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Model Studies on Settlement of an Expansive Soil Slope Stabilized with GGBS

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ABSTRACT

Expansive soils present significant challenges in civil engineering due to their tendency to undergo volumetric changes with variations in moisture content, often resulting in slope instability and settlement issues. This study investigates the effectiveness of stabilizing expansive soil slopes using Ground Granulated Blast Furnace Slag (GGBS) as an additive. The research employs laboratory-scale model studies to simulate the behaviour of expansive soil slopes subjected to varying levels of GGBS stabilization. The settlement characteristics of the stabilized slopes are analysed under different loading conditions and moisture contents. Experimental results indicate that the incorporation of GGBS enhances the properties of expansive soils, reducing settlement and improving slope stability. The findings contribute to the understanding of sustainable solutions for mitigating settlement issues in expansive soil slopes, offering insights for practical applications in geotechnical engineering.

Keywords: Expansive soil, GGBS, Moisture Content, Settlement and Suction

I. INTRODUCTION

Expansive soils, characterized by significant volume changes in response to variations in moisture content, present formidable challenges in civil engineering projects, particularly in the construction of embankments, slopes, and foundations. The unpredictable nature of these soils can lead to detrimental effects such as slope instability, foundation failures, and structural damage, posing risks to infrastructure integrity and safety. Traditional stabilization methods often rely on chemical additives or mechanical reinforcements to mitigate the adverse effects of expansive soils. However, these approaches may have limitations in terms of effectiveness, sustainability, and environmental impact.

In recent years, alternative materials such as Ground Granulated Blast Furnace Slag (GGBS) has garnered attention in geotechnical engineering for their potential to improve soil stabilization performance while offering environmental benefits. GGBS, a by-product of the iron and steel industry that can enhance soil strength, reduce permeability, and mitigate volume changes associated with expansive soils.

II. METHODS AND MATERIAL

SOIL:

Soil is collected at Veldurthi Region of Kurnool District at a depth of 3m below Ground Level. Index and Engineering tests are conducted on the soil.

From the Test results, Soil is Classified as CH (High Plasticity Clay). Settlement studies are Carried on the Soil with and without addition of Admixtures.

GROUND GRANULATED BLAST FURNANCE SLAG (GGBS):

Blast furnace slag is a byproduct of Iron manufacturing in Blast Furnaces. Molten Blast Furnace Slag is extremely hot, ranging from 1300 to 1600°C. To prevent Crystallization, the Slag is rapidly cooled. Rapid cooling produces Granulated Granulated Blast furnace slag (GGBS). GGBS is collected from Astra Chemicals, Chennai. The composition of GGBS (provided by supplier) are Silicon Dioxide (SiO_2) - 35.43, Calcium Oxide (CaO) - 25.6, Aluminium-13 Magnesium Oxide (MgO)- 8.00, Iron (FeO or Fe2O3)- 0.37, Manganese Oxide (MnO)-0.55, Sulphur(S)-1.4.

Fig1. Granulated Blast Furnace Slag (GGBS)

PHYSICAL MODEL TANK

Dimensions of Model Tank 27x23x25 cm. Dimensions of Prepared Earth Slope is 22x23x15 cm.

WOODEN WEDGES

Wooden Wedges are used to prepare Sloping Surface with an angle of 45°

TENSIOMETER

A Tensiometer is a device used to measure surface tension, which is the force acting on the surface of a liquid that causes it to behave as though it were a stretched elastic membrane. Surface tension is caused by the attraction between molecules at the surface of a liquid.

DIAL GAUGE WITH MAGNETIC STAND

A Dial Gauge with a magnetic stand is a tool used for precise measurements in machining and engineering. The Dial Gauge, which has a needle-like pointer, measures small linear distances or deviations. The magnetic stand provides a stable base by attaching securely to metal surfaces using a powerful magnet. This combination allows for accurate measurements of dimensions, alignments, and deviations in mechanical components and assemblies, aiding tasks like checking tolerances and aligning parts during assembly.

