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IMPROVING THE SUBGRADE SOIL STABILITY BY ADDING LIME GYPSUM AND BRICK BALLAST

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Abstract
Weak subgrade soils pose a significant challenge to the continuity and stability of road structure due to their low strength and high malleability. This study evaluates the enhancement of subgrade soil stability by incorporating lime, gypsum, and slipup cargo in different blend rates (6:2.5:10), (8:5:20), and (10:7.5:30). Laboratory tests, including Atterberg limits, Modified Proctor Test, unrestrained Compressive Strength (UCS), and California Bearing rate (CBR), were conducted to assess the effectiveness of these stabilizers. The results indicate a substantial improvement in soil parcels. The liquid limit dropped from 39.05 to, while the plastic limit increased from 11.9 to 19.6, reflecting bettered soil thickness. The UCS bettered from 0.8 KN to 1.41 KN, and the CBR increased from 4 to 11, demonstrating a significant increase in cargo-bearing capacity. likewise, the Maximum Dry Density (MDD) bettered, indicating better contraction characteristics. Among the tested rates, the blend of (10:7.5:30) handed the stylish stabilization results. This study concludes that the addition of lime, gypsum, and slipup cargo effectively stabilizes weak subgrade soil, reducing malleability while enhancing strength and contraction parcels. This stabilization fashion presents a sustainable and cost-effective result for perfecting road subgrades, thereby adding pavement life and performance.

I. INTRODUCTION

Subgrade soil plays a crucial role in the overall performance and durability of road infrastructure. However, weak subgrade soils, characterized by low strength and high plasticity, pose significant challenges to road construction and maintenance. Such soils are highly susceptible to volume changes due to moisture fluctuations, leading to structural failures in roads, bridges, and other infrastructures (Bell, 1996) [4]. Therefore, improving the engineering properties of weak subgrade soils
is essential for enhancing the stability and longevity of pavements.

Various soil stabilization techniques are available to enhance subgrade properties, including mechanical and chemical stabilization methods. Among them, the use of stabilizing agents such as lime, gypsum, and brick ballast has gained attention due to their cost-effectiveness and environmental benefits (Al-Mukhtar et al., 2012) [3]; (Güllü & Fedakar, 2017) [8]. Lime improves soil properties by reducing plasticity and increasing strength through pozzolanic reactions (Little, 1999) [10], while gypsum enhances soil stability by modifying its swelling behavior (Güllü & Fedakar, 2017) [8]. Additionally, brick ballast, a recycled construction waste material, provides granular support, improving soil compaction and load-bearing capacity (Fattah et al., 2014) [7].

The objective of this study is to evaluate the effect of adding lime, gypsum, and brick ballast in different proportions to weak subgrade soil and analyze their impact on soil strength, plasticity, compaction, and bearing capacity. Laboratory tests, including Atterberg limits, Modified Proctor Test (ASTM D698-12e2, 2012) [2], Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) (AASHTO, 2010) [1], were conducted to assess the improvements in soil properties.

This research aims to provide a sustainable and cost-effective approach to subgrade soil stabilization, reducing construction and maintenance costs while enhancing the performance of road infrastructure. The results of this study will contribute to the optimization of stabilization techniques, making weak subgrade soils more suitable for road construction and long-term serviceability (Consoli et al., 2010) [5]; (Chauhan et al., 2008) [6].

II. STATEMENT OF THE PROBLEM

Weak subgrade soils present significant challenges in road construction due to their low strength, high plasticity, and susceptibility to volume changes caused by moisture variations. These unfavorable soil conditions often result in pavement failures, reduced load-bearing capacity, and increased maintenance costs. Expansive soils, which swell upon absorbing water and shrink during drying, further contribute to these issues, making them unsuitable for subgrade layers.

To ensure long-term stability and durability of road infrastructure, it is essential to enhance the engineering properties of weak subgrade soils. Traditional methods, such as soil replacement, are often expensive and time-consuming. Therefore, a more efficient and cost-effective stabilization technique is required to improve the strength and durability of weak subgrade soils while maintaining sustainability.

This study explores the potential of adding lime, gypsum, and brick ballast in different proportions to enhance subgrade soil properties. Lime improves soil strength by reducing plasticity and increasing pozzolanic reactions, while gypsum helps control swelling behavior. Brick ballast, a recycled material, enhances compaction and provides structural support. Through laboratory testing, this research aims to determine the optimal mix ratio that maximizes soil stability, load-bearing capacity, and long-term performance. The findings will contribute to the development of an effective and sustainable stabilization method for road construction.

