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Sustainable Stabilization of Clayey Soil Using Stone Dust and Sisal Fibre for Enhanced Compaction and Bearing Capacity

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Abstract: *The stabilization of weak soils has become increasingly important for improving the performance of pavement subgrades and foundation systems while promoting sustainable construction practices. This study investigates the combined effect of stone dust, an industrial by-product, and sisal fibre, a renewable natural fibre, on the engineering properties of a locally available clayey soil. Initially, the untreated soil was characterized by determining its index properties and classified according to IS 1498. Stone dust was incorporated at 10%, 15%, 20%, 25%, and 30% by dry weight of soil, followed by the addition of sisal fibre at 0.40%, 0.60%, and 0.80% to the optimum stone dust mixture. Standard Proctor compaction and soaked California Bearing Ratio (CBR) tests were conducted to evaluate the compaction characteristics and bearing capacity of the stabilized soil. The results indicated that the maximum dry density increased from 2.05 g/cm³ for the untreated soil to 2.13 g/cm³ at 25% stone dust, while the optimum moisture content decreased from 9.40% to 8.75%. The soaked CBR value improved from 4.53% for the untreated soil to 9.40% with 25% stone dust. The incorporation of sisal fibre further enhanced the bearing capacity, with the optimum combination of 25% stone dust and 0.60% sisal fibre achieving the highest soaked CBR value of 11.00%, representing an improvement of approximately 143% over the untreated soil. Although higher fibre contents caused a slight reduction in compaction efficiency, the reinforcing action of sisal fibre significantly improved the load-bearing performance of the stabilized soil. The findings demonstrate that the combined use of stone dust and sisal fibre provides an economical, environmentally sustainable, and effective stabilization technique for weak clayey soils used in pavement subgrades and other geotechnical engineering applications.*
Keywords: Soil stabilization; Stone dust; Sisal fibre; Clayey soil; Standard Proctor test; California Bearing Ratio (CBR); Maximum Dry Density (MDD); Optimum Moisture Content (OMC); Sustainable construction; Pavement subgrade

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I. Introduction

Soil forms the foundation of nearly all civil engineering infrastructure, and its engineering properties directly influence the stability, durability, and service life of structures such as highways, embankments, railways, and foundations[1], [2], [3]. However, many naturally occurring soils exhibit low bearing capacity, high compressibility, excessive plasticity, and poor resistance to moisture variations, making them unsuitable for engineering applications without improvement[4], [5], [6], [7]. The increasing demand for transportation infrastructure, coupled with the scarcity of suitable borrow materials, has made soil stabilization an economical and practical alternative to complete soil replacement. Conventional soil stabilization techniques commonly employ cement, lime, or bituminous materials to improve the strength and durability of weak soils. Although these stabilizers are effective, their production is associated with high energy consumption, significant carbon emissions, and increased construction costs[8], [9], [10]. Consequently, recent research has focused on developing sustainable stabilization techniques by incorporating industrial by-products and renewable natural fibres. Such approaches not only improve the engineering performance of soils but also promote the beneficial utilization of waste materials, thereby supporting sustainable construction practices[11], [12], [13].

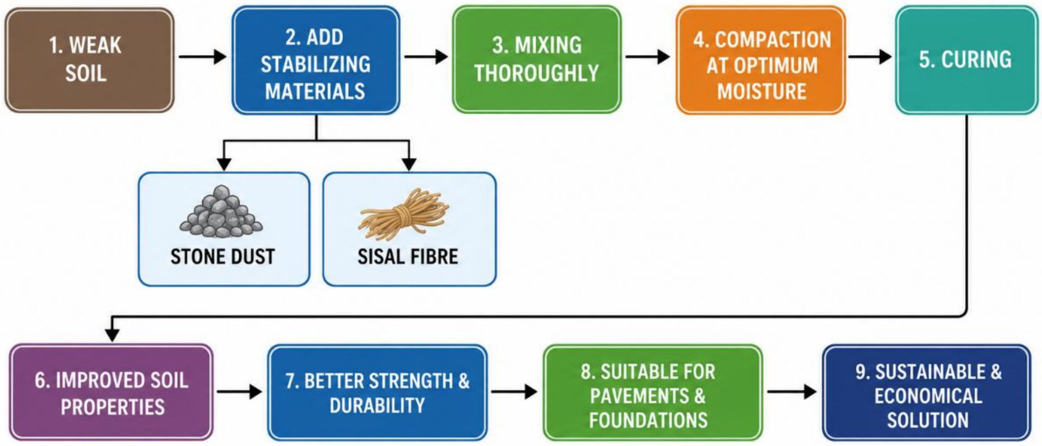

Figure 1: Schematic flowchart illustrating the soil stabilization process using stone dust and sisal fibre.