MOISTURE CONTENT SENSOR

A Moisture content sensor is a device that measures the amount of water present in a substance or material. It utilizes various methods such as electrical, capacitive, or optical principles to gauge moisture levels. These sensors are used in agriculture, construction, and food processing industries to optimize processes, ensure quality, and prevent damage caused by excess moisture.

LOADING PLATES

The Loading plates are designed such that the Weight of each Loading plate is 1.6 Kpa and the Dimensions of the Loading Plate are 22x5x1cm.
These Loading Plates are placed over steel plate on the Crest of the Slope such that the Applied Load acts Uniformly on the Slope. The Applied Load is incremented for every 24 hr.

MODEL DESIGN

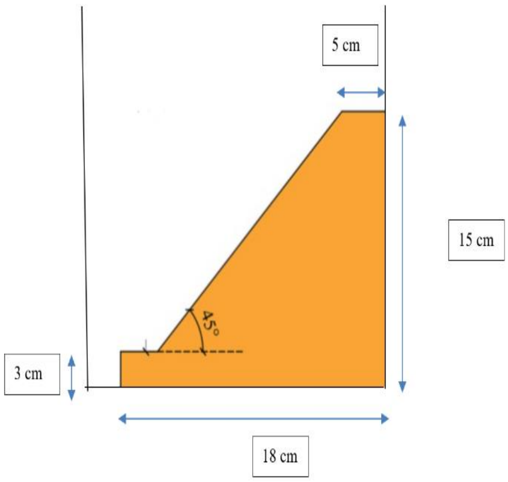

Fig2: Model Design of a Soil Slope

Soil and Water required to prepare the soil slope is arrived based on the dimensions of the Model tank. Laboratory Physical Model tank of dimensions 27x23x25 cm is prepared. Soil slope of 22x23x15cm is prepared. A Magnetic Dial Gauge, Moisture Content Sensor, and Tensiometer are placed on the Crest of the Slope. A Loading Plate 22x5x1cm is placed on the crest of the soil slope with the length of plate running the full width of the model. Slope angle of 45^0 is maintained to be safe against Stability Failure.This Investigation aims to analyse how external load, Suction, Moisture Content, and Settlement individually and Collectively influence on the behaviour and stability of selected expansive soil slope.

PREPARATION OF SOIL SLOPE

The soil slope is prepared in 3 Layers by making an angle 45^0 with the help of wooden wedges and each layer of the soil slope is compacted adopting required compaction energy.

Fig3. First stage of soil slope preparation

The amount of soil used for Layer1 is 3.73 kg and the compaction energy used for Layer1 is 378kN/m^2.

Fig4. Second stage of soil slope preparation

The amount of soil used for Layer2 is 2.63 kg and the compaction energy used for Layer2 is 404kN/m^2.

Fig 5 : Final stage of soil slope preparation

The amount of soil used for Layer3 is 1.45 kg and the compaction energy used for Layer3 is 397kN/m2.

Fig 6. Prepared Soil Slope

The total amount of soil used is 7.89 kg and the total amount of water used is 1260ml.

Fig 7. Unsaturated Soil Slope

The Fig7. Shows an unsaturated soil slope with Tensiometer, Moisture Content Sensor, Loading Plates and Dail Gauge on the crest of the slope.

ction, Moisture Content and Settlement are taken from Tensiometer, Moisture Content Sensor, and Dial Gauge respectively. The applied load is incremented with respect to time.

It is observed that the outside of the physical model tank is fully covered with saturated sand such that the OMC of the soil slope is constant.

Fig 8. saturated soil slope

The Fig 8. Shows a saturated soil slope with Tensiometer, Moisture Content Sensor, Loading Plates and Dial Gauge on the crest of the slope.

The soil slope is Fully covered with saturated sand. The saturation of the slope is carried until the Moisture Content of the soil slope gets constant. The load is applied after saturation process.

III. RESULTS AND DISCUSSION

Atterberg's limits was determined as per IS:2720(part5)-1985, Liquid Limit decreased and Plastic Limit increased with increasing percentage GGBS and the plasticity decreased with increasing percentage GGBS as observed in Fig9, Fig10, Fig11 respectively.

