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Evaluation of Properties of Soil Subgrade Using Dynamic Cone Penetration Index – A Case Study

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Abstract:—The performance of pavements depends to a large extent on the strength and stiffness of the subgrades. Subgrade strength (CBR) plays a major role in pavement design. Since determination of CBR value in field requires need of equipment and also time consuming alternatively one can be predict CBR value of subgrade in field from other soil support tests namely Dynamic Cone Penetrometer Index (DCPI) which has evolved as the most versatile rapid, in situ evaluation device currently available for use in determining sub grade properties. Correlations of DCPT index to CBR and its use in performance evaluation of pavement layers make it an attractive alternative to more expensive and time consuming procedures. In this paper an attempt has been made to develop relationship equations between DCPT index to Index and engineering properties of few subgrades with low plasticity characteristics. The tests include determination of DCP index in field and engineering properties in the lab. Studies are extended for both pre monsoon and post monsoon periods to know the effect of moisture on all properties.

Keywords:—Dynamic Cone Penetrometer test (DCPT), California Bearing Ratio (CBR) test, Penetration Index, Natural Moisture content (NMC), total density, unconfined compressive strength, pre and post monsoon

I. INTRODUCTION

A. About Subgrade soil:

The soil subgrade is a layer of natural soil prepared to receive the layers of pavement materials placed over it. The loads on the pavement are ultimately received by the soil subgrade for dispersion to the earth mass. It is essential that at no time the soil sub-grade is over stressed. It means that the pressure transmitted on the top of subgrade is within allowable limit, not to cause excessive stress condition to deform the same beyond the elastic limit. Therefore it is desirable that at least top 50 cm layer of subgrade soil is well compacted under controlled conditions of optimum moisture content and maximum dry density. It is necessary to evaluate the strength properties of the soil subgrade.

B. Correlations and Comparisons of CBR with Index and Engineering Properties of Soil Subgrades Discussions by Some Authors:

There lies a linear correlation between the CBR soaked and un-soaked values also influenced by the nature of index properties **[1].** There is Predictive equations were developed to relate fines percent, liquid limit and specific gravity to compaction characteristics. Positive relations exist between OMC, and liquid limit. On the other hand negative relations exist between fines, MDD and specific gravity **[2].**There is relationship between NMC and DI is significant while the relationships between OMC and DI and PI are not significant **[3].**

C. Correlation with DCPT to CBR Observations and Discussions by Some Authors :

The relationship between the soil properties and the penetration index can be improved by normalizing the quantities in a different ways [4]. There lies a correlation between the DCPI to index and engineering properties of soils **[5].** There is a very good correlation between penetration index with other index and engineering properties obtained for each type of soil tested, the coefficient of determination R^2 ranges between 0.96 to 0.99 and the standard error of estimation is relatively low **[6]. . Few authors developed correlation equations and are shown in Table I.**

Table I Correlation Equations among Various Properties (Source [7])

Author	**Year**	**Correlation equations developed**	**Soil Type**
Ayers, et al.	(1989)	DS = A - B(DCPI) DS = shear strength, and A and B are regression coefficients.	Granular soils
Livneh	1987	Log (CBR) = 2.56. 1.16 log (DCPI)	Granular and cohesive
Harison	(1987)	Log (CBR) = 2.55. 1.14 log (DCPI	Granular and cohesive
Livneh et al.	(1992)	Log (CBR) = 2.45. 1.12 log (DCPI)	Granular and cohesive

