PERFORMANCE OF CLAYEY AND SANDY SUBGRADE SOIL STABILISED WITH RBI GRADE 81

Abstract

The performance and longevity of roads are greatly influenced by the characteristics of the underlying subgrade soil. Unstable subgrades often pose challenges due to their inherently weak mechanical properties, leading to suboptimal pavement performance. To address these challenges, soil stabilization techniques have been widely implemented to enhance the engineering parameters of the subgrade. Among various stabilizers, RBI Grade 81 has gained significant attention as a promising solution to enhance the performance of weak subgrade soils. The present study investigates the efficacy of RBI Grade 81 in stabilizing both clayey and sandy subgrade soils. A comprehensive series of laboratory experiments were conducted to analyze the engineering properties, including Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR) of the stabilized subgrade soils. The findings of this study reveal that the incorporation of RBI Grade 81 at 2, 4 and 6% to both clayey and sandy subgrade soils resulted in significant improvements in compaction characteristics and CBR values. Furthermore, the paper discusses the effect of different curing periods on the subgrade soils' behaviour. It identifies the optimal RBI Grade 81 dosage required to achieve maximum benefits in terms of soil stabilization and presents a correlation between the stabilizer content and the corresponding mechanical properties. In conclusion, RBI Grade 81, has been proven to be a promising stabilizer for improving subgrade strength and durability.

Keywords: Clayey subgrade; Sandy subgrade; Compaction characteristics; CBR; RBI Grade 81.

Authors

Arijit Kumar Banerji
Department of Civil Engineering
Dr. B. C. Roy Engineering College
Durgapur, India

Md. Hamjala Alam
Department of Civil Engineering
Dr. B. C. Roy Engineering College
Durgapur, India

Chanchal Das
Department of Civil Engineering
Dr. B. C. Roy Engineering College
Durgapur, India

Koyndrik Bhattacharjee
Department of Civil Engineering
Dr. B. C. Roy Engineering College
Durgapur, India
koyndrik.bhattacharjee@bcrec.ac.in

Satabdi Saha
Department of Civil Engineering
Elitte College of Engineering
Kolkata, India

I. INTRODUCTION

The subgrade is the natural soil layer on which the pavement structure is built. It provides a solid foundation for the pavement layers above, distributing loads effectively and mitigating the detrimental effects of traffic-induced stresses and environmental factors. A subgrade with high strength has the ability to withstand greater loads without experiencing deformation or fracture. Consequently, the likelihood of pavement experiencing rutting, potholes, and other types of damage will be reduced. In contrast, a subgrade with low strength exhibits a higher propensity for deformation when subjected to applied loads, hence increasing the risk of premature deterioration of the pavement structure. Several variables can influence the stability of the subgrade, such as the soil composition, moisture levels, and the existence of underlying bedrock [1]. By implementing measures to enhance the subgrade's stability, engineers can contribute to the longevity of pavements and reduce the need for frequent maintenance.

In the majority of conditions, it is observed that in-situ soil lacks the ability to withstand the imposed traffic loads, resulting in the failure of roads mostly attributed to inadequate soil subgrade conditions [2]. In general, soils that are characterized by a higher proportion of sand or gravel particles have greater strength compared to soils with higher clay content. The significance of sandy soil subgrade in the context of highway pavements lies in its ability to withstand higher loads without experiencing deformation, in contrast to alternative soil types like clayey soil. Sandy soils typically exhibit favorable drainage characteristics, facilitating rapid percolation of water through the soil [3]. The implementation of an effective drainage system serves to mitigate the likelihood of water collection and subsequently decreases the possibility of subgrade deterioration or frost heave in freezing weather conditions. In addition, it is worth noting that sandy soils frequently demonstrate a notable capacity to withstand heavy loads and a reduced tendency to undergo shrinkage and swelling. These characteristics contribute to the provision of reliable and consistent support to the upper layers of pavement. Whereas, the distinctive properties of clayey subgrade soils have been widely recognized for their detrimental effects on structures and roadway pavements [4]. These soils have a high shrink-swell potential, which leads to significant volume changes with variations in moisture content, exerting tremendous pressure on structures and pavements. Additionally, their poor drainage properties result in water accumulation, weakening the subgrade's load-bearing capacity and causing deformation under building and traffic loads. Clayey soils are characterized by their low bearing capacity and compaction challenges, which therefore lead to uneven settlement and pavement deterioration [5]. Their sensitivity to moisture and frost susceptibility further exacerbate the problem. In order to avoid these problems, these soils must be stabilized in advance of the start of construction.

