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California Bearing Ratio of Fine Grained Soil and its Correlation

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Abstract: *A series of laboratory California Bearing Ratio (CBR) tests and laboratory compaction tests have been performed to study the CBR value for both unsoaked and soaked condition of fine grained soil and also compaction characteristics of the fine grained soil. Six types of fine grained soil have been used in the present investigation. From the experimental results, it has been found that average degree of saturation of fine grained soil at optimum points (OMC and MDD) are around 81%. With the increase in compaction energy, the CBR values for both unsoaked and soaked condition increases when sample prepared at OMC of respective compaction energy. To estimate the unsoaked CBR and soaked CBR of fine grained soil nonlinear power model has been developed.*

Keywords: *Clay, CBR, MDD, OMC, Unsoaked, Soaked.*

1. Introduction

There are two major aspects viz., compaction characteristics of the soil, as well as California Bearing Ratio (CBR) of subgrade soil, needs more attention in the preparation of subgrade for any types of roads. Embankment of road subgrade is prepared based on the optimum moisture content (OMC) and maximum dry density (MDD) for particular compaction energy, at the same time design of road has been made based on soaked CBR value compacted at MDD and OMC of a particular subgrade soil. A number of literatures are available on compaction characteristics and also on CBR of soil. Gurtug and Sridharan (2002) developed a correlation for MDD and OMC in terms of plastic limits of fine grained soil. Taskiran (2010) investigate the applicability of artificial neural network and gene expression programming for prediction of CBR of fine grained soil from basic soil properties, and he has also pointed out that the dry density of subgrade soil has great influence on the CBR value of subgrade soil. Horpibulsuk et al. (2013) studied the compaction characteristics and California Bearing Ratio, values of fine-grained soils, lateritic soils and crushed rocks. Ramasubbarao and Siva Sankar (2013) proposed a mathematical model for predicting soaked CBR value in terms of other engineering properties of soil. Yadav et al. (2014) developed the linear regression model of soaked CBR of fine grained soil in terms of OMC, MDD and other index properties of fine grained soil. Talukdar (2014) developed a correlation between CBR and other engineering properties of soil collected from Assam, India. Shirur and Hiremath (2014) developed the relationship between CBR value and other physical properties of Soil. Nguyen and Mohajerani (2015) developed a mathematical model for CBR from physical properties of fine grained soils. Korde and Yadav (2015) performed the correlation study between CBR value and physical properties of some soils. Wang et al. (2016) performed an experimental study on California bearing ratio (CBR) of high-liquid-limit lateritic soil. From the previous literature, it has been found that the most of the mathematical models for CBR are linear, whereas the scatter plots between CBR (soaked/unsoaked) with other soil parameters are not linear. In the present paper, an attempt has been made to investigate the behavior of compaction characteristics of soil and CBR of soil in soaked and unsoaked condition by considering the other soil parameters. In the present investigation, an attempt has also been made to developed mathematical model for soaked CBR and unsoaked CBR.

2. Materials

Six types of fine grained soil may be designated as soil1, soil2, soil3, soil4, soil5, and soil6 has been chosen for the present laboratory tests. Among six types of soils, soil1 collected from a site of North 24 Parganas district of West Bengal, India. Both soil2 and soil3 have been collected from Serampore, Hooghly district, West Bengal, India. Remaining three soils Soil4, soil5 and soil6 were commercially kaolinite soil, montmorillonite soil and also commercially prepared yellowish swelling type soil respectively procured from local market of Kolkata, India. The grain size analysis tests of the above six soil have been performed in the geotechnical laboratory, IIEST, Shibpur, India. The plots of grain size distribution curve for soils are shown in Fig.1. Other physical properties of the soils such as Atterberg's limits, specific gravity of the respective soils also performed in the geotechnical laboratory, IIESTS, Shibpur, India. Table 1 presents the engineering properties of fine grained soil. In accordance with ASTM 2487 (1992) the above soils may be classified as ML, ML, ML, CL, CH, and ML for soil1, Soil2, Soil3, Soil4, Soil5 and Soil6 respectively.

