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An Empirical Model to Assess the California Bearing Ratio Value for Cohesive Soils

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Abstract — **One of the important design parameters in the design of pavement courses in the construction of roads is California Bearing Ratio (CBR). In order to determine CBR usually involves time and laborious experimental programme. The present investigation focusses on proposing a framework for predicting the CBR based on simple soil parameters normally obtained in routine soil investigation. The soils considered in the present investigation are typically clayey soils with fine fraction (<75µ) ranging from 35-85%, significant enough to govern the overall behaviour. The consistency limits are modified to account for coarse fraction. The framework proposed consists of obtaining compaction properties for different energy levels the soils are subjected to depending on engineering applications. The strength of the compacted soil depends on dry density and moisture content representing the degree of saturation, these two factors are considered variables to determine the strength for each of the soils adopted in the present investigation. The unconfined compressive strength and corresponding CBR values have been determined for soil samples at respective maximum dry densities and at moisture content on either side of optimum to represent different degrees of saturation. The data has been analysed to propose a suitable framework for use by practicing engineers to predict compaction properties and CBR values based on easily determinable soil parameters.**

Keywords* — *Compaction of Soils, Compaction properties, Strength properties: unconfined compression, CBR, dry density, degree of saturation

Nomenclature

E	*Void ratio*
S_r	*Degree of Saturation*
$(\gamma_d)_{max}$, *MDD*	*Maximum Dry density*
UCC	*Unconfined Compression*
q_u	*Unconfined Compressive strength*
CBR	*California Bearing Ratio*

I. INTRODUCTION

India has widespread road network measuring thirty-three lakh kilometres. It occupies second largest position in the world. Passenger traffic and freight carried by the roads constitute to 80% and 65% respectively. Annually, on an average of 10.6% growth rate is recoded over the last 5 years, in terms of number of vehicles using the roadways [9]. Determination of soil properties to characterise the soil and to plan and design the foundations of infrastructure projects assume significance in geotechnical engineering practice. However, the determination of certain soil properties such as compaction and CBR is time consuming and involves labour. Correspondingly, laboratory test takes 2 – 4 days [3] to determine strength parameters to be used in the design. As a result, they are expensive and time-consuming. Further trained personnel are required for sample preparation and taking precise measurements. As a consequence, these tests are many a time, avoided in many soil investigation schemes. Therefore, innovative approaches are needed for their evaluation which is the need of hour.

For right decisions in engineering, prediction is a crucial tool. Hence, it is essential for engineers to quickly predict in infrastructures about the behaviour of geomaterials used. In design of pavement, shear strength and stiffness modulus of sub grade will be evaluated by performing the California Bearing Ratio (CBR) test. Though it is a common lab test it is included of strenuous job and for the quick assessment of CBR Value, new models are to be developed. An attempt has been made to develop valid model for evaluate of CBR value from index properties of soil from standard method of testing. Predictive models are developed by Authors from 59 set of soil samples containing both fine grained and coarse grained soil samples. On 25 set of soil samples were tested separately with newly developed three models. For coarse grained soil and fine grained soils, a separated model is developed by the Authors. These models were developed, based on liquid limit and plasticity index for fine grained soil, the coefficient of uniformity and maximum dry density for coarse grained soil [10].

In civil engineering the investigation of subgrade materials for pavement design works become necessary to optimize structural safety and economical aspects of the road infrastructures. California Bearing Ratio (CBR) is a parameter that measures the strength of road soils and used as an integral part of pavement design. This test involves sampling, transporting, preparing, compacting, soaking, and penetrating with a plunger of CBR machine to measure the soil resistance. Therefore, predicting CBR value from Proctor, Modified proctor test and exploiting it during performance evaluation of pavement layers makes better option than using costly and time intensive procedures. The intention of this research is to establish a relationship between CBR and Proctor, Modified

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proctor which helps to predict CBR value from Proctor, modified Proctor test result that suits for the subgrade materials. The aim of this research is to develop relationships between Proctor, modified Proctor and laboratory determined CBR for local subgrade materials.

- To examine possible relationship that predicts CBR value for Tirupati sub grade materials both in a soaked and in an unsoaked conditions.
- To examine possible relationship between CBR and the unconfined compression (UCC) strength values
- To examine the strength value with state parameter, that reflects void ratio and moisture content rather than index properties which are determined at remoulded condition

II. BACKGROUND INFORMATION

Several investigators have made attempts to correlate strength properties to basic properties of soils in the recent past. [8] presented one to one relationship among soil properties such as Plastic Limit (PL), Plasticity Index (PI), Liquid Limit (LL), Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). [1] explained that soil type, density, moisture content plays an important role in soil relationship and correlated soil expansion index and plasticity index, fine fraction and weighted plasticity index (That is product of PI and percentage passing 0.425mm). Apart from index properties, some researchers like [7] and [11] observed that California Bearing Ratio depends on other factors such as type of soils, permeability of soil, maximum dry density and optimum moisture content. To correct overlapping problem and uncertainty in prediction, [12] applied multiple regressions to improve the ability of predicting soil properties, and better model the extent of their relationship. [6] present the correlation results between index properties of soils and California Bearing Ratio (CBR). Laboratory tests was conducted to evaluate soaked California Bearing Ratio, Liquid Limit, Plastic Limit, Plastic Index, Optimum Moisture Content and Moisture Dry Density on soil samples collected from Ibiono, Oron and Onna L.G.A. in AkwaIbom State and the results indicate strong and weak correlations between CBR and basic properties for two soils tested.

