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Enhancing California Bearing Ratio through Optimized Compaction Efforts: A Study on Alluvial Soils in North India

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Abstract

The quantity of soil required for embankment construction is enormous. Often the soil is brought to the site in dumpers in multiple rounds. This to and from movement of the wagons leads to the deterioration of the existing flexible pavement. In the absence of good earth nearby, using existing soils to act as a subgrade material upon meeting the desired strength and stability characteristics is the need of the hour. The California Bearing Ratio (CBR) is an indicator of soil's strength, which further depends on the degree of compaction of soil. In this study, an effort has been made to find the required compaction efforts to achieve maximum CBR value finding its applicability for both conventional flexible and perpetual pavements. Three different types of alluvial soils in North India were tested for CBR with varying compaction efforts using the modified Proctor test. The effect of mixing different soils was also considered to find the effectiveness of mechanically mixing soils on the required compaction efforts. It was observed that there is a constant upsurge in the CBR of soils upon an increase in the percentage compactive effort up to a certain limit. In the case of clayey soils, the rate of increase is less as compared to the well-graded sands. This study also highlights the effect of mechanical mixing of such soils with sandy soils in desired proportions giving rise to amplified values of CBR ratio of the soil blend. The regression analysis was also conducted to examine a correlation between the compactive effort and CBR values and it was best represented by exponential function for different types of soils.

Keywords: *California Bearing Ratio, Compactive Effort, Modified Proctor Test Flexible Pavement, Perpetual Pavement*

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I. INTRODUCTION

An elaborate road network providing connectivity to different destinations is an indicator of prosperity and growth of a nation. A flexible pavement is made up of different layers of bitumen bound aggregates with a soil subgrade layer at the bottom. In the construction of a pavement, the subgrade preparation plays a pivotal role. The sub base or base thickness is governed by the CBR value of sub grade layer. Weaker subgrade essentially requires thick pavement layers while stronger subgrade does suffice with thinner pavement layers. Even though the genuineness of the CBR test is broadly recognized, the testing procedure is laborious and time consuming. Numerous CBR tests are essential on the subgrade samples for a complete stretch of pavement to obtain a characteristic design CBR value. CBR values are intended to vary as the soil characteristics may differ over the various portions of the highway alignment under consideration. In the preliminary stages of a highway construction project, alternate and quick methods to ascertain the strength of subgrade layer would be a gainful insight in this regard.

A peep in the literature shows a significant relation between the various index properties and the CBR test results. Many researchers have furnished a correlation between the CBR values and the plasticity characteristics of cohesive soils. Moisture content also has a substantial impact on the subgrade strength as changes in moisture content of soil subgrade owing to precipitation, capillarity action or fluctuations in water table leads to fluctuations in the strength of subgrade layer.

Reference [1] studied the unconfined compressive strength, compaction characteristics and CBR values of sand and clay mixed in varying proportions. It was concluded from the study that the soil mixes with greater proportions of sand attained the maximum CBR with a minor change in water content and vice-versa as shown in Fig. 1. This behavior is mainly attributed to the water absorption capacity of fines available in the specimen.

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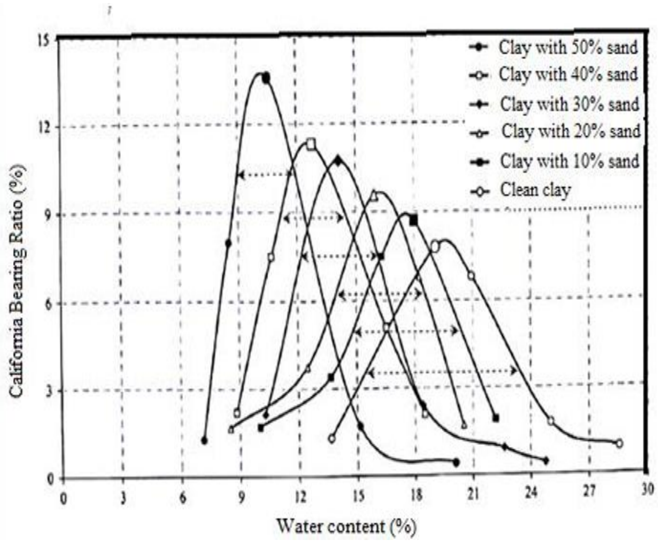

