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Experimental Investigation on Bitumen Emulsion Used in Gravel Road Stabilization

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Abstract- This experimental study investigates the use of cationic medium-setting (CMS) bitumen emulsion in stabilizing gravel soils to improve their strength for road subgrade applications. Gravel soil, often used in road construction, typically requires stabilization to enhance its load-bearing capacity. The study examines the effects of CMS bitumen emulsion combined with small amounts of cement on the California Bearing Ratio (CBR) and other key engineering properties of gravel soil. Laboratory tests were conducted, varying mixing conditions, compaction efforts, and curing times. The results showed that the addition of CMS bitumen emulsion, particularly with 3% bitumen emulsion and 2% cement, significantly improved the soil's CBR values and dry density, indicating enhanced subgrade strength. The best results were observed under Case D conditions, where the soil was mixed with 3% bitumen emulsion and 2% cement and allowed to rest for 5 hours before testing. The stabilization process proved to be cost-effective, environmentally friendly, and suitable for locally available gravel soils, providing a more economical and efficient alternative to traditional stabilization methods. This approach offers reduced pavement structural thickness and can contribute to sustainable road infrastructure development, particularly in regions with limited resources or high material costs. The study highlights the potential of bitumen emulsion as a sustainable and effective solution for improving the mechanical properties of gravel soils, especially for rural roads and low-traffic areas.

Keywords- soil stabilization, California Bearing Ratio (CBR), bitumen emulsion, gravel soil, road construction, sustainable infrastructure.

I. INTRODUCTION

The foundation of any pavement structure lies in the quality of the subgrade soil, which often requires stabilization to meet structural requirements. Traditional stabilizers like cement and lime have been extensively used but come with limitations, such as high energy consumption and environmental impact. Bitumen emulsion, a water-based dispersion of bitumen particles, emerges as an alternative that offers benefits including moisture resistance, ease of application, and reduced environmental footprint.

Bitumen emulsion works by binding soil particles together, enhancing cohesion and reducing water infiltration. While its application in pavement surfaces is well-documented, its role as a soil stabilizer is still evolving, necessitating further exploration into its effectiveness under various soil conditions and climatic scenarios.

II. LITERATURE REVIEW

Soil stabilization is a well-established engineering technique aimed at improving the properties of soils for construction purposes. Among various methods, the use of bitumen emulsion as a chemical stabilizer has shown promise, especially in road construction applications. Cement, often used as a complementary binder, enhances strength and durability. While significant research has been conducted globally on soil stabilization using bitumen, the body of work in India remains limited, particularly for red gravel soils. This chapter consolidates and critically examines past research on soil stabilization with bitumen and cement, highlighting mechanisms, methodologies, and gaps in current knowledge.

