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Prediction of California Bearing Ratio through Empirical Correlations of Index Properties for Tropical Indian Soils

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Abstract - California Bearing Ratio (CBR) property of the subgrade soil is the most crucial parameter. The flexible overlay thickness is designed for the expected traffic loads based on CBR. The CBR property is dependent on the type of soil and its engineering properties. The detailed project report (DPR) and pre-feasibility reports for Greenfield Project roads need CBR property at all locations as per the code stipulations and guidelines. Estimation of CBR property along the project corridor may be constrained due to limited resources and time. The aim of this study is to predict CBR property reasonably through available simple regression models developed for similar soil groups. The present paper deals with the results of the correlation between the engineering properties of soils and CBR values. Laboratory tests were carried on the soils collected along the Greenfield Highway to determine soaked CBR, LL, PL, PI, MDD and OMC, Free Swell Index and Fraction of Fines. In Uttar Pradesh state, Chitrakot region, India, 105 soil samples were collected from tropical soils largely belonging to clay family from the agricultural and fallow lands. Correlation relationships between CBR and soil index properties were developed using Simple Linear Regression Analysis. A comparison between laboratory and predicted CBR values obtained from SRA models indicates that a high correlation exists between soaked CBR and soil engineering properties. The deviations between the predicted and original CBR values are not significant.

Keywords: Atterberg limits, characteristics, compaction, regression, soil

I. Introduction

The highways are the basic infrastructure facility to provide accessibility and connectivity to the Greenfield developments. Highways are designed based on mechanical engineering properties of the soil and traffic loads expected to carry in their lifetime. To establish basic engineering properties of soil, large quantities of soil samples are required to be collected along the proposed alignment, which requires time and budget resources. The soil property California Bearing Ratio (CBR) is the most prominently used parameter for estimation of overlay thickness of flexible pavements in India. Civil engineers often encounter problems in establishing the correct engineering property, the CBR of the soil while designing the thickness of Sub-Base and Base –Course layers. While designing a new alignment or a green field expressway, where the alignment is passing through open lands and agricultural fields insist a large number of soils are to be collected to establish CBR properties based on which the overlay thickness is designed. But while carrying a pre-feasibility study or detailed project report collection of large samples of CBR data is constrained by time and budget resources. Under such situations, CBR data for the project corridor can be derived through the published correlations between CBR and index properties of the soil as they provide them reasonable and cost-effective solutions.

From the literature review, it was observed that some researcher has attempted to establish the correlation between CBR as a function of Index property of soils. The research carried was a limited sample basis on fine-grained soils but could not be used for estimation of CBR value on generalization. The main objective of the current study is to develop a correlation between CBR and engineering properties of fine-grained soil with large soil samples, chosen from highway construction site passing through the tropical regions of the country. The parameters considered for correlation are Index properties, OMC, FSI and MDD.

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Over the years, various researchers have attempted to establish correlations between CBR and index properties of soil with limited laboratory data samples. But while carrying flexible pavement designs for large stretches of Greenfield expressway, correlations developed with limited, data may not support the rationality of using those equations. In this technical paper the data collected from field and laboratory investigations while planning and designing a new greenfield express highway in the Northern State of India, Chitrakoot-Kanpur region of Uttar Pradesh state is taken as the basis to establish correlations between the CBR and engineering properties of soil. The equations developed are used for predicting the CBR of soils and are cross verified with the CBR values established through laboratory experimentation. Out of 500 samples tested for a length of about more than 250 km project length, 105 samples of in 125 Km project, road length is considered for establishing the correlations between CBR and index properties of the soil. Correlations are developed between CBR and index properties of the soil will facilitate the pavement engineers to establish the CBR values for other stretches with similar soil properties and also facilitate to review the correctness of the CBR value established through laboratory investigations.

Over the last three decades many researchers carried laboratory investigations to understand the relationship between CBR and index properties of different category of soils. Laboratory investigations could demonstrate moderate to good correlations between CBR and the properties of soil (Black, W.P.M. 1962), Investigations were carried out on the Laterite soils of ILE-IFE Nigeria, and found more than 90% correlation between CBR and engineering properties of soil (Ayodele 2009). Regression models were developed in five different soils with 100 samples and observed a good agreement between the observed and predicted CBR values (Dharamveer, 2011). The correlations were established between MR and index properties of fine-grained and coarse (sandy) soil using triaxle laboratory tests to predict subgrade soil Moduli (Rahim2005).