Fig. 1: Variation of CBR values with moisture content in sand-clay mixes (Ali Firat et al. 2015)

The National Cooperative Highway Research Program [2] of USA represented a relationship between grain size corresponding to sixty percent passing (D_{60}) and the CBR value.

For plastic fine grained soils,

$$CBR = \frac{75}{1 + 0.728\, wPI}$$

For non-plastic coarse grained soils,

$$CBR = 28.09\, D_{60}^{0.358}$$

Authors of [3] projected a mathematical relation to estimate the CBR value based on the maximum dry unit weight, unit weight of water and optimum moisture content for the fine-grained soils. [4] proposed various prediction models to estimate the CBR value, maximum dry density and the optimum moisture content of granular soils based on their index properties including D_{50}, D_{30} and coefficient of uniformity obtained from the results of grain size analysis. [5] developed correlations between various engineering properties of soils including maximum dry density, optimum moisture content and California bearing ratio (CBR) test values in soaked conditions. A rigorous regression analysis revealed strong empirical correlations between various soil properties to estimate the CBR values. [6] developed prediction models for estimating the compaction results i.e. OMC and MDD using the plasticity characteristics using the 106 samples of fine-grained soils from various Hydropower projects of India. [7] gave an estimation of the California bearing ratio (CBR) from sieve analysis, Atterberg limits, maximum dry unit weight and optimum moisture content of the soils in terms of certain correlation developed using the SRA, MRA and ANN models for the soils procured from various regions of Turkey. [8] studied the effect of clay mineralogy on the CBR values of fine-grained soils with the index and engineering properties of soil and conducted an exhaustive experimental program on nearly forty soils. They developed separate correlations to relate the CBR value with the plasticity characteristics, compaction test results for kaolinitic and montmorillonitic soils. It was observed that soils have separate CBR correlations with maximum dry unit weight based on clay minerals present.

$(CBR)_k = 1.94\, \gamma_d$ max - 25.67

$(CBR)_m = 0.31\, \gamma_d$ max - 3.26

$(UCS)_k = 65.49\, \gamma_d$ max - 869.75

$(UCS)_m = 12.05\, \gamma_d$ max - 123.25

where, γ_d = dry unit weight of soil.

Strong correlations have been cited in literature [9, 10, 11] between the CBR values, Atterberg's limits and the compaction test results. [12] corelated the soil CBR with various index parameters including specific gravity (G), coefficient of uniformity (Cu), coefficient of curvature (Cc), liquid limit (LL), plastic limit (PL), plasticity index (PI), optimum moisture content (OMC) and maximum dry density (MDD) for alluvial soils. [13] studied the influence of maximum dry density and CBR of the soil. Correlations were also developed in the study between CBR and maximum dry density with which CBR values can be predicted.

Researchers of [14] developed a correlation between unsoaked CBR value and the unconfined compression test value of soil using regression analysis to obtain the CBR value of soil. According to the authors, multiple regression equations can be used to predict the CBR values of sands as a quick alternative for laboratory testing of CBR values repeatedly for different sections of the pavement. Two types of sands viz. clayey sand (SC) and poorly graded sand (SP) were considered in the study and the following polynomial regression equations were obtained to predict the CBR values for the two types of soil:

Unsoaked CBR (%) = $0.0011\, (UCC)^2 + 0.0315\, (UCC) - 0.627$ for SC soil

Unsoaked CBR (%) = $-0.0028\, (UCC)^3 + 0.304\, (UCC)^2 - 9.2633\, (UCC) + 84.918$ for SP soil

Authors of [15] devised statistical correlations using the SPSS software to predict the CBR values of Transvaal soils from various indicator properties. The term Transvaal used in the study refers to the area included by the current provinces of Gauteng, Mpumalanga, Limpopo and North West in South Africa. This study also acknowledges the Kleyn's method [16] for the prediction of the maximum soaked CBR at Proctor compaction from the grading modulus and plasticity index. According to the authors, prediction methods do not act as a substitute for the CBR test but rather complement it by reducing the requirement of the number of these relatively time consuming, material intensive and costly tests. Also, these statistical relations provide a check on gross errors overall.