In Construction of Pavement usually suitability and stability of soil were determined in advance of it use. Suitable investigations need to confirm in Civil Engineering projects like Buildings, Road Infrastructure, rail, irrigation projects (dams) remain safe and free to withstand settlement and collapse. It is difficult to expect the behaviour of soils due to geographical variability in soil conditions may change from one site to another. Hence, for making suitable design, it is necessary to thoroughly investigate on soil conditions at every location [2]. In the pavement design the stiffness modulus and shear strength of sub grade is commonly evaluated by using California Bearing Ratio (CBR). To design the pavements, Transportation Engineers are difficult to obtain the California Bearing Ratio values. California Bearing Ratio values are differing with different parameters like type of soil and different soil properties possessed by the soil. With the properties of PL, PI, LL, OMC and MDD of cohesive soils a model is suggested for correlation the California Bearing Ratio values [9].

California Bearing Ratio value is a vital parameter in design of pavement. California Bearing Ratio value can be evaluated at the laboratory test with respect to IS 2720 part 16 on the soil sample obtained from site and it will take minimum four (4) days to evaluate the California Bearing Ratio values of each soil sample at the lab. California Bearing Ratio values is influenced with type of soil and different soil properties. An alternate method is developed by the author with an attempt of correlation California Bearing Ratio with soil properties and further suggested it can be a rapid than the CBR Test at lab. Author has given and indicated to acquire California Bearing Ratio with Soil Index Properties which is appropriate for Surat City. It may be used for other alluvial deposits judiciously and after check tests.

III. MATERIALS AND METHODS

A. Materials

For the purpose of the present study, the soil samples from 6 different locations from the surroundings of Tirupati town and Kadapa have been selected. They are designated as S7, S8, S9, S10, S11 &S12. The data pertaining to S1-S6 have been used elsewhere. In order to develop a framework, a carefully planned experimental work has been devised which takes into account wide spectrum of variations in terms of inherent grain size, plasticity characteristics that is normally encountered in practice. The range of fine fraction is in between from 43% to 78% which can be quite significant in so far as influencing the overall behavior of soil. The plasticity index is ranging from 18-53%. The soils are predominantly clayey. Precisely the soils are classified as Clayey Sand (SC) to Clay with High compressibility (CH) as per IS 1498-1970.

B. Method

The soils collected from the site were pulverized with wooden mallet to break lumps and then air-dried. Subsequently it was sieved through 19mm sieve and then air dried for 24 hours.

The tests conducted on soil samples include determination of basic properties such grain size distribution, consistency limits, compaction properties using Standard Proctor and Modified Proctor. Unconfined compression Tests and CBR tests were conducted at Optimum moisture content at moisture content ranging over 2% on either side of the optimum moisture content. All the tests were conducted based on Bureau of Indian Standards specification of each test as mentioned in Table 1.

TABLE I. EXPERIMENTAL METHODS

Serial Number	Description	Code of Practice
1	Liquid Limit	IS:2720 (part V) – 1995
2	Plastic Limit	IS:2720 (part V) – 1995
3	Specific Gravity	IS:2720 (part III) - 1997

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Serial Number	Description	Code of Practice
4	Sieve Analysis	IS:2720 (part IV) - 1995
5	Free Swell Index	IS:2720 (part IV) - 1995
6	Standard Proctors	IS:2720 (part VII) - 1997
7	Modified Proctor Test	IS:2720 (part VIII) - 1997
8	Unconfined Compression Test	IS:2720 (part X) – 1995
9	California Bearing Ratio Test (CBR)	IS:2720 (part XVI) - 1987

The soil properties are mentioned in Table 2.