SOIL PROPERTIES		
1	**Specific Gravity**	**2.60**
2	**Grain Size Distribution**	
a	Gravel (%)	0.0
b	Sand (%)	9.8
c	Silt (%)	31.3
d	Clay (%)	58.9
3	**Plasticity Characteristics**	
a	Liquid Limit (%)	55.5
b	Plastic Limit (%)	16.5
c	Plasticity Index (%)	39.0
4	**Free Swelling Index (%)**	120.00
5	**Classification of Soil**	Clay of High Compressibility (CH)
6	**Compaction Characteristics**	
a	Maximum Dry Density (kN/m^3)	17.30
b	Optimum Moisture Content (%)	16.4
7	**Shear Strength Parameters**	
a	Cohesion (C) (kPa)	39.00
b	Angle of internal friction(ϕ)$^\circ$	20.0
8	**Consolidation Characteristics**	
a	Compression Index (Cc)	0.356
b	Swelling Pressure (kPa)	180.00

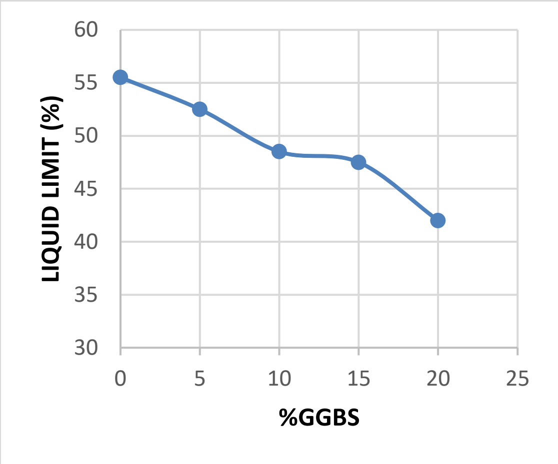

Fig 9. Variation of Liquid Limit with (%) GGBS

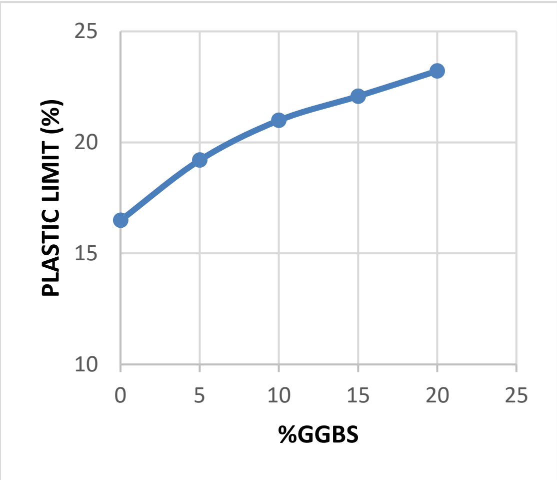

Fig 10. Variation of Plastic Limit with (%) GGBS

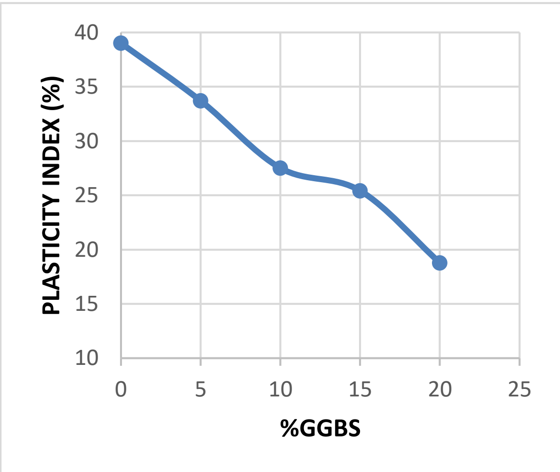

Fig 11. Variation of Plasticity Index with (%) GGBS

Compaction Characteristics:

Compaction Characteristics were conducted in accordance with IS: 2720 (part8) – 1983 and variation of MDD and OMC is shown in Fig12 and Fig13 respectively. It is observed that OMC decreased and MDD increased upto 15% GGBS and further increasing the %GGBS OMC decreased and MDD increased.

