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FEM MODELLING OF STABILIZATION OF FLEXIBLE PAVEMENTS WITH RBI GRADE – 81

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Abstract: Due to the non-availability of coarse-grained soils in large quantities, it is imperative nowadays to use fine-grained soils for embankment-related work. The presence of clay minerals in fine- grained soils makes its behaviour more complex. Five expansive soils having different clay mineralogy were selected based on physical and index properties. RBI Grade-81 admixture is blended in different percentages of weight with the soils. The blended soils were kept for a maturation period for equilibration. Compaction tests were conducted (SP, RSP, MP& RMP) on the blended soils. The compaction characteristics of these soils that are Maximum dry density (MDD) and optimum moisture content (OMC) were determined for various compaction energies, including Standard Proctor (SP), Modified Proctor (MP), Reduced Standard Proctor (RSP), and Reduced Modified Proctor (RMP). The soil compacted to different energy levels with reference to MDD & OMC was kept for the soaked condition The CBR tests were conducted on the soaked soils. In the current experimental study, the compaction characteristics and CBR were linked with the index properties of soils. Regardless of the soils' clay mineralogy, the plastic limit can be better connected with compaction characteristics than the liquid limit. Reduction in thickness of pavement ranging from one-fold to four folds was observed, for the compacted subgrade soils having different clay mineralogy blended with admixture, which saves associated time and cost. FEM modelling was carried out for different dynamic loading conditions with particular reference to material composition to compare the results of the experimental study.

Keywords: *Compacted; Clay mineralogical composition; Fine-grained soils; Pavement thickness; Subgrade*

1 Introduction

A pavement is a prepared surface made of materials that are installed on a location that primarily supports automotive traffic, such as a road or highway. Pavement is often a multi-layered construction that rests over the soil in a cutting or an embankment. Cobblestones and granite sets were widely utilised in the past, but asphalt or concrete today predominately replaces these surfaces. The flexible pavement is made up of top-notch bituminous topping pavement and upper layers of superior-quality granular layers.

Through the points of contact in the granular structure, flexible pavements will transfer grain-to-grain stresses to the lower layers. The tension on the pavement caused by the wheel load is dispersed over a larger area and diminishes with depth. These properties of the distribution of stress are typical of flexible pavements, which frequently contain numerous layers. The top layer of flexible pavement must be of the highest quality to withstand the greatest compressive stress as well as abrasion. Therefore, the flexible pavement may be built in a variety of layers. Lower tiers might use inferior materials because they won't be under as much pressure. Bituminous materials are used to build flexible pavements. These might be asphalt concrete surface courses or surface treatments. The top layer deformation in flexible pavement layers is reflected in the layer below. The stresses produced by flexible pavements should be kept substantially below the maximum stresses permitted for each pavement layer because they are builtbased on their total performance. Over the years, there have been numerous changes made to pavement design. The strength of the compacted earth within the pavement, referred to as the subgrade traditionally serves as the basis for the construction of both types of pavements. The strength of the subgrade soil and the anticipated traffic volume are determined before designing the layers of pavement that will be laid over it. The subgrade strength of the soil greatly influences pavement design. The fundamental requirement for design criteria is layer thickness. A stronger subgrade requires thinner pavement layers, whereas a weaker subgrade requires thicker layers. The Indian Road Congress (IRC) lays out the precise steps for designing the pavement layers based on the subgrade's strength. The California Bearing Ratio is typically used to describe the strength of subgrade soil (CBR). Engineers confront a lot of obstacles or challenges while designing pavement because of the changeable nature of the soil and the inconsistent variations in subgrade strength. The moisture content has a big impact on the subgrade strength. It is essential to enable or comprehend the subgrade in accordance with the variation of moisture since the subgrade is designed to change in moisture as a result of floods, precipitation, or any other climatic variations.

The subgrade supports the crust of a pavement, whether it is flexible or rigid. The term "subgrade" refers to a layer that is compacted and typically made of locally available dirt. It is thought that this layer is 500/300 mm thick and serves as the pavement's foundation. The two layers of the subgrade in an embankment are typically compacted to a higher quality than the lower portion of the embankment. For the subgrade soil to be able to withstand the strains brought on by traffic loads, it must be of high quality and well compacted. Due to the traffic loads, the subgrade soil is normally under stress to a certain minimum level of stress. As a result, the entire pavement thickness is reduced. The subgrade soil, on the other hand, is distinguished for its strength when it comes to analysis and pavement design. The percentage of CBR was used in this study for design pavement thickness determination and it was compared with Finite Element Analysis to assess the vertical stress variation along the flexible pavement thickness or depth of soil layers with respect to various compositions of RBI Grade-81 of soils under consideration.