Webster et al.	(1992)	Log (CBR) = 2.46. 1.12 log (DCPI)	Various soil types
Kleyn	(1975)	Log (CBR) = 2.62. 1.27 log (DCPI)	Unknown
Ese et al.	(1995)	Log (CBR) = 2.44. 1.07 log (DCPI)	Aggregate base Course
NCDOT Pavement	1998	Log (CBR) = 2.60. 1.07 log	Aggregate base course and cohesive
Shongtao Dai and Charlie Kremer	2006	$\text{Log CBR}_{lab} = 2.438\text{-}1.065{*}\text{logDPI}_{field.}$	Granular material
Shongtao Dai and Charlie Kremer	2006	$\text{Log CBR}=2.2\text{-}0.71{*}(\text{logDPI})^{1.5}$	Granular material
Shongtao Dai and Charlie Kremer	2006	$\text{LogCBR}=2.14\text{-}0.69{*}(\text{LogDPI})^{1.5}$	Granular material
Varghese George	2009	CBR = 88.37(DCPI) -1.08	Unsoaked blended soils

D. Factors Affecting DCPT Test Results

DCP index is influenced by various soil and material factors. Among notable factors influencing are subgrade type, vertical confinement effect and side friction effect of subgrade. Various factors namely soil type, density, gradation, and moisture content **[7].** For fine grained soils DCP index is significantly affected by moisture content, AASHTO soil classification, and dry density and coefficient of uniformity, maximum size aggregate size are effecting the index in granular materials **[8].** An increase in the percentage of the fines generally decreases the DCP value for the same target density. Similarly, an increase in the density for a similar gradation or individual material type decreases the DCP value. DCP Index is also affected by vertical confinement effect **[9].** Vertical confining effect is considerable for granular subgrade than fine grained subgrade. The side friction effect between soils to cone have also influence on DCP index **[10].** In such a case DCP device not being truly vertical while penetrating soil, the penetration resistance would be apparently higher due to side friction. This effect could be more pronounced with a manual DCP. Correction to DCP index through a correlation factor based on the side friction is to be used for DCP/CBR correlation equation **[10]**.The apparent resistance is higher in collapsible (granular) soil and minimal in clay material based on preserving a gap between DCP rod and sides of the hole **[12].**

E Objective

- The main objective of this project is to determine the penetration index using Dynamic Cone Penetrometer.
- The primary objective is to explore the feasibility of employing DCP testing for subgrade soil characterization.
- Determination of laboratory CBR and Engineering properties for a number of different soil sub-grades viz., clayey soils and silty soils of varying plasticity characteristics.

F. Background

1) About Dynamic Cone Penetrometer: The Dynamic Cone Penetrometer has been increasingly used in many parts of the world in soil (subgrade), granular material, and lightly stabilized soils through its relationship with in-situ California Bearing Ratio (CBR) **[5].** In the last two decades, sufficient data have been compiled relating DCP index to CBR, making it possible to estimate the in-situ strength of subgrades and pavement layers. The structure of the DCP consists of two. Vertical shafts connected to each other at the anvil. The upper shaft has a handle and hammer. The handle is used to provide a standard drop height of 575 mm (22.6 in) for the hammer as well as a way for the operator to easily hold the DCP vertical. The hammer is 8 kg (17.6 lb) and provides a constant impact force. The lower shaft has an anvil at the top and a pointed cone on the bottom. The anvil stops the hammer from falling any further then the standard drop height. When the hammer is dropped and hits the anvil, the cone is driven into the ground. The standard hammer mass is 8 kg,. The DCP tip can either be a replaceable point or a disposable cone. Manual or automated methods are available to gather penetration measurements. The reference ruler can be attached or unattached to the DCP. Fig. 1 shows the typical configuration of Dynamic cone penetrometer.