TABLE II. BASIC SOIL PROPERTIES

S.No	Description	S7	S8	S9	S10	S11	S12
1	Gravel (%)	5.56	12.15	6.41	1.47	1.40	1.75
2	Sand (%)	46.12	40.92	1.47	55.40	35.56	22.82
3	Silt+ Clay (%)	48.32	46.93	78.69	43.13	63.04	75.43
4	Liquid Limit (%)	57.00	68.00	55.00	33.00	37.00	55.00
5	Plastic Limit (%)	20.00	15.00	16.00	14.60	16.00	17.00
6	Plasticity Index (%)	35.00	52.80	39.00	18.40	18.00	38.00
7	IS Classification (ISC:1498-1970)	SC	SC	CH	SC	CI	CH
8	Free Swell Index (%)	80.00	90.00	120.00	45.00	90.00	110.00
9	Degree of Expansion	Medium	Medium	High	Low	Medium	High
10	Specific Gravity	2.69	2.65	2.65	2.65	2.64	2.69
	Standard Proctor's Test						
11	Maximum Dry Density,MDD, (kN/m^3)	17.80	18.59	16.79	18.97	17.70	17.38
12	Optimum moisture Content ,w_{omc},%	14.00	12.00	15.00	12.00	16.00	17.00
	Modified Proctor's Test						
13	Maximum Dry Density,MDD, (KN/m3)	20.64	20.26	18.51	20.97	18.80	18.82
14	Optimum moisture Content ,w_{omc},%	12.00	10.00	12.00	10.00	13.00	14.00

C. *Compaction Test Results*

The compaction test results on soil samples conducted are presented in Figures 1-6. The test results indicate that the compaction curves lie below respective Zero Air Voids curves. The maximum dry density increases with increase in compactive effort and optimum moisture content reduces with increase in compactive effort

D. *CBR Test Results*

California Bearing Ratio tests were conducted on six soil samples for both unsoaked and soaked condition. The moisture content is varied over a range of 2% on either side of optimum that is at -2% of optimum moisture content, at optimum moisture content and +2% of optimum moisture content. The test results are shown in Figures 7 to 12. It may be seen that CBR values vary with moisture content in that for moisture content 2% less than optimum moisture content the CBR values are more consistently for all the soil samples. However, the CBR values for the moisture content 2% above the optimum moisture content the CBR values for all the soil samples are less than the tests conducted at optimum moisture content. Though the dry densities at ±2% optimum moisture content are nearly same, variation in resistance against plunger penetration is different owing to possible change in degree of saturation. It may be inferred that the degree of saturation plays key role in determining the strength properties of compacted soils.

The test results CBR tests conducted on soaked and unsoaked conditions are presented in Figures 13-15. It may be seen that the CBR values for soaked conditions are consistently lower compared to CBR values for the unsoaked condition. The CBR values for unsoaked conditions are found to be nearly 30% higher compared to corresponding CBR values for unsoaked condition given by

$$(CBR)_{unsoaked} = 1.30\ (CBR)_{soaked}$$

E. *Unconfined Compression (UCC) Test Results:*

Unconfined compression tests are conducted at ±2% and at optimum moisture contents. The test results are shown in Figures 16-21. It may be observed that the UCC strength values are higher at -2 % of optimum moisture content, the value at optimum moisture content is lower and the unconfined compression strength value at -2% of optimum is the lowest. The degree of saturation increases with increase in moisture content as the compaction curve at and above optimum moisture content approaches the zero air voids line representing 100% saturation. At lower degree of saturation, the soils exhibit higher resistance owing to capillary menisci apart from possible flocculated structure the soil is likely to have on dry side of optimum.

Conduct of CBR test involves considerable labour and time compared to unconfined compression test. Further these values reflect the strength offered by the soil under given conditions, though method of loading is different. For preliminary designs and estimates, it often required to know the CBR value to estimate the crust thickness of the pavement. An attempt has been made to find out possible relationship between CBR value and unconfined compression strength values. The relationship is depicted in Figure 22. It may be noticed that the respective strength values bear close correlation as given by:

$$(CBR)_{soaked} = 0.017(q_u) \quad where \quad q_u = unconfined\ compression\ strength\ in\ kPA$$

F. *Importance of state of soil (e) and degree of saturation (Sr)*

It is widely known that the strength of soil depends on dry density or void ratio at which the soil is present. In the compacted soils, it may be observed the soils assume same dry density at two moisture contents, on dry side of optimum and the other on wet side of optimum. But the soils on either side of optimum exhibit contrasting strength values, the strength being more on dry side of optimum compared to wet side of optimum. The reason could be attributed to change in degree of saturation the samples attain at these moisture contents. It has been shown [4] and [5] that the microstructure of partly saturated soils, the volume changes are dependent on sate parameter $e\sqrt{S_r}$.