Stone dust, a by-product generated during aggregate crushing operations, has emerged as a promising stabilizing material because of its abundance, low cost, and well-graded particle size distribution. The addition of stone dust improves particle packing, reduces the void ratio, and enhances compaction characteristics, resulting in increased maximum dry density (MDD) and California Bearing Ratio (CBR). Similarly, natural fibres have gained considerable attention as environmentally friendly reinforcing materials due to their biodegradability, renewability, and high tensile strength. Among these, sisal fibre has demonstrated excellent reinforcing capability by increasing tensile resistance, controlling crack propagation, and improving the ductility and post-peak behaviour of stabilized soils[14], [15], [16]. Although several studies have independently investigated the stabilization of weak soils using stone dust or natural fibres, comparatively limited research has examined their combined effect. The simultaneous use of stone dust as a granular stabilizer and sisal fibre as a reinforcing material is expected to produce a synergistic improvement in soil behaviour by enhancing compaction, increasing bearing capacity, and improving resistance to deformation[17], [18], [19]. Identifying the optimum combination of these materials is essential for developing a sustainable, economical, and efficient stabilization technique suitable for pavement subgrades and other geotechnical applications. The present study investigates the stabilization of a locally available clayey soil using varying proportions of stone dust (10%, 15%, 20%, 25%, and 30%) and sisal fibre (0.40%, 0.60%, and 0.80% by dry weight of soil). Laboratory tests, including Atterberg limits, Standard Proctor compaction, and soaked California Bearing Ratio (CBR), were conducted to evaluate the influence of these stabilizing materials on the engineering properties of the soil. The study aims to determine the optimum combination of stone dust and sisal fibre that provides maximum improvement in compaction characteristics and bearing capacity while offering an environmentally sustainable alternative for ground improvement and pavement construction[20], [21], [22].

II. Materials and Methodology

2.1 Materials

The experimental investigation was conducted using locally available clayey soil, stone dust, and sisal fibre as the constituent materials. The untreated soil was collected from Mullanpur, New Chandigarh, SAS Nagar, Punjab, India. After collection, the soil was air-dried, pulverized, and sieved in accordance with IS 2720 procedures to obtain a uniform sample for laboratory testing. The index properties of the soil, including specific gravity, liquid limit, plastic limit, and plasticity index, were determined to classify the soil according to IS 1498 before stabilization. Stone dust, used as the primary stabilizing material, was obtained from the Material Testing Laboratory, Department of Civil Engineering, National Institute of Technical Teachers Training and Research (NITTTR), Chandigarh. Stone dust is a finely crushed by-product of aggregate production and was selected because of its well-graded particle size distribution, high specific gravity, and ability to improve soil compaction and bearing characteristics by reducing the void ratio. Sisal fibre was procured from Go Green Products, Chennai, India. The fibre was selected due to its high tensile strength, biodegradability, renewability, and availability. When incorporated into the soil matrix, sisal fibres act as randomly distributed reinforcement, improving tensile resistance, restricting crack propagation, and enhancing the ductility of the stabilized soil.

2.2 Methodology

The experimental programme was designed to evaluate the combined effect of stone dust and sisal fibre on the engineering properties of the clayey soil. Initially, the untreated soil was characterized by determining its specific gravity, liquid limit, plastic limit, and plasticity index following the relevant Indian Standard (IS) specifications. These tests established the baseline properties of the soil before stabilization. Stone dust was then incorporated into the soil at proportions of 10%, 15%, 20%, 25%, and 30% by dry weight of soil. Based on the compaction performance of these mixtures, the optimum stone dust content was selected. Sisal fibre was subsequently added to the optimum stone dust mixture at dosages of 0.40%, 0.60%, and 0.80% by dry weight of soil. The materials were thoroughly mixed to ensure uniform distribution of both stone dust and fibres within the soil.

The engineering behaviour of the prepared mixtures was evaluated through Standard Proctor Compaction and soaked California Bearing Ratio (CBR) tests, conducted in accordance with relevant Indian Standard codes. The Standard Proctor test was performed to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of each soil mixture, while the soaked CBR test was conducted to assess the improvement in bearing capacity resulting from stabilization.

