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Review Article

Subgrade Soil Stabilization Using Various Fibrous Materials and Evaluation of Strength Using CBR: A Review

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***Abstract -** This study explores the effectiveness of subgrade soil stabilization using fibrous materials, with a particular focus on evaluating soil strength through the California Bearing Ratio (CBR) test. A comprehensive literature review was conducted to summarize the existing research on soil stabilization methods, the use of fibrous materials, and the significance of the CBR test in soil engineering. Key findings from the literature review highlighted the promising potential of fibrous materials, both natural and synthetic, in enhancing soil stability and load-bearing capacity. However, gaps and limitations in the current literature, such as inconsistencies in methodologies and the need for long-term performance studies, were identified, indicating areas for further research. Building upon the insights gained from the literature review, this study presents experimental investigations into subgrade soil stabilization using fibrous materials and CBR evaluation. Laboratory experiments were conducted to assess the effectiveness of various fibrous materials in improving soil properties, including shear strength and cohesion. The CBR test was employed to evaluate soil strength before and after stabilization, providing valuable insights into the performance of stabilization treatments. The findings of this study contribute to the understanding of soil stabilization techniques and evaluation methods, offering insights into the selection and application of fibrous materials for soil improvement. Moreover, this study highlights the importance of considering factors such as fiber type, distribution, and soil characteristics in stabilization treatments. Overall, this research provides a foundation for further studies aimed at optimizing soil stabilization techniques and enhancing the sustainability and resilience of infrastructure systems.*

***Keywords -** Subgrade soil stabilization, Fibrous materials, California Bearing Ratio (CBR) test, Soil engineering, Pavement engineering, Fibrous materials.*

1. Introduction

This literature review serves as a critical examination of previous research within the domain of subgrade soil stabilization and the application of fibrous materials. Its purpose is to provide a comprehensive overview of existing knowledge, trends, and findings in this field. By delving into past studies, researchers can gain insights into the historical context and current state of soil stabilization techniques, including the effectiveness of various fibrous materials in improving soil properties. This thorough analysis enables researchers to identify gaps, inconsistencies, and areas requiring further investigation, thus guiding the direction of future research. Moreover, the literature review elucidates the importance of reviewing the literature, emphasizing its role in informing decision-making processes and fostering innovation. Subgrade soil stabilization has always been a problem for road construction where the bearing capacity of the soil is not adequate. As we know, the different parts of India have different soil properties. Hence, in locations where soil-bearing capacity is not adequate, it has always been a challenge for the construction of roadways. Hence, various types of soil stabilization techniques have been evolved to enhance the stability and bearing capacity of the subgrade soil, such as lime, flyash, cement, stone dust, etc. Specifically, this study aimed to assess the efficacy of different soil stabilization methods, with a focus on fibrous material utilization, and to evaluate the applicability of the California Bearing Ratio (CBR) test in assessing soil strength.

Overall, the objectives of the literature review are multifaceted: to synthesize previous findings, highlight key insights, and delineate pathways for advancing knowledge and practice in subgrade soil stabilization.

2. Subgrade Soil Stabilization Methods

The exploration of subgrade soil stabilization methods encompasses a wide spectrum of traditional techniques and recent innovations [1]. Traditionally, soil stabilization has relied on methods such as chemical stabilization, involving the addition of lime, cement, or other chemical agents to improve soil properties, and mechanical stabilization, which entails compaction or reinforcement through techniques such as soil nailing or geogrid installation [2]. These methods have been widely employed and studied, offering established approaches to enhancing soil strength and durability for construction projects [3]. However, recent advancements in soil stabilization have introduced new techniques and materials, including the use of fibrous materials such as natural or synthetic fibers [4]. These materials offer promising alternatives for improving soil stability, with potential benefits such as increased tensile strength and reduced environmental impact compared to traditional methods [5]. Despite these advancements, each stabilization method has its advantages and limitations. Chemical stabilization, for instance, can be effective in a variety of soil types but may pose environmental concerns and require careful handling of chemicals [6]. Mechanical stabilization methods, while providing immediate results, may be limited in their long-term effectiveness or suitability for certain soil conditions [7]. Therefore, a comprehensive understanding of the advantages and limitations of different stabilization methods is essential for selecting the most appropriate approach for addressing specific soil stabilization challenges [8]. Figure 1 provides an overview of subgrade soil stabilization methods, while Table 1 details advancements in subgrade soil stabilization techniques.

