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A Study on Improving CBR Value by using EPE foam in Addition to GGBS Slag for Subgrade Soil

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Abstract

This paper identifies the use of industrial by-product Ground Granulated Blast Furnace Slag (GGBS) as a stabilizing agent in expansive soil with high swelling property causing severe damage to buildings built on it, and this study identifies the optimal percentage of GGBS for increasing the strength of clayey soil. Using GGBS slag to improve the CBR value of subgrade soil can have potential benefits. Ground Granulated Blast Furnace Slag (GGBS) are known to have various engineering applications, and their combined with EPE (Expanded Polythene Foam) use may slightly enhance the subgrade soil's strength and stability. The study explored the effects of incorporating GGBS slag 20%, 25% & 30% with clay soil and it is long-term performance in improving the California Bearing Ratio (CBR) of the subgrade soil. The result indicates that a stabilization ratio of 75% clay soil and 25% GGBS is compatible with all desirable sub-grade requirements. The California Bearing Ratio (CBR) is an essential engineering measure used to evaluate the subgrade soil's strength and its ability to support loads in construction projects. This thesis investigates the potential of utilizing Expanded Polythene Foam (EPE) and Ground Granulated Blast Furnace Slag (GGBS) as stabilizing agents to improve the CBR value of subgrade soil. The research aims to evaluate the effectiveness of these materials in enhancing the soil's strength, deformation characteristics and long-term performance through laboratory experiments.

Keywords: Prosocial, early childhood, android, object detection, etc

INTRODUCTION

Soil stabilization, Durability & CBR value is one of the prime things in Flexible pavement construction. In Bangladesh, most of the roads are flexible pavement based. So, on this basis, developing on flexible pavement constructions is very essential & also cost-effective process can be helpful to developing the economic system [1-4].

The construction process heavily depends on the subsoil's capacity to support loads, leaving us with just three options: modify the design, modify the soil, or permanently vacate the site. Due to inadequate load-bearing capability, there are a growing number of abandoned sites. Here, in situ and ex-situ stabilization of the soil takes place. Draining and compaction are the two easiest soil stabilization techniques [5-7].

For the construction of roads, flexible pavement will be the best option. The natural soil is always the sub-grade material, but its index properties and strength are insufficient. Stabilization will then attain the uniformity of the subgrade. To attain stability and incompressibility, various additives, such as fly ash, rice husk ash, pond ash, copper slag, and other industrial wastes, are tested as stabilizers [9].

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Slag is typically a combination of metal oxides and silicon dioxide. Slags, in contrast, can include metal sulfides and elemental metals. The principal components of these slags are calcium, magnesium, silicon, iron, and aluminum oxides, with minor levels of manganese, phosphorus, and other elements depending on the raw materials utilized. Furthermore, slag can be categorized based on the presence of iron, among other key components [18].

Expanded polyethylene (EPE) beads generate a very flexible closed-cell foam with a high level of resiliency. This material can withstand repeated deformations while retaining its dimensions and cushioning capacity.

EPE foam is a durable, strong, and flexible closed-cell material. It starts as a thermoplastic and is then expanded into a foam structure through a blowing process. Polyethylene's high compression rates allow it to maintain its resilience in the face of repeated impact. It also provides the material with excellent load bearing properties. Its application versatility is impressive [12].

Soil stabilization encompasses a broad range of techniques, including physical, chemical, mechanical, biological, or combination approaches, that are employed to modify a natural soil in order to fulfill certain engineering objectives. Enhancements encompass enhancing the load-bearing capacity, tensile strength, and overall efficacy of unstable subsoils, sands, and waste materials with the aim of fortifying road pavements [17].

CBR The California Bearing Ratio (CBR) is a metric utilized to assess the structural integrity of the subgrade in roadways or other paved surfaces, as well as the quality of the materials employed during its construction.

The ratio is quantified by the utilization of a standardized penetration test that was initially devised by the California Division of Highways specifically for the field of highway engineering [13].

Flexible pavements are designed to "flex" or bend under traffic loads, which helps reduce damage and minimizes the need for frequent repairs. These pavements consist of multiple layers of materials that work together to allow for this flexibility and distribute the load effectively [2].

In engineering practice, earth construction necessitates compactions of existing subgrade by increasing the density and strength of the strata. All sorts of earth buildings, such as highways and pavements, lie directly on the soil beneath them. The bearing capability of the earth on which these entities are built determines their safety. As a result, thorough soil property analysis and compression parameter design are required to ensure that these constructions remain stable and safe against unequal settlements. The California bearing ratio is one of the parameters commonly used to establish the acceptability of any soil type for use as sub grade, subbase or base material (CBR) [4].

Generally, pavement surface roughness is measured by the irregularities in the pavement surface that reduce the travel comfort of vehicles and, by extension, the comfort of the user. Roughness is one of the most essential pavement characteristics because it affects riding quality, delay costs, fuel consumption, and maintenance expenses. The measurement of longitudinal pavement roughness as expressed by the International Roughness Index (IRI) has recently become an essential indicator for evaluating the overall condition of road networks [2].

LITERATURE SURVEY

The goals of this review of the literature were to locate previously written studies on soil stabilization & CBR that were concerned with the construction of Flexible pavement, types of soil stabilization & CBR that were primarily focused on GGBS slag and EPE, their impact on the characteristics of the subgrade soil [14, 16].

Subgrade Soil

Sub Grade as the function of subgrade soil is to transmit loads from the pavement to the layer below, it must have sufficient load carrying capacity. There are numerous locations on Earth where clayey soil can be located. For geotechnical engineers, the design and construction of pavement over this unstable and expansive type of soil is quite challenging and problematic [10].

Soil Properties

Color, texture, structure, porosity, density, consistence, aggregate stability, and temperature are all physical properties of soil. These features affect processes like water infiltration, soil erosion, nutrient cycling, and biological activity. These properties also influence the suitability of soil for various applications, such as infiltration of storm water and subgrade for roads.

Soil categorization has become essential, particularly for geotechnical civil engineering, due to the wide variances among soil types. On finding and categorizing soil characteristics, a classification strategy known as "index properties" is built. Examples of common soil index properties include the plasticity index, liquid limit, and plastic limit. The liquid limit is the moisture content at which clay soil shifts from a solid to a liquid state. Due to the low shear strength of clayey soil, the strength and liquid limit fall as the water content rises.

The liquid limit and plastic limit can be subtracted to give the plasticity index (PI), which is a measurement of soil plasticity [20].

EPE (Expanded Polyethylene)

Expanded polythene (EPE foam) refers to polyethylene-based foams. EPE foam is typically produced from expanded pellets, also known as EPE beads, which are expanded using a blowing agent and molded in a steam chamber, similar to the process used for creating expanded polystyrene foam.

Properties of EPE (Expanded Polyethylene)

EPE foam is a low-density, semi-rigid, closed-cell material, falling between expanded polystyrene and polyurethane in terms of stiffness and flexibility. The manufacturing process is similar to that of expanded polystyrene foam but starts with polyethylene particles. The foam typically has densities ranging from 29 to 120 kg/m^3 (49 to 202 lb/cu yd), with lower densities being more common.

Producing densities as low as 14 kg/m3 (24 lb./cu yd) is possible [13].

California Bearing Ratio

The CBR rating quantifies the load-bearing capacity of road-building soil. The greater the CBR rating, the surface's hardness index [9].

CBR is the ratio of the force per unit area needed to penetrate a soil mass at a rate of 1.25 mm/min using a standard circular plunger with a diameter of 50 mm to that needed to do the same in a standard material. Typically, the ratio is established for penetrations of 2.5 and 5 mm.

The CBR value of a clayey soil is often low (less than 8). Sands often have CBR values between 15 and 35, are more granular better. The best CBR values, often 25 and higher, are found in gravel. It is advised to save the best material for capping the subgrade because of this [11].