A study was carried out on index properties of fine-grained soils from two highway projects in Malaysia and correlations are proposed to predict the CBR based on research field data, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). It was concluded that currently published correlations are not suitable for Malaysian highway project soils (Mak Wai Kin, 2006). The Multiple Linear Regression Analysis (MLRA) on CBR as a function of the Plasticity Index (PI), MDD, index properties, and OMC were developed. (Vinod P, 2008). The CBR values are inversely proportional to the Plasticity Index (PI). If PI values increase CBR values decreases (Patel RS 2010). It was demonstrated that CBR and angle of friction can be estimated from fine-grained soils for varied index properties of soil and air content (Datta 2011, Magdi 2012). Based on 33 samples of expansive soil data collected from the on-going road construction site, it was established that Single Linear Regression Analysis (SLRA) and MLRA on CBR and engineering properties of the soil. It was concluded that there is a good correlation between CBR values and soil index properties (Valentine Yato Katte 2017).

II. Methodology and Materials

Soil samples collection

From the proposed highway construction site 105 soil samples were collected along the alignment as well as from the identified barrow areas. The soil samples are largely of fine-grained soils and mostly from the clay family belongs to tropical regions of Northern India falling under Uttar Pradesh State (Etawah, Banda, Chitrakoot regions) for a length of about 300Km. The highway construction has been taken up is passing through green fields for providing connectivity to the backward regions. Basic soil engineering property identification was done through laboratory tests, such as grain size distribution, LL, and plastic limit (PL) were conducted in accordance with Indian Standard Codes (IS: 2720). **Table 1** summarizes the summary of soil classification and their compaction characteristics and **Table:2** Summary of the index properties of the soils.

Table : 1 Classification of Samples Tested on the Project Road

Sl.N0	Soil Classification	No of Samples	%	MDD(g/cm^3)) [Max-min]	OMC(%)) [Max-min]
1	CL	20	19%	2.01-1.865	11.14-9.5
2	CI	45	43%	1.92-1.789	13.86-10.36
3	CH	24	23%	1.92-1.789	16.63-13.54
4	ML-CL	16	15%	2.10-1.94	9.88-9.89
		105			

Table:2 Index Properties of the Soils

Sl.No	WL(%)[Max-min]	No of Samples	Wp(%)) [Max-min]	No of Samples	FSI(%) [Max-min]
1	0-30	21	NP	8	0-20
2	30-40	17	0-20	59	20-40
3	40-50	44	>20	38	40-55
4	>50	23			>55
		105		105	

Specimen preparation and Geo Technical Testing

For estimating the subgrade soil strength characteristics heavy compaction proctor procedure was used to prepare CBR samples. Uniform compaction procedure was used in the present study at 56 blows, at OMC, ± 1%. Each of CBR sample was compacted in five layers of soil using predetermined number of blows and water content. A total of 105 field soil samples were prepared for CBR testing and for each CBR test evaluation a minimum of three specimens (105 samples each soil x 3 specimens). OMC and maximum dry density of the compacted sample was estimated using Proctor's compaction test for each of the soil sample. As the sub grade soils in the field are affected by variations in water table during rainy seasons, both un-soaked and soaked CBR values of the compacted sample was determined in accordance with IS 2720-Part 16:1987. An addition to CBR property, Free Swell Index (FSI) of each soil sample was also established.

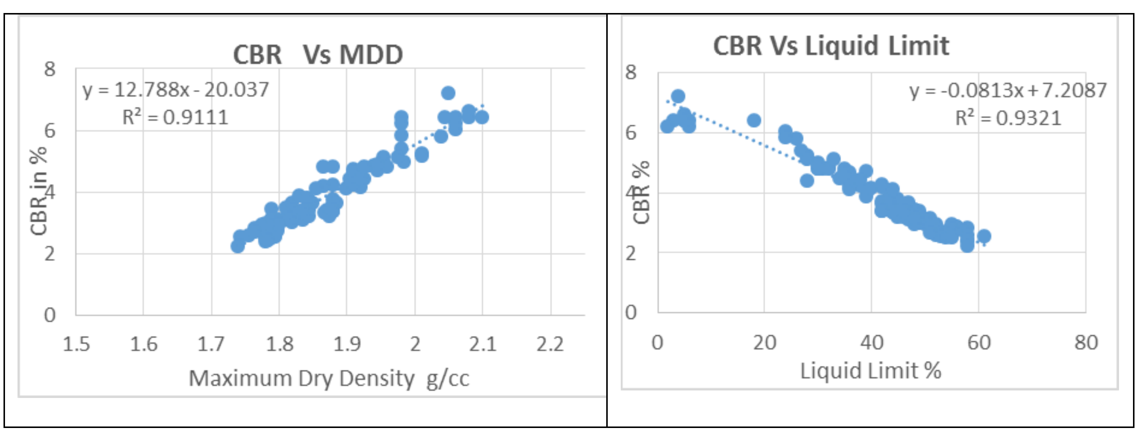
Simple linear regression analysis -development of models