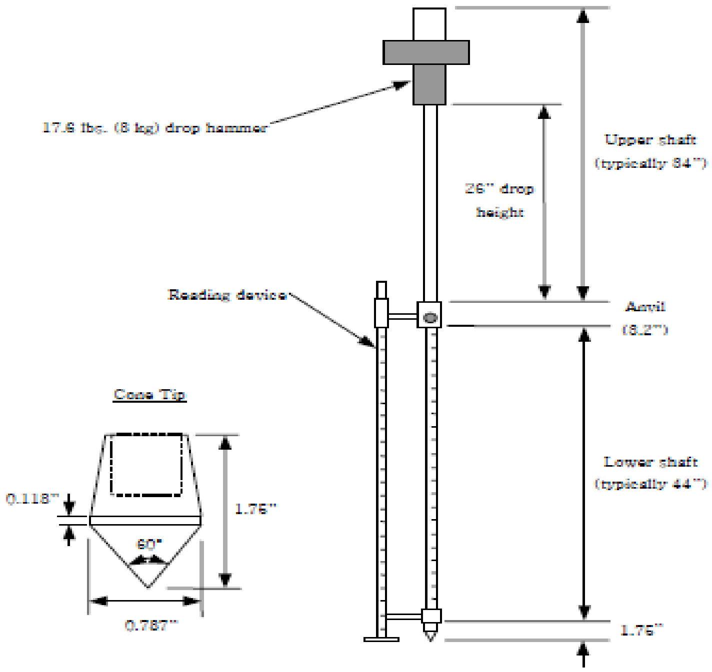

Fig. 1 Structure of Dynamic Cone Penetrometer

2). Calculations:

As shown in Fig. 2(a&b), a graph is drawn between of number of blow counts versus penetration depth. Results of DCPT in general are given as incremental values defined as follows:

$DCPI_1 = \Delta D_{p1}/\Delta BC_{1,}$ $DCPI_2 = \Delta D_{p2}/\Delta BC_{2,}$ $DCPI_3 = \Delta D_{p3}/\Delta BC_3$

$DCPI = (DCPI_1 + DCPI_2 +_{,} DCPI_3)/3$

Where,

DCPI = DCP penetration index in units of length divided by blow count;

ΔDp=Penetration depth;

BC = blow counts corresponding to penetration depth ΔDp.

As a result, Values of the penetration index (PI) represent DCPT characteristics at certain depths.

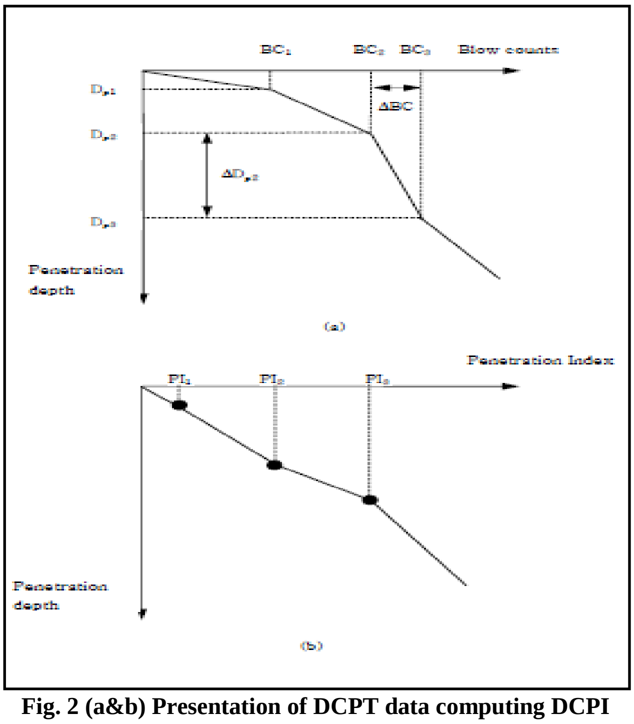

Fig. 2 (a&b) Presentation of DCPT data computing DCPI

II. EXPERIMENTAL STUDY

A. Parameters determined:

Experiments are carried on different subgrades with varying plasticity characteristics. Total 5 locations are identified for subgrades testing. The testing program is divided into three phases. In the first phase DCPT index is determined for subgrades. In the second phase Undisturbed soil samples (UDS) of respective subgrades is collected. In the third phase, the samples are tested in the laboratory for their index and engineering properties. The DCPT and UD sampling is carried out in both pre monsoon and post monsoon seasons. On an average two DCPT tests are conducted at each location and based on DCPT data samples are collected from depths averaging from 0.4 to 0.8m below ground level. The average of DCPT index and density is taken for analysis. The following parameters are determined during experimental program.

i. Index properties : Gradation and Atterberg limits
ii. Physical properties : Natural Moisture Content, Total Density
iii. Engineering properties : DCPT index, California Bearing Ratio (CBR),Unconfined compressive strength(UCS).