GGBS Slag

Ground granulated blast-furnace slag (GGBS or GGBFS) is produced by rapidly cooling molten slag, a byproduct of iron and steel production, with water or steam. This cooling process forms a glassy, granular material, which is then dried and finely ground into a powder. GGBS is known for its latent hydraulic properties, meaning it reacts with water to form calcium silicate hydrates (C-S-H), contributing to the strength and durability of concrete.

One of its key advantages is its ability to improve the performance of concrete, particularly in terms of durability and resilience. It is commonly used in metallurgical cement and blended cements. GGBS plays an important role in regulating the heat of hydration during the curing process, especially in large concrete structures. By slowing down the release of hydration heat, it helps prevent thermal cracking, making it suitable for use in massive structures or in warm climates where controlling temperature rise is crucial during the cement setting process [15].

Uses of Slag

Granulated blast furnace slag has been utilized as a raw material for cement manufacturing, as well as an aggregate and an insulator along with granulated slag as sand blasting shot materials. Because of its latent hydraulic qualities, blast furnace slag is most frequently used as a cement addition and in concrete construction. This characteristic also enables its use as mortar for building and in stabilizing soil.

The addition of 25% steel slag to soil raises the unconfined compressive strength from 94.3 to 170.6 kPa, according to tests on unconfined compressive strength. According to the California Bearing Ratio test, the California Bearing Ratio value rises from 3.64 to 6.82% with a 25% addition of steel slag [19].

Slag as Soil Stabilizer

As a stabilizer, copper slag was used to cleanse the clay soil. To enhance the physical properties of clay soil, three distinct fractions of copper slag (10%, 20%, and 30%) were incorporated into the soil. The aforementioned mixture of treated soil samples was evaluated for water content, desiccated density, and load bearing capacity [9].

The purpose of chemical stabilization is to increase the soil's strength and bearing capacity by reducing or eliminating the undesirable engineering properties of the soil through the addition of chemical materials. A multitude of stabilization materials, including cement, limestone etc. [8].

Previous Research About Slag & Improvement

Less expensive admixtures reduce the amount of copper dross and GGBS required to make the soil non-plastic, thereby reducing the cost. It has been discovered that the addition of copper slag and GGBS to subbase increases the value of unconfined compressive strength more than conventional methods, thereby reducing the costs associated with ground enhancement [5].

In tandem with the inclusion of copper slag during the stabilization process, the CBR value increases continuously. A 30% addition of copper slag with a higher CBR value improves the conformity of flexible pavement design, particularly in the reduction of sub base course thickness. The combination of 70 percent clay soil and 30 percent copper slag is a compatible stabilization ratio that enhances all desirable subgrade characteristics [9].

Existing soil has a CBR of 6.29 %; at 2% limestone + 10% glass slag, the highest CBR value is 8.86 %; and at 4% limestone + 10% glass slag, the highest CBR is 10.50 % [8].

The unconfined compressive strength of clay soils treated with steel slag depends on the initial compaction conditions. While the zero slag compacted soil exhibits a decrease in UCS with increasing slag content, the compacted soil with varying steel slag content exhibits a nearly insignificant change in UCS with increasing slag content 7].

In this study, ground granulated S, a byproduct of the steel industry in Chonburi Province, Thailand, was used as a precursor in the production of S geopolymer. S's particle size distribution curve was determined through laser particle size analysis. The average particle size of S was 428 m. The chemical composition of S was determined using XRF analysis. The XRF analysis revealed that S was composed of 26.78 percent SiO2, 11.25 percent Al_2O_3, 20.65 percent Fe2O3, and 30.45 percent CaO. XRD analysis detected the peaks of the principal trace phases, including calcite, calcite aluminum oxide, and calcite silicate, as well as sub minerals such as gehlenite and hematite [3].

PROBLEM STATEMENT

In engineering practice, earth construction necessitates compactions of existing subgrade by increasing the density and strength of the strata. All sorts of earth buildings, such as highways and pavements, lie directly on the soil beneath them. The bearing capability of the earth on which these entities are built determines their safety. As a result, thorough soil property analysis and compression parameter design are required to ensure that these constructions remain stable and safe against unequal settlements. The California bearing ratio is one of the parameters commonly used to establish the acceptability of any soil type for use as sub grade, subbase or base material (CBR) [4].

Generally, pavement surface roughness is measured by the irregularities in the pavement surface that reduce the travel comfort of vehicles and, by extension, the comfort of the user. Roughness is one of the most essential pavement characteristics because it affects riding quality, delay costs, fuel consumption, and maintenance expenses. The measurement of longitudinal pavement roughness as expressed by the International Roughness Index (IRI) has recently become an essential indicator for evaluating the overall condition of road networks [2].

OBJECTIVE

- To find the optimum percentage of slag & optimum number of EPE (Expanded polyethylene foam) layer for soil stabilization.

METHODOLOGY

The methodology will include the study's location, research design, sampling strategy and sample size, data types, and data collection method.

Percentage of EPE and Slag

- Slag 20% + EPE 1 layer
- Slag 25% + EPE 1 Layer
- Slag 30% + EPE 1 Layer

Following Steps are Followed for Analyze the Soil

- Specific gravity of soil
- Determination of Atterberg's Limits
- Grain size analysis
- Modified proctor test
- California Bearing Ratio test

SPECIFIC GRAVITY TEST

The specific gravity test, conducted in accordance with ASTM D 854-00, is used to determine the specific gravity of soil using a pycnometer. This test measures the ratio of the mass per unit volume of soil to the mass per unit volume of gas-free distilled water, both measured at the same temperature Table 1.

Calculation: Calculating the specific gravity of the soil as follows:

$$Gs = \frac{M2-M1}{(M4-M1)-(M3-M2)}$$

Table 1. Determination of formulation.

M1	Weight of Pycnometer
M2	Weight of Pycnometer +Soil
M3	Weight of Pycnometer +Soil+Water
M4	Weight of Water + Pycnometer
GT	Specific gravity of distilled water

ATTERBERG LIMIT TEST

Atterberg, a Swedish agriculturist, classified the full range from liquid limit state to solid state into four stages in 1911:

The following stages define the states of consistency in soils:

- The liquid state
- The plastic state
- The semi-solid state
- The solid state

Atterberg limits, also known as consistency limits, were established to define the boundaries between these states. These limits are determined by the water content at which the soil transitions from one state to another.

The Standard Test Method for determining the liquid limit, plastic limit, and plasticity index of soils is performed according to ASTM D 3318. For particle-size analysis, the method follows ASTM D 322.

This procedure is used to calculate the relative abundance of various soil grain sizes. Coarse particle distribution is determined using mechanical or sieve analysis, while fine particle distribution is determined through the hydrometer approach. Soil's engineering qualities are influenced by the distribution of its various grain sizes. Soil classification relies on grain size analysis, which reveals the grain size distribution.

Compaction Test

The purpose of this laboratory procedure is to establish a correlation between soil dry density and moisture content at a certain compaction effort. How much force is used to compact a quantity of soil is known as the compaction effort. Soil can be compacted in the field using a variety of means, such as tamping, kneading vibration, or static load compaction. There are two names for this examination: the Proctor test and the actual examination.

Compaction Tests

- *Standard Proctor Test:* Soil is compacted in a mold using a 5.5 lb hammer dropped from a height of one foot. The soil is added in three layers, each receiving 25 blows. This test helps establish the relationship between soil moisture and dry density.
- *Modified Proctor Test:* Similar to the Standard Proctor, but a 10 lb hammer is used, dropped from 18 inches. The soil is compacted in five layers, each receiving 25 blows. This test provides higher compaction energy for denser results.

Molds

- Smaller mold: 3 inches in diameter, volume ~933 cm^3.
- Larger mold: 6 inches in diameter, volume ~1/13.333 ft^3.

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California Bearing Ratio (CBR) Test

The CBR test measures soil strength by comparing the force required to penetrate the soil with a 50 mm plunger at 1.25 mm/min to that required for standard material. CBR is typically measured at 2.5 mm and 5 mm penetration. For railway formation and similar projects, the test is conducted on remolded, soaked soil samples, offering insights into soil load-bearing capacity for construction Table 2.