1. Studies on Soil Stabilization Using Bitumen Emulsion

- Chinkulkijniwat and Man-Koksung (2010) conducted a detailed investigation into the compaction behavior of gravelly soils using an innovative small compaction device. The primary focus of their study was to understand how variations in gravel content and particle size distribution impact the optimum moisture content and overall compaction characteristics of such soils. By systematically testing different gravel compositions, the researchers developed a correlation between the gravel content and the optimum moisture content of the fine fractions present in gravelly soils. The findings highlighted that the gravel fraction significantly influences the compaction process, as larger particles create a framework that alters the distribution and interaction of finer soil particles. This framework affects the soil’s ability to retain moisture and achieve maximum dry density during compaction. Their study revealed that as gravel content increases, the optimum moisture content tends to decrease, and the soil's compaction behavior becomes more dependent on the properties of the finer fractions within the soil matrix. These insights have practical implications for pavement construction and soil stabilization projects, as understanding the interplay between gravel composition and compaction parameters can lead to more efficient design and field implementation. The small compaction device used in the study also demonstrated its effectiveness in mimicking field conditions, making it a valuable tool for laboratory assessments. This research provides foundational knowledge that can guide the design of gravelly soil mixtures for road construction and other civil engineering applications.
- Razouki et al. (2002) conducted an in-depth experimental study on granular stabilized roads, emphasizing the versatile role of bitumen in enhancing soil properties. In their research, bitumen was utilized both as a binder and as a waterproofing agent, showcasing its dual functionality in soil stabilization. As a binder, bitumen improves the cohesion among soil particles, leading to better structural integrity and load-bearing capacity. This property is particularly critical for the construction of road bases and surfaces, where strength and durability are essential. Simultaneously, bitumen’s waterproofing capability plays a crucial role in protecting stabilized layers from the detrimental effects of moisture infiltration. By creating a hydrophobic barrier, bitumen reduces water penetration, thereby preventing the weakening of soil due to saturation. This property is especially beneficial in regions with high rainfall or fluctuating moisture conditions, where water-induced damage to road layers is a significant concern. The study demonstrated that soil-bitumen systems, when properly designed, could achieve superior mechanical properties such as increased stability and load resistance, as well as enhanced hydrological performance, which contributes to longer service life and reduced maintenance costs.
- Michael (1993) conducted a comprehensive study on the application of asphalt emulsions for stabilizing soils contaminated with organic pollutants, emphasizing their dual role in enhancing soil strength and mitigating environmental hazards. The research explored the effectiveness of ambient-temperature asphalt emulsion stabilization technology, particularly focusing on its ability to treat and immobilize contaminants within the soil matrix. The findings revealed that asphalt emulsions provide significant improvements in soil strength by coating soil particles and forming a cohesive, durable mass. This stabilization process ensures that the treated soil meets the structural requirements for road construction and other engineering applications. Additionally, the emulsions create a waterproof barrier that limits water penetration, reducing the risk of leaching contaminants into surrounding areas. One of the most critical aspects of the study was the demonstration of asphalt emulsions' capacity to immobilize organic pollutants. By encapsulating contaminants within the stabilized matrix, the technology minimizes their mobility and potential for environmental harm. This dual benefit—enhanced soil mechanical properties and environmental protection—makes asphalt emulsions a promising solution for managing contaminated sites while supporting infrastructure development.

2. Mechanisms of Soil Stabilization with Bitumen

- Paul et al. (2011) highlighted two fundamental mechanisms—waterproofing and adhesion—underpinning the process of asphalt stabilization. Waterproofing involves coating soil particles or aggregates with asphalt, forming a protective barrier that prevents water ingress. This barrier is crucial for maintaining the strength and durability of the stabilized layer, especially in environments prone to moisture exposure. Without water penetration, the potential for material degradation and loss of strength due to swelling or weakening is significantly reduced. Adhesion, on the other hand, refers to the cohesive binding of soil particles by the asphalt layer. This mechanism enhances the mechanical stability and load-bearing capacity of the stabilized soil, ensuring it can withstand traffic loads and environmental stresses. Paul et al. demonstrated that these mechanisms work synergistically to produce a robust, durable subbase or base course for pavement applications, making asphalt stabilization a reliable solution for improving the performance of various soil types.
- Marandi and Safapour (2012) investigated the combined use of cement and bitumen emulsion for base course stabilization, focusing on their complementary roles in enhancing soil properties. The study revealed that while bitumen primarily contributes through its waterproofing capabilities, cement plays a crucial role in improving bonding and increasing stiffness. The waterproofing effect of bitumen minimizes moisture-induced degradation, protecting the soil layer from water-related issues such as swelling or loss of cohesion. Cement, by contrast, chemically reacts with soil particles to form stronger bonds, significantly enhancing the stiffness and structural integrity of the stabilized layer. This dual approach leverages the strengths of both materials, providing a more durable and resilient base course. The researchers concluded that bitumen-cement stabilization offers an effective alternative to traditional stabilization techniques, particularly in regions where high-quality materials are scarce. This method not only enhances the mechanical performance of the pavement but also extends its service life, making it a cost-effective and practical solution for road construction projects.