III. OBJECTIVES OF THE STUDY

The primary objective of this study is to evaluate the effects of adding lime, gypsum, and brick ballast on the strength and stability of weak subgrade soil. The specific objectives include:

1. **To analyze** the impact of lime, gypsum, and brick ballast on the engineering properties of weak subgrade soil, including plasticity, compaction characteristics, and strength.
2. **To determine** the changes in Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) with varying proportions of lime, gypsum, and brick ballast.
3. **To identify** the optimum mix ratio of lime, gypsum, and brick ballast that provides the best improvement in soil stability and load-bearing capacity.
4. **To assess** the suitability of this stabilization method as a cost-effective and sustainable solution for enhancing subgrade performance in road construction.
5. **To compare** the stabilized soil properties with untreated weak subgrade soil to determine the effectiveness of the proposed stabilization technique.

IV. PREVIOUSLY STUDY

4.1. Effects of Lime on Strength

Lime has been widely studied as a soil stabilizer due to its ability to reduce plasticity and increase soil strength. Researchers have found that adding lime to weak subgrade soils enhances their bearing capacity and durability by initiating pozzolanic reactions. These reactions lead to the formation of cementitious compounds, improving the soil's structural integrity. Lime stabilization is particularly effective in reducing swelling and shrinkage, making it suitable for expansive soils.

4.2. Effects of Brick Ballast on Strength

Studies have shown that brick dust and crushed brick ballast improve soil compaction characteristics and strength. The use of demolished brick waste (DBW) as a stabilizer has been investigated in various studies, with findings suggesting that incorporating up to 40% DBW increases Maximum Dry Density (MDD) while reducing the Optimum Moisture Content (OMC). Brick ballast enhances soil gradation, making it a sustainable and cost-effective alternative for soil stabilization.

4.3. Effects of Gypsum on Strength

Gypsum has been studied as an additive to weak subgrade soils due to its ability to improve density and reduce swelling. Research has shown that incorporating gypsum (ranging from 2% to 8%) can significantly decrease the soil's swelling potential while enhancing its bearing capacity. At an optimal dosage of 4% gypsum, the swelling of expansive soil has been observed to decrease from 47% to 4.16%, with a corresponding increase in the California Bearing Ratio (CBR) from 2.73% to 7.57%.

4.4. Gap in Existing Research

While individual studies have explored the effects of lime, gypsum, and brick ballast on soil stabilization, there is limited research on their combined impact. No comprehensive study has investigated the optimal ratios of these three materials for improving weak subgrade soils. This research aims to fill this gap by evaluating the combined effects of lime, gypsum, and brick ballast in different proportions to determine the most effective stabilization mix for enhancing soil strength and durability.

V. MATERIALS AND METHODOLOGY

5.1. Materials Used

This study utilizes three key stabilizing materials to improve weak subgrade soil:

- **Lime:** Enhances soil strength by reducing plasticity and triggering pozzolanic reactions, leading to long-term stability.
- **Gypsum:** Improves compaction characteristics, reduces soil swelling, and enhances bearing capacity.
- **Brick Ballast:** Provides mechanical stabilization, improves gradation, and increases soil density for better load distribution.

The weak subgrade soil selected for this study is expansive soil (black cotton soil), which was collected from multiple locations where subgrade failure is commonly observed.

5.2. Data Collection and Sampling Process

- A preliminary **field investigation and visual inspection** were conducted to identify areas with weak subgrade conditions.
- Representative soil samples were obtained from **depths of up to 1.5m** to exclude organic matter interference.
- Soil samples were selected based on their **expansive nature and poor engineering properties** requiring stabilization.

5.3. Laboratory Testing and Analysis

The collected soil samples were subjected to **various laboratory tests** to evaluate their geotechnical properties before and after stabilization. The tests included:

- **Atterberg Limits Test:** To determine the liquid limit and plastic limit, assessing the soil's plasticity behavior.
- **Modified Proctor Test:** To measure the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).
- **Unconfined Compressive Strength (UCS):** To evaluate strength improvement in stabilized soil.
- **California Bearing Ratio (CBR):** To assess load-bearing capacity under simulated field conditions.

The stabilization process involved **mixing lime, gypsum, and brick ballast** with the soil in predefined ratios: **6:2.5:10, 8:5:20, and 10:7.5:30** (lime: gypsum: brick ballast). Each mix was tested, and the results were analyzed to determine the most effective combination for improving subgrade soil stability.

This systematic approach ensures a reliable evaluation of how lime, gypsum, and brick ballast contribute to strengthening weak subgrade soil, making it suitable for road construction applications.