Preparation of Test Specimen

- *Remolded Specimen:* The soil sample was first sieved, allowing particles smaller than 19 mm but retaining those larger than 4.75 mm. The dry density of the remolded specimen was determined using the heavy compaction method in accordance with relevant standards. Water was added based on the optimum moisture content or the natural moisture of the soil.
- *Dynamic Compaction:* A soil sample weighing around 5.5 kg (or more for granular soils) was thoroughly mixed with water. The exact amount of soil and water needed to reach the maximum dry density at the optimum moisture content was carefully measured.
- The mold was prepared by assembling the extension collar and base plate, inserting a spacer disc at the base, and placing filter paper on top.
- The soil was compacted in three layers, each receiving 55 blows using a 4.89 kg rammer.
- After compaction, the extension collar was removed, and the surface of the soil was trimmed to the top of the mold. Any voids on the surface were patched with finer soil particles. The mold and soil were weighed, and the perforated base plate, spacer disc, and filter paper were removed. The mold was then inverted, and another filter paper was placed on the compacted soil. The perforated base plate was reattached.
- A final layer of filter paper was placed on top of the soil specimen, and a perforated plate was secured.

Procedure for Penetration Test

- The prepared mold and soil specimen were placed on the lower plate of the penetration testing machine. A 2.5 kg weight was placed on the surface of the soil to prevent any soil from rising through the holes in the surcharge weights. The penetration plunger was then positioned, and the remaining surcharge weights were added.
- The piston was carefully placed at the center of the specimen, applying minimal initial load.
- The load and deformation gauges were reset to zero, and the load was applied to the piston at a steady rate of 1.25 mm per minute.

This approach ensures a standardized method for testing soil properties, following established procedures for accurate measurement of compaction and penetration resistance.

The load was recorded readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10 and 12.5 mm Table 3.

Observation and Recording

Calculation

If the initial part of the curve is concave upwards, apply a correction by drawing a tangent at the point of steepest slope and adjust the origin. Then, determine and record the corrected load value for each penetration.

$$\text{C.B.R.} = \left(\frac{PT}{PS}\right) 100$$

Table 2. Standard load values.

Penetration	Load(kN)
2.5	13.43
5.0	20.15

Here,

If the initial segment of the load-penetration curve is concave upwards, a correction is made by drawing a tangent at the point of steepest slope and adjusting the origin. The corrected load values for each penetration should then be determined.

The **California Bearing Ratio (C.B.R.)** is calculated as:

$$C.B.R. = \left(\frac{PT}{PS}\right) \times 100$$

Where:

- **PT** is the corrected load corresponding to a specific penetration depth from the load-penetration curve.
- **PS** is the standard load for the same penetration depth, as specified in reference tables.

The C.B.R. values are usually calculated at penetration depths of **2.5 mm** and **5.0 mm**. Typically, the C.B.R. at 2.5 mm is higher than at 5 mm, and in such cases, the 2.5 mm value is used for design. If the C.B.R. at 5 mm exceeds that at 2.5 mm, the test should be repeated, and if similar results are obtained, the C.B.R. at 5 mm is used for design purposes Figure 1.

Table 3. Dial gauge reading.

Penetration (mm)	Load (kN)
0.5	1
1	1.5
1.5	2.1
2	3.7
2.5	6.5
3	7.9
4	9.11
5	11
7.5	11.7
10	13

Figure 1. Apparatus used in CBR.

RESULTS AND DISCUSSIONS

Specific Gravity of Soil

Sample Test 1

$$Gs_1 = \frac{M2-M1}{(M4-M1)-(M3-M2)} = 2.74$$

Sample Test 2

$$Gs_2 = \frac{M2-M1}{(M4-M1)-(M3-M2)} = 2.76$$

Sample Test 3

$$Gs_3 = \frac{M2-M1}{(M4-M1)-(M3-M2)} = 2.77$$

Average specific gravity $= \frac{2.74+2.76+2.77}{3} = 2.75$

The specific gravity of sand falls within the range of 2.65 to 2.68, whereas the specific gravity of gravel falls within the same range. Both silty sand and silt fall within the range of 2.66 to 2.7 Inorganic clay has a specific gravity that ranges from 2.68 to 2.8, but organic soil has a specific gravity that is lower than 2. Table 4, Table 5, Table 6 shows the data for specific gravity. The specific gravity of this soil is 2.75, which indicates that it is an inorganic clay soil Table 5 and 6.

Atterberg Limit

Liquid limit

Calculations
Can weight 25.20gm
Can weight +Soil sample weight = 46.02gm
Can weight + Dry soil sample weight =40.42 gm
Dry soil = (4o.42-25.20) gm =15.22 gm
Pore water = (46.02-40.42) gm = 5.6 gm
Water content = Pore water/ Dry soil ∗ 100% = 36.79 %
Number of blow need = 41

Table 4. Data sheet for specific gravity of sample 1 by pycnometer method.

M1	Weight of Pycnometer (gm)	233
M2	Weight of Pycnometer +Soil (gm)	483
M3	Weight of Pycnometer +Soil +Water (gm)	1387
M4	Weight of Water + Pycnometer (gm)	1228

Table 5. Data sheet for specific gravity of sample 2 by pycnometer method.

M1	Weight of Pycnometer (gm)	233
M2	Weight of Pycnometer +Soil (gm)	471
M3	Weight of Pycnometer +Soil +Water (gm)	1380
M4	Weight of Water + Pycnometer (gm)	1228

Table 6. Data sheet for specific gravity of sample 3 by pycnometer method.

M1	Weight of Pycnometer (gm)	233
M2	Weight of Pycnometer +Soil (gm)	530
M3	Weight of Pycnometer +Soil +Water (gm)	1418
M4	Weight of Water + Pycnometer (gm)	1228

Table 7 shows the liquid limit of the soil. For subgrade liquid limit is 24.9% < 45% ,which is shown in Figure 2.

Plastic Limit

Calculations

Can weight 36.89 gm
Can weight +Soil sample weight = 38 gm Can
Weight + Dry soil sample weight =37.78 gm
Dry soil = (37.78-36.89) gm =0.89 gm
Pore water = (38-37.78) gm = 0.22 gm
Water content = Pore water Dry water ∗ 100% = 0.22 0.89 ∗ 100% =24.90 %

Clay, medium plasticity soil plastic limit is 18 to 25. From the Table 8, it can be shown that the water content in this soil is 23.82% Table 7-8 and Figure 2.

Table 7. Data sheet for liquid limit.

Serial no	1	2	3
Can + wet soil	46.02	51.40	43.12
Can + dry soil	40.42	45.95	38.24
Can weight	25.20	27.33	28.87
Loss of moisture	5.6	5.45	4.88
Wt. of dry soil	19.6	21.88	23.99
Moisture content %	28.57	24.90	20.34
Number of blows	41	26	24

Table 8. Data sheet for plastic limit test.

Can no	1	2	3
Empty Can Weight (gm)	36.89	28.62	27.45
Can +Wet Soil weight (gm)	38	30.07	28.54
Can +Dry Soil weight (gm)	37.78	29.8	28.33
Dry Soil (gm)	0.89	1.18	0.88
Pore water (gm)	0.22	0.27	0.21
Water Content %	24.71	22.88	23.86
Average = 23.82			

Clay, medium plasticity soil plastic limit is 18 to 25.