B. Subgrade materials used:

The Soils are varying in their plasticity characteristics particle gradation and location details of samples collected in given in table II. Samples are collected based on DCPT Index on an average samples collected from depth 350mm to 600 mm.

Table II Location details of samples collected

Sample no.	Location
1	Maruthinagar, Rajam, AP
2	V.R.Agraharam, Rajam, AP
3	Babanagar, Rajam, AP
4	Chukkavalasa, Therlam AP
5	Gopalapuram, Rajam, AP

III. PRESENTATION OF RESULTS AND DISCUSSION

The results of tests are summarized in table III & IV and presented from fig. 3 to fig. 9.

Table III Physical, Index Properties of Soil subgrades

Sample no.	%Fines	Void ratio	NMC (%) before monsoon	NMC (%) after monsoon	Natural density before monsoon kN/m^3	Natural density after monsoon kN/m^3	Liquid limit (%)	Plastic limit (%)	Classification of soil
Sample 1	32.86	0.75	20.37	22.275	18.21	20.84	55.4	19.69	SC
Sample 2	28.27	0.62	20.47	27.75	19.6	22.62	47.8	18.96	SC
Sample 3	24.79	0.84	18.23	22.63	17	20.075	44.9	18.25	SC
Sample 4	52.41	0.7011	21.87	23.2	18.98	20.01	59.6	19.16	SC
Sample 5	21.81	0.8878	17.56	24.13	16.5	19.74	35.4	17.63	SC

Table IV Engineering Properties of Subgrades

Sample no.	CBR (%)	DCPI mm/blow before monsoon	DCPI mm/blow after monsoon	UCS kPa
Sample 1	4.15	17.6	20.1	59.154
Sample 2	3.5	19.4	70.5	25.65
Sample 3	2.84	25.7	54.2	45.127
Sample 4	3.5	15.4	19.28	50.71
Sample 5	2.62	19	54.1	42.28

A. DCPT Curves for different subgrades

The field DCPT conducted on five types of soil subgrade. The DCPT curves are presented in Fig.3.

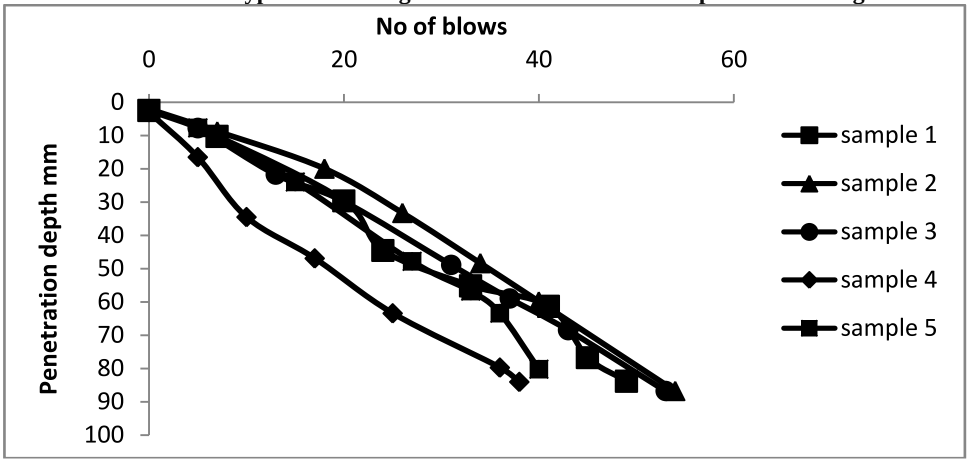

Fig. 3 Presentation of DCPT data for 5 Soil subgrades

B. Variations of physical , index and engineering properties of soils

1) Natural Moisture Content for Different Subgrades: Variation of NMC at different locations-effect of monsoon is presented in fig 4. As expected NMC of the soil is increased during post monsoon. For sample 1 and sample 4 the moisture content variation is negligibleI due to uneven distribution of railfall ..