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2.1 Compaction of Fine Grained Soil:

Compaction of the subgrade soil is one of the important steps for construction of any types of roads. Compaction of subgrade soils depends on mainly molding moisture content and also compaction energy to be imparted in the subgrade soils. To know the effect of compaction energy on optimum moisture content and maximum dry density a series of laboratory compaction tests has been performed on six different soils (Soil1, soil2, soil3, soil4, soil5, and soil6). The three types of laboratory compaction methods have been chosen such as modified proctor compaction tests (compaction energy around 2700 kJ / m^3), standard proctor compaction tests (compaction energy around 600 kJ / m^3), and also reduced proctor compaction tests (compaction energy around 300 kJ / m^3). In the present investigation for every soil, all types of compaction tests have been performed in the compaction mold of size 10.15 cm (inside diameter) × 11.2 cm (height) [ASTM D698 (1992)]. After compaction tests performed dry density versus moisture content curve has been plotted, and optimum moisture content and maximum dry density have been determined for the six soils. Fig2. Show the typical compaction curve with varying compaction energy for soil5. Figs.3-4 shows the MDD versus compaction energy curve and OMC versus compaction energy curves respectively. From both the figure it is found that with an increase in compaction energy (300 kJ/m^3 to 2700 kJ / m^3) the values of MDD increases (Fig.3), whereas the values of OMC decreases with increase in compaction energy (Fig.4). Gurtug and Sridharan (2004) also reported the similar types of results in the case of compaction of fine grained soil with varying compaction energy. Fig.5 shows the degree of saturation at MDD and OMC versus compaction energy curve. From the figure (Fig.5) it has been found that degree of saturation lies around 81 % within the range of compaction energy under study (300 kJ/m^3 to 2700 kJ/m^3). Benson and Boutwell (1992) also opined that in the case of clay the OMC usually attained at the degree of saturation of 85 %.

3. California Bearing Ratio of Subgrade Soil:

California bearing ratio (CBR) of fine grained soil mainly depends on moisture content, dry density and also types of soils. In the present investigation a series of CBR tests have been performed in both soaked and unsoaked condition with varying dry density and moisture content. Table 2 presents the plan of work of CBR tests both in soaked and unsoaked condition. To know the effect of dry density and moisture content with varying compaction energy (300 kJ/m^3 to 2700 kJ/m^3) on CBR value, plan of CBR tests both in soaked and unsoaked condition has been chalked in three series(A, B and C).

Table 1: *Engineering Properties of fine grained soil*

Engineering Properties	Property value					
	Soil1	Soil2	Soil3	Soil4	Soil5	Soil6
Sand Content(%)	4.00	13.00	1.00	5.00	15.0	14.00
Silt Content (%)	68.00	57.00	49.00	28.00	59	37.20
Clay Content (%)	28.00	30.00	50.00	67.00	26	48.80
D_{50} (mm)	0.0070	0.0074	0.0021	0.00055	0.0022	0.0025
Specific Gravity	2.69	2.67	2.68	2.65	3.02	2.76
Liquid Limit (%)	41.65	33.60	33.89	41.00	297.00	43.00
Plastic Limit (%)	26.19	24.42	25.43	25.00	43.29	26.39
Plasticity Index (%)	15.46	09.18	8.46	16.00	253.71	16.61
Soil type (USCS)	ML	ML	ML	CL	CH	ML

