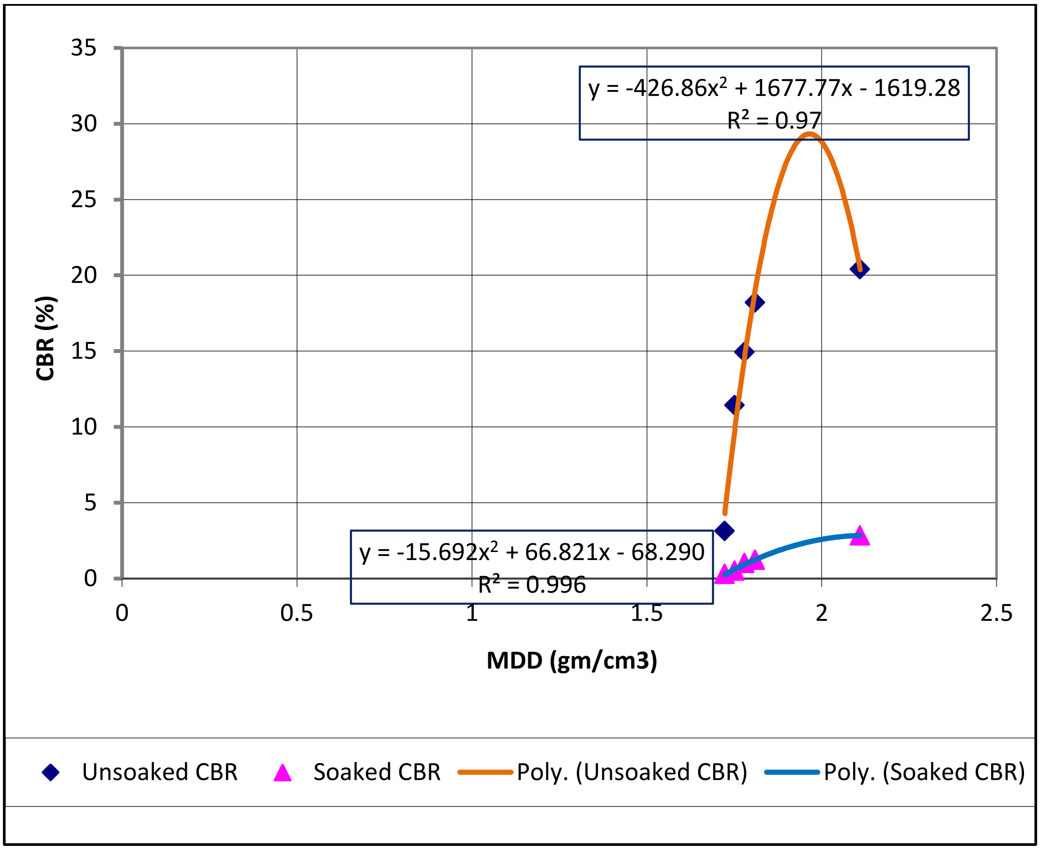

Figure 4: Graph of Soaked and Unsoaked CBR v/s MDD

From Figure 4, regression equations for soaked and unsoaked CBR values corresponding to various MDD are obtained and given below

- Polynomial Regression equation for Unsoaked CBR
  CBR(unsoaked) = -426.86(MDD)^2 + 1677.77(MDD) - 1619.28; $R^2 = 0.970$

- Polynomial Regression equation for Soaked CBR
  CBR(soaked) = -15.692(MDD)^2 + 66.821(MDD) - 68.29; $R^2 = 0.996$

The above mentioned regression equations can be used to predict the soaked and unsoaked CBR values for the CL soil based on the MDD obtained from MPCT thus avoiding the tedious work and saving the time involved in conducting CBR tests.

4.0 Conclusions

As per ISCS, soil was classified as CL (Silty Clay of low plasticity). As compaction energy increased from 1082 kJ/m^3 to 5949 kJ/m^3, OMC decreased from 8.5 % to 6.41 % and MDD increased from 1.723 gm/cm^3 to 2.11 gm/cm^3. MDD increased gradually from 10 blows per layer to 45 blows per layer but drastic increase in MDD was observed at 55 blows per layer, thus indicating that maximum amount of dry density for CL soil can be achieved when 55 or more number of blows per layer are given. Soaked and unsoaked CBR values of soil increased as the OMC decreased and MDD increased due to the presence of lesser voids with increasing compactness of soil. Percentage decrease in soaked CBR with respect to unsoaked CBR can be considered to be 91% which can be used in predicting the soaked CBR value of CL soil from unsoaked CBR test which is less time consuming compared to soaked CBR test.

Regression equations to predict the soaked and unsoaked CBR values for the CL soil based on the OMC determined from MPCT are given as

a) Linear Regression equation for Unsoaked CBR
   CBR(unsoaked) = -7.857(OMC) + 69.891; $R^2 = 0.982$

b) Power Regression equation for Soaked CBR
   CBR(soaked) = 1E+06(OMC$)^{-7.16}$ $R^2 = 0.897$

Regression equations to predict the soaked and unsoaked CBR values for the CL soil based on the MDD determined from MPCT are given as

a) Polynomial Regression equation for Unsoaked CBR
   CBR(unsoaked) = $-426.86(MDD)^2 + 1677.77(MDD) - 1619.28$; $R^2 = 0.970$

b) Polynomial Regression equation of Soaked CBR
   CBR(soaked) = $-15.692(MDD)^2 + 66.821(MDD) - 68.29$; $R^2 = 0.996$

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