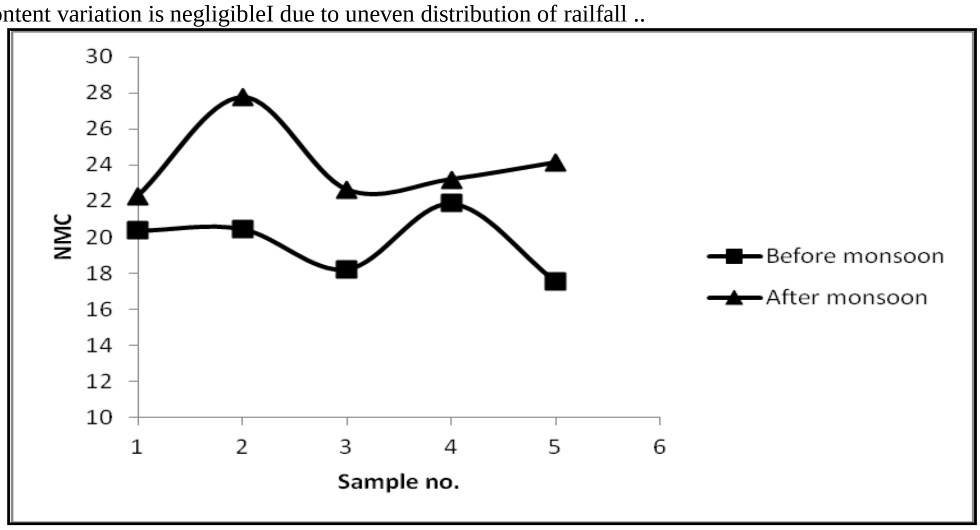

Fig. 4 Variation of NMC at different locations-effect of monsoon

2) Variation of Natural Density for Different Subgrades: Effect of monsoon on density is depicted in fig 5. It can be seen that the density has increased in post monsoon over pre monsoon. The amount of increase is not same in all locations due to uneven rainfall..