Numerous authors [11, 13, 17] have predicted and correlated the CBR values with the maximum dry density. But, the relationship between CBR and percentage compaction in the literature was found to be missing. The soils cannot be essentially compared on density. For a particular type of soil, as the compaction effort increases, the density increases and in turn leads to increased CBR value. Different types of soils behave differently under varied compactive efforts in terms of CBR strength values. In case of clayey soils, the rate of increase in the CBR value is less as compared to the well graded sands.

Thus, a detailed literature review indicates the presence of many correlations of the CBR values with various index and engineering properties for different soil types. But, a rigorous analysis of the soil type under consideration is mandatory to ascertain the most suited correlation to determine the CBR value for a pre-feasibility study of the subgrade thickness and strength analysis by correlating it with different compactive efforts. This research is an attempt to evaluate and correlate the required compactive efforts to achieve the maximum CBR value of three different types of soils of North India. The grain size analysis, soil classification, modified Proctor and CBR tests in compliance with the relevant Indian standards were performed on the soil samples. Then the effect of mechanical mixing of these soils was also carried out to furnish the variation in the CBR value under different compactive efforts. Also, a rigorous regression analysis was performed on the experimental test results and correlations were formulated to predict the CBR values based on varying compactive efforts.

II. Problem Statement

Due to the imposed mining restrictions, the availability of sand and natural aggregates for the construction of embankments is meagre. It is a common site to see the various projects getting delayed due to soaring prices and unavailability of sand and aggregates due to tightening of noose on illegal mining by different states of India [18, 19, 20]. The overconsumption and in turn huge demand in various infrastructure projects has led to investigation of alternate materials to be used in place. The soil available in the vicinity does not always satisfy the requirements to act as a subgrade material. In this regard, this study is an effort to improve the characteristics of the existing soil to meet the requirements of soil subgrade by improving its California Bearing Ratio (CBR) values. The long-term performance of the flexible pavement depends upon the California Bearing Ratio (CBR) of the soil. In the field, the in-situ density of the soil achieved in the range of 93-97 percent upon compaction has a CBR value reaching to 60-70 percent only. This implies that in case of the old constructed pavements using the Standard Proctor density instead of the Modified Proctor density values used nowadays, the optimum strength of the soil is not utilized due to lack of compaction. The increase in CBR value can be accomplished by increasing the compactive effort. Also, resorting to mechanical mixing of soils is another means of augmenting the CBR value of soil, which would in turn ensure sufficing with a reduced thickness of overlying granular sub-base and wet mix macadam layers.

This ideology finds its applicability in case of the newly introduced perpetual pavements in addition to the conventional flexible pavements. Perpetual pavements are the long-lasting pavements with multiple layers of durable asphalt with a design life period of nearly 50 years requiring periodic surface rejuvenation only and no major maintenance of the underlying layers. In conventional pavements, to accommodate the increasing traffic and wear and tear, the pavement thickness is increased from time to time which warrants heavy consumption of the construction materials. This is a very uneconomical and unsustainable solution of this problem. The CBR of the soil subgrade falls in the range of 15-20% in case of perpetual pavements. This amplified CBR value can be attained with greater compactive efforts. Thus, it is intended to increase the CBR value of the soil and reduce the material demand by fortifying the available soil to act as a soil subgrade. A stronger subgrade layer would also lead to a reduced thickness of the overlying bituminous and granular subbase layers saving on the construction materials in turn.