Accordingly, an attempt has been made to find out the relationship between $e\sqrt{S_r}$ and CBR in soaked condition. The relationship is shown in Figure 23. It may be seen that CBR

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soaked value bear the following relationship with state parameter $e\sqrt{S_r}$ having strong correlation coefficient.

$$(CBR)_{soaked} = -6.76\ln\left(e\sqrt{S_r}\right) - 1.588$$

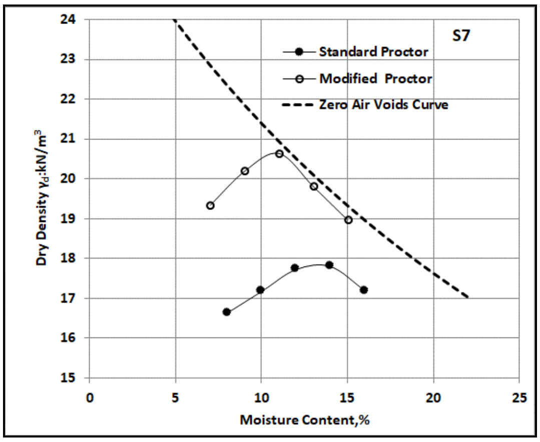

Fig. 1. Compaction Properties for Soil Sample S7

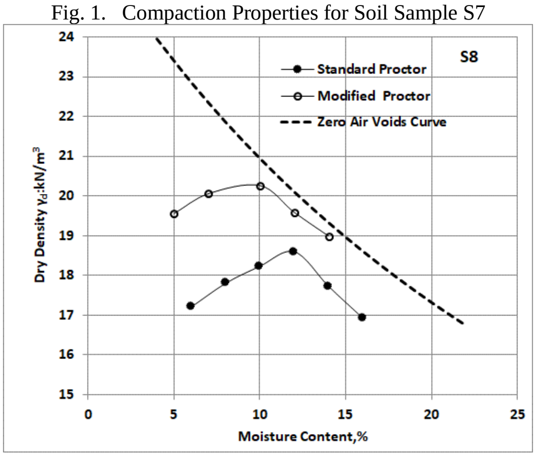

Fig. 2. Compaction Properties for Soil Sample S8

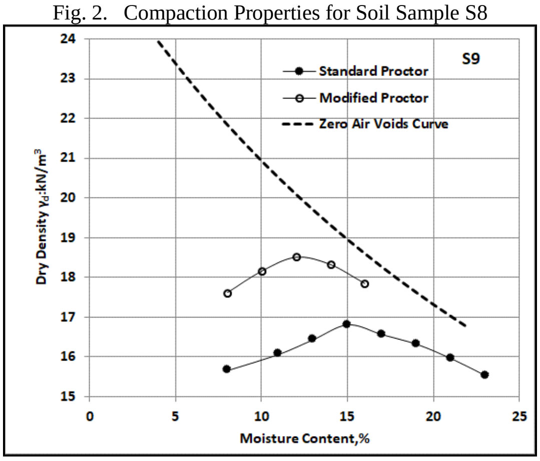

Fig. 3. Compaction Properties for Soil Sample S9

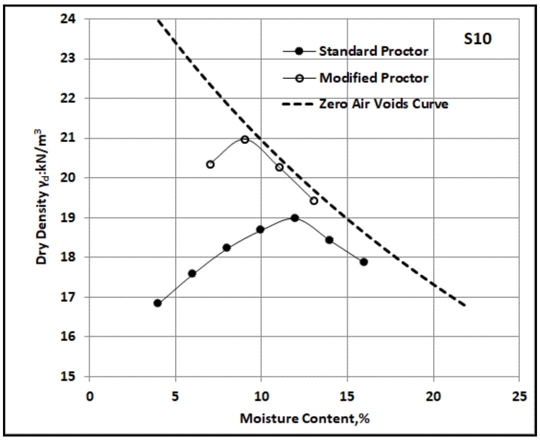

Fig. 4. Compaction Properties for Soil Sample S10

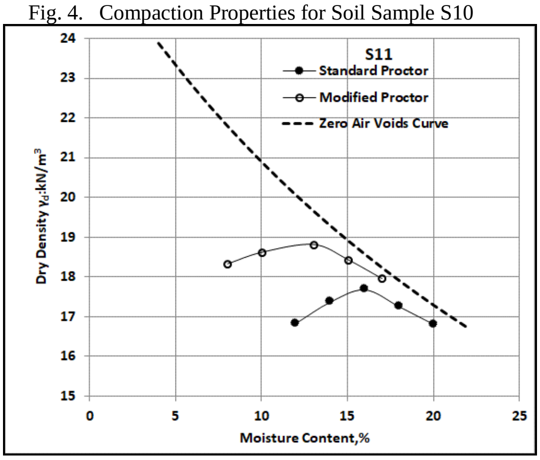

Fig. 5. Compaction Properties for Soil Sample S11

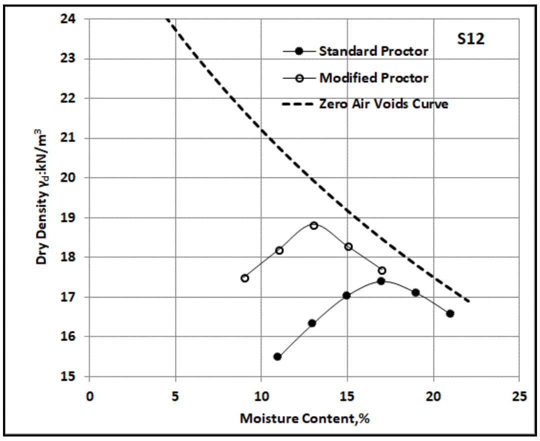

Fig. 6. Compaction Properties for Soil Sample S12

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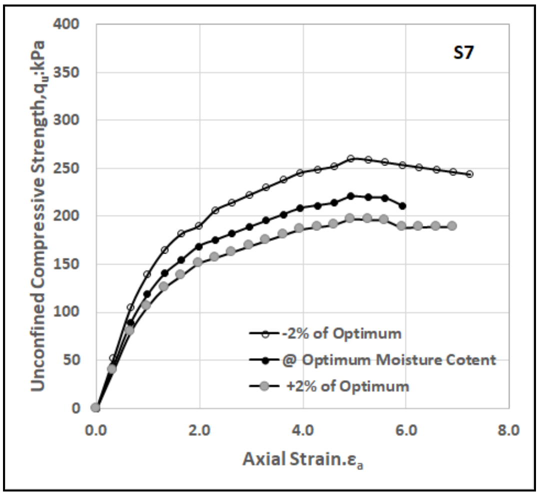