A single linear regression analysis was carried and models were developed to predict CBR value using data established from 105 soil samples. While developing the linear regression models, soaked CBR is taken as the dependent variable and: OMC, MDD, PL, LL, FSI, and % of fines (Silt and Clay fraction) are taken as independent variables. The developed models are presented below:

Where,
CBR: Soaked California Bearing Ratio (CBR) (%),
OMC: Optimum Moisture Content (%),
MDD: Maximum Dry Density (gm/cc),
LL : Liquid Limit
PL: Plastic Limit of soil (%).
PI: Plasticity Index (%)
FSI: Free Swell Index (%)
Fines: Silt and Clay (%)

III. Results and Discussions

All the listed parameters are examined as independent variables against four day soaked CBR as dependent variable and presented in the following graphs in Figure:1



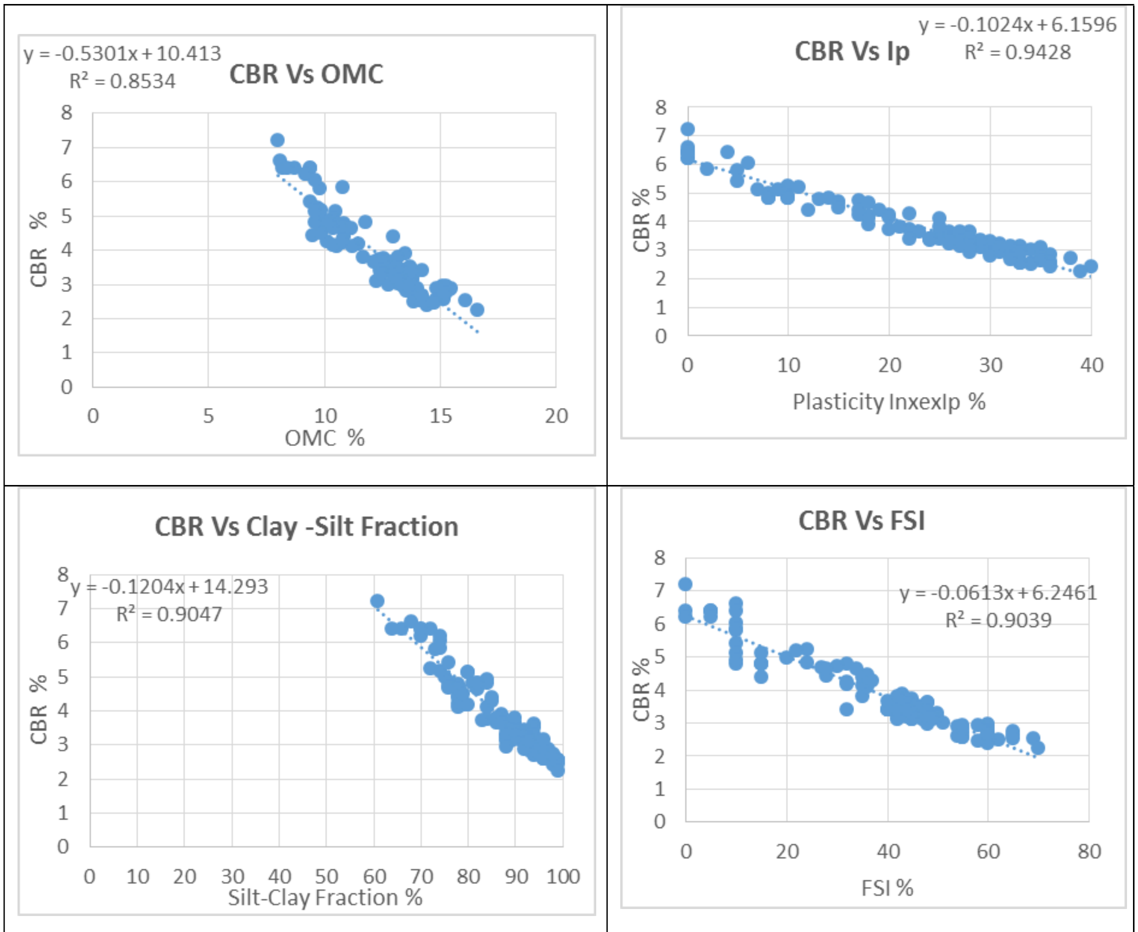
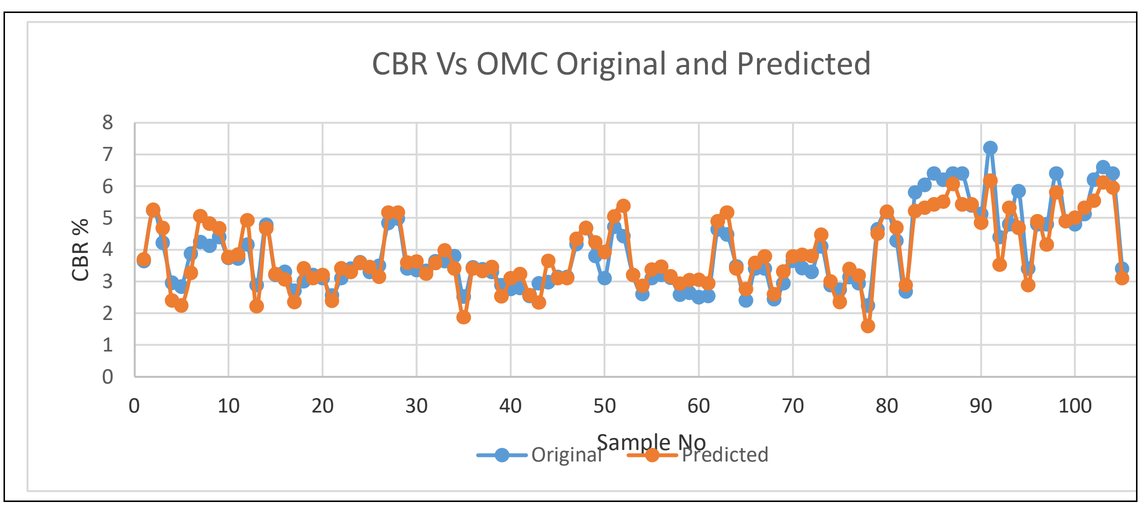
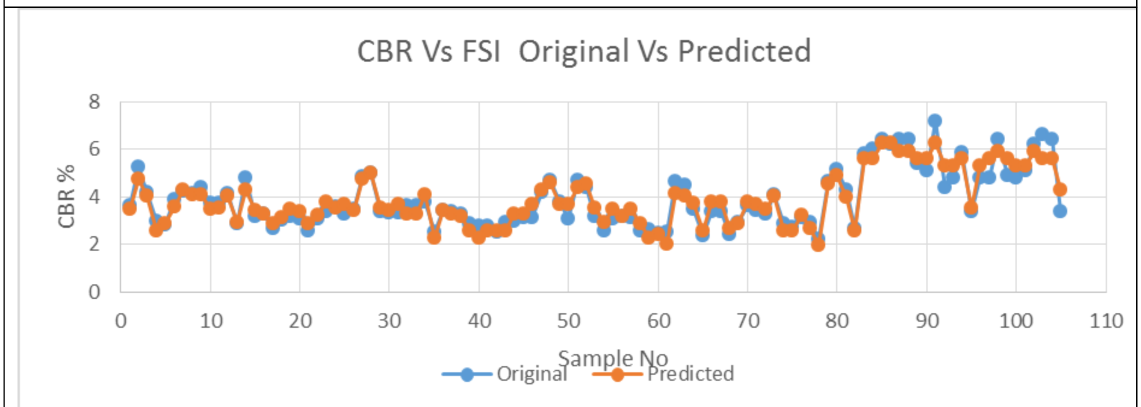