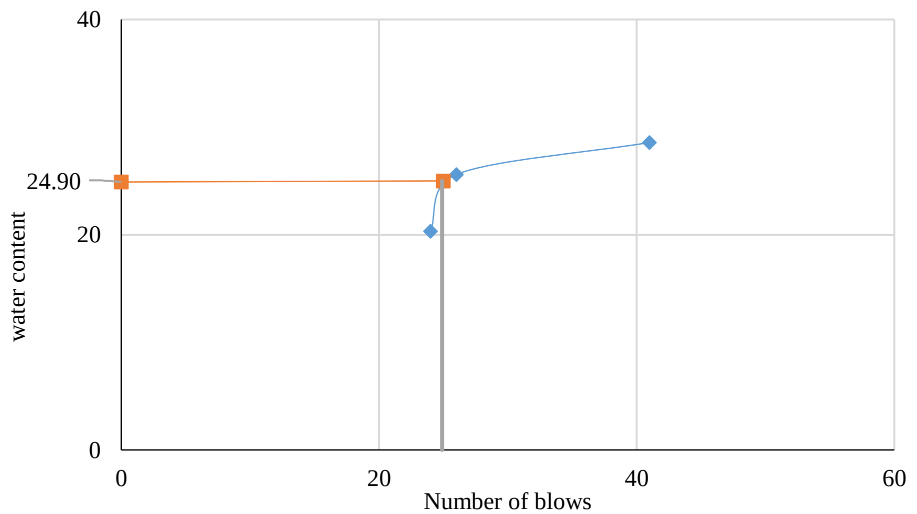

Figure 2. Liquid limit.

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Grain Size Analysis

Figure 3 depicts the results of the examination of the soil's grain size. According to the graph, the values of D10, D30, and D60 are 0.075, 0.153, and 0.229, all of which are respectively Figure 3.

Soil classification

MIT System. (Massachusetts Institute of Technology)

According to the data shown in Table 9, this type of soil is characterized as silty clay.

Compaction Properties

Compaction Test for Control Soil Sample

The dry density increases when water is added. After attaining the optimal water content percentage, the dry density will decrease. Table 10 displays the results of the standard proctor test performed on the control soil. The optimal moisture content is 16.23%, as shown in Figure 4, which summarizes the information.

Treated Soil Sample

Treated Soil with Soil 80% & Slag 20%

The dry density increases when water & slag is added. After attaining the optimal water content percentage, the dry density will decrease. Table 11 represent the data for standard proctor test. After calculation the optimum moisture content of the soil is found 14.69%, which is illustrated in Figure 5.

Table 9. Particle size distribution by MIT system.

Particle Name	Particle Name	Particle Size (mm)	Percentage of particle
Clay	Clay	0.000 to 0.002	26%
Silt	Fine	0.002 to 0.006	13%
Silt	Medium	0.006 to 0.02	21%
Silt	Course	0.02 to 0.06	28%
Sand	Fine	0.06 to 0.2	12%
Sand	Medium	0.2 to 0.6	0%
Sand	Course	0.6 to 2	0%

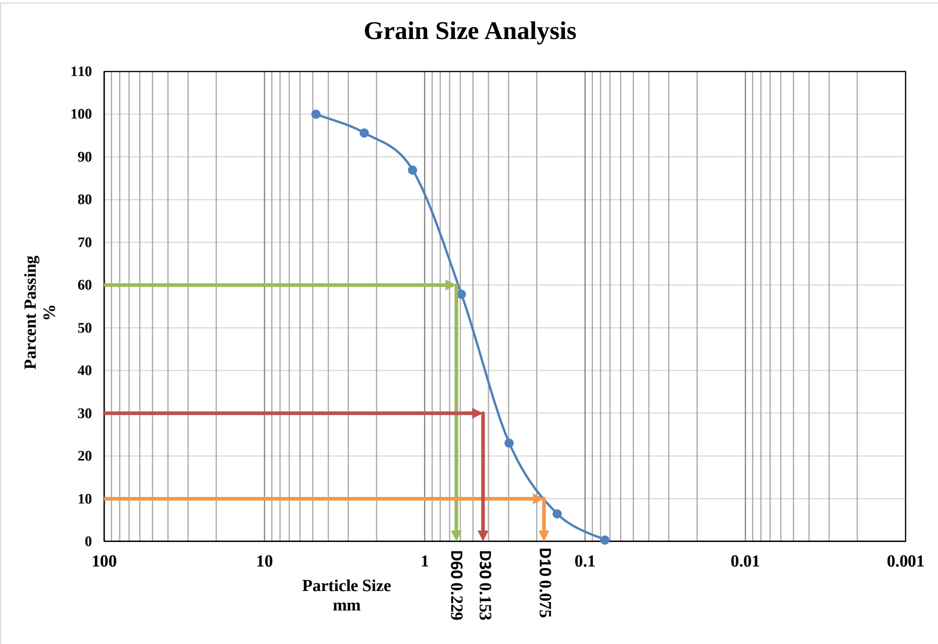

Figure 3. Grain size analysis graph.

Table 10. Data sheet for standard proctor test of control soil.

Description	1	2	3	4	5
Weight of Mold + wet soil (g)	3633.00	3717.00	3762.00	3757.00	3732.00
Weight of Mold (g)	2003.00	2003.00	2003.00	2003.00	2003.00
Weight of Soil (g)	1630.00	1714.00	1759.00	1754.00	1729.00
Volume of Mold (cc)	1121.27	1121.27	1121.27	1121.27	1121.27
Wet Density g/cc	1.45	1.53	1.57	1.54	1.54
Dry Density g/cc	1.29	1.33	1.35	1.31	1.23
Container No	**1**	**2**	**3**	**4**	**5**
Weight of Container + wet soil (g)	74.83	96.60	72.40	79.00	85.65
Weight of Container + Dry soil (g)	69.60	89.00	65.80	71.20	73.83
Weight of Container	28.33	37.27	25.13	27.50	27.95
Weight of Dry soil	41.27	51.73	40.67	43.70	45.88
Weight of Moisture	5.23	7.60	6.60	7.80	11.82
Moisture content	12.67	14.69	16.23	17.85	25.76

Table 11. Data sheet for standard proctor test of soil 80% & slag 20%

Description	1	2	3	4
Weight of Mold + wet soil (g)	3873.00	3969.00	3975.00	3935.00
Weight of Mold (g)	2003.00	2003.00	2003.00	2003.00
Weight of Soil (g)	1870.00	1966.00	1972.00	1932.00
Volume of Mold (cc)	1121.27	1121.27	1121.27	1121.27
Wet Density g/cc	1.67	1.75	1.76	1.72
Dry Density g/cc	1.48	1.53	1.51	1.46
Container No	**1**	**2**	**3**	**4**
Weight of Container + wet soil (g)	74.83	96.60	72.40	79.00
Weight of Container + Dry soil (g)	69.60	89.00	65.80	71.20
Weight of Container	28.33	37.27	25.13	27.50
Weight of Dry soil	41.27	51.73	40.67	43.70
Weight of Moisture	5.23	7.60	6.60	7.80
Moisture content	12.67	14.69	16.23	17.85

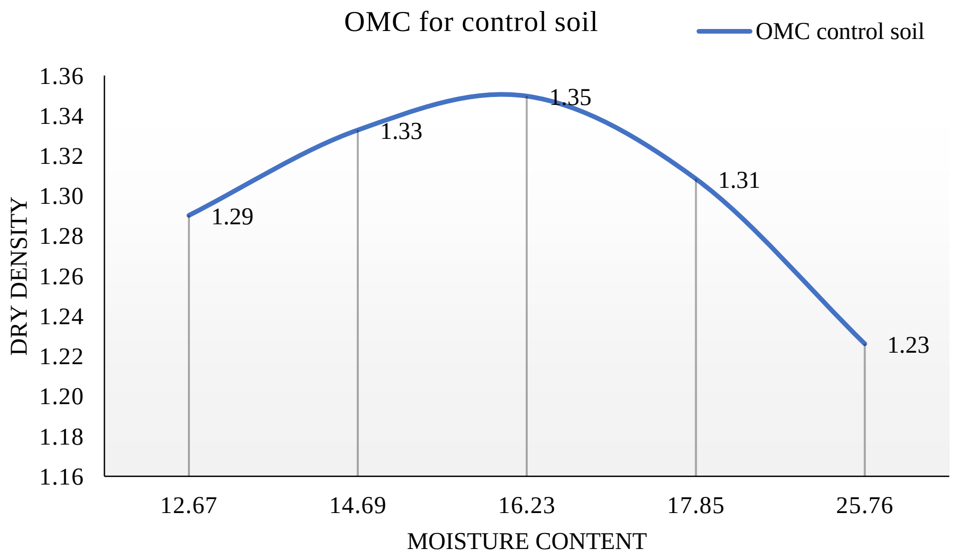

Figure 4. Optimum moisture content of soil.