2 Literature review

The subgrade has a significant impact on the stability and performance of pavements since it acts as the basis for them. Roads on black cotton soils make it difficult to choose an effective method of soil modification. The durability of a pavement subgrade determines the pavement's quality. According to IRC-37, sub-grade soil must meet the necessary strength standards (2012). If not, either new soil with better strength and compressibility properties needs to be used in place of the natural soil, or the existing soil needs to be modified to meet the needs. In this study, RBI-81 as a stabilizer was employed.

Najia Nouf1 & Sureka Naagesh (March 2014) in the study report the effect of admixture i.e RBI- Grade 81 on the characteristics of soil treated with 20% fly ash and varying the percentage of RBI-81 from 0% to 6%. The expansive soil's plasticity qualities can be effectively decreased with the stabilizer RBI-81. The addition of a 6% stabilizer enhanced the soil's saturated CBR values by three times. The sample's soaked CBR value increased 7.7 times after being cured for 28 days. This suggests that under soaking conditions, a stabilizer increases the strength of expanding soil. This also demonstrates how unsoaked CBR values will increase immediately. After the sample has been properly cured, the strength of the expansive soil increases even more. In accordance with CBR values, the expansive soil used in this study is suitable as a subgrade when stabilized with 4% RBI-81 since the swelling pressure is 90% lower. However, using RBI-81 alone as a stabilizer may not be advised if the expansive soil must be utilized as a sub-base material because it does not meet the required UCC value.

Dilip K T (2014) reports the relation between CBR values with other properties of soil. There is a substantial association between the CBR value of expansive soil (ML and MI) and PI, MDD, and OMC. CBR value increases with an increase in MDD but drops with an increase in soil water content and PI. There is a little discrepancy between the CBR value calculated using the multiple linear regression model involving index and compaction characteristics determined in the laboratory.

Saklecha P.P et.al, (2011) in their study reports that, according to the results of SIMPLE REGRESSION ANALYSIS (SRA), SRA Model 2 (R= 0.68, R2 = 0.46) has a modest ability to generalize with foundation soil's characteristic strength CBR. Low correlations were reported by other SRA models. These correlations could, however, be employed as a metric to demonstrate the impact of a

Saklecha P.P et.al, (2011) in their study reports that, according to the results of SIMPLE REGRESSION ANALYSIS (SRA), SRA Model 2 (R= 0.68, R2 = 0.46) has a modest ability to generalize with foundation soil's characteristic strength CBR. Low correlations were reported by other SRA models. These correlations could, however, be employed as a metric to demonstrate the impact of acertain mechanical attribute of the foundation soil on the characteristic strength CBR. The SRA revealed that OMC, PI, LL, and PI, in decreasing order, have the least impact on the CBR value of foundation soil and that MDD has the most impact. MULTIPLE REGRESSION ANALYSIS (MRA) findings revealed noticeably enhanced correlations. Model 3 demonstrated strong generalization by producing R and R2 values of 0.8 and 0.63, respectively. A combination of soil characteristics, including MDD, OMC, LL, PL, and PL, was found to have the greatest impact on the strength characteristic CBR. The strength characteristic CBR of foundation soil (subgrade soil) was found to correlate strongly with a combination of soil parameters, including MDD, OMC, LL, and PL and PI, as opposed to a single soil component. As a result, it can be said that spatial correlation of the mechanical characteristics of the foundation soil can be utilized as a tool to characterize foundations instead of using field and laboratory approaches.Santhosh G et al. (2012) in their study reports that, the aforementioned sections mainly examined the rate of lateritic soil consolidations under various test settings employing vertical drains. The findings from this investigation will have a significant impact on how embankments for roads and railroads are built on subgrades of soil. Additionally, natural coir fibres can be employed to speed up consolidation because they make it easier for pore-water pressures to dissipate during overburden decomposition after the soil has acquired adequate strength through consolidation. Three vertical sand drains reinforced with 1% coir fibre were used to analyse drained soil samples. The conclusions from this investigation are as follows. It can be observed from sections 8.0 and 9.0 and tables 5 that the soil reached stability about 121 minutes after the application of the preloads. Using this as a baseline, it was found that the effect of randomly adding fibres to soils was insignificant when preloads greater than 450kg were applied. The Cr (UR v/s RR-VD) values remains constant at roughly 9.59%, whereas the Cr (UR v/s UR-VD) values varied from 16.8% and 22.08% for the percentage increase in consolidation for UR v/s RR-VD. In light of the average numbers, there appears to be an additional 10% increase in the pace of consolidation. Nevertheless, the relative advantage is inconsequential in light of the time and effort required to prepare randomly reinforced soil layers.

Based on detailed literature review, the following objectives were arrived to bridge the gaps envisaged.