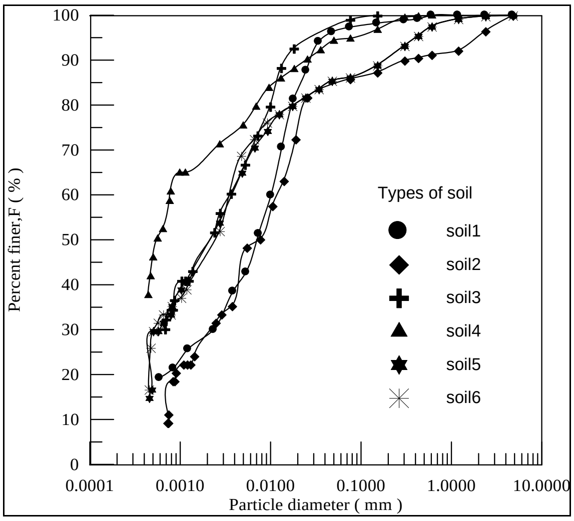

Figure 1: *Grain size distribution curve for six different soils*

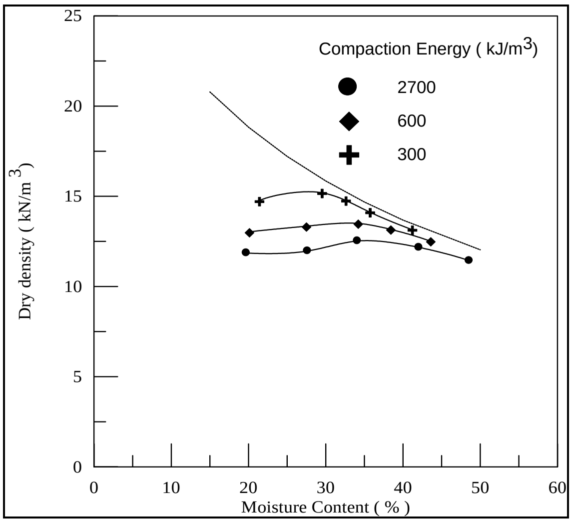

Figure 2: *Typical compaction curve for soil5*

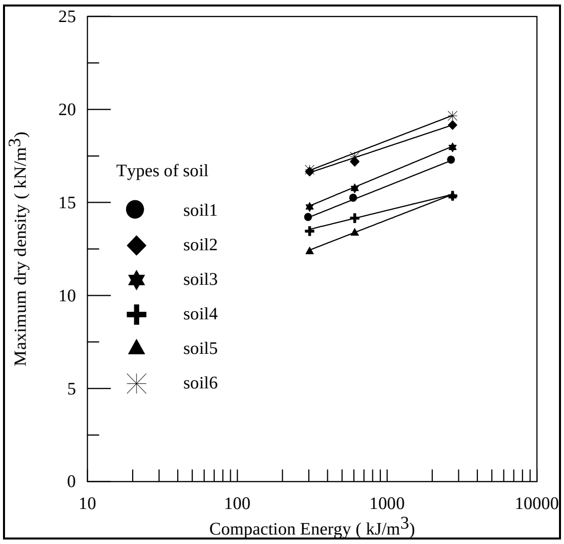

Figure 3: *MDD versus compaction energy curve*

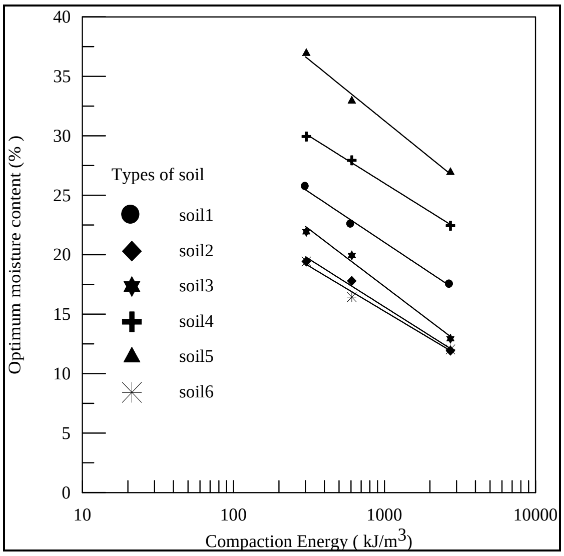

Figure 4: *OMC versus compaction energy curve*

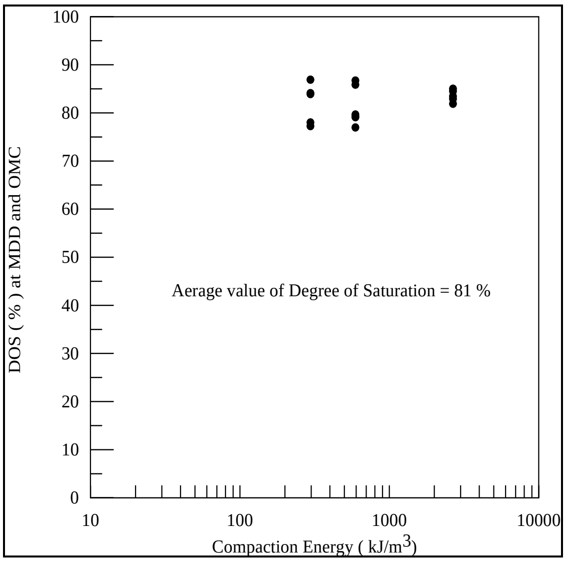

Figure 5: *Degree of saturation at MDD and OMC versus compaction energy curve*

Table 2: *Plan of CBR tests (Soaked & Unsoaked)*

Series	Types of Soil	Moisture content	Compaction Energy (kJ/m^3)
A	Soil1, Soil2, Soil3, Soil4, Soil5, Soil6	OMC_H	2700,600,300
B	Soil1, Soil2, Soil3, Soil4, Soil5, Soil6	OMC_S	2700,600,300
C	Soil1, Soil2, Soil3, Soil4, Soil5, Soil6	OMC_R	2700,600,300

In the series A, CBR samples have been prepared based on dry densities obtained from different level of compaction (300-, 600-, and 2700kJ/m^3), whereas water content kept as OMC_H (Optimum moisture content obtained from heavy compaction tests). In the series B and Series C moulding water content kept as OMC_s (optimum moisture content obtained from standard compaction tests), and OMC_R (optimum moisture content obtained from reduced compaction tests) respectively. For each case samples were tested under the soaked and unsoaked conditions. After the tests performed load versus penetration curve have been papered.

3.1 Results and Discussions

Fig.6 shows the typical load versus penetration curve with varying the dry density and moisture content for soil5 in unsoaked condition.Fig.7 show the unsoaked CBR (%) versus compaction energy curve with varying OMC. Figs.8-10 show unsoaked CBR (%) versus compaction energy curve with varying types of soil at $OMC_{H,}$ unsoaked CBR (%) versus compaction energy curve with varying types of soil at $OMC_{s,}$ and unsoaked CBR (%) versus compaction energy curve with varying types of soil at OMC_R respectively. Figs.11-12 shows the unsoaked CBR (%) versus OMC curve with varying compaction energy and unsoaked CBR (%) versus OMC curve with varying types of soil respectively. Fig.13 shows the CBR (%) versus compaction energy curve for soil5.

Based on the results presented in the previous section discussions are made by highlighting the following points:

- Effect of compaction energy on unsoaked CBR value
- Effect of OMC on unsoaked CBR value
- Soaked CBR

3.1.1 Effect of Compaction Energy on CBR Value

