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Research Article

EVALUATION OF EXISTING ALLUVIAL SOIL SUBGRADE USING DYNAMIC CONE PENETROMETER AND INDEX PROPERTIES

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A B S T R A C T

The pavement structural failure of properly designed roads is major cause of concern for road authorities. The cost of rectification is huge and no one take the onus of failure. Most of the major roads are built with financial assistance of various development agencies thus the failure of roads defeats the primary aim of development of necessary road network that paves the way for further development activities. The performance evaluation of a flexible pavement is based upon its stability against the following failures

1. **Pavement structure failure:** Fatigue (Alligator) Cracking, Block Cracking, Edge Cracks, Reflection Cracking, Upheaval/Swell etc are considered as pavement structure failure and need lot of resources for rectification or reconstruction.
2. **Surface failure:** Pot Hole, Raveling/Weathering, Bleeding, Polished Aggregate Loss of Aggregate on Surface Treatments, Longitudinal/Transverse Streaking
3. **Miscellaneous:** local failure such as Utility Cuts/Patch Failure

The subgrade being the natural foundation, plays a crucial role in performance of road crust. In-situ subgrade strength can be estimated through a California Bearing Ratio(CBR) prediction model using Dynamic Cone Penetrometer (DCP), index properties of soil and laboratory CBR test procedure. The aim of the study is to find in-situ Million Standard Axel (MSA load carrying capacity without formation of ruts not more than 20 mm deep and development of not more than 3 mm wide cracks in 10% surface area. In this study, a stretch of 20 Km of 45 Km long State Highway No 11 section Ludhiana to Malerkotla is investigated. From the studies, it is found that expected performance of road can be evaluated based upon the perdition model. In this study, prediction model with three different soil groups, non-plastic soils having (PI=0), low plasticity index (PI 1 to 4) and soils with medium plasticity index (PI 5 to 7), is used. The effect of moisture on DCPI is used to evaluate the in-situ CBR at worst moisture conditions. To find the crust sufficiency equation based on Equivalent Single Wheel Load (ESWL) is used.

INTRODUCTION

Failure Mechanism of Flexible Pavement

A flexible pavement as per Indian Specifications consists of following four distinctive layers consisting of Soil subgrade, Sub-base course, Base course, and Surface or wearing course. If any of the above layers loses its stability, it leads to failure of the pavement. There are many types of failures in flexible pavement, such as development of pot holes, ruts, cracks, depression etc. presence of any of above defect is an indication of pavement failure. Common causes of failure of flexible pavement are subgrade failure or failure of sub-base or base course or failure of surface or wearing course.

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Among these, the failure of soil subgrade is very prominent. Primary reasons of failure of soil subgrade are

1. ***Inadequate stability*****:** Stability is the resistance to deformation under stress. When soil used for construction of subgrade is of inferior quality, it will not be able to resist the load coming from wheel, and ultimately it will fail. Another reason causing loss of stability of subgrade soil is improper compaction of soil during construction. Presence of excessive moisture at subgrade level without proper drainage control also affects the stability of subgrade.
2. ***Excessive stress application*****:** Thickness of the pavement should be so designed, that it can distribute the wheel load properly. If pavement thickness becomes less than that of the required value, then it will result in failure of subgrade. Also if the wheel load

applied on pavement is in excess of design value, it will result in failure of subgrade.

Performance of flexible pavement greatly depends upon the accurate evaluation of subgrade strength, anticipated traffic load in terms of MSA and maximum wheel load. There are many other factors which affects riding quality but in-situ strength of subgrade soil and maximum wheel load is one of the major controlling factor, Hopper [1]. As per revised Indian Road Congress (IRC) [2] subgrade soil should be non-expensive in nature having CBR more than 8%. but most of the roads constructed prior to this code of practice do not conform to this further more due lack of awareness on the part of field engineers it is considered that some plasticity is considered helpful in compaction and easy to maintain profile leads to long term complications.

to affect the in-situ load bearing capacity of subgrade such as grain size, liquid limit, plastic limit, maximum dry density and field density along with moisutre conditions.