- To study the compaction characteristics of plain and blended fine-grained soils.
- Correlating the index and compaction characteristics and CBR of soils having different clay mineralogy.
- Finite element analysis through Abaqus will be used to compare the vertical stress variation along the flexible pavement thickness or depth of soil layers with respect to different compositions of RBI grade-81 of soils under study by referring the percentage of CBR.

3 Materials and Methodology

The clay mineralogy in the fine-grained soils is having a major role in determining engineering properties. The presence of the extreme clay minerals in natural soils like kaolinite, montmorillonite, and combinations of kaolinite and montmorillonite in varying amounts. Engineering behaviour, in particular the physico-chemical behaviour of naturally occurring fine-grained soils is caused by these minerals. The natural soil's relative activity is determined by the quantity of these clay minerals in that soil.

3.1 Materials

Five natural expansive soils having different clay mineralogy from Mysuru district of Karnataka were selected for the present experimental study. Table 1 shows the location of the soils

Table 1 Location of soils

Sl.No.	Source of Soil	Dominant Clay Mineral
1	J.P. Nagar Mysuru	Kaolinite
2	Adithya Circle Mysuru	Kaolinite
3	T.Narasipura	Kaolinite-Montmorillonite
4	Nanjanagudu	Kaolinite-Montmorillonite
5	H.D. Kote	Montmorillonite

3.2 Methods

The Following physical tests were conducted on the selected soil samples:

A. Free swell ratio test (FSI) (IS: 2911(Part-3)-1980)
B. Specific Gravity test (G) (IS:2720 part-III (sec-I)-1980)
C. Grain size analysis (IS:2720(PART-IV)1985)
D. Sedimentation analysis (IS:3104-1965)
E. Atterberg limits (IS 2720(Part V)-1985)
    - Liquid Limit (W_L)
    - Plastic Limit (W_P)
    - Shrinkage Limit (W_S)
F. Cone penetration method both in distilled water and kerosene
    - Liquid Limit
G. Compaction Tests
    - Standard Proctor test (SP) (IS:2720(Part VII)-1974
    - Reduced Standard Proctor Test (RSP)
    - Modified Proctor Test (MP) (IS:2720(Part VII)-1980/1987)
    - Reduced Modified Proctor test (RMP)
H. CBR tests (IS:2720-PartXVI,1987)

Table 2 shows the results index properties & soil classification.

Table 2 Physical and index properties of Soils

S. No	Soil	FSI	G	W_L (%)	W_P (%)	I_p (%)	W_S (%)	I_s (%)	Grain Size Distribution (%)			Type of Clay Mineral	IS classification
									Sand size	Silt size	Clay Size		
1	Soil-1	1	2.65	36	22.29	14.71	17.6	9.4	52	18	30	K-Soil	CI
2	Soil-2	0.93	2.66	43	23.00	12.00	16.8	10.7	45	20	35	K-Soil	CI
3	Soil-3	1.3	2.64	42	24.68	16.32	8	18	36	36	28	KM-Soil	CI
4	Soil-4	1.7	2.64	38	20.10	19.80	16.7	11.8	26	25	49	KM-Soil	CI
5	Soil-5	3.8	2.62	165	30.68	135.32	16.7	11.8	15	13	72	M-Soil	CH

RBI Grade 81

The RBI Grade 81 soil stabiliser is a special and cutting-edge solution designed to stabilise a variety of soils effectively and affordably. The powder known as RBI Grade 81 is made up of various naturally occurring substances. It is a powder with no smell. Saturated paste has a pH of 12.5. It enhances a variety of soils' structural qualities. It works especially well with fine-grained soil that has poor engineering characterization. RBI Grade-81 creates a containment layer to counteract extreme weather conditions including thermal behaviour related to the temperature and it is suitable for all pavements and different load categories, according to field studies conducted by Alchemist Technology Limited, which led to the conclusion that RBI Grade-81 satisfies the requirement for an environment friendly natured and economical method. It boosts the compressive and flexural strength, the CBR, the reduction of PI and swell, and the durability under all weather conditions. It also provides relative impermeability to the pavement layers and prevents moisture from evaporating through the subgrade into the upper layer. Table 3 shows the chemical composition of RBI Grade-81.

Table 3 Chemical composition of RBI Grade-81

Composition	Percentage (%)
Calcium	25 – 45
Silica	5 – 20
Magnesium	5 – 10
Iron	2 – 5
Potassium	2 – 5
Aluminium	2 – 5
Copper	1% - 2%
Zinc	1% - 2%
Manganese	1% - 2%

Flexible pavement design

The design of flexible pavement was based on the CBR technique and anticipated traffic by IRC:37-1970). Remoulded soils were employed in the lab for the CBR tests. For design purposes, it is not advisable to test on-site. The specimens were prepared using dynamic compaction. It is crucial to follow the standard test protocol exactly. The flexible pavement subgrade was compacted to the MDD with particular OMC for the application of new roads and existing roads. Before applying it to the roads, the compacted soil samples of specimens were subjected to a CBR test for the soaked condition. It is important to anticipate how much traffic will be handled by a road's pavement at the end of its expected lifespan while also accounting for potential increases in traffic owing to shifting load usage. Major road paving should be planned to last at least ten years with the applied to anticipate traffic flow. From this anticipated traffic and CBR value, the flexible pavement thickness will be found accordingly for different layers of pavement.