VI. RESULT AND DISCUSSION

6.1 The Effect of Lime Gypsum and Brick Ballast on Atterberg Limit

The addition of lime, gypsum, and brick ballast influences soil consistency by altering its liquid limit, plastic limit, and plasticity index. Lime reduces plasticity, gypsum enhances bonding, and brick ballast improves drainage. Table 1 below presents the variations in Atterberg limits for different mix ratios.

Table 1: Effect of Lime, Gypsum, and Brick Ballast on Atterberg Limits

Natural Soils and Percent of Stabilizer	LL (%)	PL (%)	PI (%)	The reduction of PI (%)
Lime+ 0% Gypsum + 0% Brick Ballast + 0%	39.05	11.9	27.15	-
Lime+ 6% Gypsum + 2.5% Brick Ballast + 10%	33.12	18.3	14.82	45.41
Lime+ 8% Gypsum + 5% Brick Ballast + 20%	29.07	20	9.07	38.79
Lime+ 10% Gypsum + 7.5% Brick Ballast + 30%	25.4	19.6	5.8	36.05

The liquid limit (LL), plastic limit (PL), and plasticity index (PI) of soil change with the addition of lime, gypsum, and brick ballast. As shown in **Graph 01** below, LL decreases while PL increases with stabilization,leading to a reduction in PI. This

The liquid limit (LL), plastic limit (PL), and plasticity index (PI) of soil change with the addition of lime, gypsum, and
brick ballast. As shown in **Graph 01** below, LL decreases while PL increases with stabilization, leading to a reduction in PI. This indicates improved soil stability and

reduced plasticity, making it more suitable for construction purposes.

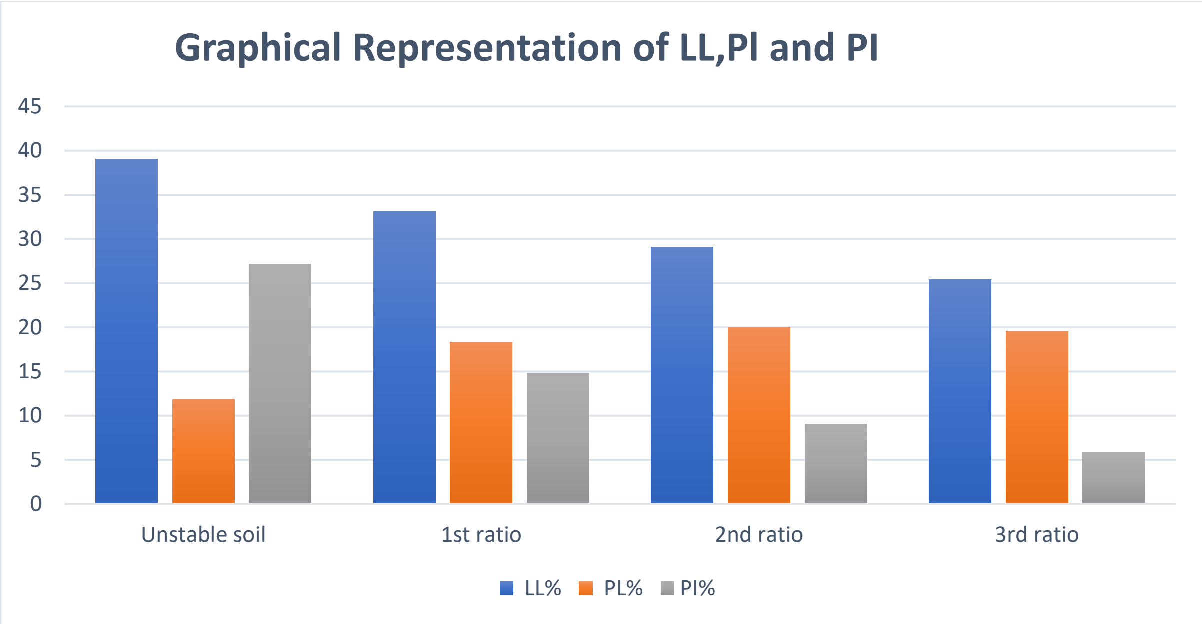

Figure 01: Laboratory test results of Atterberg Limit

Based on the test results presented in **Figure 01**, the plasticity index (PI) of the subgrade soil decreased significantly with the addition of lime, gypsum, and brick ballast. Initially, the natural soil exhibited a **PI of 27.15%**, which was gradually reduced as stabilizers were incorporated. The highest reduction in plasticity index was observed at a **combination of 30% brick ballast and 6% gypsum**, where the PI decreased to **5.8%**, reflecting a **total reduction of 36.05%** from the untreated soil.
Conversely, the lowest reduction in PI was recorded at a **combination of 10% brick ballast and 2% gypsum**, where the PI was **14.82%**, marking a **45.41% reduction** compared to the initial soil condition.