REVIEW OF LITERATURE

Performance of soil subgrade of a flexible pavement is influenced by load repetitions, crust thickness, bed and side slope, berm width initial state of the pavement layers, temperature and moisture conditions, maximum load, loading rate, loading history, tyre pressure and degree of saturation. The deformation of the soil subgrade of flexible pavement can be divided into two main parts elastic or resilient and permanent deformations. Permanent deformations are called plastic and are irreversible.

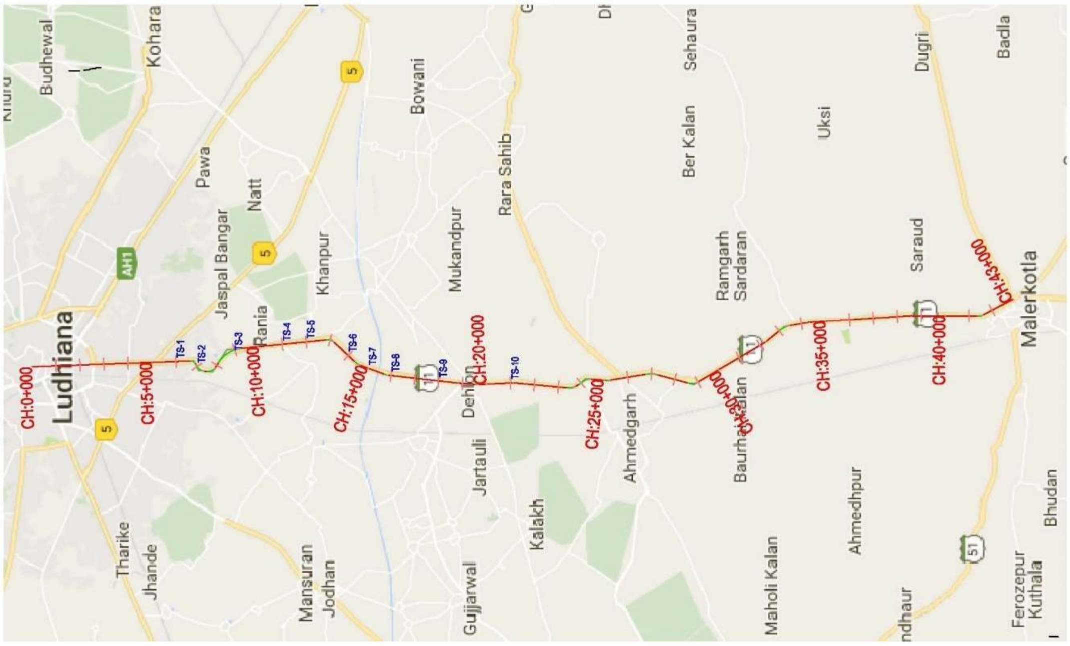

Figure 1 Key Plan Showing the Location of Testing Location on Ludhiana Malerkotla Section of Punjab SH -11

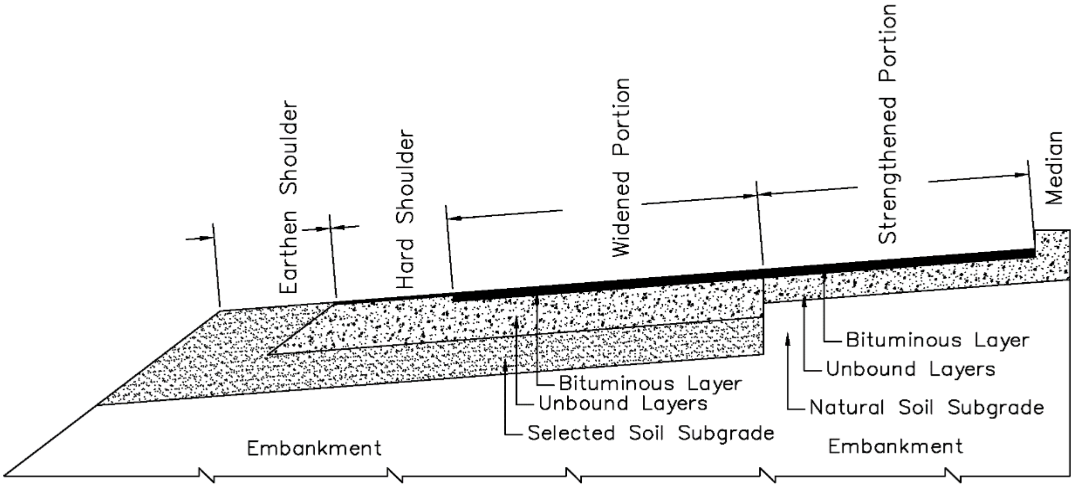

Figure 2 Half Cross Section of Pavement Showing Strengthened and Widened Potions of Road