Various types of soil stabilization methods are utilized, depending on the specific soil conditions and project requirements [1]. Mechanical stabilization involves adding aggregates or other materials to enrich the load-bearing ability of the soil. Chemical stabilization uses additives like lime, cement, or fly ash to alter the soil's properties and increase its strength. Additionally, soil stabilization through geo-synthetics, such as geo-grids and geotextiles, improves soil reinforcement and prevents differential settlement. The importance of soil stabilization lies in its ability to create a strong and stable foundation, reducing the risk of pavement deformations, cracks, and other structural failures [6].

In recent times, research professionals have shown interest in RBI Grade 81 as a leading stabilizer [5-16]. The RBI Grade 81 is patented globally, including in India. It is a soil stabilizer produced by Road Building International as part of the Make in India initiative. The utilization of this stabilizing agent promotes expedited application times, as the road can be made accessible to vehicular traffic within a 24-hour timeframe subsequent to the completion of compaction [7]. Additionally, it offers the advantage of a surface that is devoid of dust particles. The implementation of this stabilization approach has the potential to yield a significant reduction of approximately 30-40% in construction expenses [8]. Additionally, the adoption of this method has demonstrated a noteworthy reduction of approximately 60% in transportation and earth movement expenditures [9].

It is also noticed from the literature [5-12] that RBI Grade 81 has been used in a variety of soil stabilization applications, including subgrades in highway construction projects, embankments and retaining walls, airfield construction projects, etc. It is a specialized stabilizer with several advantages in road building and soil stabilization applications. Firstly, it improves the load-bearing capacity of weak or substandard soils, making them suitable for supporting heavy traffic loads and pavement structures [10-12]. Secondly, RBI Grade 81 helps in reducing the permeability of soils, enhancing their resistance to water penetration. This feature is crucial in areas with high rainfall or where poor drainage is a concern, as it helps prevent water-related damage, such as erosion and pavement deterioration [11-14]. Moreover, it minimizes the volume changes in the subgrade caused by freezing and thawing cycles, thereby preserving the stability of the road and preventing frost-related damages. Some researchers [6-11] found that RBI Grade 81 enhances the compressive strength (UCS) of clayey soils. The rise in UCS is positively correlated with the increase in the content of stabilizers. The statistical analysis revealed a significant relationship at a significance level of 6% for RBI [6]. Furthermore, many past studies [8-13] found that RBI Grade 81 improves the California Bearing Ratio (CBR). The incorporation of RBI Grade 81 at an amount of 8% led to a substantial rise in the CBR of the subgrade, exhibiting an enhancement of approximately 3.5 times when related to the unmodified subgrade [6]. However, a considerable alteration in the soaked CBR was observed when using RBI Grade 81 above 6%. The application of RBI Grade 81 has been seen to lead to a decrease in the Plasticity Index (PI) [12-16]. The additional application of the stabilizer dosage led to a notable decrease in the liquid limit. The goal of this study is to study the impact of RBI Grade 81 on the strength characteristics of soil subgrades, as indicated by the literature reviews mentioned earlier. A sequence of geotechnical laboratory experiments was accompanied to assess the impact of various RBI Grade 81 percentages. The conducted tests consisted of the investigation of index characteristics, standard compaction, and the CBR test. Additional information regarding the investigation is provided in the subsequent sections.

II. MATERIALS USED

1. **Subgrade Soil:** Subgrade soil refers to the natural soil layer underlying the pavement and provides the foundation upon which the road structure rests. The soil samples utilized in this investigation were obtained from the Fuljhore site (23.53°N, 87.33°E), Durgapur, West Bengal; and Jaydev (23.64°N, 87.43°E), Birbhum district, West Bengal. Soil samples are obtained through the excavation of trial pits. The region is predominantly characterized by the presence of mixed soil, which has a relatively variable bearing capacity.The soil sample underwent a comprehensive pulverization process within a large

tray to disintegrate any clumps present. Subsequently, the sample was subjected to oven drying at 110°C for 24 hours, thereby eliminating all moisture content within the soil. The geotechnical behaviour of the soil is presented in Table 1. Based on the classification criteria outlined in IS 1498-1970 [17], the analysis of Table 1 reveals that the soil sample of the Fuljhore site can be identified as silty clay and the soil sample of the Jaydev area (located on the banks of Ajay River) as sandy soil.