Additionally, the **liquid limit (LL) decreased consistently** with increasing stabilizer content. The untreated soil had a **LL of 39.05%**, which gradually declined to **25.4%** at the highest stabilizer proportion. Meanwhile, the **plastic limit (PL) showed an increasing trend**, rising from **11.9% to 19.6%**, indicating improved soil workability and reduced susceptibility to moisture variations.
These results confirm that the combination of **lime, gypsum, and brick ballast** significantly enhances soil stability by reducing plasticity, lowering liquid limit, and increasing soil strength.

Table 1: Soil Classification

SAMPLE	ATTERBERG LIMIT			SOIL CLASSIFICATION
	LL, %	PL, %	PI, %	AASHTO
Expansive soil	39.05	11.9	27.15	A-7-5
WSS+10%CWB+2%G	33.12	18.3	14.82	A-6
WSS+20%CWB+4%G	29.07	20	9.07	A-6
WSS+30%CWB+6%G	25.4	19.6	5.8	A-4

The table 1 shows the effect of stabilization on soil properties using the AASHTO classification system. Expansive soil has a high LL (39.05%) and PI (27.15%), classifying it as A-7-5, indicating poor stability.
With the addition of crushed brick ballast (CWB) and gypsum (G), LL and PI decrease while PL increases, improving soil quality. At 10% CWB and 2% G, the soil shifts to A-6, showing reduced plasticity. Further stabilization (30% CWB and 6% G) improves the classification to A-4, making the soil more stable and suitable for construction. The variation graph is given below in Figure 2:

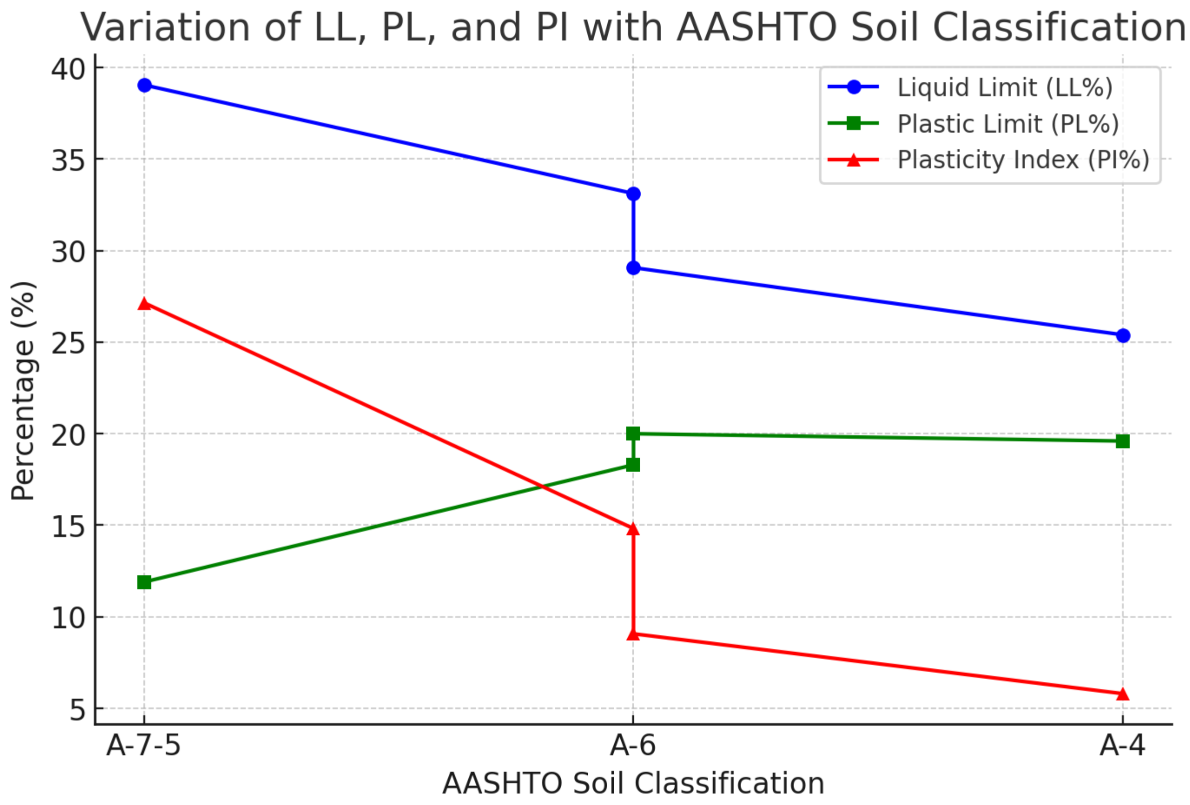

Figure 2: Soil Classification

*The **Figure 2** shows how the liquid limit (LL), plastic limit (PL), and plasticity index (PI) change with AASHTO soil classification. As soil stabilization improves, LL and PI decrease, while PL increases, indicating better soil stability and reduced plasticity.*