In most of the districts of Punjab, the soils when compacted to modified proctor density gives laboratory CBR more than 8% at natural moisture content. In-spite of such a higher CBR, the premature failure of roads is very often. In this study, an effort has been made to find the probable life of the soil subgrade with the existing traffic load, using in-situ DCPT CBR in combination with other properties of soil that are most likely

At low stress levels the deformations are mainly reversible or elastic, when the stress level rises the proportion of the plastic deformation also causes higher deformations. The Road Structure Research Programme (TPPT) studies by Alkio *et al*. [3] have specified that void ratio, effective shear and mean stresses, saturation degree, grain size distribution, the level of the deformations, maximum grain size, stress history, mineralogy of the grains, secondary time factors, the structure of the soil sample and temperature are major controlling factors for permanent deformation of road pavement. Kolisoja [4] have demonstrated that in addition to grain size distribution and degree of compaction, water content with mineralogy had effects on the deformation properties. Hoff [5] concluded that the maximum grain size affects both resilient and permanent deformation properties, bigger the maximum grain size, the lower the deformations. Ekblad [6] have shown that the resilient modulus is inversely proportional to the content of fines (grain size < 0.075 mm). He proved that the rise of water content decreases more the stiffness of the materials with high contents of fines. If the content of fines is small then the bigger grains can contact each other and distribute the load, while the fines fill the empty voids between grains. As the content of fines increases, the bigger grains do not necessarily contact each other to distribute the load Kolisoja [7]. As a result, there is a decrease in the deformation modulus. Besides water content and grain size distribution, one of the most important factors of permanent deformation is the degree of compaction of the material. Lekarp has demonstrated that the degree of compaction has an even stronger effect on the permanent deformations than on the resilient deformations Lekarp *et al.* [8]. Van Niekirk [9] has addressed the fact that the degree of compaction has a more important effect on the permanent deformation than the grain size distribution. Uthus [10] demonstrates that the dry density, the degree of saturation and the stress level seem to be key parameters for determining the permanent deformation behavior, but mineralogy, fines content and grain size distribution are also of importance. The observations of the full-scale test roads of TPPT research have shown almost twice as deep rut depths for the looser pavements than for the dense ones Alkio *et al.* [3]. Odermatt *et al.* [11] observed that the effect of the degree of compaction is more important for crushed coarse materials than for natural materials. The natural gravel deformed slower than the crushed rock structure. After mineralogical and other additional studies, Odermatt *et al.* [11] concluded that the crushed rock material needed more compaction effort. Arnold G and S Werkemeister [12] from their extensive research concluded that in thinner pavement subgrade has major contribution in total rutting depth. Various researchers tried to test the in-situ strength of unbound pavement layers most relevant to present studies are listed below.

Correlations with DCPI and CBR

Webster *et al.* [13] have reported the development of a relationship between the CBR and the penetration rate (DCPI) expressed in mm per Equation (1) by the U.S. Army Corps of Engineers for a wide range of granular and cohesive materials. they also found that that the effects of soil moisture content and dry density influence both CBR and DCP test values in similar ways hence not considered for the correlation where moisture and density is kept constant.

$$\text{Log CBR} = 2.465 - 1.12 \text{ Log (DCPI)} \quad (1)$$

This correlation was adopted by many researchers for their work with different soils and reported similar results, prominent and relevant to the present problem is (2) given by Livneh *et al.* [14] with granular and cohesive soil.

$$\text{Log(CBR)} = 2.45\text{-}1.12 \text{ log(DCPI)} \quad (2)$$

Webster *et al.* [15] developed a much similar correlation relation (3) after conducting tests on various soils.