3. Use of Fibrous Materials in Soil Stabilization

The utilization of fibrous materials in soil stabilization represents an innovative approach aimed at enhancing the engineering properties of soil [9]. Fibrous materials, including both natural fibers such as jute, coir, or sisal and synthetic fibers such as polypropylene or polyester, are incorporated into the soil to reinforce its structure and improve its stability [10]. Numerous studies have investigated the effectiveness of these fibrous materials in soil stabilization, assessing their impact on factors such as shear strength, cohesion, and permeability. Research findings have highlighted the potential of fibrous materials to enhance soil performance and mitigate issues such as erosion, settlement, and pavement distress [11]. The mechanisms through which fibrous materials improve soil properties vary depending on factors such as fiber type, length, and orientation within the soil matrix [12]. Natural fibers, for instance, may enhance soil cohesion through interlocking mechanisms, while synthetic fibers contribute to increased tensile strength and reduced crack propagation. Additionally, fibrous materials can enhance soil–water interactions, promote better drainage and reduce the risk of water-induced damage. Overall, the use of fibrous materials in soil stabilization offers a promising avenue for addressing soil instability and improving the sustainability of construction projects [13]. Table 2 shows a comprehensive analysis of fibrous materials used for soil stabilization, showing the engineering performance, properties, advantages, and disadvantages of various fibrous materials commonly used for stabilizing soil in construction projects.