3. Experimental Investigations

- Jones et al. (2012) conducted a detailed evaluation of the mechanical properties of bitumen-stabilized soils using a combination of laboratory tests, including Indirect Tensile Strength (ITS), Unconfined Compressive Strength (UCS), and Marshall Stability tests. Their study demonstrated that the use of asphalt emulsions significantly enhances the strength and stability of treated soils, making them suitable for road construction and other infrastructure applications. One key finding was that asphalt emulsions are effective at ambient temperatures, simplifying the handling and application process while reducing energy consumption during stabilization. The ability of the emulsions to provide early strength allows for rapid curing, facilitating early traffic accommodation. This attribute improves construction efficiency and minimizes disruptions, particularly in projects requiring quick turnaround times. Jones et al. emphasized that the combined mechanical properties obtained through these tests validate the use of bitumen stabilization as a robust and practical solution for improving soil performance in various engineering contexts.
- Cokca et al. (2003) explored the critical role of moisture content in determining the shear strength of unsaturated soils during compaction. Their experimental study revealed that the shear strength of soil reaches its maximum value at optimum moisture content, where the balance between soil compaction and moisture availability is ideal. Beyond this point, as moisture content increases, shear strength declines due to the reduction in frictional resistance and cohesion among soil particles. This research underscores the importance of precise moisture control during the stabilization process. Achieving the right moisture content ensures that the soil's mechanical properties are optimized, resulting in enhanced stability and durability. Conversely, deviations from the optimum moisture content, whether on the dry or wet side, can lead to suboptimal performance and potential issues such as reduced load-bearing capacity or increased susceptibility to deformation. Cokca et al.'s findings highlight the need for careful monitoring and adjustment of moisture levels during soil stabilization and compaction to achieve the desired engineering outcomes.
- Hussain (2008) conducted an insightful study establishing a relationship between the California

Bearing Ratio (CBR) and undrained shear strength derived from vane shear tests. The findings revealed a direct correlation: as the plasticity index of the soil increased, both the CBR and undrained shear strength exhibited corresponding growth. This implies that soils with higher plasticity indices tend to have better load-bearing capacity and resistance to shear failure under undrained conditions. However, the study also highlighted the adverse impact of moisture content on these parameters. Higher moisture content resulted in a significant reduction in both CBR and shear strength, emphasizing the critical need for moisture control in designing stabilized layers. Hussain's research provides a valuable framework for predicting the performance of stabilized layers, allowing engineers to optimize material selection and design parameters for improved durability and stability.

- Martin et al. (2009) investigated the potential of foam bitumen stabilization as a cutting-edge technique for pavement rehabilitation. Their study utilized a mix comprising 3.5% bitumen foam and 2% cement, which demonstrated remarkable improvements in the structural and functional performance of stabilized layers. The foam bitumen technique combines bitumen, air, and water to produce a foam-like substance that evenly coats aggregates, enhancing the mixture's cohesion and load distribution capabilities. Key benefits identified in the study included increased durability, faster construction processes, and enhanced compatibility with a wide range of aggregates. The rapid application and curing associated with foam bitumen stabilization make it particularly advantageous for rehabilitation projects requiring minimal downtime. Additionally, the process's resilience to weather variations further underscores its effectiveness as an innovative solution for extending pavement life while reducing maintenance costs. Martin et al.'s findings confirm foam bitumen stabilization as a promising alternative for modern pavement construction and rehabilitation.
- Lauren (2011) investigated the application of polymer emulsions as a modern soil stabilization technique, focusing on their effectiveness in enhancing soil performance. The study involved testing various polymer emulsions, which demonstrated remarkable improvements in California Bearing Ratio (CBR) values. These results highlighted the potential of polymer emulsions to provide substantial mechanical benefits, making them suitable for constructing subgrades, subbases, and base courses in roads and runways. A key takeaway from Lauren's research was the environmental advantage of polymer emulsions. Unlike traditional stabilizing agents such as cement or lime, polymer emulsions are less resource-intensive and produce lower emissions, aligning with sustainable construction practices. Additionally, their ability to form strong bonds with soil particles ensures improved durability and resistance to external factors such as water infiltration and deformation under load. Lauren's findings emphasized the long-term promise of polymer emulsions as a future-ready alternative for soil stabilization, combining environmental benefits with superior mechanical performance. This makes them a compelling choice for infrastructure projects aiming to balance technical efficiency with sustainability.

4. Advances in Stabilization Techniques

- Yuehuan et al. (2010) conducted a comprehensive study on the application of foam bitumen stabilization in Western Australian pavements, highlighting its growing popularity as an alternative to traditional soil-cement stabilization. The research demonstrated that foam bitumen offers superior flexibility and fatigue resistance, which are essential for pavements exposed to dynamic loading and varying environmental conditions. The study detailed the adaptability of foam bitumen across a wide range of aggregate types and its suitability for stabilizing flexible pavement subgrades. Yuehuan et al. emphasized the technique's efficiency in enhancing pavement longevity and performance, making it an innovative choice for modern infrastructure needs.