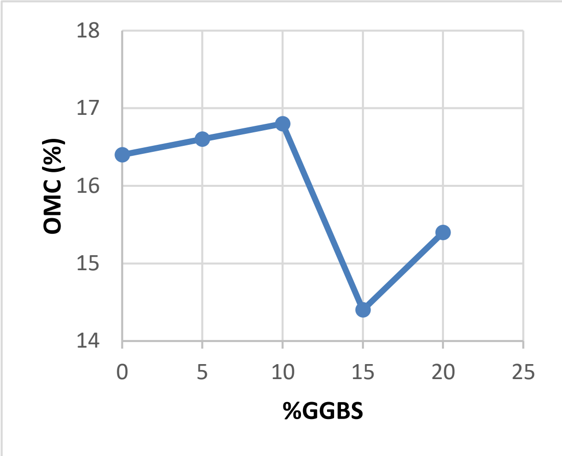

Fig 12. Variation of OMC with (%) GGBS

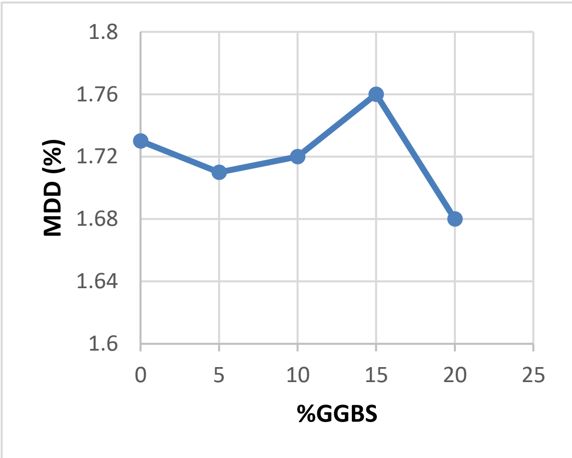

Fig 13. Variation of MDD with (%) GGBS

Shear strength Characteristics:

Triaxial shear test were conducted in accordance with IS: 2720 (part 12)- 1981. The triaxial shear test is a laboratory method used to determine the shear strength and stress-strain behaviour of soil or rock samples under controlled conditions.

From the Fig 14 it is observed that cohesion increased with increase in percentage of GGBS. Angle of internal friction decreased with increase in percentage of GGBS.

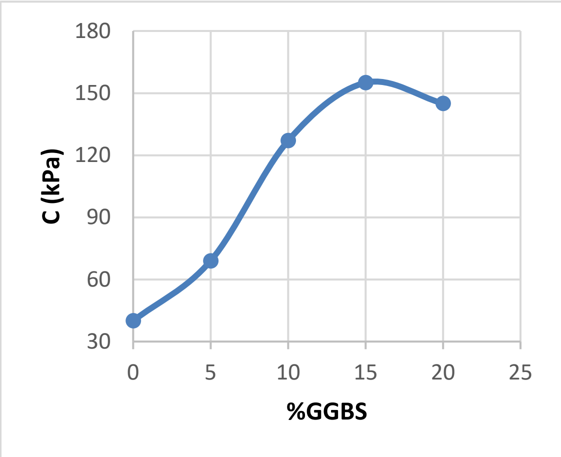

Fig14. Variation of Cohesion (C) with (%) GGBS

Consolidation Characteristics:

Compression Index and Swelling Pressure tests were conducted in accordance with IS: 2720 (part 15)-1977 on soil sample prepared with optimum percentage of GGBS. From the Fig15, Fig16 it is observed that both Compression Index and Swelling Pressure decreases with addition of optimum percentage of GGBS to CH soil.