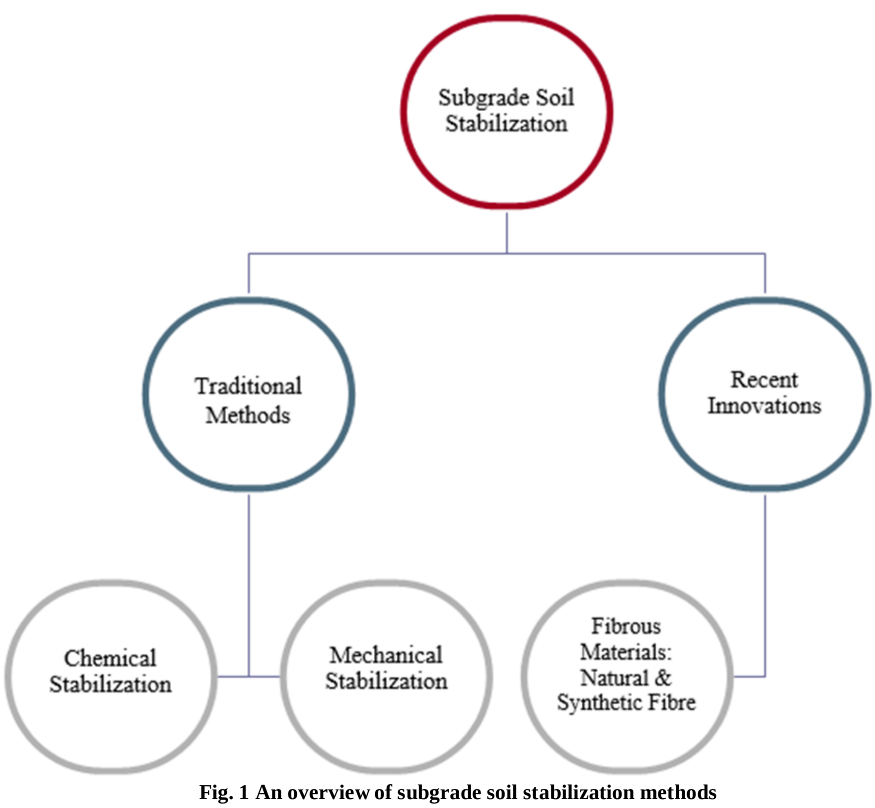

Fig. 1 An overview of subgrade soil stabilization methods

Table 1. An overview of the advancements for subgrade soil stabilization

Aspect	Description	Traditional Methods	Benefits	Recent Innovations	Limitations	References
Methods	Traditional techniques and recent innovations	Chemical stabilization: Addition of lime, cement, or other chemical agents. Mechanical stabilization: Compaction or reinforcement (e.g., soil nailing, geogrid installation).	Established approaches to enhancing soil strength and durability for construction projects	Introduction of new techniques and materials, including fibrous materials like natural or synthetic fibers.	Each stabilization method presents its own set of advantages and limitations.	[1, 2, 3]
Benefits	Established approaches to enhancing soil strength and durability for construction projects.	-	Increased tensile strength reduced environmental impact compared to traditional methods.	-	-	[4, 5]
Limitations	Each stabilization method presents its own set of advantages and limitations.	-	-	-	-	[6]
Chemical Stabilization	It is effective in various soil types but may pose environmental concerns and require careful handling of chemicals.	Addition of lime, cement, or other chemical agents	-	-	It may pose environmental concerns and require careful handling of chemicals.	[7]
Mechanical Stabilization	It provides immediate results but may have limited long-term effectiveness or suitability for certain soil conditions.	Compaction or reinforcement (e.g., soil nailing, geogrid installation)	-	-	It may have limited long-term effectiveness or suitability for certain soil conditions.	[8, 9]

Table 2. Comprehensive analysis of the effects of fibrous materials on soil stabilization

Aspect	Description	Natural Fibers	Synthetic Fibers	Enhanced Soil-Water Interactions	Overall Impact	References
Utilization of Fibrous Materials	Represents an innovative approach aimed at enhancing the engineering properties of soil.	-	-	-	It offers a promising avenue for addressing soil instability and improving the sustainability of construction projects.	[9]
Types of Fibrous Materials	Natural fibers such as jute, coir, or sisal Synthetic fibers like polypropylene or polyester.	Jute, coir, sisal	Polypropylene, polyester	-	-	-
Effectiveness of Fibrous Materials	Numerous studies have investigated their impact on factors such as shear strength, cohesion, and permeability.	-	-	-	-	[11]
Benefits of Fibrous Materials	Highlighted potential to enhance soil performance and mitigate issues such as erosion, settlement, and pavement distress.	-	-	-	-	[11, 12]
Mechanisms of Improvement	Varies depending on factors such as fiber type, length, and orientation within the soil matrix.	Enhance soil cohesion	Contribute to increased tensile strength and reduced crack propagation.	Promote better drainage and reduce the risk of water-induced damage.	-	[13]

4. California Bearing Ratio (CBR) Test

The California Bearing Ratio (CBR) test is a fundamental tool in soil engineering for assessing the strength and load-bearing capacity of soils, particularly those intended for road and pavement construction [14]. This test involves subjecting a soil sample to penetration by a standard piston, measuring the resistance encountered at different depths.

The significance of the CBR test lies in its ability to provide engineers with crucial insights into soil behavior under load, aiding in the design and construction of durable and safe infrastructure [15]. A comprehensive review of the literature pertaining to the CBR test reveals its widespread application across various soil types and engineering projects [16].

Studies have explored its utility in assessing subgrade soil conditions, pavement design, and the effectiveness of soil stabilization techniques. Moreover, a significant body of research has focused on comparing CBR values between stabilized and nonstabilized soils, elucidating the impact of stabilization methods on soil strength and load-bearing capacity [17]. These comparative studies contribute valuable insights into the efficacy of soil stabilization techniques and assist engineers in making informed decisions regarding soil improvement strategies. Overall, the CBR test serves as a cornerstone in soil engineering, facilitating the evaluation and characterization of soil properties essential for successful construction projects [18]. Table 3, overview of California Bearing Ratio (CBR) Test in Soil Engineering, summarizing the significance, procedure, utility, and insights provided by the CBR test in assessing soil strength and load-bearing capacity for construction projects.