Table 1: Geotechnical Behaviour of Subgrade Soil

Parameters (units)	Sample 1 (Fuljhore site) Values	Sample 2 (Jaydev) Values
Particle size distribution		
Gravel (%)	00	03
Sand (%)	08	70
Clay (%)	52	08
Silt (%)	40	19
Physical Properties		
Liquid Limit (%)	47.4	8
Plastic Limit (%)	21.8	5.1
Plasticity Index (%)	25.6	2.9
Maximum Dry Density (g/cm^3)	1.77	1.67
Optimum moisture content (%)	15.8	14.1
CBR (Soaked) %	4.3	16.9
Cohesion (kPa)	42	12

2. **RBI Grade 81:** RBI Grade 81 is a proprietary cementitious modifier [18-19] that is used to enhance the stability of the subgrade. Table 2 provides an overview of the properties of RBI Grade 81 [6]. It consists of calcium oxide, silica, and alumina and appears as a fine grey particle. RBI Grade 81 reacts with water to create a matrix that binds the soil particles together. This reaction takes place over a period of time, so it is important to allow the RBI Grade 81 to cure properly before using the soil.

Table 2: Characteristics of RBI Grade 81

Physical Characteristics	
Specific gravity	2.6
Appearance	Grey colour
Bulk Density	1.4 g/cm3
% passing through 75 µ	97
Residue at 105℃	99.3 (loss on ignition at 105℃ 0.7%
Chemical Characteristics	
$NaHCo_3$	95

kcl	4
Ca	25-45
Si	5-20
Mg	5-10
Fe	2-5
K	2-5
$CaSo_4.2H_2O$	58

III. EXPERIMENTAL PROGRAM

Various laboratory investigations were performed in accordance with the IS codes. Three distinct percentages of RBI Grade 81, specifically 2%, 4%, and 6% are combined with two types of soil samples. The grain size analysis test is conducted following the guidelines provided in IS: 2720 (Part 4)-1985 [20]. This test helps to classify the soil based on its grain size and provides valuable information about the behaviour of soil. The grain size distribution test provides information about the proportion of different particle sizes present in the soil sample. The mineralogical investigation included identifying and quantifying key components, such as clay minerals, quartz, feldspar, and other constituents present in the soil by using the technique of X-ray diffraction (XRD) analysis [21]. In this test, the soil specimen is exposed to X-ray radiation. The collected soil sample is dried and finely ground to a powder. This powder is homogenized to ensure that the XRD analysis provides an accurate representation of the soil's mineral composition. When the X-rays interact with the crystalline structure of minerals in the soil, they are diffracted at specific angles, producing a diffraction pattern. By analyzing the angles and intensities of these diffraction peaks, the mineral composition of the soil can be identified and quantified. The results of the XRD analysis are typically reported as a mineral composition chart, listing the identified minerals and their estimated proportions in the soil sample. The mineral composition directly influences the soil's strength, compressibility, and permeability, which are crucial factors in pavement design and foundation engineering. Moreover, XRD analysis helps to identify expansive clay minerals, which can be responsible for soil swelling and volume changes under varying moisture conditions. This technique relies on the unique diffraction patterns exhibited by different minerals, allowing for the precise determination of mineral composition.

In the tests conducted, the key tests include the soil index properties which determine the liquid limit (LL) and plastic limit (PL) in accordance with the Indian Standard (IS) code 2720 (Part 5)-1985 [22]. The liquid limit provides valuable information about the soil's consistency and its tendency to deform under varying moisture conditions. The plastic limit indicates the minimum moisture content at which the soil can be moulded into a specific shape without breaking apart. It is a critical parameter for understanding the soil's plasticity and its potential for deformation under stress.

The Compaction Test was conducted in accordance with the specifications outlined in IS: 2720 (Part 7)-1980 [23]. The experiment involves changing the moisture content of the soil across multiple compaction trials in order to determine the moisture content that yields the maximum dry density (MDD). The optimum moisture content (OMC) is the moisture level at which the soil achieves its maximum dry density.The OMC is a critical parameter for construction projects, as it guides engineers to achieve the optimal moisture content for compaction, resulting in better soil compaction and engineering properties.

Figure 1: Soaked CBR Test setup.