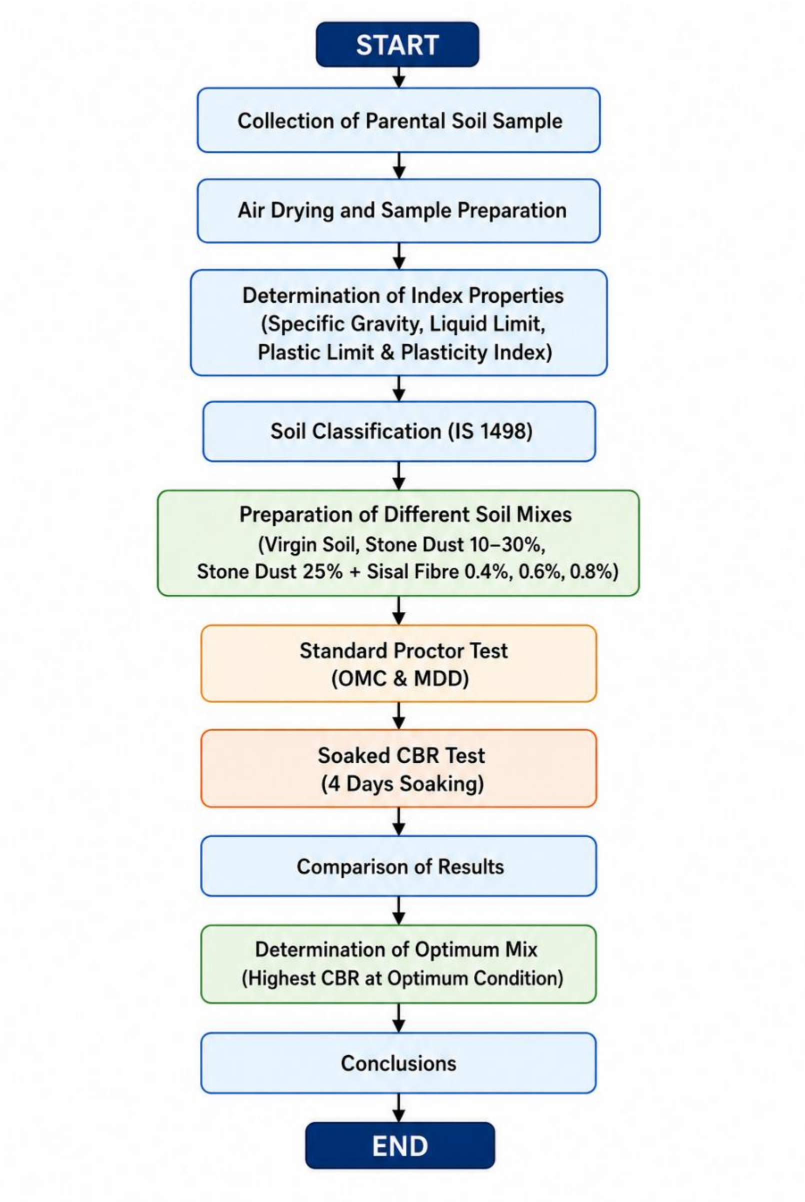

Figure 2: Methodology adopted for Conducting this research study

The experimental methodology adopted in the present study is illustrated in **Figure 2**. The results obtained from the laboratory tests were compared to identify the optimum combination of stone dust and sisal fibre capable of providing maximum improvement in the compaction characteristics and bearing capacity of the clayey soil.

III. Results and Discussion

3.1 Compaction Characteristics

The Standard Proctor test results for all soil mixtures are summarized in **Table 1**. The untreated soil exhibited a maximum dry density (MDD) of **2.05 g/cm³** at an optimum moisture content (OMC) of **9.40%**. Incorporation of stone dust progressively increased the MDD, reaching a maximum value of **2.13 g/cm³** at **25% stone dust**, indicating improved particle packing and reduced void ratio. However, a slight decrease in MDD was observed at **30% stone dust**, suggesting that the optimum stone dust content had been exceeded. The addition of sisal fibre to the optimum stone dust mixture caused a gradual reduction in MDD and a marginal increase in OMC. This behaviour can be attributed to the lower specific gravity of sisal fibres, increased void formation, and greater water demand during compaction. Although fibre addition reduced the dry density, it was expected to enhance the reinforcing behaviour of the stabilized soil.

Table 1. Summary of Standard Proctor test results for different soil mixtures.