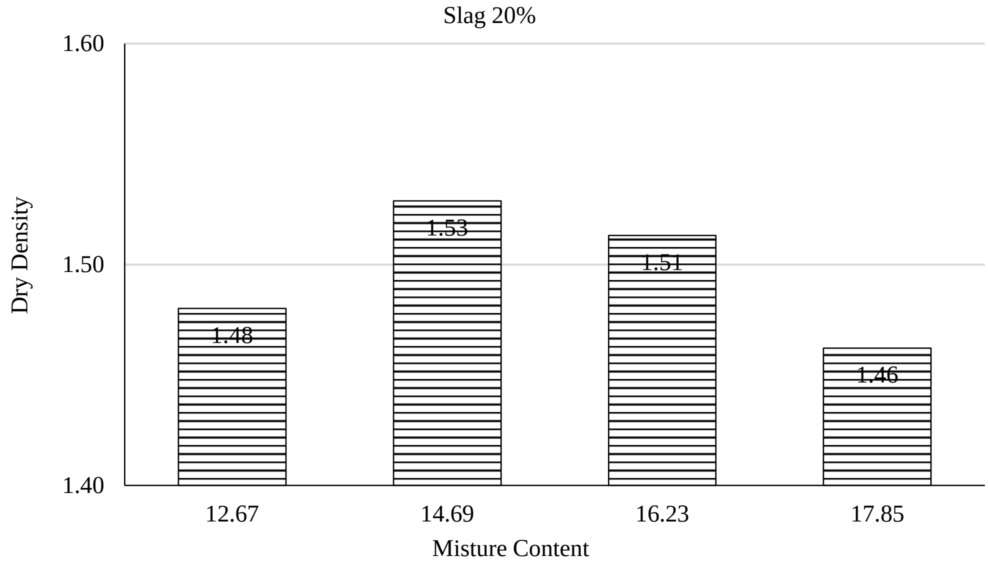

Figure 5. Optimum moisture content of slag percentage.

Treated Soil with Soil 80% & Slag 25%

Dry density is increased by adding water. After reaching the optimum percentage of water content dry density ware decrease. All of the information for the standard proctor test is included in Table 12. Figure 6 depicts the optimal moisture content of the soil, which was determined to be 15.78% after thorough calculation.

Treated Soil with Soil 80% & Slag 30%

Dry density rises with the addition of water. After reaching the optimum percentage of water content dry density ware decrease. Table 13 contains all important details on the standard proctor test. Figure 7 illustrates the optimal soil's moisture content, calculated to be 15.09%.

California Bearing Ratio (CBR) Test

Untreated Soil Sample

From the Table 14, untreated soil sample penetration at 2.5mm and 5mm was 9.69% and 9.36%, respectively. A CBR value between 5% and 15% is optimal. In Figure 8, the value of load and penetration are plotted in a graph.

Table 12. Data sheet for standard proctor test of soil 80% & slag 25%.

Description	1	2	3	4	5
Weight of Mold + wet soil (g)	3637.00	3726.00	3815.00	3859.00	3838.00
Weight of Mold (g)	2003.00	2003.00	2003.00	2003.00	2003.00
Weight of Soil (g)	1634.00	1723.00	1812.00	1856.00	1835.00
Volume of Mold (cc)	1121.27	1121.27	1121.27	1121.27	1121.27
Wet Density g/cc	1.46	1.54	1.62	1.66	1.64
Dry Density g/cc	1.31	1.36	1.42	1.43	1.39
Container No	**1**	**2**	**3**	**4**	**5**
Weight of Container + wet soil (g)	78.02	79.37	83.19	92.97	111.21
Weight of Container + Dry soil (g)	72.35	72.84	76.20	84.23	98.78
Weight of Container	21.22	21.82	26.00	28.86	27.97
Weight of Dry soil	51.13	51.02	50.20	55.37	70.81
Weight of Moisture	5.67	6.53	6.99	8.74	12.43
Moisture content	11.09	12.80	13.92	15.78	17.55

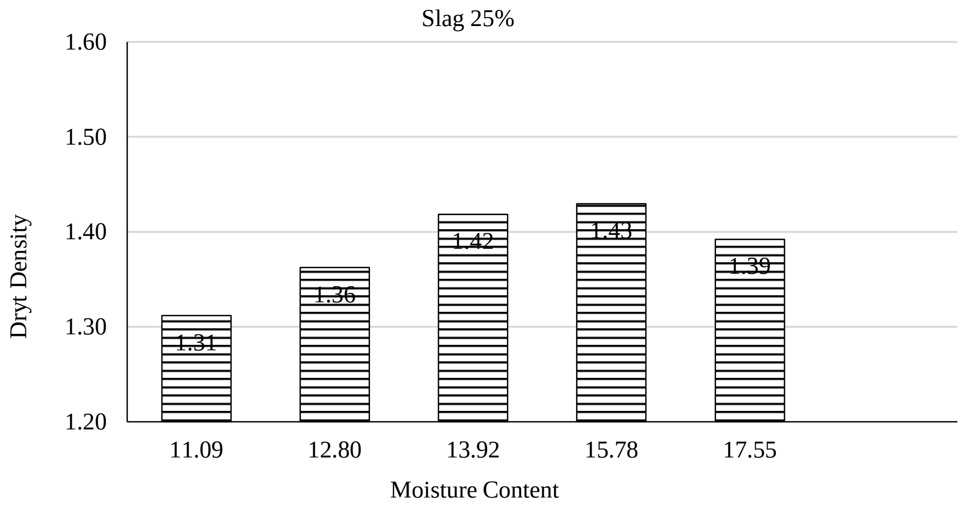

Figure 6. Optimum moisture content of slag percentage.

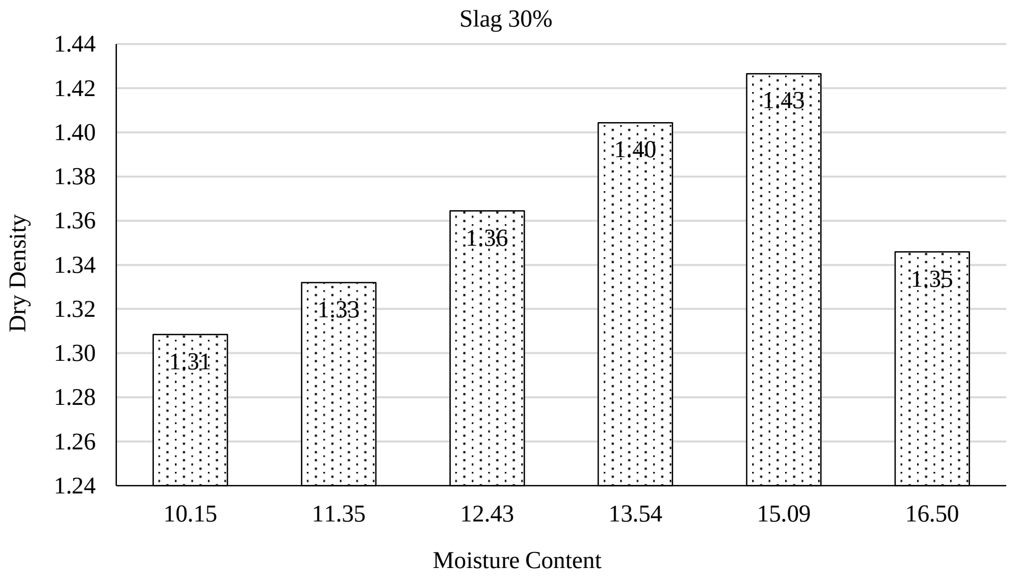

Figure 7. Optimum moisture content of slag percentage.