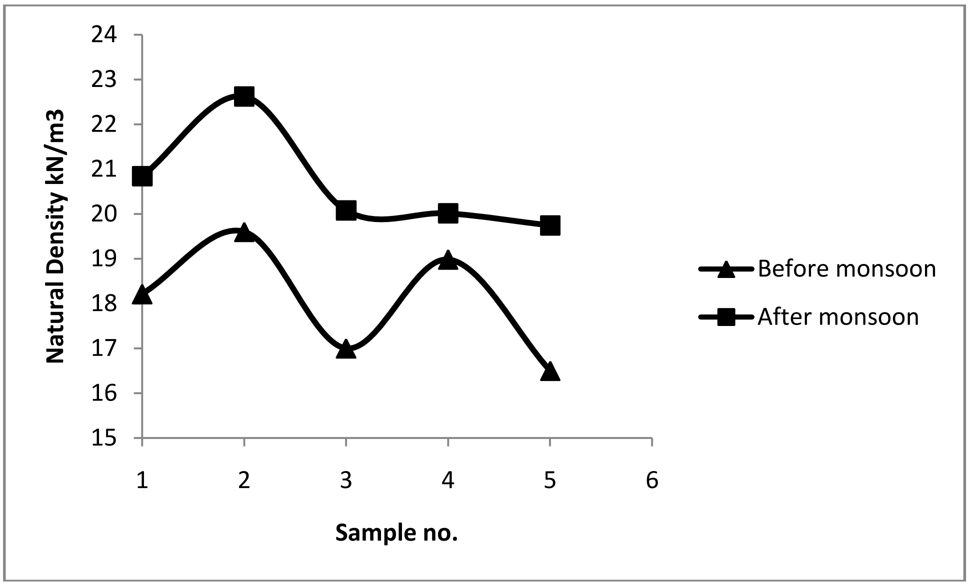

Fig. 5 Variation of Natural density at different locations-effect of monsoon

3) Variation of Consistency Limits with fines (%) for Different Subgrades: The variation of Consistency limits (liquid limit, plastic limit) with fines (%) is presented in fig 6. It is observed that both liquid limit and plastic limit increased with fines (%). The increase of liquid limit is steep when compared to plastic limit. The reason for this can be increase in affinity to water molecules with increase in fines. With fines (%) increase from 21.81 (%) to 52.41(%) liquid limit is formed to increase from 35.4(%) to 59.6(%) and plastic limit from 17.63(%) to 19.69(%) respectively.

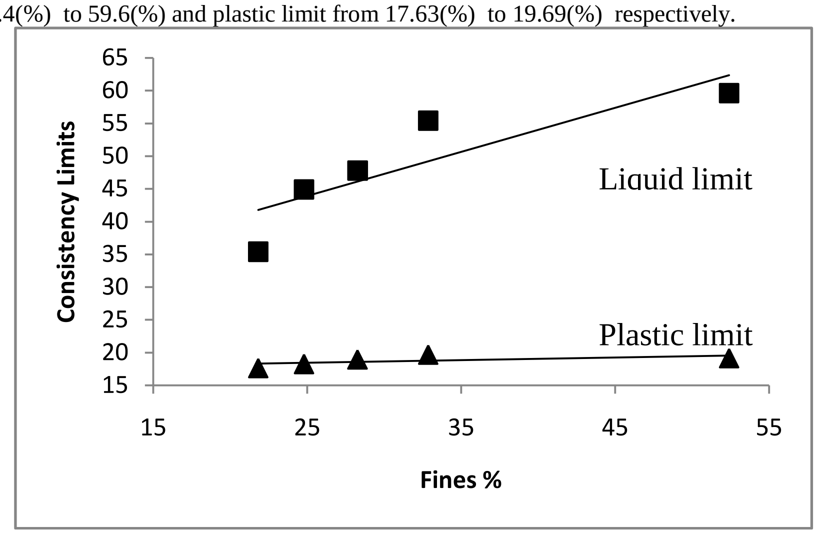

Fig. 6 Variation of Consistency Limits with fines(%)

4) Variation of Void Ratio with Fines for different Subgrades: The variation of the void ratio with fines (%) is presented in fig 7. It is observed that with the increase in % fines there is a decrease in void ratio. With the increase in % fines the volume of voids decreases thereby decreasing the void ratio. With fines (%) increase from 21.81(%) to 52.41(%) the void ratio is found to be decreasing from 0.84 to 0.62 respectively.