The CBR test evaluates the subgrade's strength and load-bearing capacity, essential for pavement design. The CBR test is crucial in pavement design and construction, as it helps engineers determine the appropriate thickness and type of pavement layers needed to distribute traffic loads effectively and prevent pavement failure. It also aids in evaluating the potential for subgrade deformation and rutting under traffic loads. The CBR test was performed following the guidelines outlined in the IS 2720 (Part 16)-1987 [24]. During the CBR test, a soil sample is compacted and then subjected to incremental loads. The test measures the penetration resistance of the soil. Furthermore, the 4-day soaked CBR test took into account three different curing periods, in particular 1, 4, and 7 days. CBR tests conducted with soaked specimens (Figure 1) aim to replicate the subgrade conditions experienced in the field during periods of rainfall. However, the subgrade may not remain continuously soaked. By allowing the soil samples to air dry for different periods before testing, engineers can assess the effect of residual moisture on the CBR value. This helps in understanding how the CBR changes under varying moisture conditions, which is crucial for accurate pavement design and construction.

IV. DISCUSSION AND DISCUSSION

1. Mineralogy

- **X-ray Diffraction (XRD) Analysis*:*** The XRD analysis results are typically presented as a graph, with the x-axis representing the diffraction angles (2θ) and the y-axis indicating the intensity of the diffracted X-rays. The identification and quantification of minerals in a soil sample are accomplished by utilizing the positions and intensities of the diffraction patterns[25]. The primary mineral in soil sample 1 was quartz, accounting for 55% of the composition. Following quartz, kaolinite comprised 34% of the soil, while chlorite and Illite made up the remaining 11%. In contrast, soil sample

2 exhibited a higher percentage of quartz at 62%, with feldspar accounting for 26% of the composition.

Additionally, carbonates were present in the soil sample at a concentration of 4%, while Illite comprised 8% of the composition. Among them, quartz is a mineral with a crystalline structure, primarily consisting of silicon dioxide. Kaolinite is a clay mineral that is composed of silicon, oxygen, and aluminium. Feldspar is a group of minerals that are composed of silicon, oxygen, aluminium, and potassium. It is a common mineral in sandy soil that has been weathered from igneous rocks. Carbonate is a common mineral in sandy soil that has been weathered from limestone rocks. Illite is a clay mineral that is composed of silicon, oxygen, aluminium, and potassium. It is a non-swelling clay, which means that it does not absorb a large amount of water and expands in volume.

The observed points in the XRD pattern of clayey-silt soil can be attributed to the distinct clay and silt minerals that are found within the soil matrix. Conversely, the peaks observed in the XRD pattern of sandy soil can be attributed to the various non-clay minerals that are present in the soil composition. Soil sample 1 (clayey-silt) with a high quartz content shows a strong peak for quartz at a 2θ angle of 26.7°. Soil sample 2 (sandy soil) with a high quartz content shows a strong peak for quartz at a 2θ angle of 26.7° (Figure 2). Furthermore, the combination of quartz with cement in the presence of water initiates the production of the hydration process. The prevalence of quartz within the soil enhances its ability to withstand weathering due to its inherent durability.

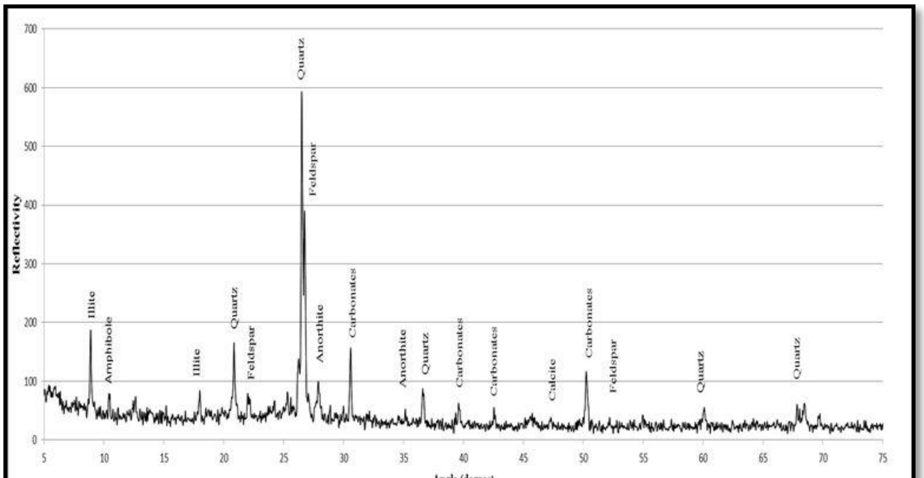

Figure 2: XRD Results of Sandy soil.