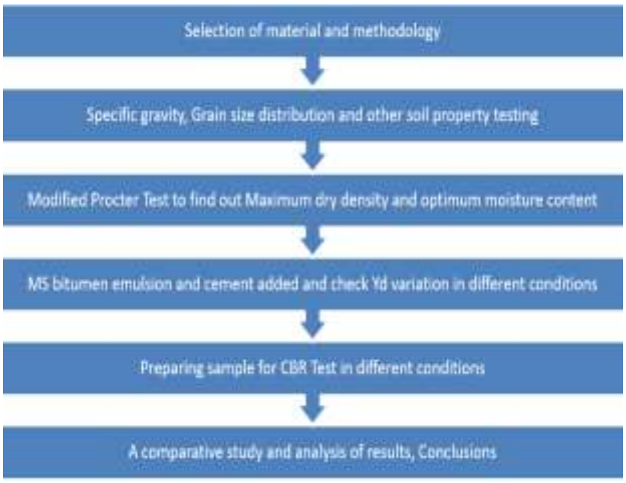
- Chritz (2006) evaluated the mixed-in-place stabilization techniques for bitumen-stabilized gravel shoulders, addressing the economic constraints frequently faced by highway maintenance agencies. The study revealed that bitumen stabilization provides a cost-effective and durable solution for maintaining gravel shoulders, reducing the need for frequent repairs. By applying stabilization directly in the field, the mixed-in-place technique minimizes material wastage and labor costs while ensuring effective binding of gravel particles. Chritz's findings support the adoption of bitumen stabilization as an economical maintenance strategy, particularly in regions with limited budgets for infrastructure upkeep.

5. Summery of findings

The literature reveals extensive global research on bitumen stabilization, highlighting its dual role in waterproofing and enhancing soil strength. Experimental investigations and emerging technologies demonstrate its applicability across various soil types and climatic conditions. However, in the Indian context, the absence of standardized procedures and limited studies on local materials necessitate further research. This study addresses these gaps by developing a systematic methodology for stabilizing red gravel soils with bitumen emulsion, paving the way for sustainable and durable road construction practices.

III. METHODOLOGY

The foundation of any experimental investigation lies in the selection of appropriate materials and methodologies. To evaluate the physical properties of soil, various tests are carried out, including specific gravity, grain size distribution through sieve analysis, and Atterberg limits tests (liquid limit and plastic limit). Subsequently, the focus shifts to determining the mixing procedure and defining the different scenarios or conditions under which further tests will be performed. The Modified Proctor Test is conducted to establish the maximum dry density of the material. However, the primary objective is to enhance soil strength, which is assessed through California Bearing Ratio (CBR) tests under varying conditions. This approach enables a comparative experimental analysis to identify strategies for maximizing the soil's bearing capacity or achieving the highest possible CBR values.



IV. RESULT ANALYSIS

1. Specific Gravity Test

Table 1 Specific Gravity Teast Result

Parameter	Sample 1 (gm)	Sample 2 (gm)	Sample 3 (gm)	Mean (gm)
M1	114.67	113.76	115.34	114.59
M2	164.67	163.76	165.34	164.59
M3	383.56	384.41	385.69	384.55
M4	351.87	352.86	353.94	352.89
Specific Gravity	2.73	2.71	2.74	2.726

The mean specific gravity of the soil was found to be 2.726, which is typical for coarse-grained soils and suitable for use as subgrade material.

2. Liquid limit and Plastic limit Test

Table 2 Liquid Limit (WL) test result

Trial No.	Container Weight (Wk, gm)	Wet Soil + Container Weight (W gm)	Dry Soil + Container Weight (Wo, gm)	Moisture Content (%)
1	20.5	36.7	34.1	28.91
2	20.6	36.9	34.3	28.75
3	20.4	36.6	34.0	29.07

Mean	20.5	36.73	34.13	28.91

The Liquid Limit (WL) is calculated as the average moisture content of the three trials, yielding a value of 28.91%.

Table 3 Plastic Limit (WP) test result

Trial No.	Container Weight (Wk, gm)	Wet Soil + Container Weight (W, gm)	Dry Soil + Container Weight (Wo, gm)	Moisture Content (%)
1	20.2	31.5	30.1	21.61
2	20.3	31.6	30.2	21.77
3	20.4	31.7	30.3	21.63
Mean	20.3	31.6	30.2	21.67

The Plastic Limit (WP) is calculated as the average moisture content of the three trials, yielding a value of 21.67%.

