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Study and Analysis of Soil Stabilization Using Admixture

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Abstract - Rapid urbanization and industrialization have led to environmental challenges, including a shortage of buildable land for infrastructure projects. Construction on clay soils is expensive due to the need for soil stabilization. Initially, engineers relied on trial-and-error methods and mechanical stabilizers; however, understanding the behavior of expansive soils has become crucial. Expansive soils, which are prevalent in southern India, can be stabilized using chemical and mechanical treatments. This study explores the use of industrial waste admixtures like fly ash (FA), rice husk ash, quarry dust (QD), and marble powder (MP) for stabilizing clay soils. The goal is to reduce construction costs and manage industrial waste. Experimental results showed that the dry strength of soils improved with the addition of QD, with the optimal ratio of 70:30 for Soil 1 and Soil 2, and 80:20 for Soil 3. The optimum moisture content (OMC) and maximum dry density (MDD) were determined for each mixture. Further experiments incorporating single- and double-layer geogrids showed significant reductions in swelling behavior, swell pressure, and improvements in the California Bearing Ratio (CBR), indicating enhanced soil stabilization. The study concluded that QD is the most effective admixture, and the inclusion of geogrids further improved the soil's stability and strength, as confirmed by Artificial Neural Network (ANN) modeling with a correlation of 0.95.

Keywords - Rapid Urbanization, Quarry Dust (QD), Fly-Ash, Marble Powder (MP),Soil Stabilization, Rice Husk Ash, Clay Soils, Artificial Neural Network (ANN).

I. INTRODUCTION

The rapid urbanization and industrial growth in many parts of the world have led to significant environmental challenges, particularly in the construction sector. As the demand for infrastructure projects increases, the availability of suitable land for construction is diminishing, forcing the construction industry to develop on less ideal terrains, including expansive clay soils. Expansive soils, known for their high swelling and shrinkage behavior, pose a significant problem for construction due to their instability, requiring effective stabilization methods to improve their engineering properties.

Historically, the stabilization of expansive soils has been addressed through mechanical methods, but over time, the need to understand their chemical and physical behavior has become apparent. This understanding is crucial to developing cost-effective and sustainable stabilization techniques. The use of chemical stabilizers, such as lime and cement, has been widely adopted, but these methods often have environmental drawbacks and can be costly. In response to the growing concern over waste management and the environmental impact of traditional stabilizers, recent research has focused on using industrial by-products and agricultural waste as alternative stabilizing agents. Materials such as fly ash, quarry dust, marble powder, and rice husk ash have shown promise in improving the properties of expansive soils while addressing waste disposal issues. This study aims to explore the effectiveness of these industrial and agricultural wastes in stabilizing expansive soils, with a focus on reducing construction costs and environmental impact. By experimenting with different admixtures and incorporating geosynthetics like geogrids, this research seeks to provide innovative and sustainable solutions for improving soil stability in construction projects.

II. NEED FOR THE STUDY

Due to the increasing urbanization and industrialization in India, infertile and agricultural lands are increasingly used for construction, creating the need for effective soil stabilization techniques. This study explores the use of various admixtures to improve the strength and stability of expansive soils, focusing on the utilization of industrial wastes and geogrid technology.

Objectives of The Study

The study aims to analyze the behavior of three types of soil (Soil 1, Soil 2, and Soil 3) with various admixtures (quarry dust, marble powder, fly ash, and geogrids). The objectives include:

- Determining the dry strength of soil with different admixtures.
- Evaluating swelling characteristics, time–swelling, and swell pressure.
- Assessing subgrade strength under soaked conditions.
- Using Artificial Neural Networks (ANN) to model and validate experimental results.

III. METHODOLOGY

Materials

This study used three types of soils: Soil 1, Soil 2, and Soil 3, with properties listed in Table 1. The properties of admixtures such as Quarry Dust (QD), Marble Powder (MP), and Fly Ash (FA) are provided in Table 2. Geogrid properties, used in single and double layers at one-third and two-thirds height, are given in Table 3. and admixtures with Soil 1, Soil 2 & Soil 3 in the proportion of 90:10, 80:20, 70:30 and 60:40.

Soil samples were collected from Chhindwara Dist., India. Based on the consistency index and free swell tests, the soils were classified as CL (Low Compressibility), CI (Medium Compressibility), and CH (High Compressibility), all exhibiting high swelling characteristics according to BIS classification [IS: 2911 (Part-3) - 1981].