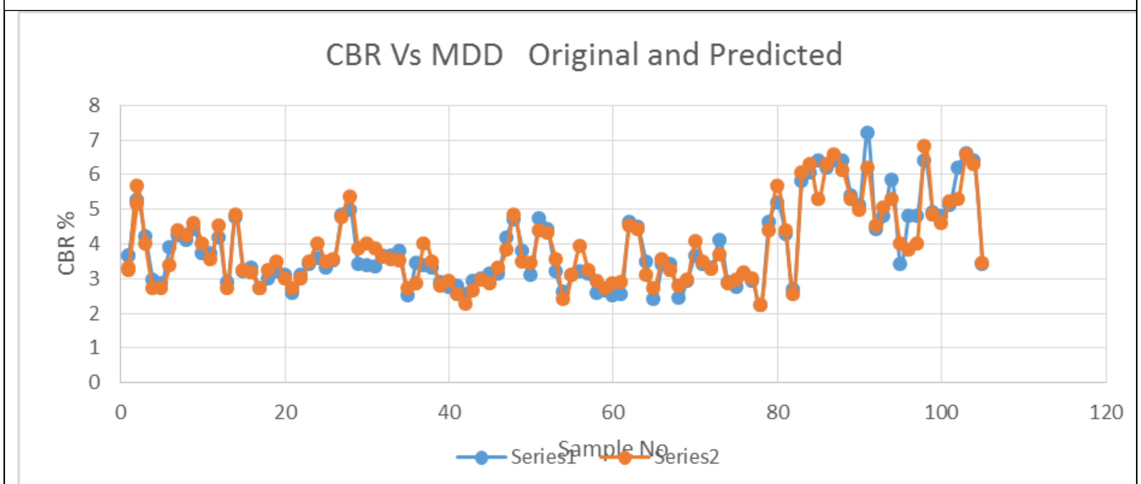
Figure: 1 Linear Regression Models for CBR Prediction

CBR Original Vs Predicted Values:

Using the index property and compaction characteristics as independent variables for the soils under study of linear regression models were developed for the for the prediction of four day soaked CBR values. Linear regression equations developed for each of the soil property is presented in Table:3. Using the equations CBR values are predicted and deviations were estimated and presented in graphs in Figure 2 below.