5. Studies on Subgrade Soil Stabilization Using Fibrous Materials and CBR Evaluation

Studies investigating subgrade soil stabilization using fibrous materials and CBR evaluation have contributed significantly to the understanding of this field [19]. A summary of relevant research articles, conference papers, and reports reveals a growing body of literature dedicated to this topic. These studies encompass a range of methodologies, including laboratory experiments, field trials, and numerical modeling, aimed at evaluating the effectiveness of fibrous materials in improving soil stability and strength [20]. Key findings from these studies indicate that the incorporation of fibrous materials, both natural and synthetic, leads to notable enhancements in soil properties such as shear strength, cohesion, and resistance to deformation [21]. Moreover, comparative analyses of the CBRs of stabilized and nonstabilized soils demonstrate the positive impact of fibrous material reinforcement on the soil load-bearing capacity [22]. The methodologies employed in these studies vary, with some focusing on direct measurement of soil parameters through laboratory tests, while others utilizing field data or computational simulations to assess performance under real-world conditions [23]. The outcomes reported in the literature underscore the importance of considering factors such as fiber type, content, and distribution within the soil matrix when designing stabilization treatments. Additionally, studies highlight the need for further research to optimize fiber selection and application methods for specific soil types and engineering applications [24]. Overall, the synthesis of findings from studies on subgrade soil stabilization using fibrous materials and CBR evaluation provides valuable insights into the potential benefits and challenges associated with this approach, informing future research directions and practical applications in soil engineering [25].

In the realm of soil stabilization, various natural fibrous materials play pivotal roles, each with distinct engineering performances, properties, advantages, and disadvantages [26]. Jute, known for its high tensile strength and biodegradability, offers an eco-friendly solution for soil reinforcement [27]. However, it is susceptible to decay under prolonged wet conditions. Coir, with its excellent water absorption and structural support capabilities, enhances soil stability and promotes vegetation growth, yet it may compact over time and require replacement [28]. The durability and resistance of sisal boasts to decay, which results in long-lasting soil stabilization, although its availability may be limited in certain regions. Hemp, characterized by high tensile strength and eco-friendly properties, is versatile in promoting sustainable land management, but regulatory constraints may pose challenges in some areas [29].

Flax, which offers good reinforcement properties and sustainability, improves soil structure and prevents erosion, albeit with limited availability in specific regions. Pineapple Leaf Fiber (PALF) enhances soil structure, reduces erosion and utilizes agricultural waste for sustainable farming, although processing may necessitate specialized equipment [30]. Kenaf, which has good tensile strength and moisture-absorbing properties, enhances soil stability in an eco-friendly manner, but its availability may be limited. With its high strength-to-weight ratio and renewable nature, bamboo is effective for soil stabilization but requires proper harvesting to avoid environmental impacts [31]. Wheat straw, which is lightweight and biodegradable, promotes vegetation growth but may attract pests and decompose relatively quickly [32]. Reeds, which are effective at enhancing soil structure and erosion control, may be invasive in some ecosystems and require management. These natural fibrous materials offer a spectrum of solutions for soil stabilization, each with unique benefits and considerations [33]. Table 4 is the Overview of natural fibrous materials for soil stabilization and their characteristics, showing the engineering properties, advantages, and disadvantages of various natural fibers commonly used in soil stabilization.

Table 3. Overview of California Bearing Ratio (CBR) tests in soil engineering

Aspect	Description	References
California Bearing Ratio (CBR)	A fundamental tool in soil engineering for assessing the strength and load-bearing capacity of soils, particularly for road and pavement construction.	[14]
Test Procedure	It involves subjecting a soil sample to penetration by a standard piston and measuring the resistance encountered at different depths.	[15]

Significance	Provides engineers with crucial insights into soil behavior under load, aiding in the design and construction of durable and safe infrastructure.	[15]
Literature Review	Reveals widespread application across various soil types and engineering projects.	[16]
Utility	Assessing subgrade soil conditions, pavement design, and the effectiveness of soil stabilization techniques	[17]
Comparative Studies	Focus on comparing CBR values between stabilized and unstabilized soils, elucidating the impact of stabilization methods on soil strength and load-bearing capacity.	[17]
Insights and Decision-Making	Contribute valuable insights into the efficacy of soil stabilization techniques and assist engineers in making informed decisions regarding soil improvement strategies.	[17]
Cornerstone of Soil Engineering	Facilitates the evaluation and characterization of soil properties essential for successful construction projects.	[18]

Table 4. Overview of natural fibrous materials for soil stabilization and their characteristics