Abaqus analysis of Flexible pavement through FEM Analysis

From Abaqus analysis, the vertical stress variation along the flexible pavement (depth of pavement or thickness) can be estimated and comparisons were made between the natural existing soil layer without adding the admixture of RBI Grade 81 and with the addition of different percentages of RBI Grade 81. This study was carried out through the recommendation of IRC for the CBR method of design (IRC:37-1970).

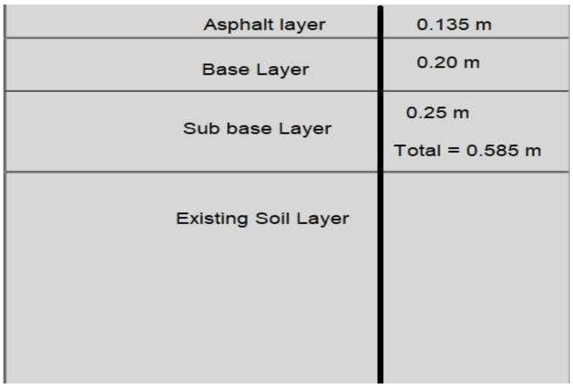

Fig. 2 Layers of Flexible pavement with assigned thickness

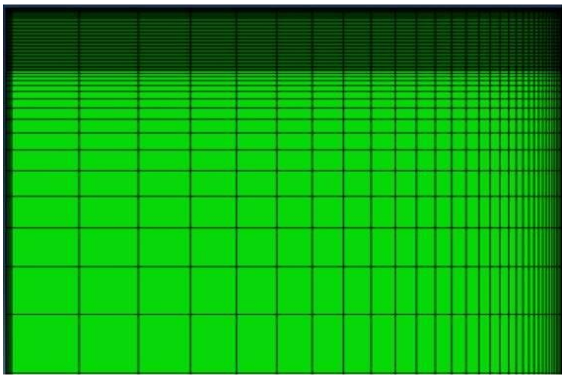

Fig. 1 Mesh elements in pavement

The stress analysis was made based on the Boussinesq stress theory and compared with a layered system of flexible pavement with a uniformly loaded circular area at the edge.

4 Results and Discussions

4.1 Variation of Compaction characteristics with index properties

Figures 3 through 6, show the variation of compaction characteristics with liquid limit and plastic limit of the soils under study for different energy levels.