III. Materials and Methods

The soil samples were taken from three different locations, named as soil A, B and C. Another soil mix D was prepared by taking 60% of soil A and 20% each of soils B and C. The CBR value was determined at four different compactive efforts of 15 blows, 35 blows, 55 blows and 65 blows. The soil samples were prepared and were tested for the grain size analysis, compaction tests and California bearing ratio tests. To determine the CBR value, representative soil samples were compacted at predetermined optimum moisture content and maximum dry density for varying compactive energies *viz.* 15 blows, 35 blows, 55 blows and 65 blows after immersing the samples in water for 4 days and sheared.

IV. Results and Discussion

The soil samples were preliminarily subjected to grain size analysis, plasticity characteristics determination and modified proctor tests. The sieve analysis results indicated that the sample A contains sand content more than 50%, sample B contains clay and silt more than 50%, sample C is essentially clay of low compressibility while sample D has sand content nearly 60%, silt and clay nearly 20% each as depicted in Fig. 2.

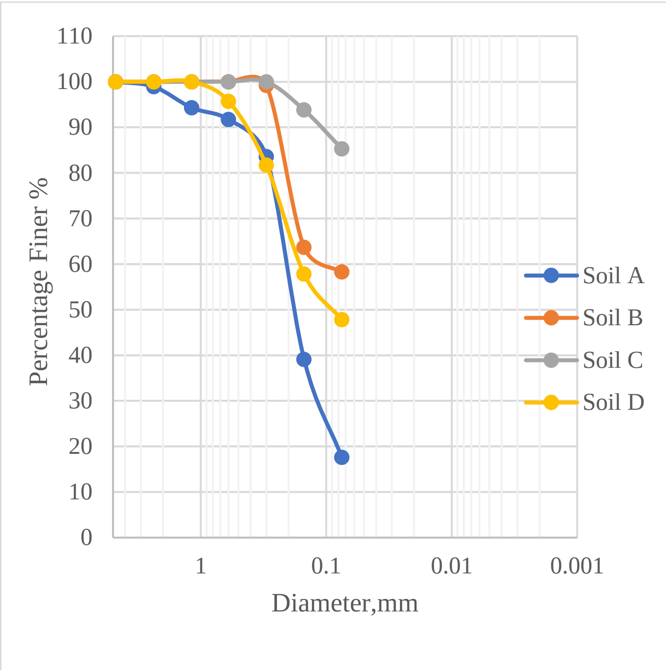

Fig. 2. Grain Size Analysis of different soils

In this soil investigation, the liquid limit of the samples was determined using the Casagrande's apparatus as per IS:2720 (Part 5), plastic limit of soil as per IS: 2720 (Part 5) – 1985 [21]. The results of all the index properties are represented in Table I. The soil A, which is classified as poorly graded sand was found to be non-plastic. The liquid limits of soil samples B, C and D were found out to be 22%, 27% and 20%. The plastic limit of soil samples B, C and D were found out to be 3%,9% and 5% respectively. The soil classification was done as per IS 1498-1970 (Reaffirmed 2007) [22].

TABLE I: TEST RESULTS OF INDEX PROPERTIES

Property	**Soil A**	**Soil B**	**Soil C**	**Soil D**	**Relevant Indian Standards**
Liquid Limit	NP	22	27	20	IS: 2720 (Part 5) – 1985
Plastic Limit	NP	19	18	15	IS: 2720 (Part 5) – 1985
Plasticity Index	NP	3	9	5	IS: 2720 (Part 5) – 1985
Soil Classification	SP	ML	CL	SW	IS 1498-1970 (Reaffirmed 2007)

A. *Modified Proctor Test*

All the four soil samples were subjected to Modified Proctor Compaction Test as per IS:2720-7(1980) [23] to determine the optimum moisture content and maximum dry density of each sample. Table II represents the values of optimum moisture content and maximum dry density of each sample. The test results depict that optimum moisture content of samples A, B, C and D are 15%, 10.2%, 14.3% and 8%. The corresponding maximum dry density values were found out to be 15.7, 19.2, 20.5 and 20.1 kN/m^3.