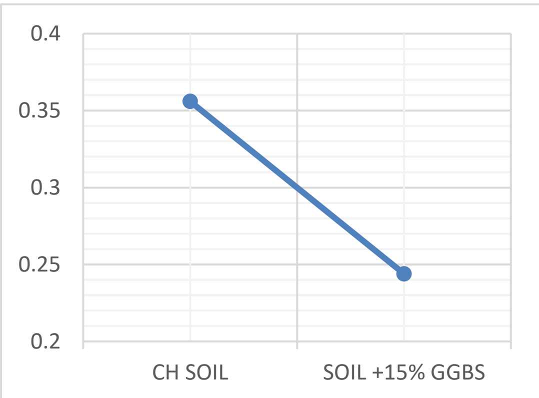

Fig 15. Variation of Compression Index of Soil, (Soil+15% GGBS) Mix

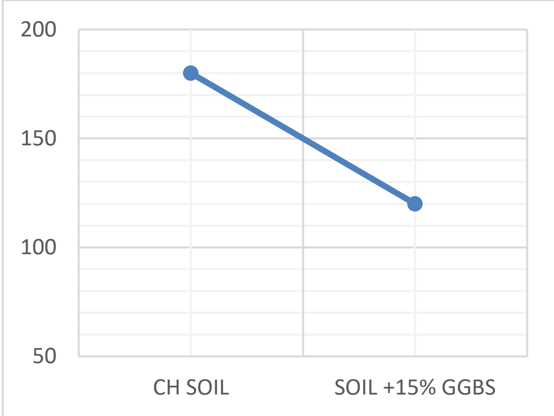

Fig 16. Variation of Swelling Pressure of Soil, (Soil+15% GGBS) Mix

Settlement Studies:

The settlement of an expansive soil slope refers to its downward movement or deformation due to changes in moisture content. Expansive soils, prone to volume changes, swell when wet and shrink when dry, causing settlement. Signs include surface cracks, tilting structures, or differential settlement. Settlement poses risks to nearby structures, but can be mitigated by improving drainage, stabilizing the slope, managing moisture, and designing flexible foundations. Understanding and managing settlement is crucial for ensuring the stability and safety of infrastructure in areas with expansive soils. Suction refers to the negative pore water pressure within the soil, influencing its moisture condition. As settlement progresses, suction tends to decrease due to the release of pore water pressure caused by soil compression. Initially high suction levels decrease as settlement continues. Settlement often leads to changes in the soil's moisture content. Initially, during wetting periods, moisture content increases due to water infiltration, causing swelling. However, as settlement progresses and excess water is expelled, the soil's moisture content tends to decrease, leading to shrinkage.

In summary, as settlement occurs, suction decreases as pore water pressure is released, while moisture content may initially increase during wetting periods but tends to decrease over time as excess water is expelled from the soil. These variations in suction and moisture content are crucial factors influencing settlement behaviour in expansive soil slopes.

Settlement studies of an unsaturated soil slope of CH soil:

Amount of Soil taken = 7.89 kg
Amount of Water used = 1.6% of 9.07 kg = 1liter 450ml