2. **Liquid Limit and Plastic Limit:** Figure 3 depicts the correlation between the Atterberg limits and RBI Grade 81. The Atterberg limit test is a laboratory test used to determine the plastic and liquid limits of soil. The addition of RBI Grade 81 to clayey soil leads to a reduction in the liquid limit, but the plastic limit shows a nearly linear increase. This matrix makes the soil less plastic and more likely to break down when it is wet. The

observed reduction in the liquid limit of clayey soil upon the addition of RBI Grade 81 can be regarded as a positive advancement, as it imparts less propensity for the soil. Nevertheless, the incorporation of RBI Grade 81 into sandy soil results in a marginal increase of the Atterberg limits of the soil. This is because RBI Grade 81 reacts with water to form a hard, durable matrix that binds the soil particles together [12-16]. This matrix makes the soil more cohesive and less likely to flow. The increase in the Atterberg limits of sandy soil with RBI Grade 81 is a positive development because it makes the soil more stable and less likely to flow. This can be beneficial for a variety of applications, such as road construction and earthworks. The increase was most pronounced at the 6% dosage level.

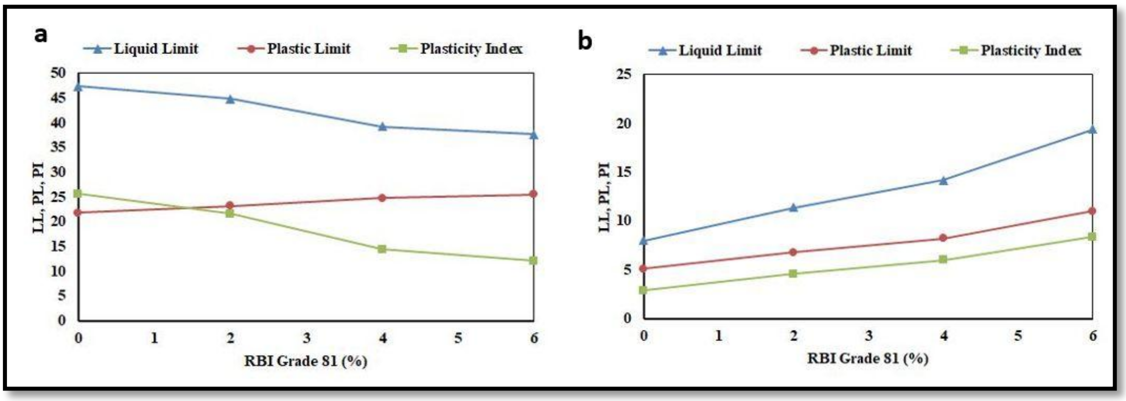

Figure 3: Effect of RBI Grade 81 on LL, Pl and PI of (a) Clayey soil; and (b) Sandy soil.

3. **Compaction Characteristics:** Compaction characterization is a critical aspect of soil engineering, as it provides essential information for constructing stable and durable pavement structures on soil subgrade [6-9]. The OMC and MDD of soil are two important properties that affect the engineering behaviour of the subgrade [2]. Figure 4 displays the presentation of OMC and MDD variations with respect to RBI Grade 81. The findings of the study revealed that the incorporation of RBI Grade 81 into the clayey soil resulted in a notable influence on its OMC. The values of MDD range from 1.77 to 1.86 g/cm^3, while the values of OMC range from 15.8 to 14.5%. The presence of the stabilizer reduces the OMC compared to the unmodified clayey soil. This means that with the appropriate amount of RBI Grade 81, the clayey soil can achieve maximum compaction at a lower moisture content. As a result, the mixture becomes more workable and easier to handle during construction. Moreover, the incorporation of RBI Grade 81 into sandy soil yields beneficial outcomes in terms of the OMC and MDD. This is because RBI Grade 81 reacts with water to form a hard mix that binds the soil particles together. The values of MDD range from 1.67 to 1.77 g/cm^3, while the values of OMC range from 14.1 to 12.9%. This matrix makes the soil more cohesive and less likely to collapse, which results in a higher MDD and a lower OMC. The observed increase in the MDD and decline in the optimum moisture content OMC of sandy soil treated with RBI Grade 81 can be regarded as a positive improvement, as it contributes to enhanced soil stability and reduced susceptibility to collapse.