Soil Mix	Stone Dust (%)	Sisal Fibre (%)	OMC (%)	MDD (g/cm³)
Virgin Soil	0	0	9.4	2.05
Mix 1	10	0	9.1	2.08
Mix 2	15	0	8.98	2.1
Mix 3	20	0	8.92	2.125
Mix 4	25	0	8.75	2.13
Mix 5	30	0	8.64	2.12
Mix 6	25	0.4	9.59	2.09
Mix 7	25	0.6	10	2.06
Mix 8	25	0.8	10.4	2.03

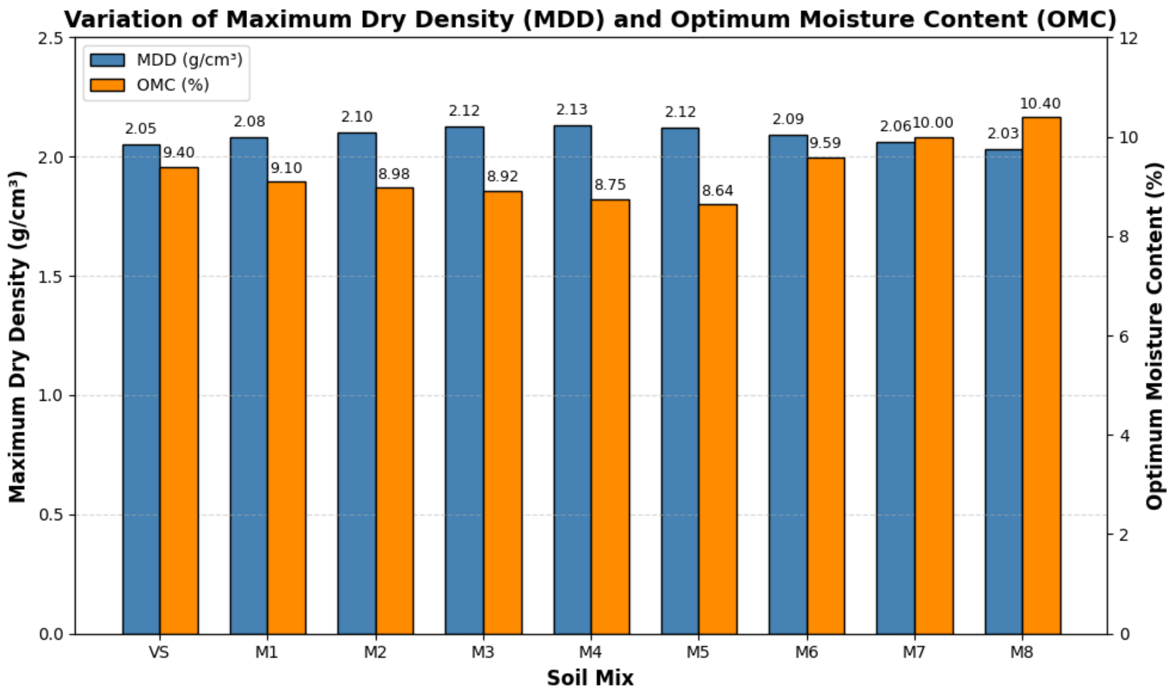

Figure 3. Variation of maximum dry density (MDD) and optimum moisture content (OMC) for different soil mixtures.

3.2 California Bearing Ratio (CBR)

The soaked CBR values obtained for all stabilized soil mixtures are presented in **Table 2**. The untreated soil exhibited a soaked CBR value of **4.53%**, indicating relatively poor bearing capacity. The addition of stone dust significantly improved the CBR value, increasing progressively from **5.20%** at **10% stone dust** to **9.40%** at **25% stone dust**. A slight reduction to **8.00%** was observed at **30% stone dust**, confirming that 25% represents the optimum stone dust content. Further improvement was achieved by reinforcing the optimum stone dust mixture with sisal fibre. The highest CBR value (**11.00%**) was obtained with **25% stone dust and 0.60% sisal**

fibre, corresponding to an improvement of approximately **143%** compared with the untreated soil. Increasing the fibre content to **0.80%** resulted in a slight decrease in CBR because excessive fibres reduced compaction efficiency and promoted fibre clustering.

Table 2. Summary of soaked CBR results for different soil mixtures.

Soil Mix	Stone Dust (%)	Sisal Fibre (%)	Adopted Soaked CBR (%)
Virgin Soil	0	0	4.53
Mix 1	10	0	5.2
Mix 2	15	0	6.3
Mix 3	20	0	8.1
Mix 4	25	0	9.4
Mix 5	30	0	8
Mix 6	25	0.4	10.2
Mix 7	25	0.6	11
Mix 8	25	0.8	9.8