Fig. 7. Stress-Strain Response in Unconfined compression for Soil Sample S7

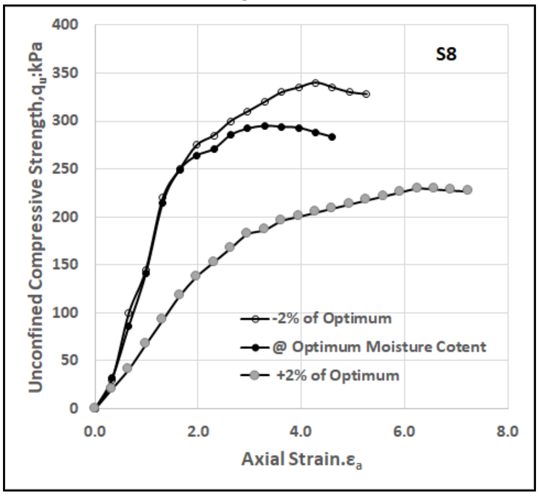

Fig. 8. Stress-Strain Response in Unconfined compression for Soil Sample S8

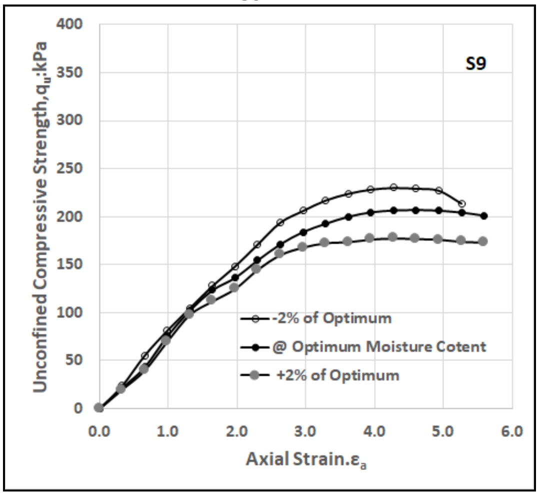

Fig. 9. Stress-Strain Response in Unconfined compression for Soil Sample S9

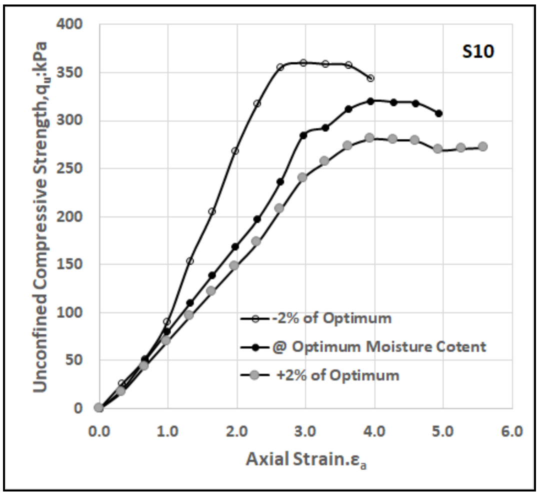

Fig. 10. Stress-Strain Response in Unconfined compression for Soil Sample S10

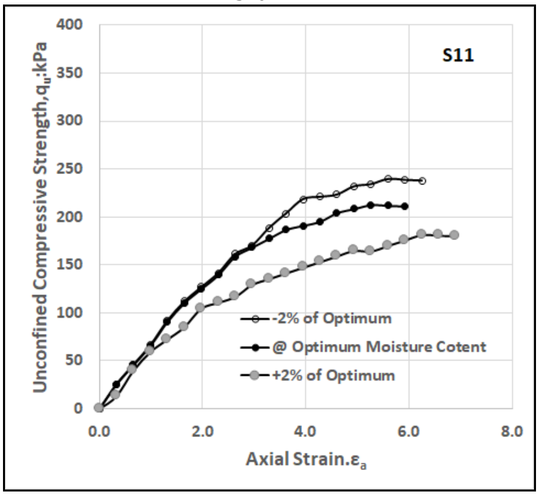

Fig. 11. Stress-Strain Response in Unconfined compression for Soil Sample S11

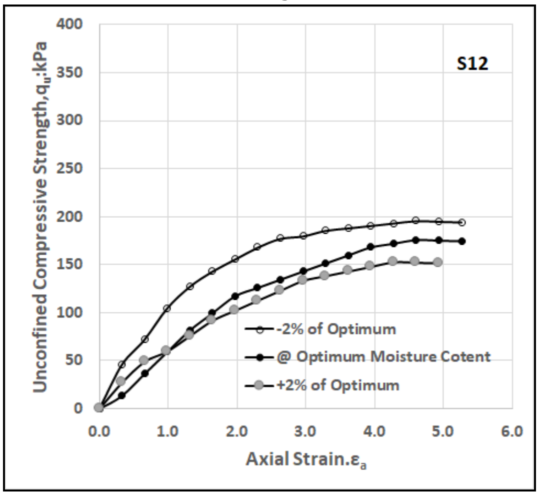