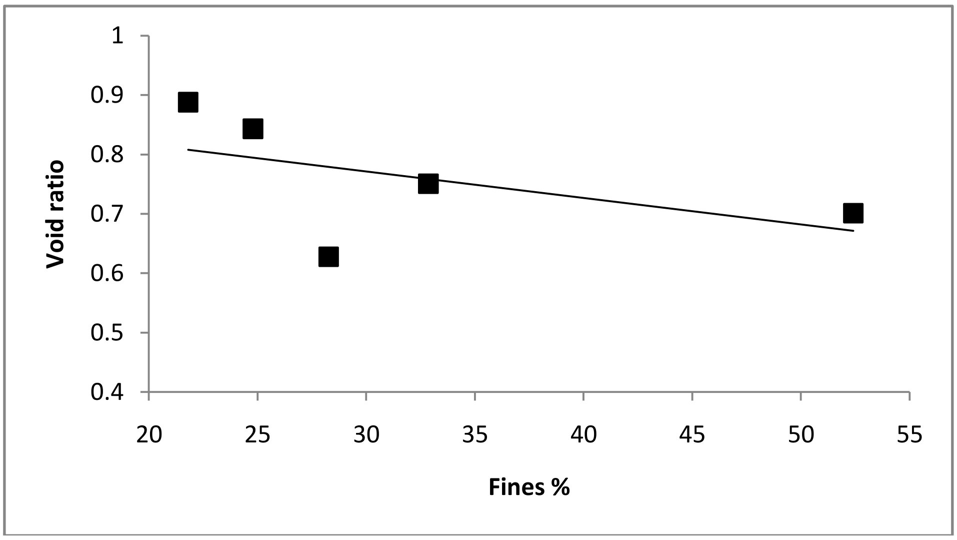

Fig.7 Variation of Void ratio with Fines (%)

5) Variation of CBR with Fines for different Subgrades: The variation of CBR % with % fines is shown in figure 8. From the graph it is observed that with the increase of % fines the CBR % increases. The reason for this can be increase in affinity to water molecules with increase in fines. With fines (%) increase from 21.81 (%) to 52.41 (%) and CBR increase from 2.62% to 4.15(%).

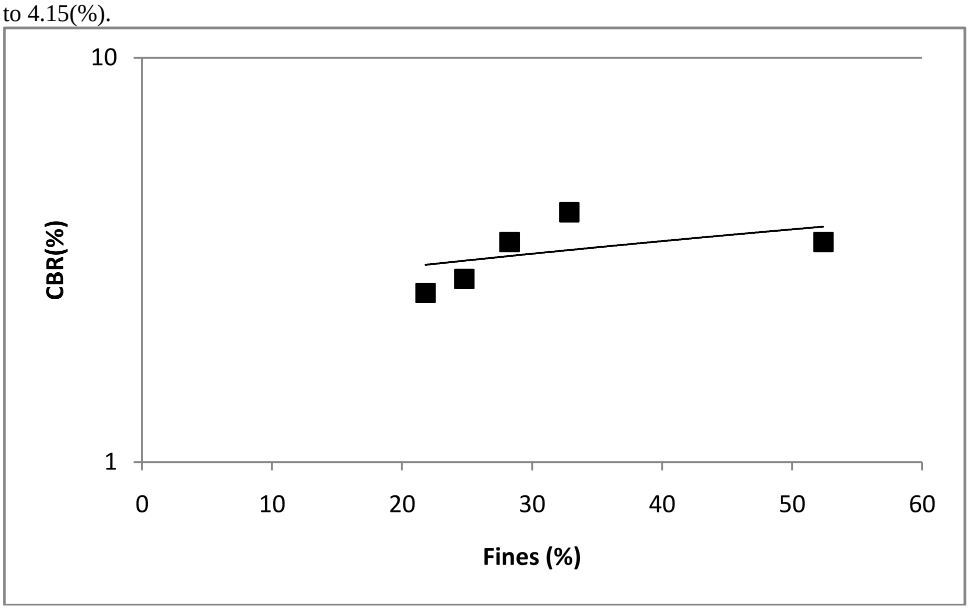

Fig.8 Variation of CBR with Fines (%)

6) Variation of DCPI with CBR of Different Subgrades: The variation of the DCPI with CBR is presented in fig 9. It is observed that DCPI decreased with increasing CBR values. CBR and DCPI both represents the penetration resistance. Higher CBR values represents the higher resistance to penetration and the higher value of DCPI characterizes the poor sub grade and vice versa. With CBR increase from 2.62% to 4.15% the DCPI is found to be decreasing from 25.7 to 15.4 mm/blow respectively.