Table 1: Properties of Soils

Properties	Soil 1	Soil 2	Soil 3
Liquid limit (%)	35	50	75
Plastic limit (%)	15	25	45
Plasticity Index (%)	20	25	30
Free Swell Index (%)	35	50	95
Maximum Dry Density (g/cc)	1.45	1.60	1.70
Optimum Moisture Content (%)	22	26	28
Gravel (%)	0	0	0
Sand (%)	40	30	12
Silt (%)	20	24	30
Clay (%)	40	46	58
Unconfined Compressive Strength (UCS) - kN/m²	60	78	90

Table 2: Properties of Admixtures

Properties	Stone Dust
Liquid limit (%)	Non plastic
Plastic limit (%)	Non plastic
Specific gravity	2.65
Maximum Dry Density (kN/m^3)	16.8
Optimum Moisture Content (%)	6.5
Gravel	2
Sand (%)	96
Silt (%)	1
Clay (%)	1

Table 3: Properties of Geogrid

Materials	Types and Sizes
Geogrid	Polyester biaxial geogrid
Tensile Strength (kN/m)	100
Aperture size (mm)	10
Rib Thickness (mm)	1
Junction Thickness (mm)	1.5
Elongation of break (%)	10
Unit Weight g/cc	550
Roll Dimension in m (LXB)	50x3

Test Analysis

Index Properties

Liquid limit and plastic limit tests were performed as per IS [2720 (Part 5) -1985]. Sedimentation analysis for clay soil was conducted using the hydrometer method as per IS [2720 (Part 4) -1985]. Free swell tests followed IS [2720 (Part 40) -1977], and Standard Proctor Compaction tests were done as per IS [2720 (Part 7) -1980].

Free Swell Index

Two equal volumes of dry soil samples were immersed—one in water and the other in kerosene. The difference in height between the two samples was calculated and expressed as the Free Swell Index, following IS [2720 (Part 40) -1977].

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Mechanical Analysis

Mechanical analysis consisted of sieve and sedimentation analyses. Sieve analysis was done by wet sieving through various IS sieves, and sedimentation analysis was carried out using Stokes' law. The particle size distribution was determined for both coarse and fine-grained soils.

Standard Proctor Compaction Test

A 5kg air-dried soil sample was mixed with water (3-5% for sandy soils, 12-16% for cohesive soils) and compacted in a 1000cc mould in three layers with 25 blows from a 4.9kg rammer. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were determined for Soil 1, Soil 2, and Soil 3 with admixtures (SD, MP, FA) in ratios of 90:10, 80:20, 70:30, and 60:40. The highest density values were obtained at 70:30 for Soil 1 and Soil 2, and 80:20 for Soil 3.

Time-Swelling Test

Soil samples, compacted to 95% of maximum dry density with optimum moisture content, were submerged in a CBR mould. The top and bottom surfaces of the mould had perforated plates to enhance swelling. Initially, a seating pressure of 70 kg/cm² was applied, and swelling was observed at hourly intervals until three consecutive dial readings were constant. The difference between the initial and final height was used to calculate swelling. Swell pressure and percentage were determined using the expanding volume method. The addition of single- and double-layer geogrids improved the swell pressure over time.

California Bearing Ratio (CBR)

In the CBR test, soil specimens were soaked for four days and placed in a mould under a surcharge weight. Load was applied through a 50mm plunger at a rate of 1.25 mm/min, and penetration was measured. The CBR value is calculated as a percentage of the load at 2.5 mm or 5.0 mm penetration compared to standard crushed stones. The test was repeated if penetration values were inconsistent. The CBR values for Soil 1, Soil 2, and Soil 3 with SD and geogrid were evaluated, with Soil 3 having the highest CBR value under 2.5 mm penetration.

Unconfined Compressive Strength (UCS) Test

The Unconfined Compressive Strength (UCS) test measures the maximum stress a clayey soil sample can withstand without confining pressure.

Artificial Neural Network (ANN) Modelling

Artificial Neural Networks (ANN) are widely used for efficient and accurate predictions in non-linear systems, providing estimates based on regression statistical equations.