Fig. 12. Stress-Strain Response in Unconfined compression for Soil Sample S12

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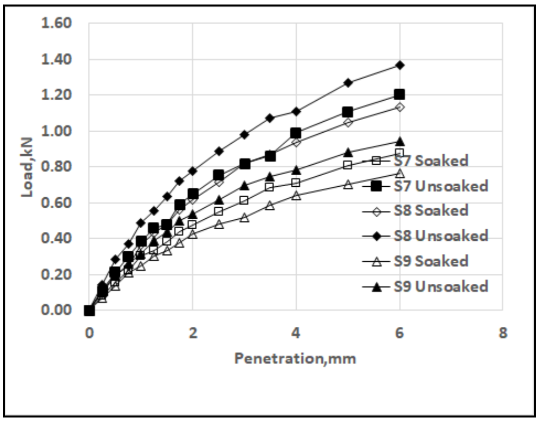

Fig. 13. Load-Deformation Curve in CBR Test for Soil Samples S7-S9

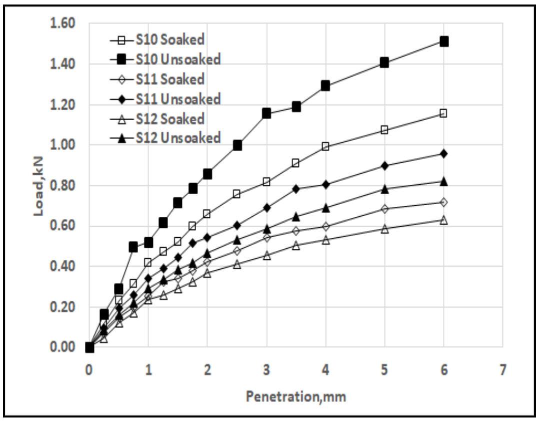

Fig. 14. Load-Deformation Curve in CBR Test for Soil Samples S10-S12

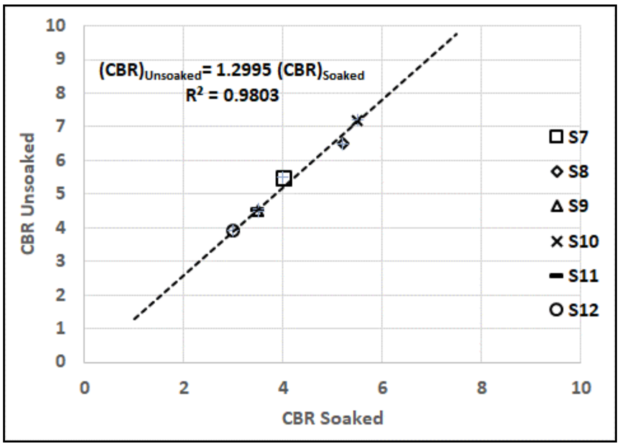

Fig. 15. Relationship between California Bearing Ratio Soaked and California Bearing Ratio Unsoaked

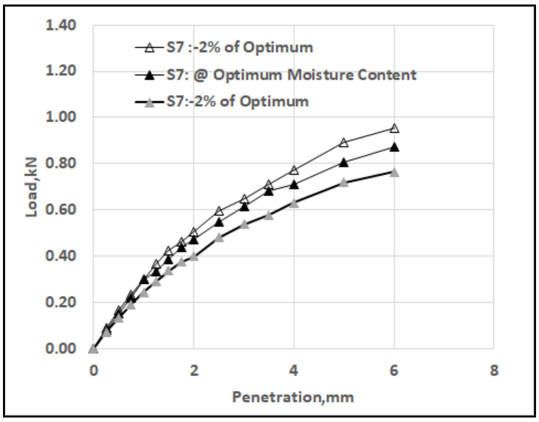

Fig. 16. Load-Deformation Curve in CBR Test at different Moisture Contents for Soil Samples S7