Material	Engineering Performance	Properties	Advantages	Disadvantages	References
Jute	High tensile strength, biodegradability	Natural, renewable, affordable	Eco-friendly solution for soil reinforcement	Susceptible to decay in prolonged wet conditions	[27]
Coir	Excellent water absorption, structural support	Resistant to decay, renewable	Enhances soil stability and promotes vegetation growth	May compact over time, require replacement	[28]
Sisal	Durable, resistant to decay	Strong tensile strength, biodegradable	Long-lasting for soil stabilization	Limited availability in some regions	[26]
Hemp	High tensile strength, eco-friendly	Biodegradable, moisture-absorbing	Versatile in promoting sustainable land management	Regulatory constraints in some areas	[29]
Flax	Good reinforcement properties, sustainable	Natural, lightweight	It improves soil structure and prevents erosion	Limited availability in specific regions	[26]
Pineapple Leaf Fiber	Enhances soil structure, reduces erosion	Sustainable, biodegradable	Utilizes agricultural waste for sustainable farming, though processing may require equipment		[30]
Kenaf	Good tensile strength, moisture-absorbing	Renewable, lightweight	It enhances soil stability in an eco-friendly manner, but availability may be limited.		[26]
Bamboo	High strength-to-weight ratio, renewable	Durable, fast-growing	Effective in soil stabilization, but requires proper harvesting to avoid environmental impact		[31]
Wheat Straw	Lightweight, biodegradable	Abundant, renewable	Promotes vegetation growth but may attract pests and decompose relatively quickly		[32]
Reed	Enhances soil structure, erosion control	Natural, abundant	It is effective in stabilizing slopes but may be invasive in some ecosystems and requires management.		[26, 33]

6. Gaps and Limitations in Existing Literature

Although the literature on subgrade soil stabilization using fibrous materials and CBR evaluation offers valuable insights, several gaps and limitations are apparent. First, there is a need for more comprehensive studies that address a wider range of soil types and environmental conditions. Many existing studies have focused on specific soil types or regions, limiting the generalizability of their findings. Additionally, inconsistencies in terminology and methodologies across studies hinder direct comparisons and synthesis of results. This highlights the necessity for standardization of experimental protocols and reporting practices within the field. Furthermore, while numerous studies have investigated the effectiveness of fibrous materials in soil stabilization, the long-term performance and durability of stabilized soils under varying loading and environmental conditions are poorly understood. Longitudinal studies tracking the behavior of stabilized soils over extended periods would provide valuable insights into the sustainability and effectiveness of stabilization treatments. Moreover, limitations in current research methodologies, such as the reliance on laboratory-based tests rather than field-scale experiments, may not fully capture the complexities of real-world soil behavior. Addressing these limitations requires interdisciplinary approaches that integrate laboratory experiments, field trials, and computational modeling to provide a comprehensive understanding of soil stabilization processes. Finally, there is a need for further investigation into the economic feasibility and practical implementation of fibrous material stabilization techniques in engineering practice. Cost-benefit analyses and case studies comparing different stabilization methods could assist engineers and policymakers in making informed decisions regarding soil improvement strategies. Overall, addressing these gaps and limitations in the literature is essential for advancing knowledge and practice in subgrade soil stabilization and CBR evaluation, ultimately contributing to the development of more sustainable and resilient infrastructure systems.

7. Conclusion

In conclusion, this review paper provides a comprehensive examination of subgrade soil stabilization using fibrous materials and an evaluation of strength through the California Bearing Ratio (CBR) test. The key points covered include an overview of traditional and innovative soil stabilization methods, the application of fibrous materials in soil improvement, and the significance of the CBR test in assessing soil strength. This review highlighted the effectiveness of fibrous materials in enhancing soil stability and load-bearing capacity, as well as the importance of considering factors such as fiber type, distribution, and soil characteristics in stabilization treatments. Limitations in the literature, such as inconsistencies in methodologies and the need for long-term performance studies, were identified, underscoring areas for further research. The significance of this literature review lies in its contribution to the current study by providing a foundational understanding of soil stabilization techniques and evaluation methods. Moving forward, the methodology and findings sections of the current study will build upon the insights gleaned from this review, employing rigorous experimental protocols to investigate the effectiveness of fibrous material stabilization and CBR evaluation under specific soil conditions.

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