Result and Discussion

The Standard Proctor Compaction Test on Soil1, Soil 2 and Soil 3 With Various Admixtures

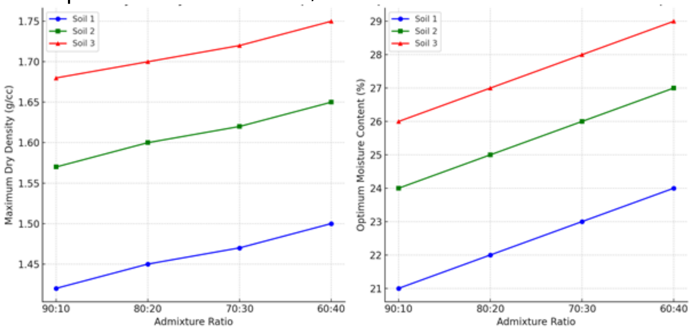

Figure 1: Result of Maximum Dry Density (MDD) & Optimum Moisture Content (OMC) of all three soils

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From Figure 1 reveal that as the admixture proportion increases (from 90:10 to 60:40), the Maximum Dry Density (MDD) of all three soils increases, indicating better compaction and higher soil density with the addition of admixtures like Quarry Dust, Marble Powder, and Fly Ash. Soil 3, with the highest clay content, shows the greatest improvement in MDD, suggesting that it benefits most from the admixtures. Conversely, the Optimum Moisture Content (OMC) increases as the admixture proportion decreases for all soils, with Soil 3 requiring the most moisture to achieve maximum compaction.

This indicates that higher admixture content helps reduce the moisture needed for compaction, especially in soils with higher clay content. Overall, the addition of admixtures improves soil density while affecting moisture requirements, with varying degrees of impact depending on the soil's properties.

Result of Swelling Behaviour of Soil 1, Soil 2 And Soil 3 with Addition of Admixtures, Geogrid Single & Double Layer.

The Figure 2 show the swelling behavior of Soil 1, Soil 2, and Soil 3 with the addition of admixtures and geogrid (single and double layers). Soil 1 shows a significant reduction in swelling as the admixture proportion increases, and the addition of a double-layer geogrid further reduces swelling, especially with the QD 70:30 mix.

A similar trend is observed in Soil 2, where swelling decreases more notably with increasing admixture and geogrid content, with the double-layer geogrid yielding the greatest improvement. Soil 3, which exhibits the highest swelling potential, shows the most substantial reduction in swelling when both admixtures and double-layer geogrid are applied, reducing swelling from 91% to around 40%. Overall, the combination of admixtures and geogrids, particularly in the double-layer form, significantly reduces the swelling behavior of all three soils, with the greatest effect seen in Soil 3.

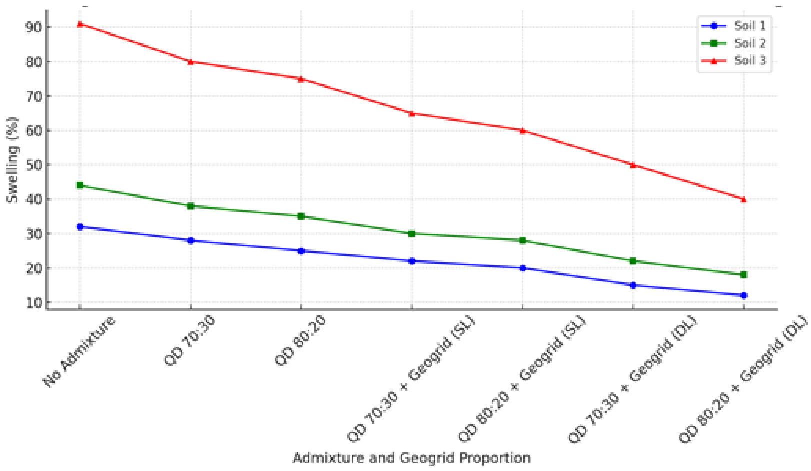

Figure 2:Result of Swelling Behaviour of Soil 1, Soil 2 And Soil 3 with Addition of Admixtures, Geogrid Single & Double Layer

Result of California Bearing Ratio (CBR) For Soil 1, Soil 2, Soil 3 with Admixture, Geogrid of Single and Double Layer

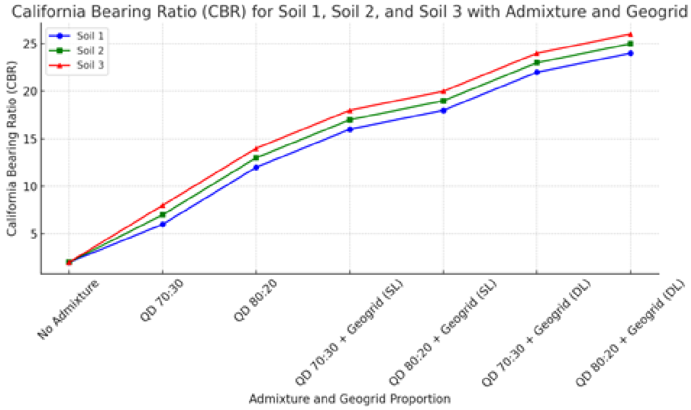

Figure 3: Result of California Bearing Ratio (CBR) For Soil 1, Soil 2, Soil 3 with Admixture, Geogrid of Single and Double Layer