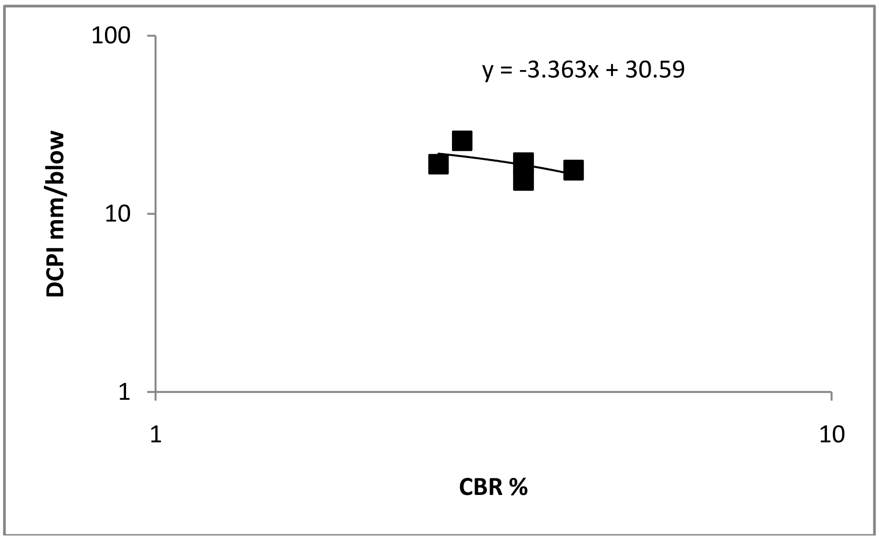

Fig. 9 Variation of DCPI With CBR

The variation of DCPI is related to CBR as

$$\log(DCPI) = -3.3636\log(CBR) + \log(30.594)$$

$$simplifying$$

$$\log(CBR) = 0.441 - 0.296\log(DCPI)$$

This is in good agrement with published data in table 1.

7) Variation of DCPI with UCS for Different Subgrades: The variation of the DCPI with UCS is presented in fig.10. It is observed that DCPI value decreased with increasing the UCS values.Higher UCS represents good degree of packing of particles representing strength. Hence DCPI is low. With UCS increase from 25 to 60 kPa the DCPI is found to be decreasing from 25.7 to15.4 mm/blow respectively.

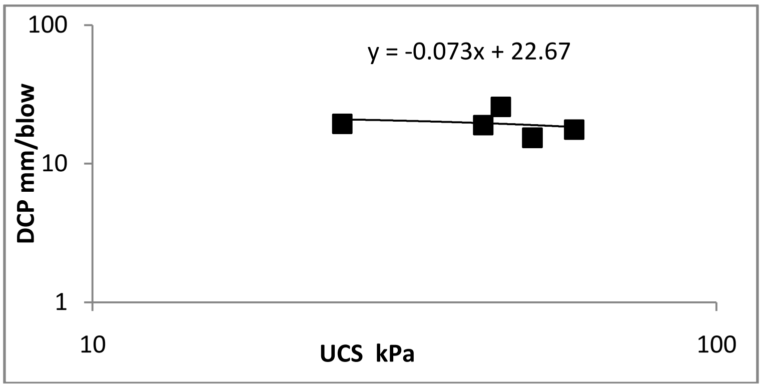

Fig. 10 Variation of DCPI with UCS

The variation of DCPI and UCS is represented as

$$\log(DCPI) = -0..0732\log(UCS) + \log(22.67)$$

$$simplifying$$

$$\log(UCS) = 18.51 - 13.66\log(DCPI)$$

III. CONCLUSIONS

From the tests conducted on various soil subgrade samples for various parameters, the following conclusions.:

- Atterberg limits of subgrade are influenced due to fines (%). As fines (%) is more liquid limit and plastic limit are more It is observed that % fines has effect on void ratio for all subgrades.
- Void ratio is effected by fines (%) for all subgrades. Void ratio decreses due to increse in fines (%).
- Moisture effect on DCPI is significant. DCPI increases with moisture.
- DCPI value decreases with the increasing CBR. The DCPI can be used to determine average CBR and the relation can be expressed as Log (CBR) = 0.441-0.296 log(DCPI) .

- DCPI value is decreased with the increasing UCS The DCPI can be used to determine average UCS of subgrade and the relation can be expressed as log(UCS)=18.51-13.66log(DCPI).

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