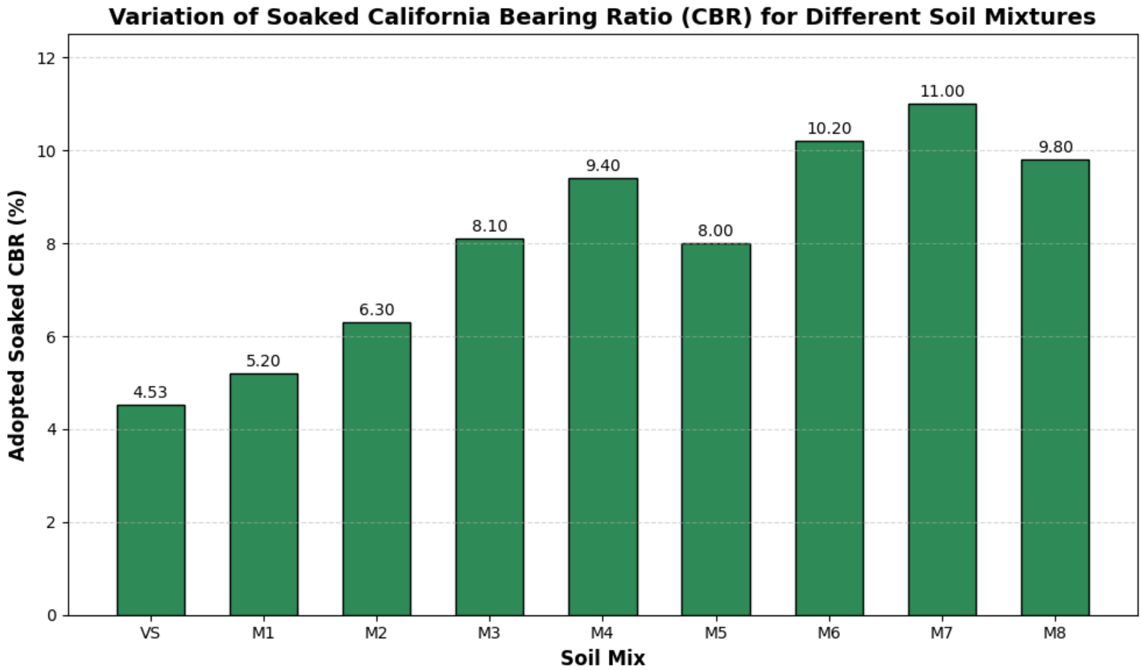

Figure 4. Variation of soaked California Bearing Ratio (CBR) for different soil mixtures.

Overall Discussion

The experimental results demonstrate that stone dust substantially improved the compaction characteristics and bearing capacity of the clayey soil, with **25% stone dust** identified as the optimum dosage. Beyond this level, excess stone dust slightly reduced performance. Although the inclusion of sisal fibre caused a modest decrease in MDD, it significantly enhanced the soaked CBR by reinforcing the soil matrix. The combination of **25% stone dust and 0.60% sisal fibre** produced the best overall performance, yielding an MDD of **2.06 g/cm³** and the highest soaked CBR value of **11.00%**. These findings indicate that the combined use of stone dust and sisal fibre provides an effective and sustainable stabilization technique for improving weak clayey soils intended for pavement subgrade applications.

IV. Conclusion

This study investigated the effectiveness of stone dust and sisal fibre in improving the engineering properties of a locally available clayey soil through Standard Proctor compaction and soaked California Bearing Ratio (CBR) tests. The experimental results demonstrated that stone dust significantly enhanced the compaction characteristics of the soil by increasing the maximum dry density (MDD) while reducing the optimum moisture content (OMC) up to an optimum stone dust content of 25%. Beyond this dosage, a slight reduction in compaction performance was observed, indicating that excessive stone dust does not provide additional benefits. The bearing capacity of the soil improved considerably with the incorporation of stone dust, with the soaked CBR increasing from **4.53%** for the untreated soil to **9.40%** at **25% stone dust**. Further reinforcement using sisal fibre enhanced the engineering performance of the stabilized soil. Among the fibre-reinforced mixtures, the combination of **25% stone dust and 0.60% sisal fibre** produced the highest soaked CBR value of **11.00%**, representing an improvement of approximately **143%** over the untreated soil. Although higher fibre contents slightly reduced the MDD because of increased void formation and reduced compaction efficiency, the fibres contributed significantly to improving the load-bearing capacity through reinforcement of the soil matrix. Overall, the findings demonstrate that the combined use of **25% stone dust and 0.60% sisal fibre** provides an effective, economical, and environmentally sustainable stabilization technique for weak clayey soils. The proposed approach not only enhances subgrade performance but also promotes the beneficial utilization of an industrial by-product and a renewable natural fibre, making it a promising alternative for pavement subgrades, embankments, and other geotechnical engineering applications. Future research may focus on field-scale validation, long-term durability under cyclic environmental conditions, and evaluation of additional mechanical properties such as unconfined compressive strength, resilient modulus, and durability characteristics.

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