6.2 California Bearing Ratio (CBR)

The soaked CBR values for all samples showed an increase as the proportion of Lime, Gypsum, and Brick Ballast in the mix was raised.

6.2.1. Impact of Lime, Gypsum, and Brick Ballast on Soaked CBR Values

The soaked California Bearing Ratio (CBR) values showed a noticeable improvement with the increased inclusion of Lime, Gypsum, and Brick Ballast in the soil mix. This trend confirms the positive role of these stabilizing agents in enhancing the load-bearing capacity and overall strength of weak subgrade soils. The test results are summarized in the table below:

Table 02 California Bearing Ratio Test

Soil Type / Mix Ratio	*Soaked CBR Value (%)*
Unstable/ Expansive Soil	4%
(Lime, Gypsum, Brick Ballast) (6:2.5:10)	6%
(Lime, Gypsum, Brick Ballast) (8:5:20)	9%
(Lime, Gypsum, Brick Ballast) (10:7.5:30)	11%

The **Table 2** results clearly indicate that untreated expansive soil had the lowest soaked CBR value of 4%, reflecting its weak strength and high susceptibility to deformation under loading conditions. However, with the addition of stabilizing materials, the CBR values increased consistently. A mix ratio of (6:2.5:10) led to a CBR of 6%, while the (8:5:20) proportion further enhanced it to 9%. The highest tested mix ratio, (10:7.5:30), achieved the maximum soaked CBR value of 11%, indicating a substantial improvement in soil stability.

This enhancement in CBR values can be attributed to several factors. Lime aids in soil modification by reducing plasticity and increasing cohesion, making the soil more stable. Gypsum helps regulate moisture absorption, thereby reducing the tendency of the soil to swell and shrink. Brick Ballast, acting as a coarse aggregate, improves compaction and particle interlocking, resulting in a denser and stronger soil structure. The combined effect of these materials enhances the durability and load-bearing capacity of the stabilized soil, making it less prone to moisture-related deterioration.

The results suggest that increasing the proportion of stabilizing agents leads to improved soil strength, which is essential for construction applications such as roads and pavements. However, to ensure long-term stability, proper curing time and moisture control measures should be implemented to maintain the integrity of the stabilized subgrade.

Figure 3 shows the effects of different ratios on soil stability:

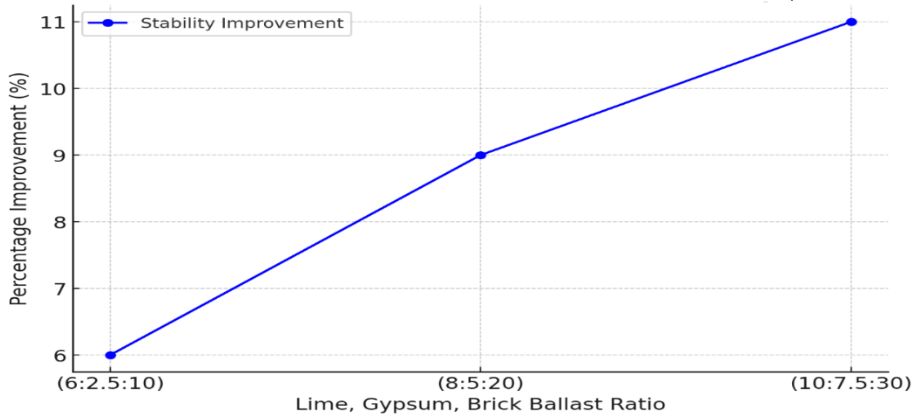

Figure 03: Effects of Different Ratios on Soil Stability

Figure 03 demonstrates the effect of varying lime, gypsum, and brick ballast ratios on soil stability improvement. The graph shows a steady increase in stability as the percentage of stabilizing materials rises. The (6:2.5:10) ratio results in around 6% improvement, while the (8:5:20) ratio enhances stability to nearly 9%. The highest ratio, (10:7.5:30), achieves the greatest improvement at 11%, indicating that higher stabilizer content leads to better soil performance.