CBR Vs FSI Original Vs Predicted
CBR %
Sample No
Original
Predicted
0
2
4
6
8
10
20
30
40
50
60
70
80
90
100
110


CBR Vs MDD Original and Predicted
CBR %
Sample No
Series1
Series2
0
1
2
3
4
5
6
7
8
20
40
60
80
100
120

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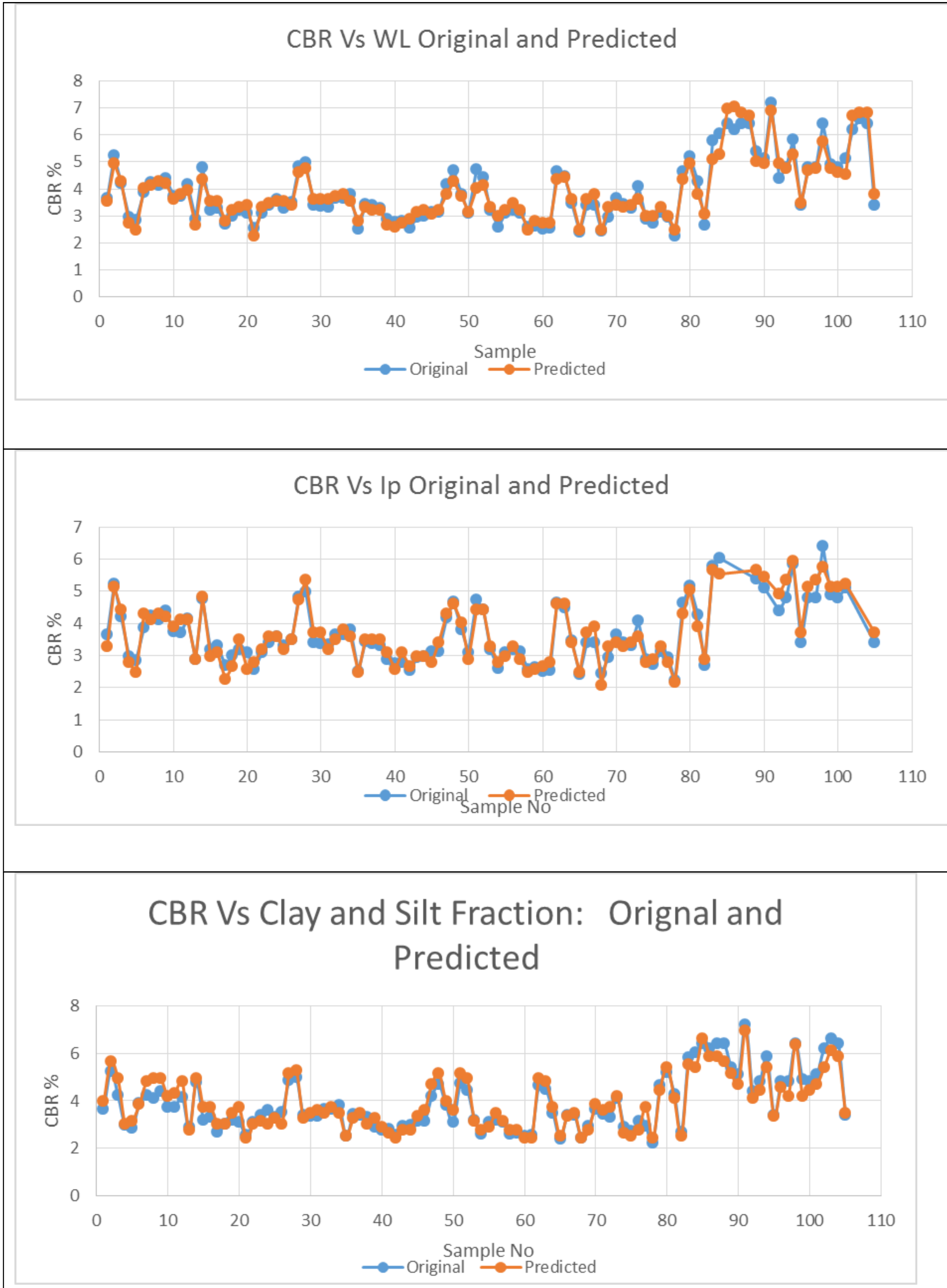