Table 13. Data sheet for standard proctor test of soil 80% & slag 30%.

Description	1	2	3	4	5	6
Weight of Mold + wet soil (g)	3619.00	3666.00	3723.00	3791.00	3844.00	3761.00
Weight of Mold (g)	2003.00	2003.00	2003.00	2003.00	2003.00	2003.00
Weight of Soil (g)	1616.00	1663.00	1720.00	1788.00	1841.00	1758.00
Volume of Mold (cc)	1121.27	1121.27	1121.27	1121.27	1121.27	1121.27
Wet Density g/cc	1.44	1.48	1.53	1.59	1.64	1.57
Dry Density g/cc	1.31	1.33	1.36	1.40	1.43	1.35
Container No	**1**	**2**	**3**	**4**	**5**	**6**
Weight of Container + wet soil (g)	75.34	94.39	78.14	104.21	101.00	89.42
Weight of Container + Dry soil (g)	70.40	86.90	71.90	94.34	90.46	79.79
Weight of Container	21.73	20.90	21.70	21.47	20.63	21.42
Weight of Dry soil	48.67	66.00	50.20	72.87	69.83	58.37
Weight of Moisture	4.94	7.49	6.24	9.87	10.54	9.63
Moisture content	10.15	11.35	12.43	13.54	15.09	16.50

Table 14. Data sheet for California bearing ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	1.2	0.555	
1	2	0.887	
1.5	2.3	1.011	
2	2.7	1.177	
2.5	3	1.302	9.69
3	3.3	1.426	
4	3.7	1.592	
5	4.5	1.924	9.36
7.5	5.7	2.422	
10	6.9	2.92	
12.5	7.7	3.25	
15	8.4	3.543	

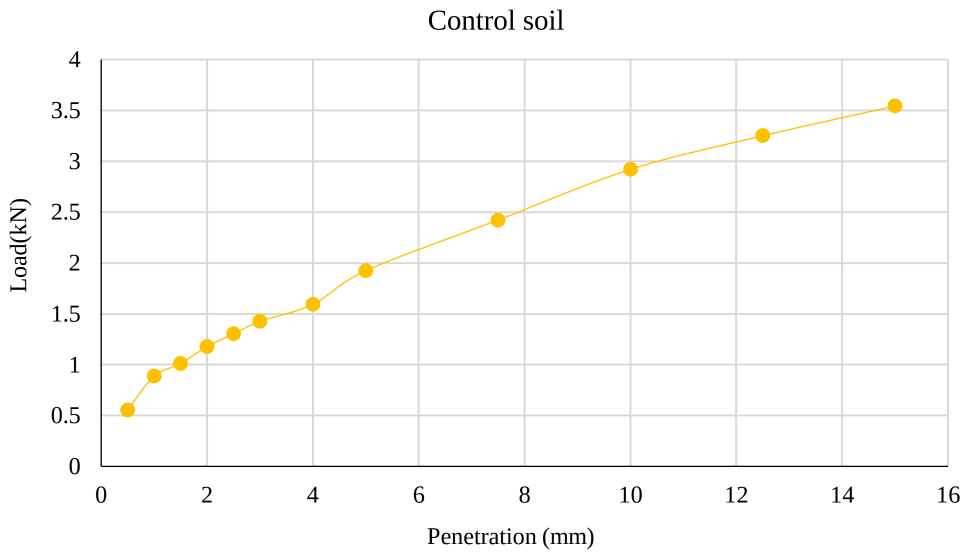

Figure 8. Control soil CBR graph**.**

Treated Soil Sample

Treated Soil with Addition of 20% Slag

After treating a soil sample with slag, an exceptional result is obtained. According to Table 15, it rises 18.39% for 2.5mm and 19.35% for 5mm. Figure 9 illustrates the graph depicting penetration over load.

Treated Soil with Addition of 20% Slag + 1 layer EPE

With the addition of 20% slag, the performance of the soil is exceptional, but with the addition of an EPE layer, the performance decreases marginally, which is shown in Table 16. Although EPE performs better than the control soil. Control soil CBR is optimal at 9.69, whereas EPE is 11.91% for 2.5mm and 10.11% for 5mm (Figure 10).

Treated Soil with Addition of 25% Slag

The increase in slag percentages leads to a corresponding increase in the CBR %. In accordance with the Table 17 and Figure 11, the slag percentage for particle sizes of 2.5mm and 5mm is recorded as 23.3% and 22.72% respectively

Table 15. Data sheet for California bearing ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	0	0.023	
1	1.2	0.5216	
1.5	3.3	1.393	
2	4.8	2.015	
2.5	5.9	2.47	18.39
3	6.9	2.88	
4	8.2	3.42	
5	9.5	3.96	19.65
7.5	12	5	
10	14.5	6.04	
12.5	16.1	6.07	
15	17.8	7.41	

Table 16. Data sheet for California bearing ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	1	0.438	
1	2	0.853	
1.5	2.5	1.06	
2	3	1.26	
2.5	3.8	1.6	11.91
3	4	1.68	
4	4.2	1.76	
5	4.9	2.05	10.17
7.5	6	2.51	
10	7.1	2.97	
12.5	8.1	3.38	
15	9.5	3.96	

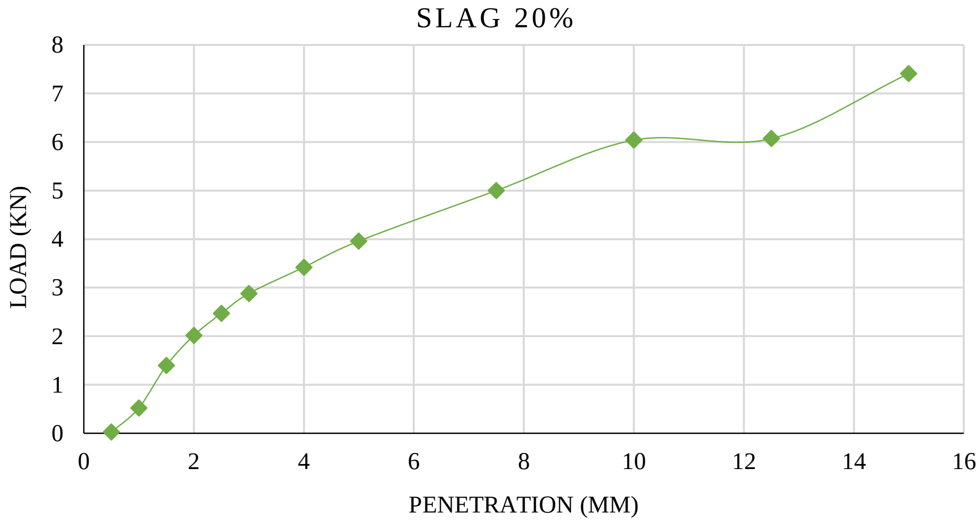

Figure 9. Addition of 20% slag CBR graph.