Table 3: Unconfined Compression Strength Results

	UCS value
Expansive Soil	0.8KN
(6:2.5:10)	0.95KN
(8:5:20)	1.09KN
(10:7.5:30)	1.41

Table 3 presents the Unconfined Compression Strength (UCS) values for untreated and stabilized soil samples. The expansive soil has the lowest UCS at 0.8 KN, indicating weak structural strength. As stabilizing materials are added, UCS increases, reaching 0.95 KN for the (6:2.5:10) ratio, 1.09 KN for the (8:5:20) ratio, and a maximum of 1.41 KN for the (10:7.5:30) ratio. This trend confirms that higher stabilizer content significantly enhances soil strength, making it more suitable for load-bearing applications.

6.3.1 Effect of Lime, Gypsum, and Brick Ballast on Unconfined Compressive Strength (UCS)

The Unconfined Compressive Strength (UCS) test was conducted to evaluate the effect of Lime, Gypsum, and Brick Ballast on the strength characteristics of expansive subgrade soil. UCS is a key parameter in assessing the load-bearing capacity and overall stability of soil, particularly in road construction applications. The test results indicate a significant improvement in UCS with the addition of stabilizing agents:

- Unstabilized expansive soil: 0.80 kN
- 6% stabilizer mix (Lime: Gypsum: Brick Ballast = 6:2.5:10): 0.95 kN
- 9% stabilizer mix (Lime: Gypsum: Brick Ballast = 8:5:20): 1.09 kN
- 11% stabilizer mix (Lime: Gypsum: Brick Ballast = 10:7.5:30): 1.41 kN

6.3.2 Discussion of Results

The results indicate a progressive increase in UCS with higher proportions of Lime, Gypsum, and Brick Ballast. This improvement can be attributed to the chemical and physical modifications that occur in the soil structure upon stabilization:

1. **Pozzolanic Reactions and Cementation Effects:**

- The addition of lime triggers pozzolanic reactions, leading to the formation of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). These compounds act as binding agents, increasing soil cohesion and strength.

- Gypsum further enhances this process by contributing to crystallization and additional cementation within the soil matrix.

2. Particle Interlocking and Improved Load Resistance:

- The presence of brick ballast improves the granular structure of the soil, reducing void spaces and enhancing interparticle bonding.
- This results in better resistance to compressive loads, as reflected in the increasing UCS values.

3. Enhanced Durability and Long-Term Performance:

- The combination of stabilizers improves the moisture resistance of the soil, reducing its susceptibility to weakening in wet conditions.
- The increase in strength properties makes the stabilized soil more suitable for subgrade applications in road construction.

Engineering Implications

The results demonstrate that Lime, Gypsum, and Brick Ballast significantly enhance the compressive strength and overall stability of expansive subgrade soil. The highest UCS value (1.41 kN) was observed at the 11% stabilizer mix, indicating a substantial improvement compared to the unstabilized soil (0.80 kN). This suggests that an optimal mix of these stabilizers can greatly improve soil performance, making it more durable, load-resistant, and suitable for infrastructure applications.

However, excessive stabilizer content beyond optimal thresholds may lead to over-stiffening, which could affect soil flexibility and long-term performance. Therefore, careful mix design and field trials should be conducted to determine the most effective stabilization proportions for specific engineering applications.

These findings confirm that Lime, Gypsum, and Brick Ballast serve as efficient and sustainable stabilizing agents, offering a cost-effective solution for improving weak subgrade soils in road construction and other geotechnical projects.

6.4 Modified Proctor Test

The graph illustrates the relationship between **Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)** for both untreated and stabilized soil samples. The **OMC remains constant at 10.1%** for all tested samples, indicating that the addition of Lime, Gypsum, and Brick Ballast does not significantly alter the moisture required for maximum compaction. However, the **MDD decreases** as the proportion of stabilizing agents increases. The **untreated expansive soil** has the highest MDD at **1. g/cm³**, while the stabilized mixtures show a gradual reduction in density—**1.870 g/cm³** (**6:2.5:10**), **1.82 g/cm³** (**8:5:20**), and **1.77 g/cm³** (**10:7.5:30**). This decline occurs because the introduction of stabilizing materials replaces heavier soil particles with lighter components, leading to a more porous structure and increased void spaces. Although the MDD decreases, the stabilization process enhances soil strength, improving its suitability for construction applications. The graph given below visually represents these findings.