Compaction energy is one of the main factors for laboratory as well as field CBR. For any particular soil with an increase in compaction energy closer packing of soil as a result of higher CBR value. Fig.7 shows the plots of unsoaked CBR versus compaction energy curve with varying OMC. From the curve, it has been found that with an increase in compaction energy the value of unsoaked CBR increases. It is may be due to that for particular soil with an increase in compaction energy MDD increases at respective OMC at compaction energy of soil as a result of unsoaked CBR value increases. Figs.8-10 shows the unsoaked CBR value versus compaction energy curve at OMC_H, OMC_s and OMC_R respectively. From the Fig.8 it has been found that with an increase in compaction energy unsoaked CBR value increases. It is may be due to that all soil samples have been compacted on OMC obtained from heavy compaction, 2700 kJ/m^3 as a result, other compaction energy (Standard and reduced) the corresponding water contents are falling less than OMC of the respective compaction. In this case with the increase in compaction energy degree of saturation increases with in optimum points, nearly S= 81 % (Fig.5). The strength of unsoaked CBR mainly depends on compaction energy and also on the degree of saturation of the soil. Generally, beyond the degree of saturation at optimum points (OMC and MDD of respective energy and respective soil) the values of unsoaked CBR are decreases. Singh et al. (2011) reported that if the soil was compacted wet side of OMC, the unsoaked CBR value for fine grained soil decreases compared to CBR value at OMC. From the figure (Fig.11) it has been found that with an increase in compaction energy up to 600kJ/m^3 (standard compaction) the values of unsoaked CBR increases after that the values of unsoaked CBR decreases (except soil4 and soil5). It is may be due to that beyond the compaction energy, 600kJ/m^3 degree of saturation increases beyond the degree of saturation of optimum points. Whereas in the case of soil4 and soil5, with an increase in compaction energy the dry density of soil also increases and plays the significant role for increasing CBR value. From the Fig.10 it is also found that with an increase in compaction energy the values unsoaked CBR decreases except soil3 and soil4. The reason is that beyond the compaction energy (300 kJ /m^3) the values of the degree of saturation above the optimum points of the respective compaction energy and respective soil. In the case of soil3 and soil5 at compaction energy of 600kJ/$m^{3,}$ the dry density of soil plays a key part as a result of higher CBR value.