$$\text{Log(CBR)} = 2.46\text{-}1.12 \text{ log(DCPI)} \quad (3)$$

Ese, *et al.* [16] carried out a detailed field and laboratory testing with DCPT, for evaluating low volume roads having gravel base course and established (4).

$$\text{Log CBR}_{(lab)} = 2.438\text{-}1.065*\text{log (DCPI)}_{field} \quad (4)$$

Some relevant correlations with index properties and CBR

NCHRP [17] for mechanistic-empirical design of new and rehabilitated pavement structures, developed prominent correlations of CBR with index properties of soil for non-plastic (5) and for plastic soils (6).

For non-plastic soils

$$\text{CBR} = 28.09 \, (D_{60})^{0.358} \quad (5)$$

Where D60 = the diameter corresponding to 60% finer in the particle-size distribution in mm and for plastic soil

$$\text{CBR} = \frac{75}{1+0.728(\text{wPI})} \quad (6)$$

Where wPI = weighted plasticity index = $P_{075} \times PI$
PI = plasticity index of the soil in %
P_{075} = % passing 0.075mm sieve in decimal.

Afeez Adefemi BELLO, [18] using Regression analysis on index properties of lateritic subgrade soil gave (7 to 10) for preliminary acceptance of soil.

$$\text{CBR un-soaked} = 0.031(\text{LL}) + 83.19 \quad (7)$$

$$\text{CBR un-soaked} = 0.8 \, (\text{PL}) + 65.31 \quad (8)$$

$$\text{CBR} = 0.22 \, (\text{LL}) + 28.87 \quad (9)$$

$$\text{CBR} = 1.04 \, (\text{PL}) + 13.56 \quad (10)$$

Daljeet Singh *et al.* [19] studied fifteen different soil in road subgrades using DCPT, grain size and Atterberg's limits in laboratory and actual field conditions at optimum moisture content and developed a CBR prediction model (11)

$$\text{CBR} = 43.73\text{-}1.043\text{N-}0.717\text{LL-}0.149\text{PL+}5.39D_{60} \quad (11)$$

With R^2 =0.995 and a standard error of 0.407

The model is very useful for verification of CBR during construction only as the field moisture conditions at OMC can only be at the time of construction or at any specific period of time after rainy season. The field moisture conditions remain changing rapidly.

As the review of previous works indicates

1. DCPI and Index Properties Grain Size and Plasticity Index have definite correlation with CBR of soil.
2. The model developed by Daljeet Singh *et al* [19] is useful for verification of CBR during construction only as the field moisture conditions at OMC can only be at the time of construction. Verification of sub grade CBR for rehabilitation, upgradation or post construction evaluation purposes is not possible as the CBR and DCPI are moisture sensitive Amini, F [20].
3. The previous researchers have primarily investigated relation of a particular parameter with CBR. The effect of other parameters if studied is only at a particular moisture content un-soaked or soaked conditions. To investigate

in-situ CBR it is essential to study the effect of moisture on DCPI and CBR.

Hence, it is felt performance of soil subgrade under flexible pavement layers can be anticipated with the help of DCPT apparatus by applying suitable moisture correction factor to the available prediction model (11).

Load Carrying capacity of flexible pavement

The design of flexible pavement in India is based on repeated standard axel loads generally in the terms of Million Standard Axel (MSA). The equivalent single wheel load carrying capacity of flexible pavement can be estimated from the semi rational method, known as Boyd and Foster method, based on the following assumptions:

equalancy concept is based on equal stress, contact area is circular, influence angle is 45 degrees, and soil medium is elastic, homogeneous, and isotropic half space.

$$\log 10\ ESW\ L = \log 10\ P + [0.301 \log 10\ (z\ d/2\ )] \div [\log 10(\ 2S\ d/2\ )] \quad (12)$$

Where P is the wheel load, S is the center to center distance between the two wheels, d is the clear distance between two wheels, and z is the desired depth

Current design practices

New construction: Design for construction of flexible pavement in India is carried out as per the details described in IRC 37 [2] "Guidelines for the design of flexible pavements".