Table 4 Modified Proctor Test Results

Sample	Optimum Moisture Content	Maximum Dry Density
Expansive Soil	10.1%	1.913g/cm3
(6:2.5:10)	10.1%	1.870 g/cm3
(8:5:20)	10.1%	1.82 g/cm3
(10:7.5:30)	10.1%	1.77 g/cm3

The **Table 4** shows the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for expansive soil and various stabilizer combinations. The OMC remains constant at 10.1% across all samples, indicating that moisture requirements for compaction do not change significantly with stabilization. However, the MDD decreases from 1.913 g/cm³ (expansive soil) to 1.77 g/cm³ (10:7.5:30 ratio). This decline suggests that as the proportion of lime, gypsum, and brick ballast increases, the soil becomes less dense, likely due to the replacement of heavier soil particles with lighter stabilizing materials, improving soil structure and reducing shrink-swell behavior.

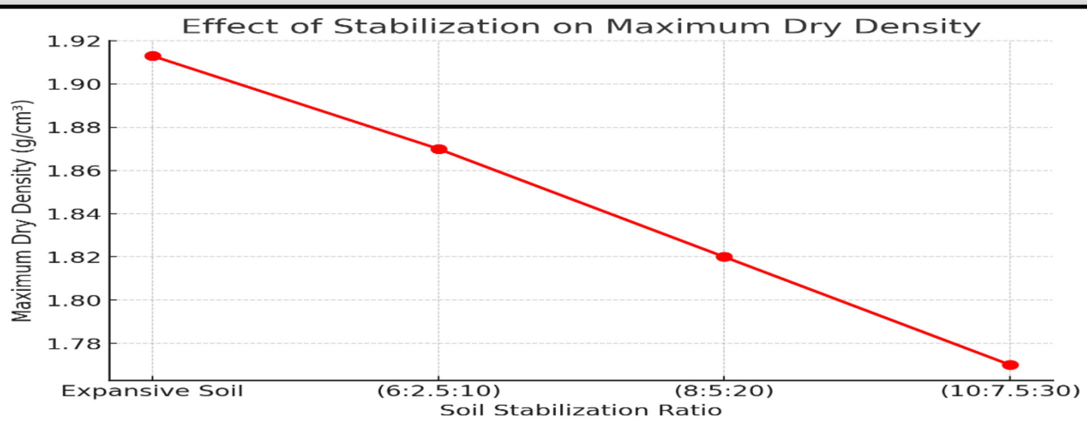

Figure 4 Relationship Between Soil Stabilization Ratio and MDD

Figure 4 presents the effect of stabilization on the **maximum dry density (MDD) of expansive soil** using different proportions of lime, gypsum, and brick ballast. The x-axis represents the stabilization ratios, while the y-axis indicates the MDD values in **g/cm³**.The data reveals a **decreasing trend** in MDD as stabilizer content increases. **Expansive soil**, without stabilization, has the **highest density (1.913 g/cm³)**. When stabilizers are added in the **(6:2.5:10)** ratio, the density reduces to **1.870 g/cm³**. Further increasing the stabilizers to **(8:5:20)** lowers the density to **1.82 g/cm³**, and the **(10:7.5:30)** mix results in the lowest density of **1.77 g/cm³**.This decline in density suggests that the **lighter stabilizers reduce the overall compaction of the soil**. The addition of lime, gypsum, and brick ballast changes the soil structure, possibly increasing void spaces and reducing the compactness. While stabilization can improve soil strength and durability, excessive stabilizer content may lead to a reduction in dry density, which should be considered in construction applications.

This reduction in **maximum dry density** suggests that the treated soil becomes **less compact and lighter** due to the inclusion of stabilizing materials. Lime and gypsum, known for their pozzolanic reactions, alter the soil structure by **reducing particle cohesion and increasing void spaces**. Additionally, the presence of brick ballast, a coarse material, further disrupts the compactness of the soil matrix. As a result, the soil exhibits a **less dense structure**, which can enhance its overall stability by minimizing **shrink-swell behavior**—a common issue in expansive soils. This transformation contributes to **improved subgrade performance**, making the soil more suitable for construction and infrastructure applications.

6.4.1. Effect of Lime, Gypsum, and Brick Ballast on Maximum Dry Density – Modified Proctor Test

The strength and stability of subgrade soil play a crucial role in the performance of road infrastructure. Expansive soils, which exhibit significant volume changes due to moisture fluctuations, often pose challenges in construction projects. One effective method to improve the engineering properties of such soils is stabilization using Lime, Gypsum, and Brick Ballast. The Modified Proctor Test was conducted to evaluate the impact of these stabilizing agents on the Maximum Dry Density (MDD) of expansive subgrade soil.