The Plasticity Index (IP) is calculated as:

$$\begin{aligned} IP &= WL - WP \\ &= 28.91\% - 21.67\% \\ &= 7.24\% \end{aligned}$$

The soil has a low plasticity index (IP = 7.24%), classifying it as a soil with low plasticity. This characteristic is advantageous for subgrade applications as it reduces susceptibility to excessive deformation under traffic loading.

3. Grain size distribution (sieve analysis)

Table ***Error! No text of specified style in document.****. Seive Analysis Result*

Sieve Size (mm)	Mass of Soil Retained (gm)	Percent Retained (%)	Cumulative Percent Retained (%)	Percent Finer (%)
12.5	0.0	0.00	0.00	100.00
9.5	99.1	4.95	4.95	95.05
6.3	318.8	15.94	20.84	79.16
4.75	397.5	19.88	40.77	59.23
2.36	510.2	25.51	66.28	33.72
1.18	255.1	12.71	79.03	20.97
0.6	166.2	8.31	87.34	12.66
0.3	132.1	6.61	93.95	6.05
0.15	48.7	2.44	96.39	3.61
Pan	72.3	3.61	100.00	0.00

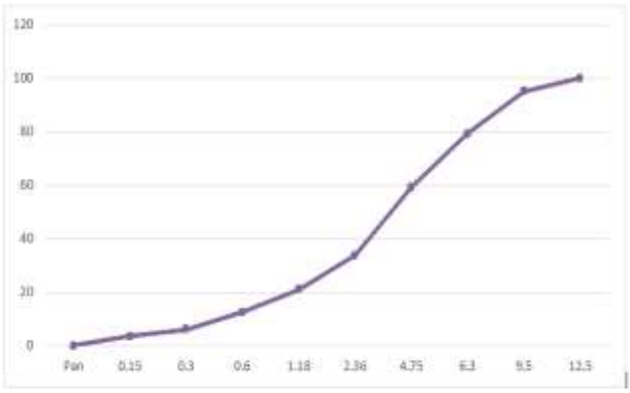
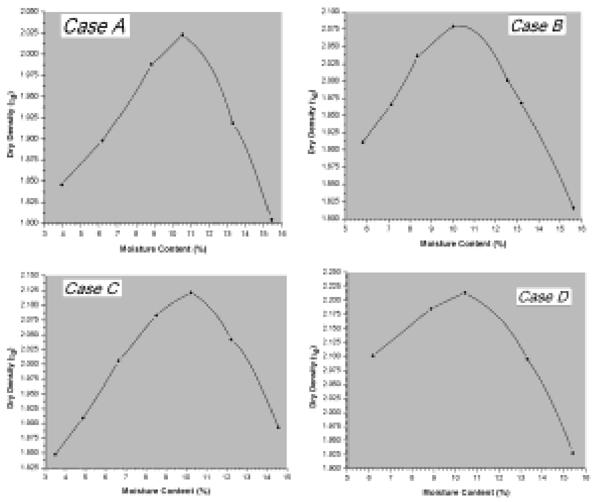
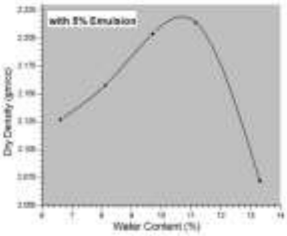


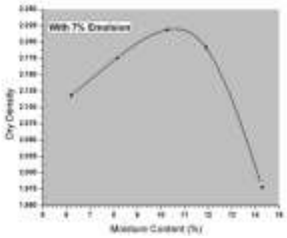
Figure ***Error! No text of specified style in document.****.1 Grain size distribution graph*

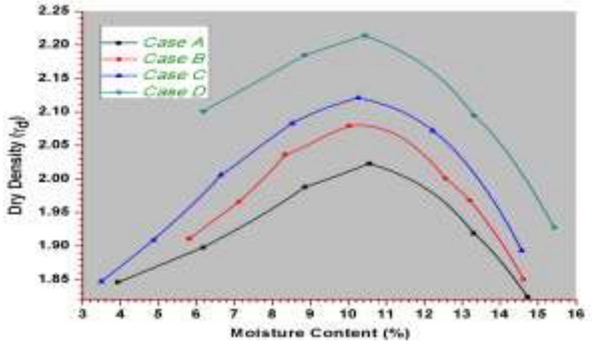
Based on the grain size distribution curve the soil is classified as well-graded, making it suitable for subgrade applications due to its stability and compaction characteristics.