Strengthening of existing roads: The design for strengthening of existing flexible pavements in India is carried out as per IRC 81 [21] "Guidelines for strengthening of flexible pavement using Benkelman Beam Deflection Technique"

Current performance evaluation techniques

As review of past work is conducted to find out the current status of existing performance evaluation techniques used to investigate premature failure of flexible pavements in revealed that in India Central Road Research Institute (CRRI) currently conducting engineering investigations on case-to-case basis**.** At present, there is no formal technique to carry out such investigations, as there are lot of variables that effect the performance of soil subgrade under flexible pavements**.**

MATERIALS AND METHODS

To investigate the level of performance and causes of underperformance of flexible pavement a 14 KM long widened and strengthened from two lanes to four lane dual carriage of SH 11 from Ludhiana to Sangrur is investigated. The selected stretch has the advantage of having different soils subgrade with different crust thickness at the same section. The existing portion of the road was strengthened based on characteristic deflection of Benkelman beam IRC-81 and in widened portion the crust is based upon the design of IRC 37 -2000 [2].

The research methodology can be classified in the following groups (a) assessment of in-situ subgrade strength at worst moisture conditions (b) Thickness of various crust layer (c) Traffic load in the form of Equivalent Standard Axel Load (ESAL). The in-situ soil strength can be measured directly from the response of the soil to applied loads or correlated to several equipment's penetration resistance. The various available techniques that can be used to measure the direct response of the soil when subjected to loads are static plate test, LWD, Benkelman Beam, Geo Gauge, time domain reflectometry and other means. In this study Standard Dynamic Cone Penetrometer (DCPT) apparatus is used. Other soil properties such as dry density, grain size, liquid limit and plastic limit and effect of moisture content is used. The Dynamic Cone Penetrometer (DCP) consists of a guiding rod fitted with a cone at the tip and is operated by dropping an 8-kg mass from a specified height. The DCP test is conducted as per standard procedure IRC-Special Publication [22] and ASTM [23]. The penetration index given by DCP can be correlated to the CBR and density of a particular soil at a particular moisture content. The other soil parameters are also used to fine tune the results and enhance the usability to a wider range of soil type. This test is conducted up to significant depth of influence of wheel load. Many researchers and agencies have developed the relationships between in-situ tests with Dynamic Cone Penetration Index (DCPI) versus CBR. Equation given by Daljeet Singh *et.al* (20) with correction moisture correction factors is used in this study being most relevant to the conditions of road under investigation. To find the effect of moisture content on DCPI and mould CBR, samples are tested at different moisture content to develop correlations. The soils are grouped based upon their Plasticity Index (PI) value into three groups. The data of Punjab State Road Sector Project for Crust thickness and traffic load is used in this study.

To estimate the minimum crust thickness requirement from ESAL criteria the equation given by

RESULTS AND DISCUSSION

The CBR of soil is determined at selected location using the standard CBR test and DCPT apparatus using Eq. (11). Since this equation gives the CBR of soil at OMC hence correction factor for moisture are developed for three different categories of soil based upon their Plasticity Index. Group A for non-plastic soils, Group B for PI value 1 to 4 and Group C for PI value 5 to 7. The graphical representation are as given below.

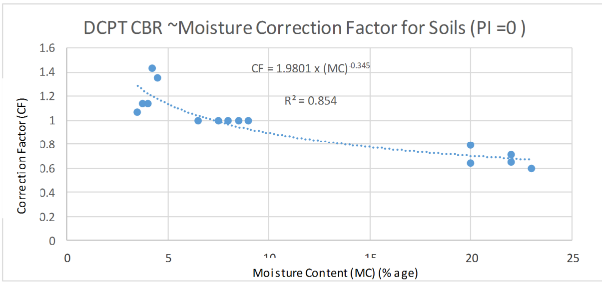

Figure 3 DCPT CBR Moisture Correction Factor Relationship for Non-Plastic Soils (PI= 0)