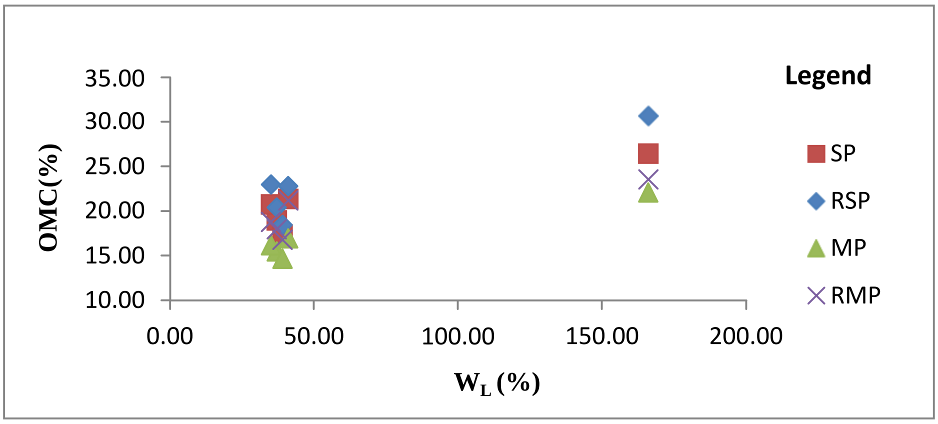

Fig.3 Variation of Optimum moisture content with W_L

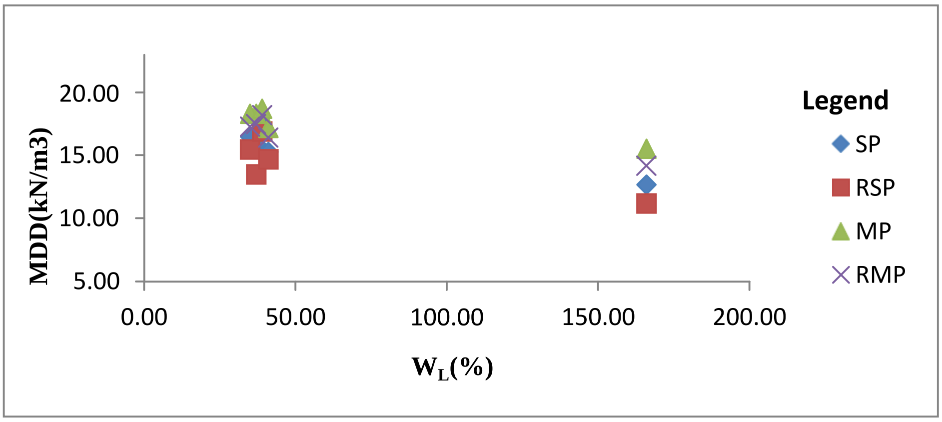

Fig.4 Variation of Maximum dry density with W_L

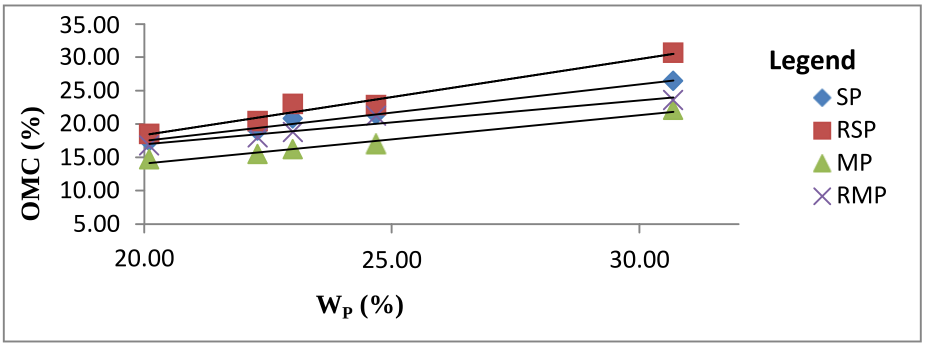

Fig.5 Variation of optimum moisture content (OMC) with W_P

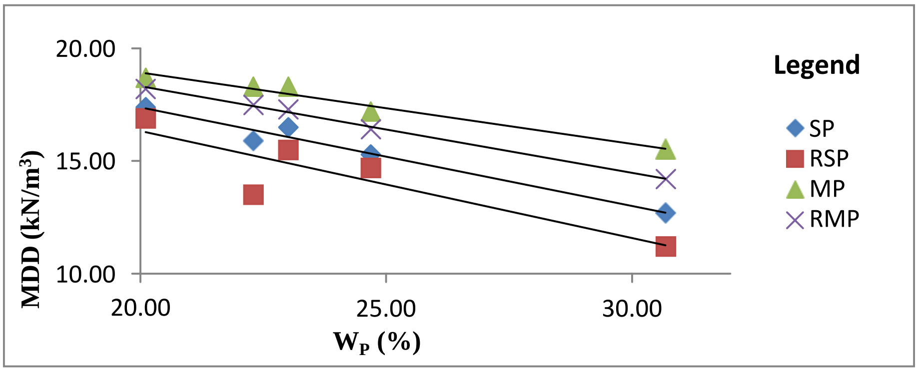

Fig.6 Variation of Maximum dry density (MDD) with W_P

From the Figures 5&6, it can be observed that the Plastic limit is having a better relationship with OMC and MDD for different compaction energy levels (SP, RSP, MP, RMP) with the Regression coefficient varying from 0.81 to 1 than the liquid limit (Irrespective of the clay mineralogy) (Figures 3&4). This demonstrates that the liquid limit may not be the only criterion. From this equation, OMC can be directly predicted without conducting the Proctor compaction test. The change in the plastic limit of the soils under study is due to the higher percentage of fines having high specific surface area influencing the amount of water entrapment into soil voids, which intern leads to an increase in the dispersion between the soil particles. This results in increasing the liquid limit and plastic limit of the soil.

From figure 5, it can be also observed that the plastic limit of the soils is having a good correlation with compaction characteristics with a regression coefficient of 0.99 for SP & MP energy levels whereas from figure 6, it is can be also observed that the compaction characteristics (RMP) are having a better correlation with a plastic limit of regression coefficient of 1 in relative comparison to other energy levels.

4.2 Variation of CBR with index properties

Figures 7 through 9, shows that the variation of CBR Values with the percentage of RBI GRADE 81 respectively of the soils under study with reference to the percentage of fines which remains constant even after adding the RBI GRADE 81, liquid limit and plastic limit.