4. Compaction Test

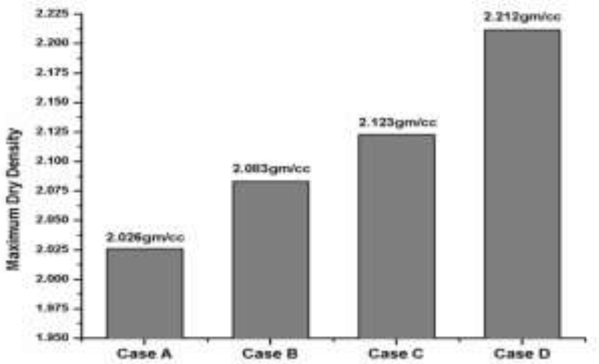








Test Case	Maximum Dry Density (gm/cc)	Optimum Moisture Content (%)
Case A	2.026	10.52
Case B	2.083	10.45
Case C	2.123	10.25
Case D	2.212	10.58

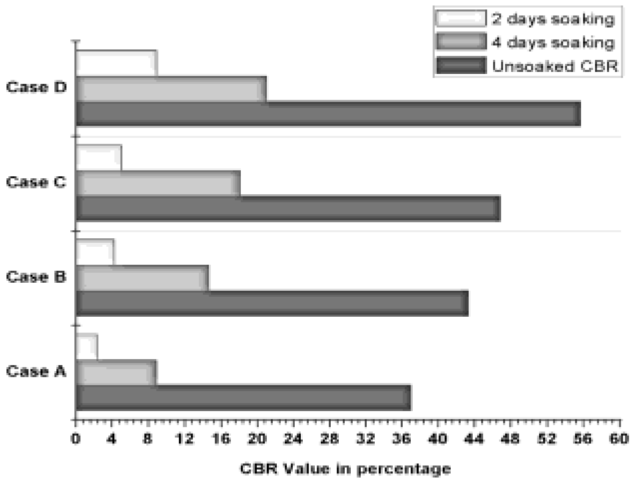


The Modified Proctor Test results confirm that the addition of bitumen emulsion and cement enhances the compaction characteristics of gravel soil, with the best results observed in Case D, where the soil was allowed to cure for 5 hours. These findings indicate that this stabilization method is effective in improving the subgrade properties of gravel soil, making it suitable for use in road construction.

5. CBR Test

Subgrade soil, located beneath the pavement crust, provides crucial support for the pavement structure. Its strength significantly impacts pavement stability and longevity. Improving subgrade strength can be achieved through soil replacement or stabilization methods. The California Bearing Ratio (CBR) test is commonly used to evaluate subgrade soil strength, where higher CBR values indicate better soil stability and suitability.

To assess the effectiveness of soil stabilization, CBR values for various treatments (e.g., untreated soil, soil with emulsion, cement, or other stabilizers) can be compared using a bar graph. The graph will visually show improvements in CBR values under different conditions (e.g., soaked and unsoaked). This comparison helps identify the most effective treatment and the optimal conditions for maximizing soil strength.



V. CONCLUSION

Following conclusions are made from this study

- **Effectiveness of Bitumen Emulsion**: Medium-setting bitumen emulsion significantly improves the engineering properties of gravel soils, enhancing CBR values and compaction properties.
- **Optimal Mixture**: The best results were achieved with a mix of 3% bitumen emulsion and 2% cement, with a 5-hour curing period.
- **Cost and Environmental Benefits**: The stabilization method is cost-effective, environmentally friendly, and utilizes locally

available materials, making it suitable for low-resource areas.

- **Potential Applications**: This technique is particularly beneficial for improving road subgrades, especially in rural and low-traffic regions.
- **Sustainability**: The approach contributes to the development of sustainable and durable road infrastructure, with a focus on reducing environmental impact.
- **Implementation and Benefits**: Proper application of this method can enhance the strength and durability of gravel roads, offering long-term benefits for road construction and maintenance.

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[21]. These references provide valuable insights into the testing methods and materials related to your work, such as CBR testing, moisture variation, and soil stabilization.