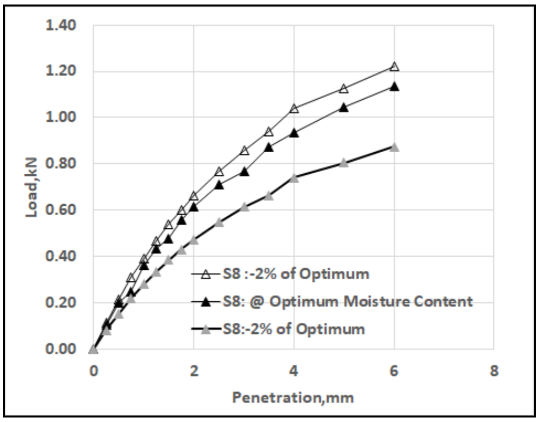

Fig. 17. Load-Deformation Curve in CBR Test at different Moisture Contents for Soil Samples S8

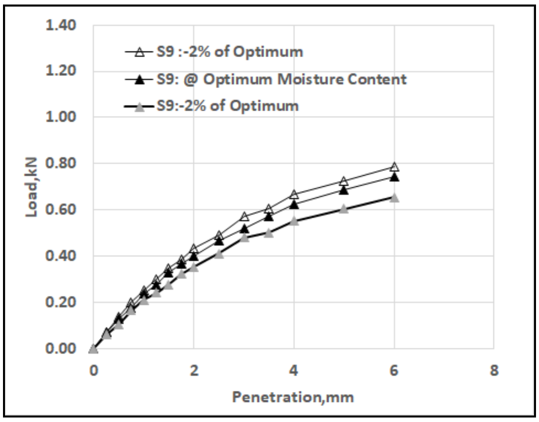

Fig. 18. Load-Deformation Curve in CBR Test at different Moisture Contents for Soil Samples S9

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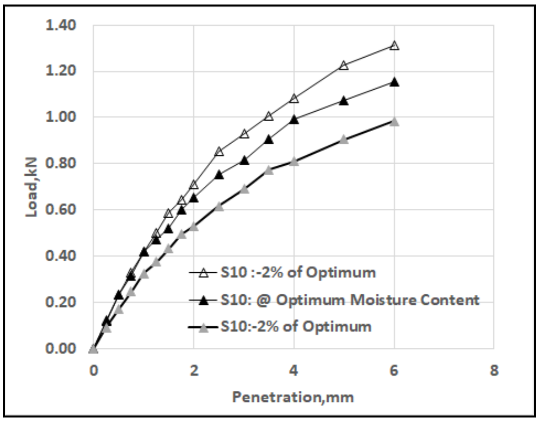

Fig. 19. Load-Deformation Curve in CBR Test at different Moisture Contents for Soil Samples S10

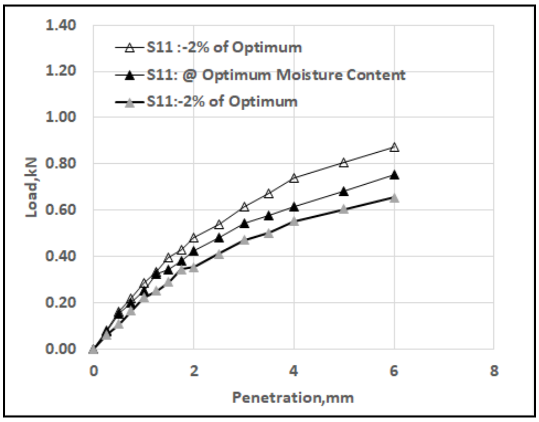

Fig. 20. Load-Deformation Curve in CBR Test at different Moisture Contents for Soil Samples S11

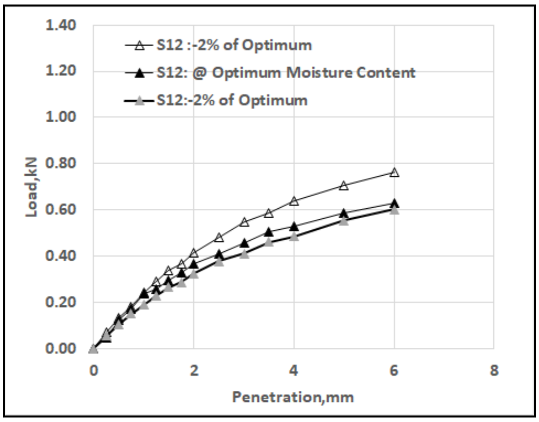

Fig. 21. Load-Deformation Curve in CBR Test at different Moisture Contents for Soil Samples S12