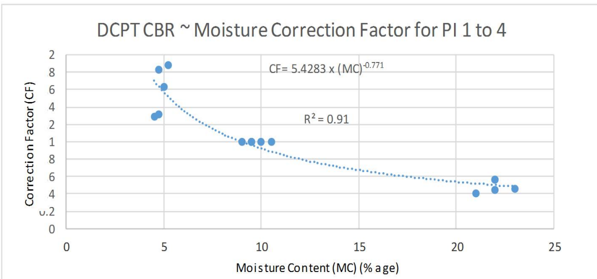

Figure 4 DCPT CBR Moisture Correction Factor Relationship for Plastic Soils (PI value 1 to 4)

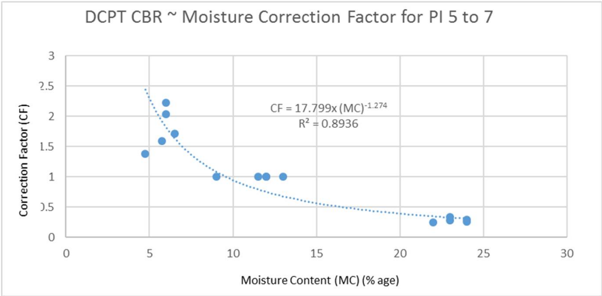

Figure 5 DCPT CBR Moisture Correction Factor Relationship for Plastic Soils (PI value 5 to 7)

The correction factor (CF) for non-plastic soils having Plasticity Index up to 2 can derived from the equation

$$CF = 1.9801 \times (MC)^{-0.345} \quad (13)$$

having $R^2 = 0.8545$
Similarly, for PI value 3 to 6 and 7 to 12 the following equations can be used respectively.

$$CF = 5.4283 \times (MC)^{-0.771} \quad (14)$$

having $R^2 = 0.9161$
And

$$CF = 17.799x\ (MC)^{-1.274} \quad (15)$$

with $R^2 = 0.8936$

The results obtained from the above equations are in accordance with correction factors used for Benkelman Beam deflection procedure defined in IRC 81. [22].

From the results shown in Table-1 (Pavement Subgrade Properties Evaluation Results-Strengthened Portion), Table-2 (Pavement Subgrade Properties Evaluation Results -Widened Portion) and Table-3 (Pavement Condition Survey Report) and photographs showing the typical pavement condition it can be concluded that that performance of pavement with selected subgrade (SSG) having uniform properties performs better as compared to natural soil subgrade. The performance of fine non-plastic soils (Silts) do not perform as good subgrade material. Increase in Plasticity of soil adversely affect the performance of subgrade. The crust thickness given by equation (12) is the minimum crust thickness that crust can take for a limited number of repetitions of that magnitude of vehicular load. The condition of road where factor of safety around 2 is available performed better during the first half of the designed life period. The road developed Class III combination of cracks where factor of safety is near unity or less. The performance of road is moderate for the section where factor of safety is around 1.5. The results shown in Table-1 (Pavement Subgrade Properties Evaluation Results-Strengthened Portion) shows that overlay design thickness based upon Benkelman Beam Deflections are not sustainable when the existing crust is not as per the design stipulations of IRC 37 [2]. The techniques developed in this study if tested in large scale can be very useful for performance evaluation before taking over the project roads constructed on Engineering Procurement and Construction (EPC) mode where the client department has least control on design, construction and quality assurance.

Table 1 Pavement Subgrade Properties Evaluation Results (Strengthened Portion)

Sr. No	Chainage	Crust thick-ness (mm)	In-situ MC (%)	Soil Type	D60	LL	PL	PI	Moisture Correction	DCPI mm/blow	In-situ CBR	Minimum Crust required	Factor of safety
1	7+050	400	12.40	ML-CL	0.095	24	19	5	1.28	19.66	4.74	420	0.95
2	9+690	435	13.60	CL	0.035	32	21	11	1.56	14.66	3.99	460	0.95
3	11+000	415	10.10	ML-CL	0.06	25	19	6	1.1	17.33	5.74	380	1.09
4	12+700	415	10.10	ML-CL	0.075	24	18	6	1.1	15.33	9.07	290	1.43
5	14+200	345	10.10	ML-CL	0.06	24	18	6	1.1	20	3.63	480	0.72
6	15+100	345	10.00	ML-CL	0.065	25	19	6	1.09	16.66	6.47	350	0.99
7	17+800	485	6.40	CL	0.03	30	22	8	0.6	12	3.94	460	1.05
8	18+800	675	14.60	ML-CL	0.085	23	18	5	1.45	22	3	530	1.27
9	19+600	675	14.60	ML-CL	0.085	24	19	5	1.45	20.66	3.77	470	1.44
10	21+300	430	8.60	CL	0.03	29	21	8	0.87	15.33	3.46	500	0.86
11	23+200	340	4.90	SM	0.17	18	18	0	0.88	21.33	8.33	310	1.1