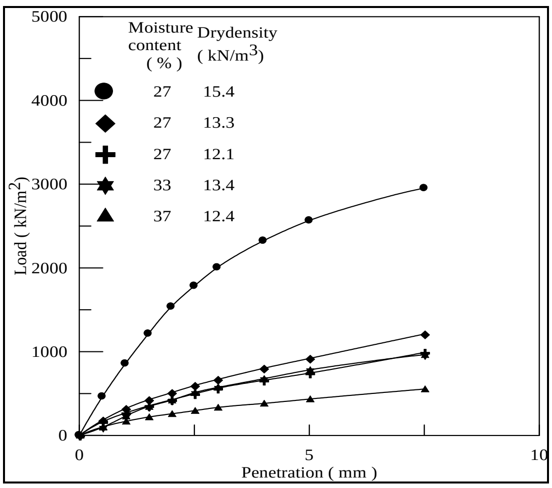

Figure 6: *Load versus penetration curve with varying dry density and moisture content for soil5 (Unsoaked)*

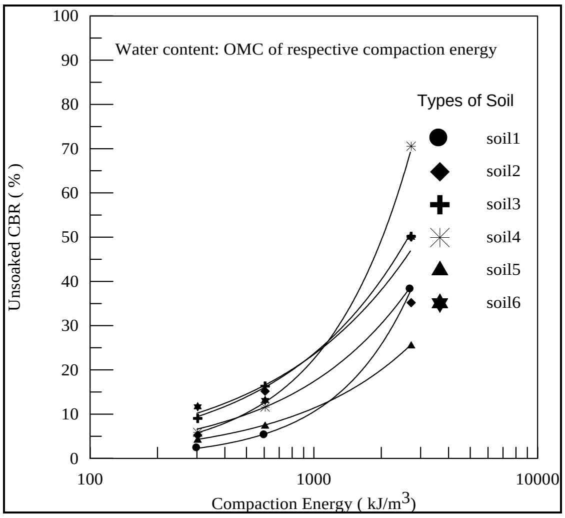

Figure 7: *Unsoaked CBR (%) versus compaction energy curve with varying OMC*

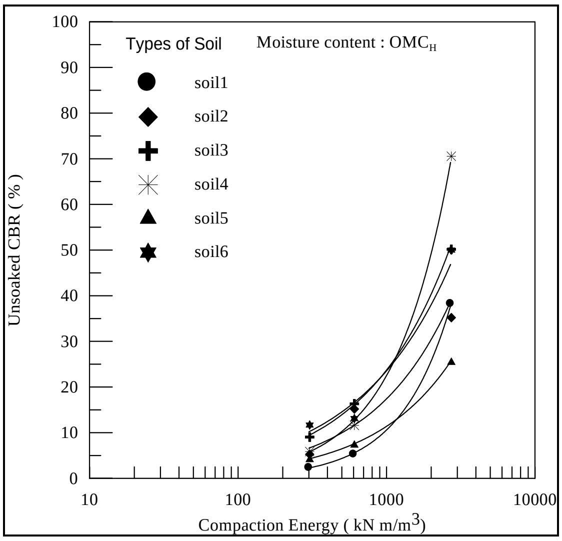

Figure 8: *Unsoaked CBR (%) versus compaction energy curve at OMC_H with varying types of soil*