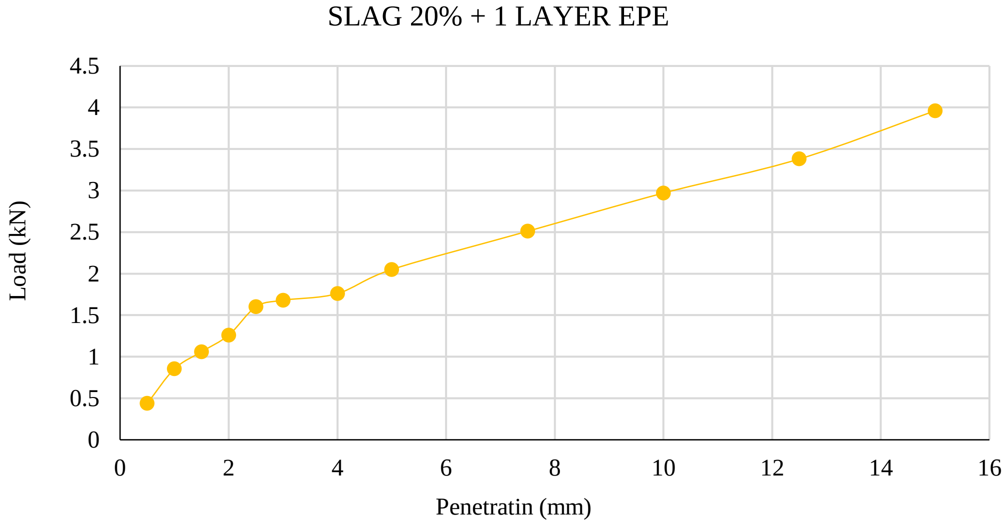

Figure 10. Slag 20% & EPE 1 layer CBR graph.

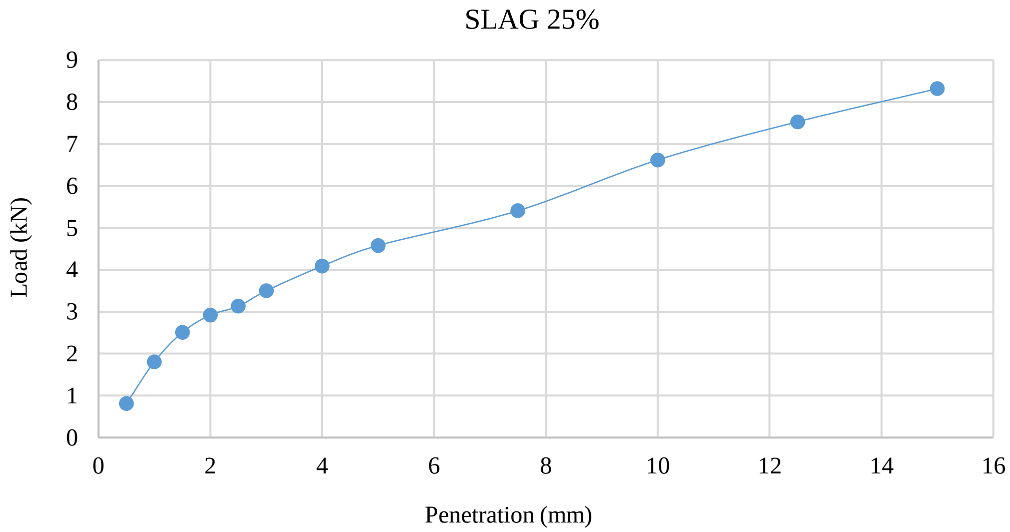

Figure 11. Addition of 25% slag graph.

Table 17. Data sheet for California bearing ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	1.9	0.812	
1	4.3	1.808	
1.5	6	2.51	
2	7	2.92	
2.5	7.5	3.13	23.3
3	8.4	3.5	
4	9.8	4.09	
5	11	4.58	22.72
7.5	13	5.41	
10	15.9	6.62	
12.5	18.1	7.53	
15	20	8.32	

Treated Soil with Addition of 25% Slag + 1 layer EPE

The inclusion of 25% slag significantly enhances soil performance; however, the introduction of an EPE layer results in a little decline in performance, despite EPE outperforming the control soil. The statistics for this treated soil are presented in Table 18.

Control soil CBR is optimal at 9.69, whereas EPE is 15.96% for 2.5mm and 5mm which is also beneficial Table 18 Figure 12.

Treated Soil with Addition of 30% Slag

The inclusion of slag at a concentration of 30% in the CBR (California Bearing Ratio) test yielded superior performance compared to the control soil. However, it should be noted that the CBR percentage was found to be more than 25% when the slag concentration exceeded this threshold. The slag percentage for particle sizes of 2.5mm and 5mm is 18.68% and 20.69% correspondingly as shown in Table 19 and Figure 13.

Treated Soil with Addition of 30% Slag + 1 layer EPE

Based on prior findings, it is evident that this experiment poses a significant level of risk. The grammatical drop in percentages is notably inadequate and lower than the percentage of control soil CBR. The penetration for a 2.5mm thickness is recorded at 6.04%, whereas the penetration for a 5mm thickness is measured at 7.32%. All the data of this treated soil are included in Table 20 Figure 14.

Table 18. Data sheet for California bearing ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	2	0.853655	
1	3	1.268655	
1.5	4	1.68	
2	4.5	1.89	
2.5	5	2.09	15.96
3	5.3	2.22	
4	7	2.92	
5	7.7	3.21	15.96
7.5	9	3.75	
10	10.7	4.46	
12.5	11.9	4.96	
15	13	5.41	

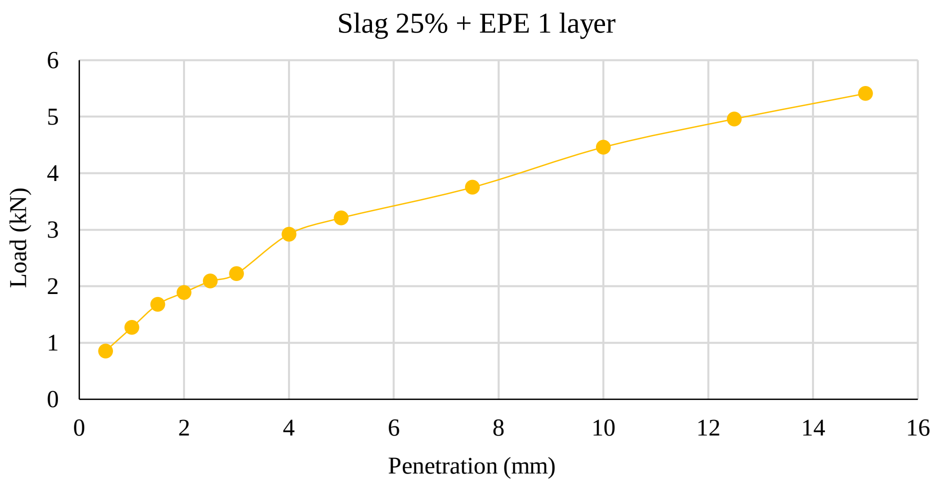

Figure 12. 25% slag with 1 layer of EPE graph.

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Table 19. Data sheet for California bearing ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	1.7	0.729	
1	3.5	1.47	
1.5	5	2.09	
2	5.6	2.34	
2.5	6	2.51	18.68
3	7.5	3.13	
4	8.8	3.67	
5	10	4.17	20.69
7.5	12	5	
10	10.7	4.46	
12.5	11.9	4.96	
15	13	5.41	

Table 20. Data sheet for California bearing Ratio test.