Table 4 shows the results of soaked CBR values of soil samples with an increase in the percentage of RBI Grade 81

Table 4 CBR characteristics of soils under study for different energy levels and RBI Grade 81

Soil	**CBR (%)**			
	RBI Grade-81 (%)			
	0	**2**	4	6
Soil-1	3.89	5.84	10.71	21.41
Soil-2	3.75	5.89	10.61	22.04
Soil-3	3.16	5.64	10.80	20.68
Soil-4	3.26	5.99	10.95	21.65
Soil-5	2.04	4.96	9.05	17.27

From Tables 2 & 4, The correlations were developed between index properties and CBR characteristics.

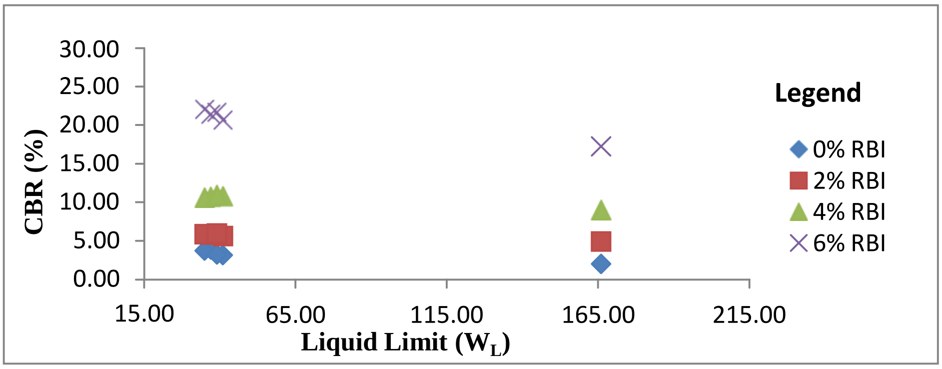

Fig.7 Variation of CBR (%) with liquid limit

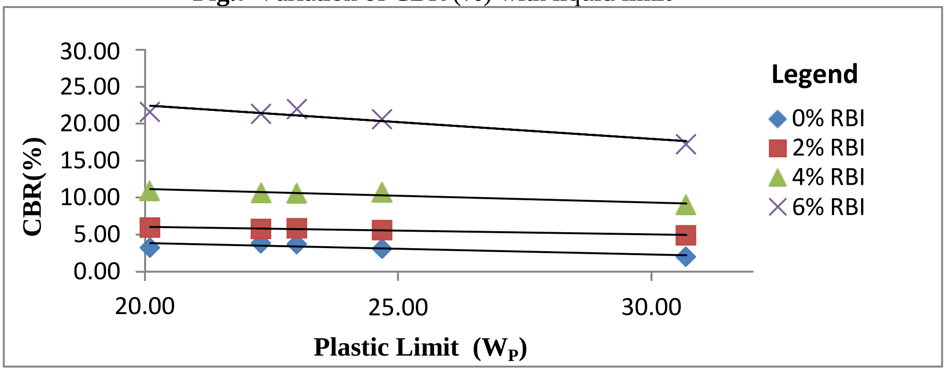

Fig.8 Variation of CBR (%) with plastic limit

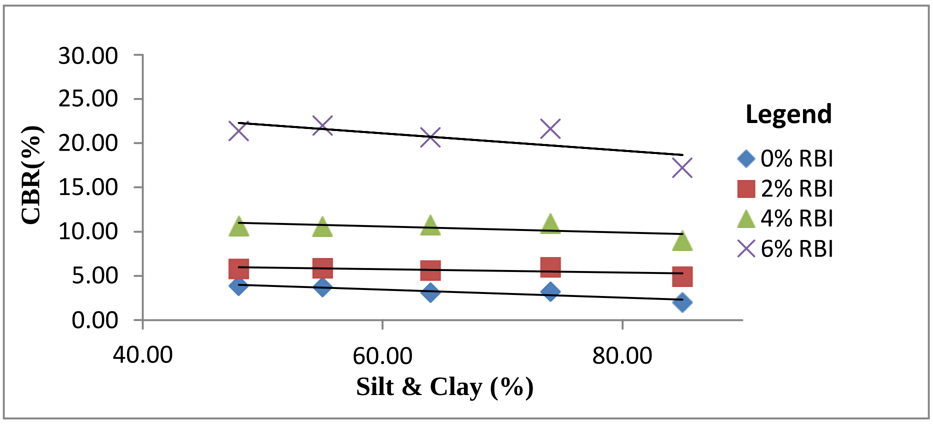

Fig.9 Variation of CBR (%) with percentage of fines (%)

From Figures 5 & 6, it is observed that CBR shows a good relationship with the percentage of RBI with reference to the plastic limit and percentage of fines whereas CBR with liquid limit is showing the scattered relationship.

Table 5 shows the values of CBR values with an increase in the percentage of RBI.