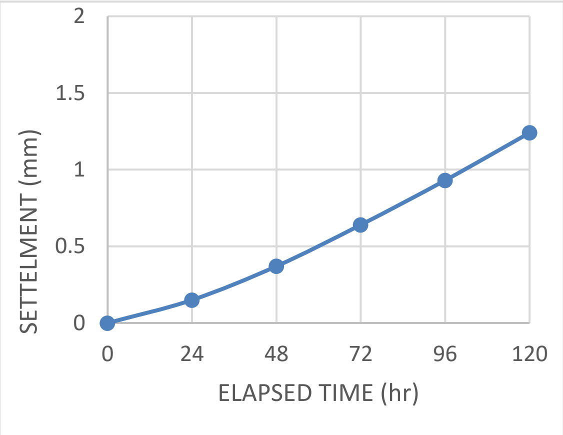

Fig17. Variation of Settlement with Elapsed time

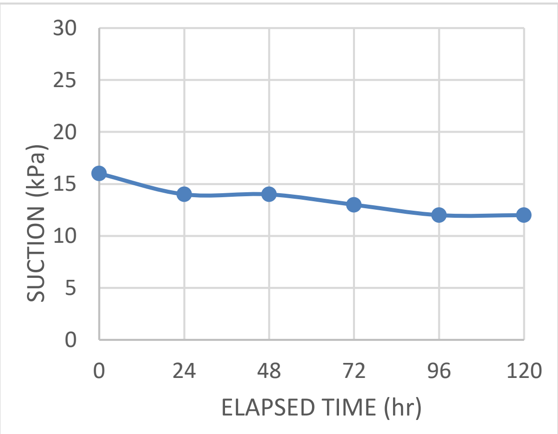

Fig18. Variation of Suction with Elapsed time

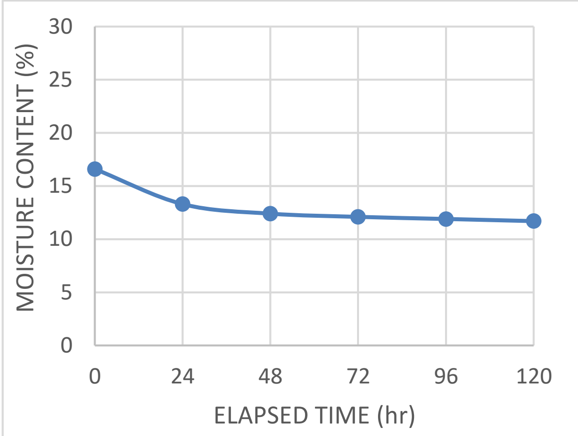

Fig19. Variation of Moisture Content with Elapased time

The Settlement occurred at 22 kN is **1.24** mm for CH Soil.

Settlement studies of a saturated soil slope of CH soil:

Amount of Soil taken = 7.89 kg
Amount of Water used = 1.6% of 9.07 kg = 1liter 450ml

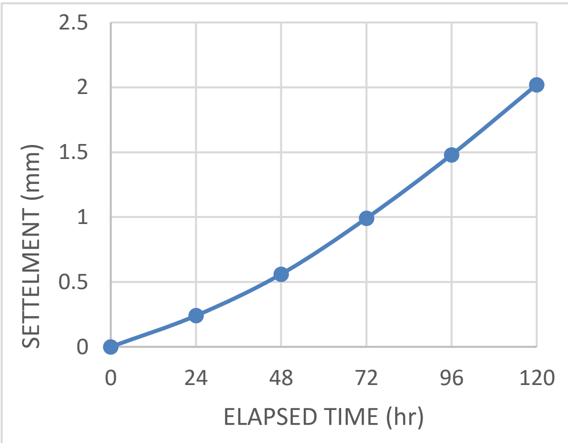

Fig 20. Variation of Settlement with Elapsed time

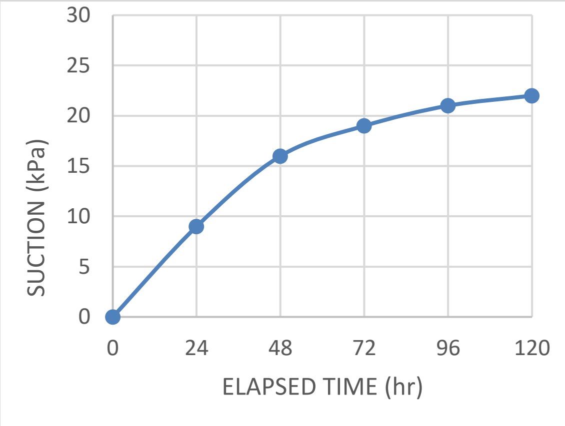

Fig 21. Variation of Suction with Elapsed time

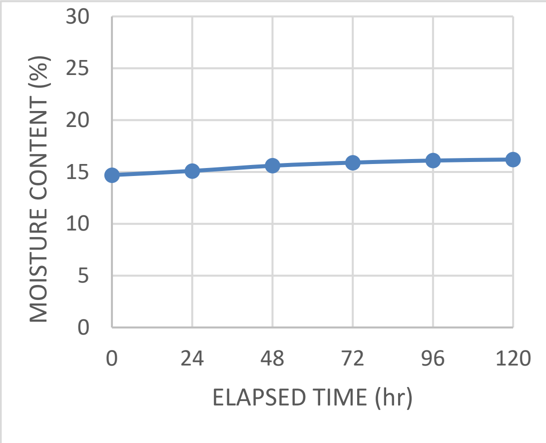

Fig22. Variation of Moisture Content with Elapsed time

The settlement occurred at 22 kN is **2.02** mm for CH Soil

Settlement studies of an unsaturated soil slope of (CH soil-15% GGBS) mix:

Amount of Soil taken = 7.89 kg

Amount of GGBS taken = 1.18 kg

Amount of Water used = 1.6% of 9.07 kg = 1liter 450ml

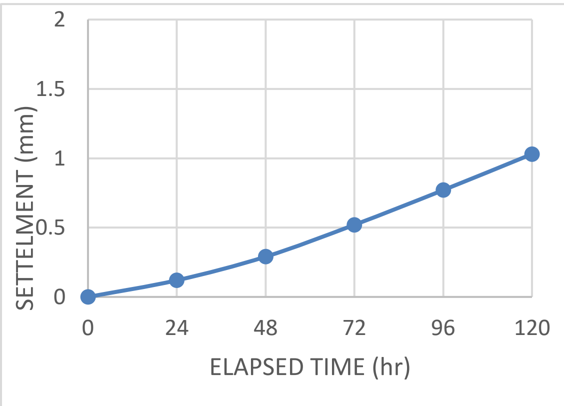

Fig 23. Variation of Settlement with Elapsed time

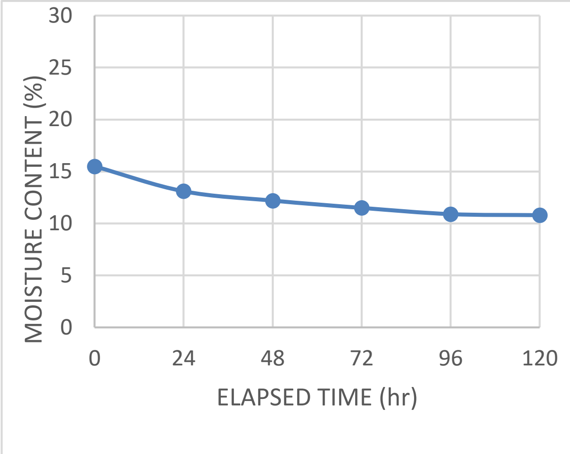

Fig 24. Variation of Suction with Elapsed time

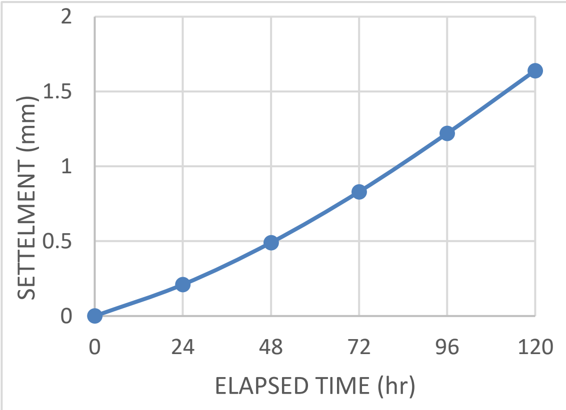

Fig 25. Variation of Moisture Content with Elapsed time

The settlement occurred at 22 kN is **1.03** mm for (CH soil+ 15% GGBS).

((1.24-1.03)/(1.03))*100 =20%

20% decrease in settlement of a soil slope is obtained addition of (15% GGBS) to (CH soil) in unsaturated condition.