TABLE II: MODIFIED PROCTOR TEST RESULTS

Soil Type	**PROCTOR TEST RESULTS**		
	Maximum Dry Density, kN/cum	***Optimum Moisture Content, %***	***Relevant Indian Standards***
Soil A	15.7	15	IS:2720-7(1980)
Soil B	19.2	10.2	IS:2720-7(1980)
Soil C	20.5	14.3	IS:2720-7(1980)
Soil D	20.1	8	IS:2720-7(1980)

B. *California Bearing Ratio Test*

The California Bearing Ratio (CBR) Test was performed on sample A, B, C and D as per the standard IS:2720 (Part-16) – 1987 procedure [24]. Table III represents the CBR values of all the four samples at different compactive efforts of 15 blows /layer, 35 blows /layer, 55 blows /layer and 65 blows /layer. Then the CBR values so obtained were correlated with the percentage compaction of the soil samples by plotting the percentage compaction as the abscissa and CBR values on the y-axis. It was observed that with increase in the compactive effort, the density of soil increases and in turn there is augmentation in the CBR values depicting higher strength of the subgrade. Fig. 3 depicts the plot of CBR values against the percentage compaction for the four different types of soils A, B, C and D. The plot shows a continuous increase in the CBR values with increase in the percentage compactive effort (PC). This increase is attributed to the increase in the density of soil and the closeness of the individual soil grains upon increase in the compactive effort ranging from 15 blows/layer to 65 blows/ layer. It can be observed that in case of soils with appreciable amount of clay content, the rate of increase in the CBR value is less as compared to the sandy soils. The soil C, which is classified as clay of low compressibility (CL) as per the IS classification system, the CBR value is 4% in contrast to 18.3% for soil A, which is poorly graded sand (SP) at 65 blows per layer. The soil D, which is 60% sand and rest is finer fractions of soil has the maximum value of CBR being achieved at 55 blows/layer itself as 19% at 100.7 percentage compaction value. Therefore, it may be concluded that in case of soil D, which includes 60% of sand with 20% of silt and clay the maximum value of CBR was attained pointing towards mechanical mixing of the soils in the field being a very viable solution to attain greater CBR value at relatively lower compactive efforts in case the natural soils fail to meet the CBR requirements at site. Table III depicts the variation of CBR values at different compactive efforts of 15 blows/layer, 35 blows/layer, 55 blows/layer, 65 blows/layer and the corresponding densities of soil samples. The regression analysis conducted to examine a correlation between the compactive effort and CBR values yielded the following relations:

CBR (%) = 1E-07 $e^{13.846PC}$
(For Soil A, R^2 = 0.9888)

CBR (%) = 2E-05 $e^{8.5013PC}$
(For Soil B, R^2 = 0.9844)

CBR (%) = 3E-05 $e^{7.2786PC}$
(For Soil C, R^2 = 0.9252)

CBR (%) = 2E-08 $e^{15.656PC}$
(For Soil D, R^2 = 0.9497)