Table 5 CBR values (%) with an increase in the percentage of RBI

Soil	CBR (%)			
	RBI (0%)	**RBI (2%)**	**RBI (4%)**	**RBI (6%)**
Soil-1	3.89	5.84	10.71	21.41
Soil-2	3.75	5.89	10.61	22.04
Soil-3	3.16	5.64	10.80	20.68
Soil-4	3.26	5.99	10.95	21.65
Soil-5	2.04	4.96	9.05	17.27

From Table 5, it is observed that for different percentages of RBI ranging from 0% to 4% there is a gradual increase in the values of CBR, whereas from 4% to 6% the values of CBR have rapidly increased. The values of CBR were increased with an increase in the percentage of RBI irrespective of soil clay mineralogy. CBR values of the subgrade are the main criteria to design the pavement thickness. When the soil is stabilized with RBI up to 6% the CBR values have increased to 22%. But as per IRC-37, 2012, the maximum CBR value for the design of Flexible Pavement is 10%. For the RBI mix, a 10% value of CBR for different soils is found from the observations and the design is made accordingly and the 6% RBI Grade mix was neglected in the FEM analysis.

Table 6 shows the variation of Design Flexible pavement thickness with respect to RBI Grade 81 mix of Corresponding CBR.

Table 6 Design Flexible pavement thickness with respect to RBI Grade 81 mix

Soil	Thickness (mm)		
	0% RBI	**2 %RBI**	**4% RBI**
Soil – 1	750	635	585
Soil – 2	750	635	585
Soil – 3	805	635	585
Soil – 4	805	635	585
Soil – 5	1075	635	585

Figures 10 through 14, show the variation of vertical stress with a depth of flexible pavement (thickness) for the soils under study and the comparisons were made between the Boussinesq stress solution and the varying percentage of RBI Grade 81.

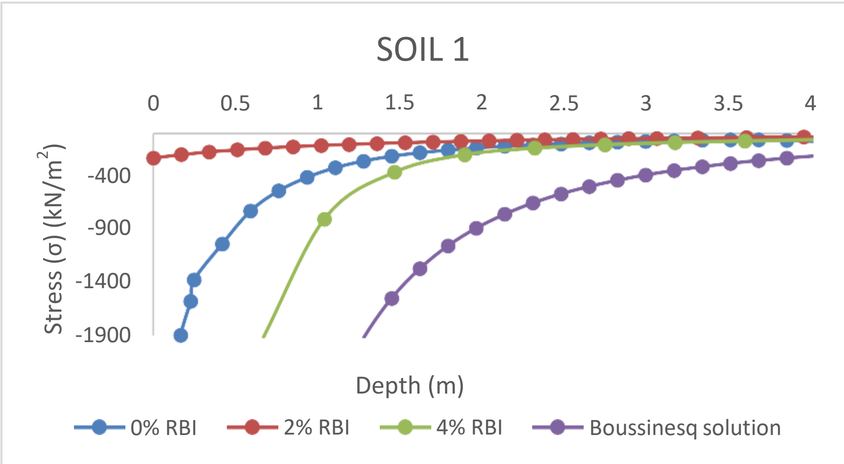

Fig.10 Variation of vertical stress (σ) with the depth of pavement (m)

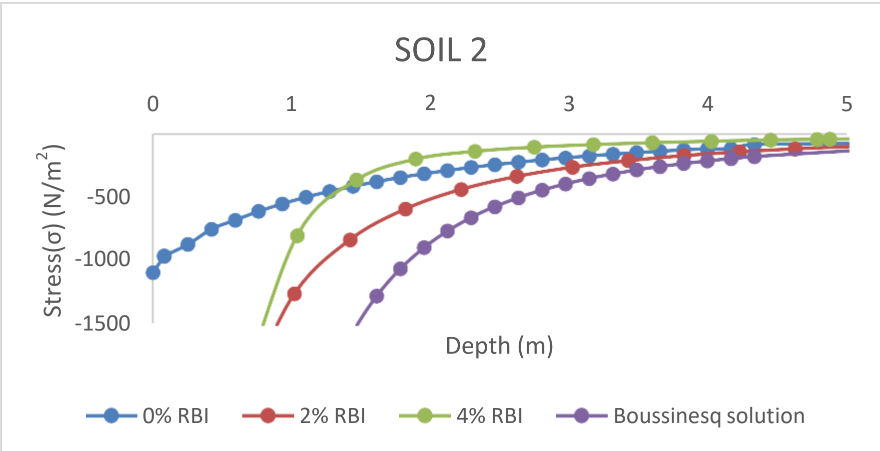

Fig.11 Variation of vertical stress (σ) with the depth of pavement (m)