Table-2 Pavement Subgrade Properties Evaluation Results (Widened Portion)

Sr. No	Chainage	Crust	In-situ MC	Soil type	D60	LL	PL	PI	Moisture Correction Factor	DCPI mm/blow	In-situ CBR	Minimum Required Thickness	Factor of safety
1	7+050	630	13	SSG	0.065	22	17	5	1.28	20	6.3	360	1.75
2	9+690	630	13	SSG	0.045	22	17	5	1.37	19.33	7.54	320	1.97
3	11+000	630	10	SSG	0.055	24	18	6	1.1	18.33	5.51	390	1.62
4	12+700	630	10	SSG	0.065	23	18	5	1.1	18.66	5.98	370	1.7
5	14+200	630	10	SSG	0.065	22	18	4	1.1	21	4.09	450	1.4
6	15+100	630	10	SSG	0.06	23	17	6	1.09	19.66	4.92	410	1.54
7	17+800	630	7	SSG	0.045	20	18	2	0.96	17.33	8.53	300	2.1
8	18+800	630	14	SSG	0.047	24	19	5	1.45	18.33	6.99	340	1.85
9	19+600	630	14	SSG	0.025	25	21	4	1.45	17.66	6.36	360	1.75
10	21+300	630	8	SSG	0.017	27	21	6	0.97	15	5.52	390	1.62
11	23+200	630	5	SSG	0.038	18		NP	0.88	23	6.18	360	1.75

Field Verification of Results

From the investigative study and corresponding field verification, it can be concluded that DCPT and index properties of soil subgrade taking due cognizance of anticipated worst field moisture content, can be a useful tool for evaluation and characterization of alluvial soil subgrades.

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Table 3 Pavement Condition Survey Report

Sr. No	Chainage	Crust Thickness		Road Surface Condition Strenghthened potion				Road Surface Condition widened potion			
		Str. Potion	Widened Potion	Class 1B	Class II	Class III	Average Rut depth	Class 1B	Class II	Class III	Average Rut depth
	K+M	(mm)	(mm)	Alligator (A), Block (B) and Combination (C)			(mm)	Alligator (A), Block (B) and Combination (C)			(mm)
1	7+050	400	630		C		13	A			12
2	9+690	435	630		C		15				8
3	11+000	415	630		C		12	A			15
4	12+700	415	630	A			8				12
5	14+200	345	630			C	22		A		15
6	15+100	345	630		C		10	C			18
7	17+800	485	630		C		13				6
8	18+800	675	630		A		15				8
9	19+600	675	630	A			8	A			8
10	21+300	430	630			C	16	B			12
11	23+200	340	630		B		8	A			10

Field Condition at Chainage 11+00

Field Condition at Chainage 14+200

CONCLUSION

From the present study, the followings conclusions are drawn:

1. In-situ CBR of Subgrade has significant effect on the long-term performance of the flexible pavement. The results indicate that the increasing the crust thickness on low CBR subgrade does not yield the desired results.
2. The results indicate that the widened potion of the road have more rut depth as compared to the strengthened portion. This can be associated with the long-term compaction under vehicular traffic load.
3. The results also indicate that overlay design for strengthening of flexible pavements that are not conforming to IRC 37 are not sustainable for traffic load of road category State Highway.
4. Fair idea of performance of road subgrade under standard axel load conditions can be made from the techniques used in this study.
5. A factor of safety 3 would be sufficient for long time performance of soil subgrade to the crust thickness calculated by Boyd and Foster method based on SEW incase the in-situ subgrade CBR is more than 10%.
6. Studies can be extended for effect of over loading on long term performance of the flexible pavements.

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