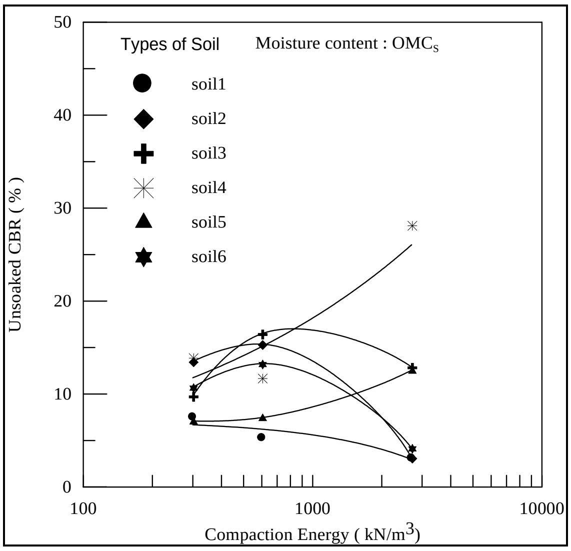

Figure 9: *Unsoaked CBR (%) versus compaction energy curve at OMC_S with varying types of soil*

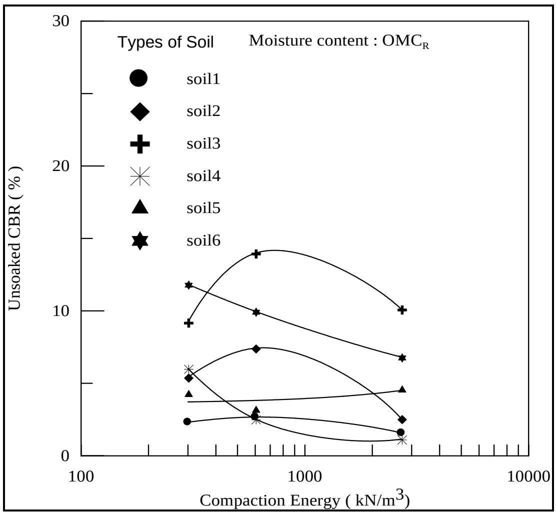

Figure 10: *Unsoaked CBR (%) versus compaction energy curve at OMC_R with varying types of soil*