The test results indicate a gradual decrease in MDD as the proportion of stabilizers increased:

- Unstabilized expansive soil: 1.913 g/cm³
- 6% stabilizer mix (Lime: Gypsum: Brick Ballast = 6:2.5:10): 1.870 g/cm³
- 9% stabilizer mix (Lime: Gypsum: Brick Ballast = 8:5:20): 1.820 g/cm³
- 11% stabilizer mix (Lime: Gypsum: Brick Ballast = 10:7.5:30): 1.770 g/cm³

6.4.2. Discussion of Results

The reduction in MDD with increasing stabilizer content can be attributed to several factors. First, lime reacts with the clay minerals in the soil, leading to flocculation and aggregation—a process where fine particles cluster together to form larger particles. This increases void spaces, reducing the overall compacted density. Additionally, gypsum acts as a binding agent, contributing to soil stabilization through crystallization and cementation effects. The brick ballast, being coarser in texture, further alters the soil structure by creating interparticle voids.

Despite the decrease in MDD, the stabilization process enhances soil strength and durability in several ways:

- Improved Load-Bearing Capacity: The flocculated structure increases intermolecular bonding, making the soil more resistant to deformation under load.
- Reduced Shrink-Swell Behavior: Lime stabilization significantly reduces the plasticity index, thereby minimizing volume changes due to moisture variations.
- Enhanced Moisture Resistance: The chemical reactions between lime, gypsum, and clay particles improve water resistance, reducing the potential for strength loss in wet conditions.

6.4.3. Engineering Implications

While the compacted density of the stabilized soil decreases, its overall performance as a road subgrade material improves. The results suggest that an optimal mix of Lime, Gypsum, and Brick Ballast can significantly enhance subgrade stability, reducing maintenance costs and increasing the lifespan of road infrastructure. However, excessive stabilizer content beyond optimal thresholds may lead to over-flocculation, potentially affecting soil cohesion and compactability. These findings highlight the potential of Lime, Gypsum, and Brick Ballast as effective stabilizing agents for weak subgrade soils, making them a sustainable and economical solution for infrastructure development.

VII. CONCLUSION

This research focused on the stabilization of weak subgrade soil by incorporating lime, gypsum, and brick ballast in varying proportions. The primary objective was to assess the impact of these stabilizers on soil properties, including plasticity, compaction characteristics, unconfined compressive strength (UCS), and California Bearing Ratio (CBR). The selected mix ratios—(6:2.5:10), (8:5:20), and (10:7.5:30)—were analyzed through a series of laboratory tests to determine their effectiveness in improving soil stability.

- The experimental results demonstrated a significant enhancement in soil properties with the addition of stabilizers. The Atterberg Limits test revealed a substantial reduction in plasticity, with the liquid limit decreasing from 39.05% in untreated soil to 25.4% in the most optimized mix (10:7.5:30), while the plastic limit increased from 11.9% to 19.6%. These changes indicate improved workability and reduced moisture susceptibility, which are essential for long-term pavement stability.
- The compaction characteristics, as determined by the Modified Proctor Test, also exhibited notable improvements. The Maximum Dry Density (MDD) increased with the addition of stabilizers, confirming better compaction potential. This indicates that the stabilized soil can achieve a denser and more durable structure, which is crucial for supporting heavy loads in road construction.
- The Unconfined Compressive Strength (UCS) test showed a steady increase in soil strength, with the highest value of 1.41 kN observed in the 10:7.5:30 mix ratio. This confirms that lime, gypsum, and brick ballast significantly enhance the soil's load-bearing capacity, making it more resistant to deformation under applied stresses. The California Bearing Ratio (CBR) test further validated these findings, with CBR values improving from 4% in untreated soil to 11% in the most effective mix. The increased CBR values suggest that the stabilized soil can better withstand traffic loads and reduce the risk of subgrade failure.
- Among the three tested mix ratios, the combination of 10% lime, 7.5% gypsum, and 30% brick ballast provided the best results across all parameters. This mix not only improved soil strength and compaction properties but also significantly enhanced the soil's resistance to moisture-related deterioration, making it an optimal choice for subgrade stabilization.
- Overall, the findings of this study highlight the effectiveness of lime, gypsum, and brick ballast as stabilizers for weak subgrade soils. The improvements observed in strength, plasticity, and load-bearing capacity make this stabilization technique a viable and cost-effective solution for road construction projects, particularly in regions where weak soil conditions pose a challenge. By using locally available materials, this method also promotes sustainability and reduces dependency on conventional stabilization techniques.
- Future research should focus on field trials and long-term performance evaluations to further validate these findings. Additionally, exploring the environmental impact and cost-benefit analysis of this stabilization approach could provide valuable insights for large-scale implementation in infrastructure projects.

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