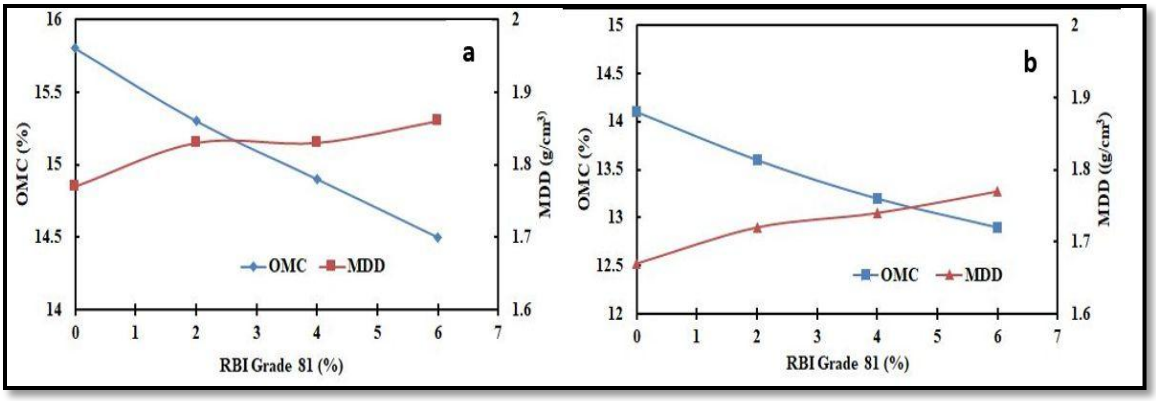

Figure 4: Effect of RBI Grade 81 on Compaction characteristics of (a) Clayey soil; and (b) Sandy soil.

4. **California Bearing Ratio (CBR):** CBR is a metric used to assess the load-bearing capacity of the subgrade layer. A higher CBR value indicates that the soil is more capable of supporting load [6-12]. This property is critical for pavement design and construction. Figures 5 and 6 display the findings of the CBR for different proportions of RBI Grade 81 mixes. The CBR test was conducted by creating soil specimens that were blended with different proportions of RBI Grade 81, typically at proportions of 2, 4, and 6%. An observation was made indicating a positive correlation between the proportion of RBI Grade 81 and the CBR value of the stabilized soil. The clayey soil exhibited a significant rise in its CBR value, with factoring of 3.8, as it increased from 4.3 to 16.6. In the same way, it was observed that the CBR value for sandy soil exhibited a significant increase of 3.4 times, that is from 16.9 to 57.1. Additionally, the utilization of RBI Grade 81 as a modifier has been found to enhance the CBR of the subgrade over various periods of curing as shown in Figures 5 and 6.

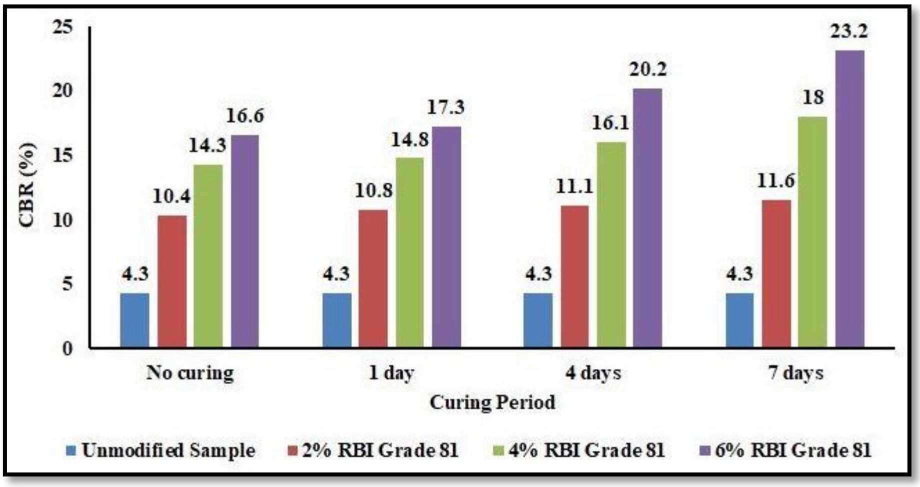

Figure 5: Outcome of RBI Grade 81 on CBR of Clayey soil.