Figure : 2 Deviations on Original and predicted CBR values for various soil engineering property as independent variable

IV. Results and Discussions

The study was carried along the proposed four lane green field highway project where in the corridor is aligned through agricultural and fallow lands. About 105 soil samples were collected and transported to the laboratory for analysis. Routine geotechnical tests were carried and thereafter correlation and regression analysis were run on the obtained results to assess the relationship between these index properties and compaction characteristic properties. From the analysis it was established that 85% of the soils belong to clay group (CL,CI and CH). Single Linear Regression Analysis(SLRA)was carried and models were developed four day soaked CBR as dependent variable and the soil properties are dependent variables. Equations developed are summarised in the following table:3

Table:3 SRA and Relationship between Soaked CBR and Engineering properties of Soil

Sl.No	Dependent Variable(Y%)	Independent Variable (X)	Model	Regression R^2 Coefficient
1	CBR	Optimum Moisture Content (OMC %)	Y = -0.5301X + 10.413	0.8534
2	CBR	Maximum Dry Density (MDD g/cc)	Y = 12.788X - 20.037	0.9111
3	CBR	Liquid Limit (LL)	Y = -0.0813X + 7.2087	0.9321
4	CBR	Plasticity Index(Ip%)	Y = -0.1024X +6.1596	0.9428
5	CBR	Clay and Silt Fraction(%)	Y = -0.1204X + 14.293	0.9047
6	CBR	Free Swell Index(%)	Y= -0.0613X + 6.2461	0.9039

From the SRA it is observed that a strong correlation is found between the CBR and engineering properties of the soil with regression coefficient found to be more than 85%.
The relationship between California bearing ratio, CBR, and the parameters associated with California bearing ratio (% passing 75 µm or silt content; LL; PI; OMC and MDD, FSI and Fraction of fines) shows relationships with marginal variations. Detailed results are presented in tables 1,2 and 3. From the table it can be seen, high correlation and relationship between CBR with soil properties.

Further, using the models CBR values are predicted and deviations are estimated for the original and predicted CBR values and for all the parameters and deviations are presented in the figure :2 in graphs. From the deviations for each of the soil parameter for original vs predicted, it was noticed the deviations varying between a minimum of 1% to a maximum of 20%. The data on soil engineering property, derived from the field investigations, used in the SRA is given in annexure-1

V. Conclusions

Subgrade soil strength (CBR) is the vital parameter based on which flexible pavement overlays are designed. But for the determination of CBR property, need large number of soil samples collection to establish compaction characteristics and four day soaked CBR. For which time and resources are required. Many times during the time of DPR preparation, where in the project corridor passing through green fields containing clay group soils establishing CBR property for each Km of the project stretch may not be feasible due to time and budget constraints. In such cases CBR property can be determined indirectly through regression models. In this technical a paper a simplified approach for the determination of CBR value by developing linear regression models for CBR prediction using engineering property of soils is attempted.

In the present study the soils selected for the study are largely belongs to clay family. Also only linear regression models are developed with single soil property as independent variable and CBR as dependent variable. From the study it is established that a strong correlation exists between CBR and soil properties and the equations can be used for prediction of CBR, where in data is availability is constrained by time and resources. As the soil samples used in the study largely belongs to Clay soils, there is a need to extend the study for other soil groups also.

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Annexure: I Soil Properties derived from the laboratory investigations

Chainage	Gravels (%)	Sand (%)	Silt + Clay (%)	Atterberg's Limit(%)			FSI (%)	Classification	Modified Proctor		4-day Soaked CBR at 97 % of MDD
				W_L	W_p	I_p			MDD (g/cc)	OMC (%)	
CH. 1+000	3	11	86	45	17	28	45	CI	1.82	12.68	3.64
CH. 2+000	6	22	72	28	18	10	24	CL	2.01	9.72	5.24
CH. 3+000	4	18	78	36	19	17	36	CL	1.88	10.82	4.22
CH. 4+000	1	5	94	55	22	33	60	CH	1.78	15.12	2.96
CH. 6+000	0	7	93	58	22	36	55	CH	1.78	15.42	2.84
CH. 7+000	1	12	87	39	21	18	43	CI	1.83	13.48	3.88
CH. 8+000	8	13	79	38	18	20	32	CL	1.91	10.1	4.24
CH. 9+000	8	14	78	36	18	18	35	CL	1.9	10.54	4.12
CH. 11+000	4	18	78	37	18	19	35	CL	1.925	10.84	4.4
CH. 12+000	4	12	84	44	22	22	45	CI	1.88	12.54	3.74
CH. 13+000	3	14	83	42	22	20	44	CI	1.845	12.38	3.72
CH. 14+000	3	18	79	40	20	20	36	CI	1.92	10.36	4.16
CH. 16+000	1	3	96	56	24	32	54	CH	1.78	15.46	2.88
CH. 17+000	4	18	78	35	22	13	32	CL	1.945	10.84	4.78
CH. 18+000	1	11	88	45	14	31	46	CI	1.82	13.54	3.2
CH. 19+000	0	12	88	45	15	30	48	CI	1.814	13.86	3.3