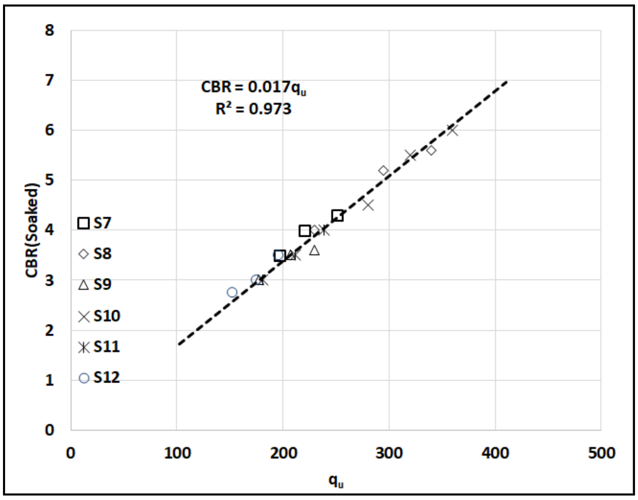

Fig. 22. Relationship between California Bearing Ratio (CBR) soaked and Unconfined Compressive Strength

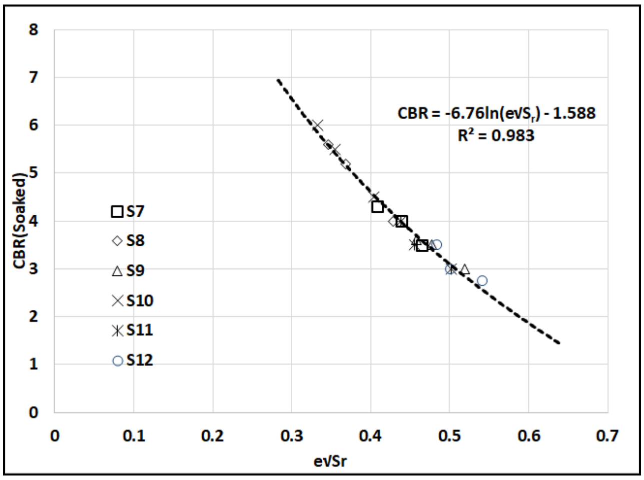

Fig. 23. Relationship between CBR $_{soaked}$ and e$\sqrt{S_r}$

IV. CONCLUDING REMARKS

Based on limited experimental programme and analysis of test results the following concluding remarks may be made.

1. The soils considered in the present investigation are predominantly clayey the range of fine fraction is in between from 43% to 78% which can be quite significant in so far as influencing the overall behavior of soil. The plasticity index is ranging from 18-53.
2. The maximum dry density increases with increase in compactive effort and optimum moisture content reduces with increase in compactive effort.
3. It may be seen that CBR values vary with moisture content in that for moisture content 2% less than optimum moisture content the CBR values are more consistently for all the soil samples. However, the CBR values for the moisture content 2% above the optimum moisture content the CBR values for all the soil samples are less than the tests conducted at optimum moisture content. Though the dry densities at ±2% optimum moisture content are nearly same, variation in resistance against plunger penetration

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is different owing to possible change in degree of saturation. It may be inferred that the degree of saturation plays key role in determining the strength properties of compacted soils.

4. The CBR values for unsoaked conditions are found to be nearly 30% higher compared to corresponding CBR values for unsoaked condition given by

$$(CBR)_{unsoaked} = 1.30\ (CBR)_{soaked}$$

5. The UCC strength values are higher at -2 % of optimum moisture content, the value at optimum moisture content is lower and the unconfined compression strength value at -2% of optimum is the lowest. The degree of saturation increases with increase in moisture content as the compaction curve at and above optimum moisture content approaches the zero air voids line representing 100% saturation. At lower degree of saturation, the soils exhibit higher resistance owing to capillary menisci apart from possible flocculated structure the soil is likely to have on dry side of optimum.
6. The relationship between soaked CBR and unconfined compression strength qu values bear close correlation as given by

$$(CBR)_{soaked} = 0.017(q_u) \quad where \quad q_u = unconfined\ compression\ strength\ in\ kPA$$

7. Conduct of CBR test involves considerable labour and time compared to unconfined compression test. Further these values reflect the strength offered by the soil under given conditions, though method of loading is different. This relationship helps to assess the CBR soaked values based on unconfined compression strength values, q_u
8. It is widely known that the strength of soil depends on dry density or void ratio at which the soil is present. In the compacted soils, it may be observed the soils assume same dry density at two moisture contents, on dry side of optimum and the other on wet side of optimum. But the soils on either side of optimum exhibit contrasting strength values, the strength being more on dry side of optimum compared to wet side of optimum. The reason could be attributed to change in degree of saturation the samples attain at these moisture contents. The CBR soaked value bears the following relationship with state parameter $e\sqrt{S_r}$, representing dry density and degree of saturation, indirectly moisture content, having strong correlation coefficient.

$$(CBR)_{soaked} = -6.76 \ln\left(e\sqrt{S_r}\right) - 1.588$$

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