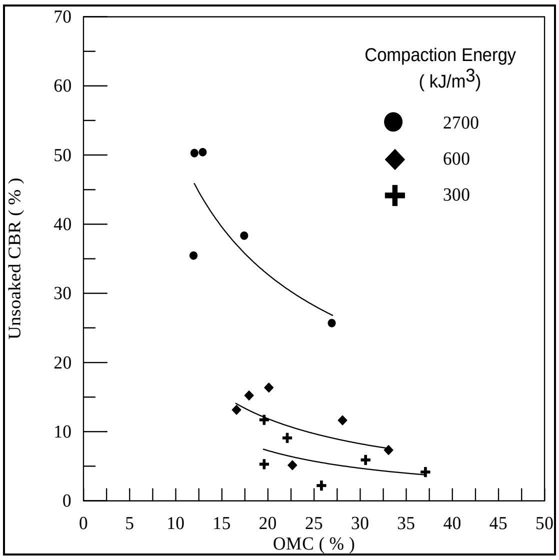

Figure 11: *Unsoaked CBR (%) versus OMC curve with varying compaction energy*

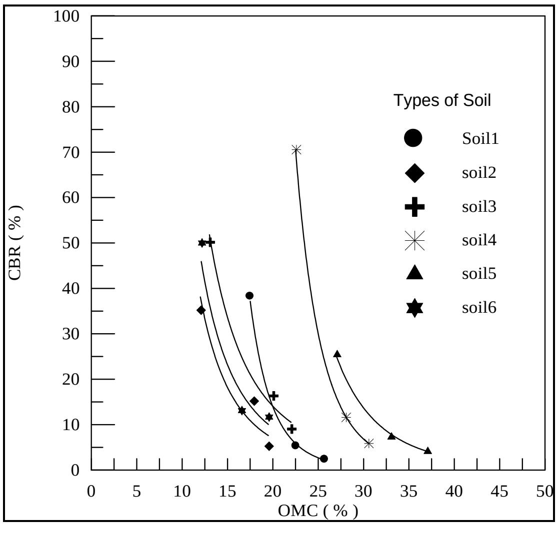

Figure 12: *Unsoaked CBR (%) versus OMC curve with varying types of soil*

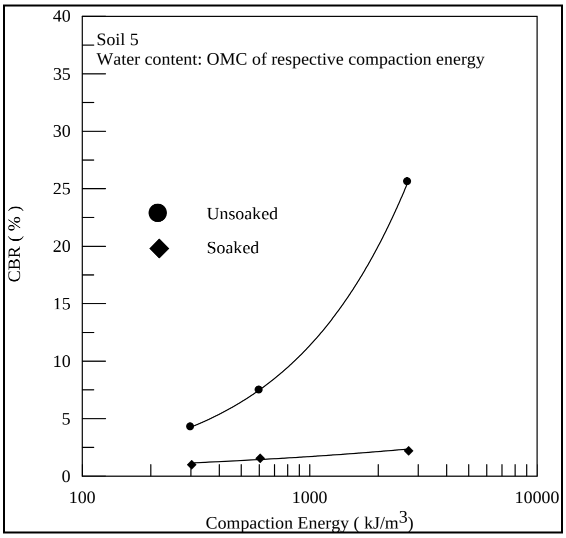

Figure 13: *CBR (%) versus compaction energy curve for soil5*

3.1.2 Effect of OMC on Unsoaked CBR Value

OMC is one of the important controlling factors for getting the maximum CBR value at the unsoaked condition for any types of soil at any particular energy level. OMC of a particular soil can be changed with changing in compaction energy or with changing types of soil at any particular energy level. Fig.11 shows the plots unsoaked CBR (%) versus optimum moisture content curve with varying compaction energy. From the figure (Fig.11) it has been found that with a decrease in OMC the values of unsoaked CBR increases. It is may be due to that with an increase in compaction energy for a particular soil the values of OMC decreases, and at the same time, the MDD increases as a result of higher CBR value. The plots of unsoaked CBR (%) versu0s optimum moisture content curve with varying types of soil at particular compaction energy shown in Fig.12. From the figure, it has been seen that with an increase in OMC with varying types of soil for particular energy level the value of unsoaked CBR decreases. From the figure (Fig.2), it is also observed that for some of the soils with decrease in OMC the unsoaked CBR value not decrease. It is may be due to that the unsoaked CBR value for particular energy level not only depends on OMC but also specific gravity and other index properties of soil. Talukdar (2014) and Shirur and Hiremath (2014) also found the similar types of results in the case of soaked CBR of soils.

3.2 Soaked CBR

Most of the road engineers are only concerns about soaked CBR rather than CBR value in unsoaked conditions in both design of roads as well as checking the performance of the road. In soaked condition, the soils are always 100% saturated and as a result of the soaked CBR value always less than the unsoaked CBR. Fig.13 shows the typical CBR value versus compaction energy curve with varying OMC of respective soil for soaked and unsoaked CBR of soil5. From the Fig.13 it has also been found that soaked CBR value is much less than unsoaked CBR value. But trends is same as unsoaked CBR with increases in compaction energy the values of soaked CBR increases when sample prepared at OMC of respective compaction energy. Singh et al. (2011) also reported the similar results.

3.3 Mathematical Model for Unsoaked CBR

From the present investigation and also previous literature (Taskiran, (2010), Singh et al. (2011)) the unsoaked CBR is depended on a number of factors such as OMC, MDD, PL, LL, Compaction energy, specific gravity, etc. Based on the present 29 numbers of experimental data point by using multiple regression analysis a nonlinear power model has been developed to estimate the unsoaked CBR in terms of OMC, MDD, PL, E, and G as follows:

$$CBR_{us} = \gamma_{dry}^{-4.18699} \times OMC_E^{-0.69156} \times PL^{-8.80923} \times G^{32.37705} \times f^{1.488682} \times E^{0.96145} \qquad (3)$$

Where,
CBR_{us}= CBR value in unsoaked condition (%),
γ_{dry}= dry density of soil (kN/m^3),
OMC_E =OMC of the respective energy (%),
PL = Plastic Limit (%),
G = Specific gravity of soil,
f = fine content (%),
E= Compaction energy (kJ/m^3).

The above model has been analyzed by using logarithm transformation. The efficiency of the model has been checked by calculating the values of R^2 (Coefficient of determination), and E_s (Estimated standard error) and corresponding values are 0.99 and 0.11(%) respectively. The model has been checked for $F_{statistics}$ and $t_{statistics}$ and found to be satisfactory. Fig. 14 shows the plot of observed CBR_{us} versus predicted CBR_{us}. From the figure, it is found that all predicted CBR_{us} values based on both types of data used in developing the model and also not used in developing the model are within +- 30% error. The above model is valid for within the range of data OMC_E of 12.1- to 37 %, PL of 24.42- to 43.29%, G of 2.65 to 3.02 and f of 85.00- to 96.25%. Beyond the above range of the data, the model has been tested with additional data.