The results of the California Bearing Ratio (CBR) tests for Soil 1, Soil 2, and Soil 3 with various admixtures and geogrid (single and double layers) show significant improvement in subgrade strength with the addition of admixtures and geogrids. For Soil 1, the CBR values increased as the admixture and geogrid content shrub, with the highest CBR achieved when both the admixture (QD 70:30) and double-layer geogrid were used. Soil 2 followed a similar trend, with the greatest increase in CBR observed with the double-layer geogrid. Soil 3, which initially had the lowest CBR value, showed the most remarkable improvement, especially when the admixture and double-layer geogrid were added, reaching the highest CBR value. Overall, the addition of both admixtures and geogrid, particularly the double-layer geogrid, significantly enhanced the CBR for all three soils, indicating an improved bearing capacity and strength for use in construction projects.

Result of Artificial Neural Networks (ANN)

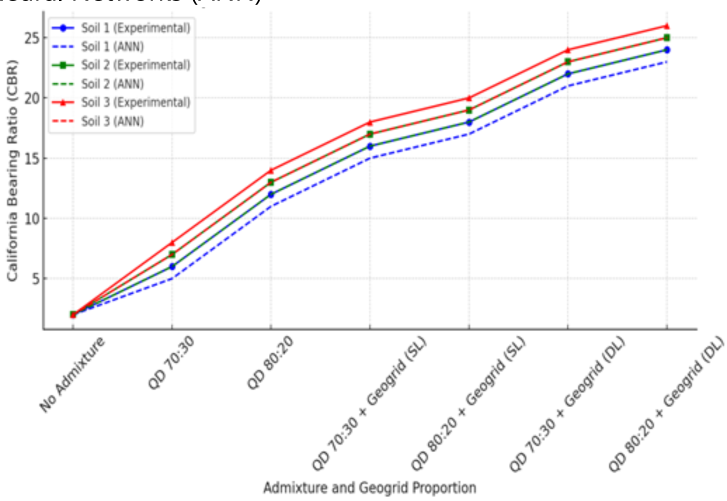

FIgure 4: Result of Artificial Neural Networks (ANN)

The results from the ANN modeling, compared to the experimental CBR values for Soil 1, Soil 2, and Soil 3 with various admixtures and geogrid (single and double layers), demonstrate a strong correlation between the predicted and observed data. The ANN model closely tracks the experimental values for all soil types, with minor deviations, indicating high accuracy in predicting soil behavior. For each soil, the CBR values predicted by the ANN align well with the experimental results, showcasing the model's ability to capture the relationship between soil properties, admixture proportions, and geogrid configurations. This confirms the potential of using ANN for reliable predictions in soil stabilization studies, reducing the need for extensive physical experimentation.

IV. CONCLUSIONS

The study present that the addition of admixtures (Quarry Dust, Marble Powder, and Fly Ash) and geogrids (single and double layers) significantly improves the engineering properties of expansive soils. The Maximum Dry Density (MDD) increased with higher admixture content, indicating better compaction, especially for soils with higher clay content like Soil 3. Similarly, the Optimum Moisture Content (OMC) decreased with the addition of admixtures, particularly for soils with lower clay content, showing that admixtures help reduce the moisture required for optimal compaction.

The swelling behavior of all soils was effectively controlled with the addition of both admixtures and geogrid, with the double-layer geogrid showing the most substantial reduction in swelling, particularly for Soil 3, which exhibited the highest swelling potential. The California Bearing Ratio (CBR) tests confirmed that the addition of admixtures and geogrids improved the subgrade strength for all soils, with the double-layer geogrid further enhancing the CBR values, especially for Soil 3.

Additionally, the Artificial Neural Network (ANN) modeling accurately predicted the soil behavior, with a high correlation between experimental and predicted values ($R = 0.95$), highlighting the potential of ANN as an efficient tool for modeling soil stabilization processes.

In conclusion, the study highlights that the combination of admixtures and geogrids, particularly the double-layer geogrid, significantly enhances the stability and strength of expansive soils, making them more suitable for construction applications. Furthermore, the ANN model provides an effective method for predicting soil behavior, offering a cost-effective alternative to traditional testing methods.

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