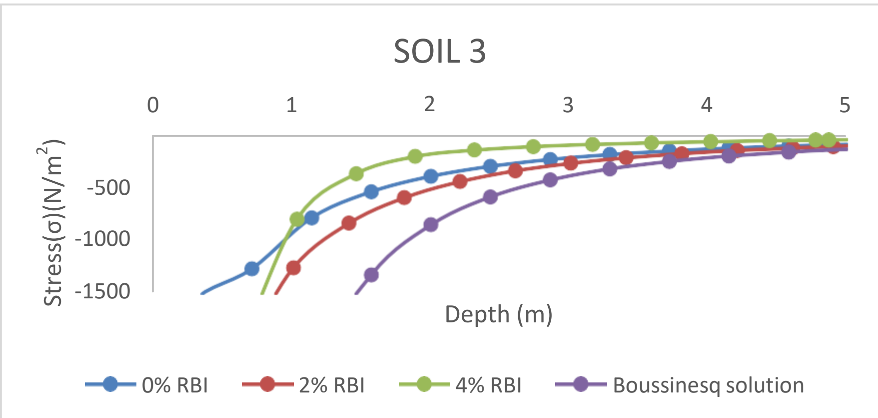

Fig.12 Variation of vertical stress (σ) with the depth of pavement (m)

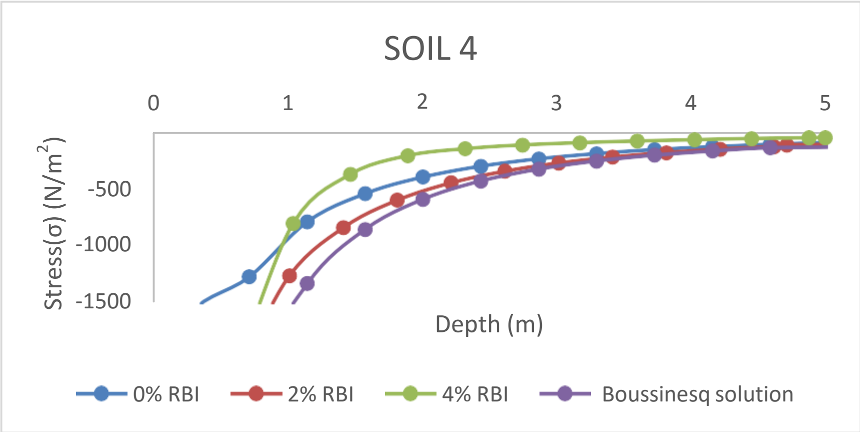

Fig.13 Variation of vertical stress (σ) with the depth of pavement (m)

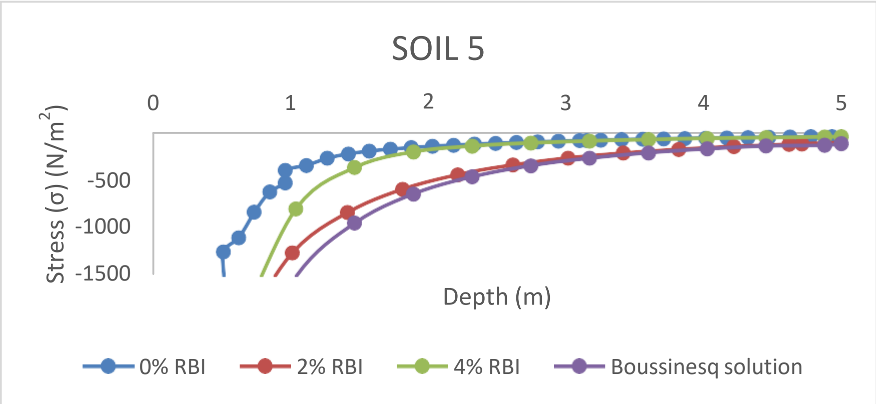

Fig.14 Variation of vertical stress (σ) with the depth of pavement (m)

From Figures 10 through 14, it can be observed that the variation of depth of pavement with the vertical stress is following the same trend as like Boussinesq stress theory i.e at the surface of the pavement layer there is more stress concentration compared to a higher depth of pavement and then it found to be constant. The FEM analysis through the Abaqus software is validated for the present experimental study.

From Figures 10 through 14, it can be also observed that the addition of RBI Grade 81 is advantageous when compared with the natural existing soil layer (0% RBI) i.e for 2% RBI mix there was a drastic amount of decrease in stress concentration on the surface depths when compared with natural existing soil layer without RBI mix.

5 Conclusions

Based on the detailed experimental and analytical study, the following conclusions were made

- The plastic limit of soil has a better correlation with compaction characteristics than the liquid limit of the soil.
- The values of CBR are increased with an increase in the percentage of RBI irrespective of soil clay mineralogy.
- The variation of the Depth of pavement to the vertical stress is following the same trend as the Boussinesq stress theory through FEM Analysis.
- Three is a drastic amount of decrease in stress concentration was observed with 2% RBI mix on the surface depths when compared with the natural existing soil layer without RBI mix through FEM Analysis.

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