Chainage	Gravels	Sand	Silt + Clay	Atterberg's Limit(%)			FSI (%)	Classification	Modified Proctor		4-day Soake
CH. 21+000	0	6	94	54	16	38	55	CH	1.78	15.2	2.7
CH. 22+000	0	6	94	49	15	34	51	CI	1.82	13.2	3.01
CH. 23+000	1	9	90	48	22	26	45	CI	1.84	13.8	3.2
CH. 24+000	2	10	88	47	12	35	47	CI	1.8	13.6	3.1
CH. 26+000	0	1	99	61	28	33	55	CH	1.78	15.14	2.56
CH. 27+000	0	6	94	48	19	29	49	CI	1.8	13.2	3.1
CH. 28+000	0	7	93	46	21	25	40	CI	1.84	13.42	3.4
CH. 29+000	1	5	94	45	20	25	44	CI	1.88	12.88	3.6
CH. 31+000	1	7	92	45	16	29	42	CI	1.84	13.14	3.3
CH. 32+000	0	6	94	47	21	26	46	CI	1.845	13.7	3.5
CH. 33+000	0	24	76	32	18	14	24	ML-CL	1.94	9.89	4.84
CH. 34+000	2	23	75	30	22	8	20	ML-CL	1.985	9.88	4.98
CH. 36+000	0	8	92	44	20	24	44	CI	1.87	12.86	3.4
CH. 37+000	0	10	90	44	20	24	46	CI	1.88	12.8	3.36
CH. 38+000	0	11	89	44	15	29	42	CI	1.868	13.52	3.34
CH. 39+000	0	10	90	43	17	26	48	CI	1.85	12.88	3.64
CH. 41+000	4	8	88	42	19	23	48	CI	1.845	12.14	3.64
CH. 42+000	2	8	90	45	20	25	35	CI	1.842	13.2	3.8
CH. 43+000	0	2	98	54	18	36	65	CH	1.78	16.12	2.52
CH. 44+000	0	8	92	48	22	26	46	CI	1.789	13.2	3.44
CH. 46+000	4	6	90	49	23	26	48	CI	1.88	13.36	3.38
CH. 47+000	0	6	94	49	23	26	50	CI	1.84	13.14	3.3
CH. 48+000	1	7	92	56	26	30	60	CH	1.785	14.86	2.88
CH. 49+000	0	5	95	57	22	35	65	CH	1.795	13.8	2.76
CH. 51+000	0	3	97	55	25	30	60	CH	1.765	13.54	2.8
CH. 52+000	0	1	99	53	19	34	60	CH	1.744	14.8	2.54
CH. 53+000	0	4	96	50	19	31	60	CH	1.775	15.24	2.94
CH. 54+000	0	4	96	49	18	31	48	CI	1.798	12.76	2.98
CH. 56+000	0	9	91	51	18	33	48	CH	1.79	13.8	3.14
CH. 57+000	0	11	89	49	22	27	42	CI	1.825	13.78	3.14
CH. 58+000	2	18	80	42	24	18	32	CI	1.865	11.46	4.18
CH. 59+000	7	17	76	36	21	15	27	CL	1.945	10.82	4.68
CH. 61+000	0	14	86	43	22	21	42	CI	1.84	11.66	3.8
CH. 62+000	0	11	89	50	18	32	42	CI	1.836	12.24	3.1
CH. 63+000	2	22	76	39	22	17	30	CL	1.91	10.12	4.72
CH. 66+000	6	16	78	38	21	17	28	CL	1.905	9.5	4.42
CH. 67+000	2	5	93	48	20	28	44	CI	1.845	13.6	3.2
CH. 68+000	0	4	96	52	19	33	54	CH	1.755	14.25	2.6
CH. 69+000	0	5	95	49	18	31	45	CI	1.81	13.28	3.1
CH. 71+000	0	10	90	46	18	28	50	CI	1.875	13.1	3.2
CH. 72+000	0	7	93	49	17	32	45	CI	1.82	13.68	3.12
CH. 73+000	0	4	96	58	22	36	55	CH	1.795	14.12	2.58
CH. 74+000	0	4	96	54	19	35	65	CH	1.78	13.9	2.64