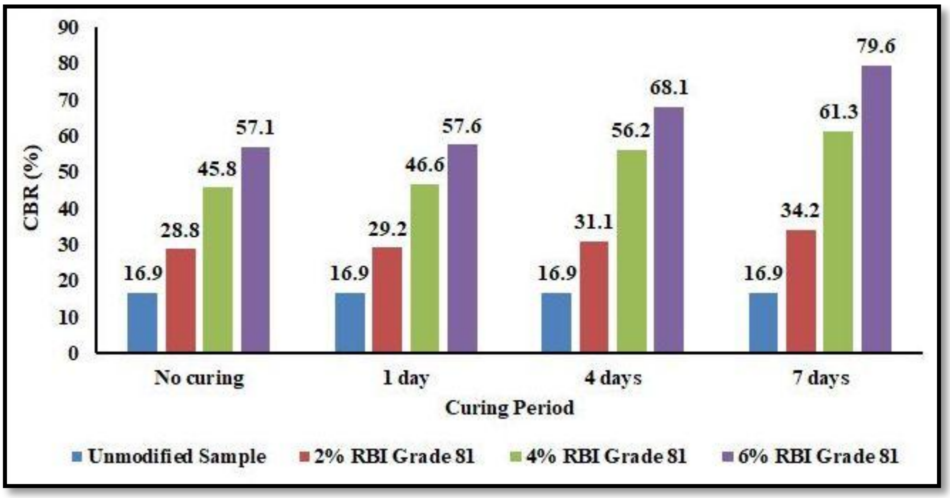

Figure 6: Outcome of RBI Grade 81 on CBR of Sandy soil.

The maximum CBR after 7 days of curing was found to be 23.2% at 6% RBI content, giving an increase of 123% from 10.4% CBR at 2% RBI content. The improvement in the CBR value exhibits a more notable trend when considering higher proportions of RBI grade 81. The CBR value of the soil, when treated with 6% RBI grade 81, exhibited a rise from 16.6% to 23.2% after a curing period of 7 days, in comparison to the soil treated with 2% RBI grade 81 (i.e. from 16.6% to 23.2%). Likewise, the results have shown that the CBR value of RBI grade 81 stabilized sandy soil positively correlates with the duration of the curing time. The maximum CBR after 7 days of curing was found to be 79.6 % giving an increase of 176% from 28.8% CBR. The addition of 6% RBI grade 81 to the sandy soil significantly increased the CBR value. Specifically, the CBR value increased from 57.1% to 79.6% after a curing time of 7 days. In contrast, the soil treated with 2% RBI grade 81 showed a smaller increase in CBR value, from 28.8% to 34.2%. As the curing period increases, the cementitious properties of RBI Grade 81 develop, leading to increased strength and improved soil stabilization. The improvement in CBR is due to the pozzolanic reaction that occurs when RBI Grade 81 is mixed with water. This reaction is very strong and they provide a strong bond between the soil particles. During the pozzolanic reaction, more C-S-H gels are formed when a higher proportion of RBI grade 81 is applied. The improved durability and rigidity of the stabilized soil can be attributed to the presence of C-S-H gels. The increased CBR value indicates that the stabilized subgrade would be better able to support the traffic loads and withstand adverse weather conditions, making it more suitable for highway pavement construction.

V. CONCLUSIONS

The performance of clayey and sandy subgrade soil stabilized with RBI Grade 81 shows promising results in improving the geotechnical parameters of both soil types. The stabilizer promotes better interlocking and cohesion among particles. On the other hand, sandy subgrade soils, known for their good drainage but lower cohesion, experience notable enhancements in stability and load-bearing capacity after stabilization with RBI Grade 81. The MDD has exhibited an increase when the amount of RBI Grade 81 has been increased, while the OMC has shown a decrease. The addition of the stabilizer to sandy soil results in improved CBR values, suggesting better support for traffic loads and enhanced pavement performance. In both clayey and sandy soil stabilized with RBI Grade 81, the CBR value is affected by the proportion of the stabilizer used and the duration curing process. Increasing the percentage of RBI Grade 81 generally improves the CBR value up to optimal content of 6%. Additionally, longer curing periods promote better soil stabilization and, consequently, higher CBR values.

This finding opens avenues for the application of RBI Grade 81 as a viable modifier in geotechnical engineering, particularly in enhancing the performance and durability of road infrastructures and construction projects. However, further research and field trials are essential to fully explore the performance in different environmental and loading conditions. The effectiveness of RBI Grade 81 may also depend on various factors, including the optimal dosage, curing time, and specific soil properties.

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