Penetration(mm)	Dial Reading	Load	CBR%
0.5	0.00	0.02	
1	0.00	0.15	
1.5	0.90	0.39	
2	1.50	0.65	
2.5	1.90	0.81	6.04
3	2.80	1.19	
4	3.00	1.27	
5	3.50	1.48	7.32
7.5	5.10	2.14	
10	7.20	3.01	
12.5	8.20	3.41	
15	9.80	4.09	

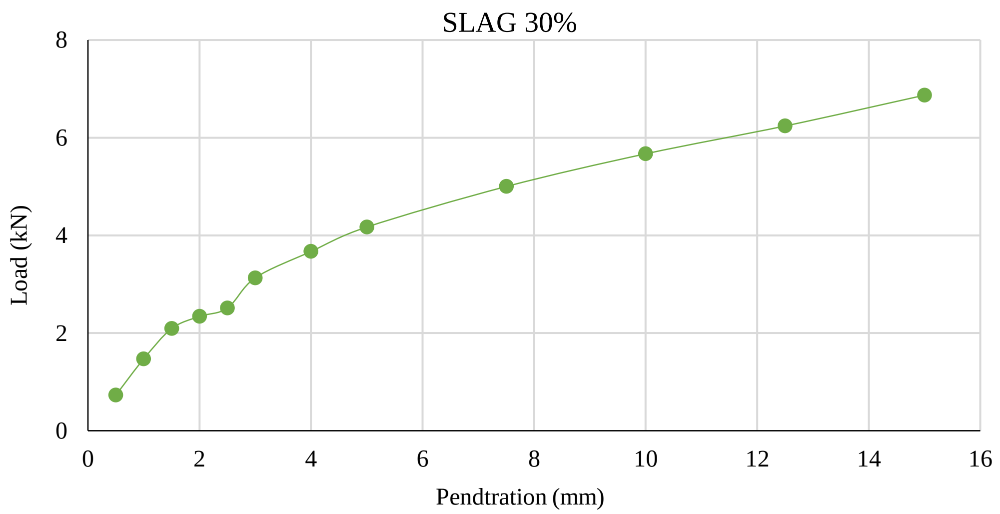

Figure 13. Addition of 30% slag graph**.**

Comparison graph between Slag & EPE

The difference between the percentages of slag is depicted in Figure 15, and the comparison of slag to EPE is shown in Figure 15-16.

The penetration of untreated soil samples at 2.5mm and 5mm was 9.69% and 9.37%, respectively. We are aware that a CBR between 5 and 15 percent is optimal. After treating a soil sample with slag, a remarkable outcome is achieved. It increases 18.39% for a thickness of 2.5mm and 19.35% for a thickness of 5mm.The performance of the soil is exceptional when 20% slag is added, but performance decreases slightly when an EPE layer is added, although EPE performs better than the control soil. The optimal CBR of the control soil is 9.69, while the EPE is 11.91% for 2.5mm and 10.11% for 5mm.The increase in slag percentages results in a proportional increase in the CBR percentage. The percentage of slag for 2.5mm and 5mm particulate sizes is 23.3% and 22.72%, respectively. With the addition of 25% slag, the soil's performance is exceptional. However, with the addition of an EPE layer, the soil's performance decreases slightly, although EPE performs better than the control soil. The optimal CBR for control soil is 9.69, while the optimal EPE for 2.5mm and 5mm is 15.96%. In the CBR (California Bearing Ratio) test, the 30% addition of slag produced superior performance compared to the control soil. It should be noted, however, that the CBR percentage exceeded 25% when the slag concentration exceeded this threshold. For particle sizes of 2.5mm and 5mm, the percentage of slag is 18.68% and 20.69%, respectively. Based on previous findings, it is clear that this endeavor poses a high degree of danger. The grammatical decline in percentages is significantly inadequate and lower than the control soil CBR percentage. The penetration rate for a 2.5mm thickness is documented as 6.04 percent, while the penetration rate for a 5mm thickness is measured as 7.32 percent.

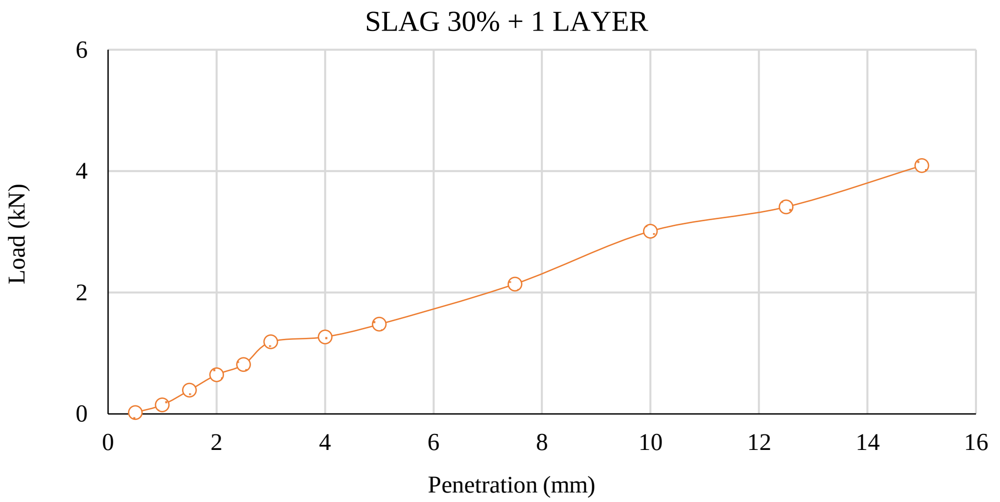

Figure 14. 30% slag with 1 layer of EPE graph.

	2.5mm	5mm
Control soil	9.69	9.36
20% slag	18.39	19.65
25% slag	23.3	22.72
30% slag	18.68	20.69

Figure 15. GGBS slag percentages CBR.

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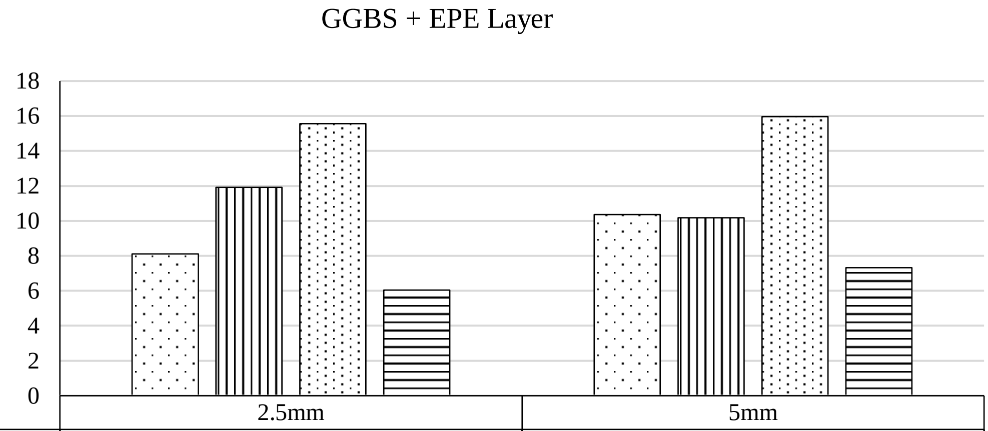

	2.5mm	5mm
Control EPE	8.11	10.37
20% EPE	11.91	10.17
25% EPE	15.56	15.96
30% EPE	6.04	7.32

Figure 16. GGBS slag percentages with EPE layer CBR graph.

CONCLUSION

This paper identifies the utilization of industrial by-product copper slag and Ground Granulated Blast Furnace Slag (GGBS) as a stabilizing agent in expansive soil with high swelling property causing severe damage to the building constructed on it, and this study identifies the optimal percentage of copper slag and GGBS for increasing the strength of clayey soil. Three different fractions, 20%, 25%, and 30% of copper slag and Ground Granulated Blast Furnace Slag (GGBS), were tested to evaluate the engineering properties of soil. The tests conducted included the determination of Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and California Bearing Ratio (CBR). The results were then compared with the specifications outlined in Indian Standards for sub-grade and flexible pavement design. The result indicates that 75% clay soil and 25% GGBS slag constitute the compatible stabilization ratio, which increases desirable subgrade specifications.

- The CBR value increases as the proportion of GGBS Slag increases. The results for 20%, 25%, and 30% are very excellent and effective.
- This increase is notable until 25% GGBS slag, after which these values begin to decrease.
- The incorporation of EPE increases the CBR value. However, 30% slag with one layer of EPE significantly reduces the percentage.
- With 25% GGBS slag, the highest CBR value is achieved.

Recommendation

Using this thesis as a comparison, determine how additional materials, such as GGBS slag and EPE foam, can alter the results as stabilizers at varying percentages. But for pavement design, the Resilient Modulus Test is essential. However, this test equipment is unavailable in Chittagong, so we are unable to conduct this test. However, the resilient modulus of subgrade is not strength but rigidity, indicating that a subgrade can support a large load with minimal deformation.

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