Chainage	Grav els	San d	Silt + Clay	Atterberg's Limit(%)			FSI (%)	Classifi cation	Modified Proctor		4-day Soake
CH. 76+000	0	1	99	55	21	34	62	CH	1.79	13.88	2.5
CH. 77+000	0	1	99	55	22	33	69	CH	1.794	14.1	2.54
CH. 78+000	4	18	78	35	20	15	34	CL	1.92	10.4	4.64
CH. 79+000	5	16	79	34	19	15	36	CL	1.912	9.88	4.48
CH. 81+000	1	11	88	44	17	27	41	CI	1.81	13.2	3.48
CH. 82+000	0	2	98	58	22	36	60	CH	1.78	14.44	2.4
CH. 83+000	1	8	91	44	20	24	40	CI	1.845	12.89	3.4
CH. 84+000	2	8	90	42	20	22	40	CI	1.82	12.5	3.4
CH. 86+000	0	1	99	58	18	40	58	CH	1.784	14.74	2.44
CH. 87+000	0	4	96	48	20	28	55	CI	1.798	13.41	2.94
CH. 88+000	1	12	87	47	20	27	40	CI	1.885	12.5	3.65
CH. 89+000	2	9	89	48	20	28	42	CI	1.84	12.4	3.42
CH. 91+000	1	11	88	47	20	27	45	CI	1.824	12.48	3.3
CH. 92+000	4	12	84	44	19	25	36	CI	1.855	11.2	4.1
CH. 93+000	0	3	97	52	19	33	60	CH	1.79	14	2.88
CH. 94+000	0	2	98	52	20	32	60	CH	1.798	15.2	2.74
CH. 96+000	0	4	96	48	20	28	49	CI	1.815	13.24	3.14
CH. 97+000	3	9	88	52	19	33	58	CH	1.8	13.64	2.94
CH. 98+000	0	1	99	58	19	39	70	CH	1.74	16.63	2.24
CH. 99+000	3	15	82	35	17	18	28	CL	1.91	11.14	4.64
CH. 101+000	9	17	74	28	17	11	22	CL	2.01	9.84	5.18
CH. 102+000	3	12	85	42	20	22	37	CI	1.91	10.8	4.28
CH. 103+000	0	2	98	51	19	32	60	CH	1.765	14.2	2.68
CH. 104+000	2	25	73	26	21	5	10	ML-CL	2.04	9.8	5.8
CH. 105+000	2	24	74	24	18	6	10	ML-CL	2.06	9.6	6.04
CH. 106+000	2	34	64	3	NP	NP	0	ML	1.98	9.4	6.4
CH. 107+000	2	28	70	2	NP	NP	0	ML	2.06	9.24	6.2
CH. 108+000	4	26	70	5	NP	NP	5	ML	2.08	8.2	6.4
CH. 109+000	3	25	72	6	NP	NP	5	ML	2.045	9.4	6.4
CH. 110+000	0	24	76	27	22	5	10	ML-CL	1.98	9.4	5.4
CH. 111+000	4	16	80	28	21	7	10	ML-CL	1.955	10.5	5.12
CH. 112+000	3	36	61	4	NP	NP	0	ML	2.05	8	7.2
CH. 113+000	0	15	85	28	16	12	15	CL	1.92	13	4.4
CH. 114+000	0	18	82	30	22	8	15	CL	1.96	9.6	4.8
CH. 115+000	4	22	74	24	22	2	10	ML-CL	1.98	10.8	5.84
CH. 116+000	0	9	91	46	22	24	44	CI	1.88	14.2	3.4
CH. 117+000	0	19	81	31	21	10	15	CL	1.865	10.4	4.8
CH. 118+000	2	14	84	30	22	8	10	CL	1.88	11.8	4.8
CH. 119+000	3	31	66	18	14	4	5	ML-CL	2.1	8.7	6.4
CH. 120+000	0	16	84	30	20	10	10	CL	1.945	10.4	4.9
CH. 121+000	0	18	82	32	22	10	15	CL	1.925	10.2	4.8
CH. 122+000	0	20	80	33	24	9	15	CL	1.975	9.6	5.12
CH. 123+000	2	24	74	6	NP	NP	5	ML	1.98	9.2	6.2

Chainage	Gravels	Sand	Silt + Clay	Atterberg's Limit(%)			FSI (%)	Classification	Modified Proctor		4-day Soake
CH. 124+000	3	29	68	5	NP	NP	10	ML	2.08	8.1	6.6
CH. 125+000	4	26	70	5	NP	NP	10	ML-CL	2.06	8.4	6.4
CH. 126+000	2	8	90	42	18	24	32	CI	1.835	13.8	3.4