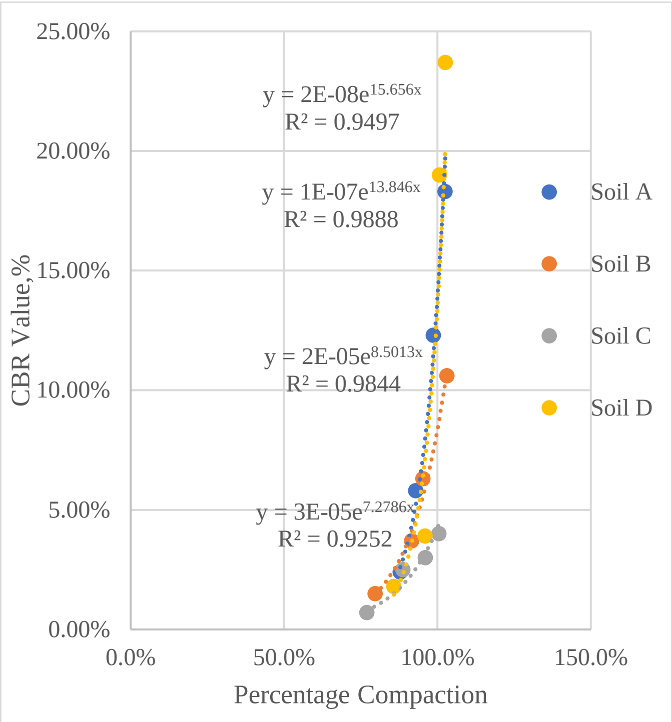

Fig. 3. Plot showing the relationship between CBR values and percentage compaction at different compactive efforts.

TABLE III: CBR VALUES AT DIFFERENT COMPACTIVE EFFORTS AND DENSITIES OF SOIL SAMPLES

Soil Type	15 blows/Layer		35 blows/Layer		55 blows/Layer		65 blows/Layer	
	Dry Density	**CBR**	**Dry Density**	**CBR**	**Dry Density**	**CBR**	**Dry Density**	**CBR**
Soil A	13.8	2.40%	14.6	5.80%	15.5	12.30%	16.1	18.30%
% age Compaction	87.9%		93.0%		98.7%		102.5%	
Soil B	15.3	1.50%	17.6	3.70%	18.3	6.30%	19.2	10.60%
% age Compaction	79.7%		91.7%		95.3%		103.1%	
Soil C	15.8	0.70%	18.2	2.50%	19.7	3.01%	20.6	4.00%
% age Compaction	77.1%		88.8%		96.1%		100.5%	
Soil D	14.5	1.80%	16.1	3.90%	28.7	19%	21.0	23.70%
% age Compaction	85.80%		96%		100.70%		102.60%	

It can be observed from the above regression equations that the coefficient of determination (R^2) values for soils A, B, C, D are very high and very close to + 1.0, it indicates that there is a strong correlation between the unsoaked CBR and the compactive effort of the soils. Thus, based on the above-mentioned exponential equations, the CBR values of the four soils under consideration in the study can be predicted from the known compactive efforts employed on the soil.

V. Future Scope of Work

The correlations between California Bearing Ratio (CBR) at various compactive efforts for four types of alluvial soils of North India have been reported in this paper. This work could be further extended to other regional deposits of India as well. Also, the inclusion of soils and waste materials including coal ash, blast furnace slag etc. stabilized using certain additives as a partial replacement to soils can be considered as a sustainable alternative to natural soils. Such studies would instill confidence to lookout for alternative materials to be used in the construction of pavements. Applicability of these initiatives in the field would serve as a huge sink for the bulk utilization of the essentially waste materials which otherwise pose a huge disposal issue occupying huge acres of useful land and reduce the burden of the naturally occurring soil deposits ensuring economic viability as well.

VI. Conclusions

Based on the current study, the following conclusions can be drawn:

- From the present study, it has been concluded that an empirical relation exists between the compactive efforts and the California bearing ratio of the soil.
- It has been observed that with increase in the compactive efforts, the California bearing ratio (CBR) increases in all types of soils. The soils with an amplified CBR value are pertinent in the perpetual pavements also in addition to the conventional flexible pavements which require soil subgrade with CBR values greater than 15 percent.
- The regression analysis conducted in the study indicates that increase in CBR value with reference to percentage compaction follows an exponential pattern of increase on upsurge in the compactive efforts.
- The increase of CBR values in case of sandy soils is more pronounced as compared to the clayey soils.
- This study also suggests that the mechanical mixing of the soils in the field can prove to be a very viable solution to attain greater CBR value at relatively lower compactive efforts in case the natural soils fail to meet the CBR requirements at site.

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