3.4 Mathematical Model for Soaked CBR

Soaked CBR of soil is highly dependent on the quantity of water absorption, dry density during tests rather than molding moisture content and corresponding density. In the present investigation by using 27 numbers of present experimental data points, a nonlinear power model has been proposed to predict soaked CBR (CBR_S) in terms of dry density and G as follows:

$$CBR_S = \gamma_{dry}^{2.175222} \times G^{-4.83731} \qquad (4)$$

Where,
CBR_s= CBR value in soaked condition (%),
γ_{dry}= dry density of soil obtained at OMC for corresponding particular energy, kN/m^3,
G = Specific gravity of soil

The efficiency of the model have been checked based on R^2 (Coefficient of determination) and E_s (Estimated standard error) and corresponding values are 0.96 and 0.147(%) respectively. The model has been checked for $F_{statistics}$ and $t_{statistics}$ and found to be satisfactory. The observed CBR_s versus predicted CBR_s are plotted in Fig15. From the figure it has been found that all predicted CBR_s values based on both types of data used in developing the model and also not used in developing the model are within ± 40% error. The above model is valid for within the range of data γ_{dry} of 12.1 to 18 kN/m^3, and G of 2.65 to 3.02.

4. Conclusions

On the basis of the experimental data presented and discussion are made in the present paper the following conclusions may be made:

- With the increase in compaction energy, the values of dry density increases and optimum moisture content decrease irrespective of types of soil.
- The average degree of saturation of fine grained soil at optimum points (OMC and MDD) are around 81 % within the range of compaction energy under study.

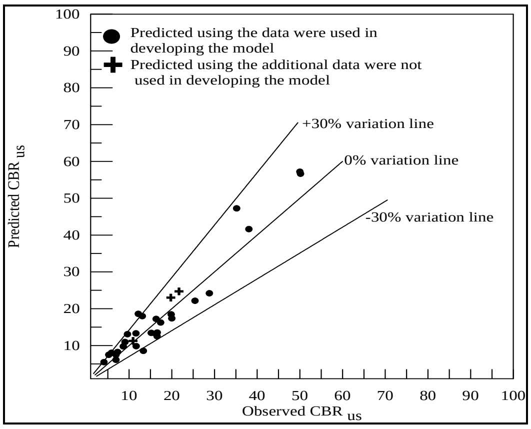

Figure 14: *Observed CBR_{us} versus predicted CBR_{us}*

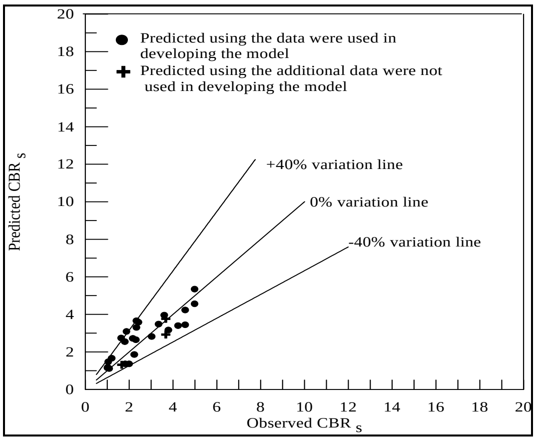

Figure 15: *Observed CBR_s versus predicted CBR_s*

- When CBR sample is prepared at OMC of the respective compaction energy the values of both unsoaked CBR and soaked CBR value increases with increase in compaction energy.
- The soaked CBR value is much less than the unsoaked CBR value and its value depends on the dry density of sample after soaking and also water absorption capacity after soaking.
- Nonlinear power model has been developed to estimate the unsoaked CBR in terms of OMC, γ_{dry}, PL, E, f and G and also a power model has been developed to predict the soaked CBR in terms of γ_{dry} and G.
- To estimate the soaked CBR value, a non-linear power model also developed in terms of γ_{dry} in the range of 12.1 to 18 kN/m^3, and G within the range of 2.65 to 3.02.

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