Settlement studies of a saturated soil slope of (CH soil-15% GGBS) mix:

Amount of Soil taken = 7.89 kg

Amount of GGBS taken = 1.18 kg

Amount of Water used = 1.6% of 9.07 kg = 1liter 450ml

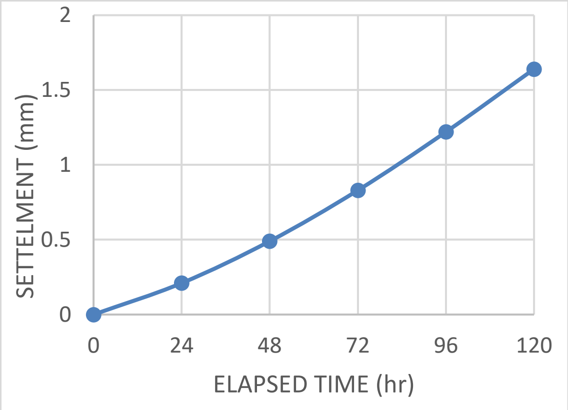

Fig 23. Variation of Settlement with Elapsed time

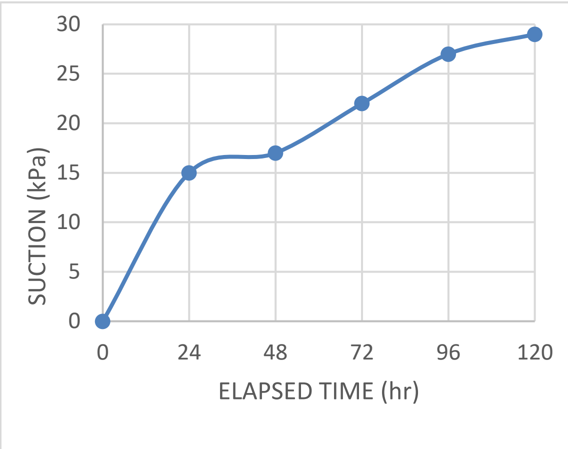

Fig 24. Variation of Suction with Elapsed time

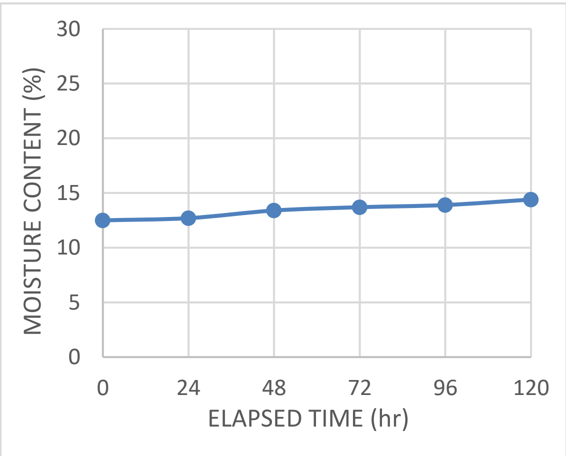

Fig 25. Variation of Moisture Content with Elapsed time

The Settlement occurred at 22 kN is **1.64** mm for (CH soil+ 15% GGBS).

((2.02-1.64)/(1.64))*100 = 23%

23% decrease in settlement of a soil slope is obtained with addition of (15% GGBS) to (CH soil) in saturated condition.

Microstructural Studies:

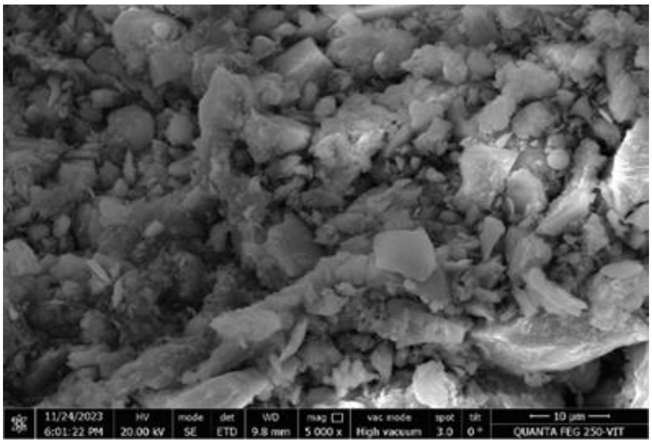

Fig 26. SEM Image of CH Soil

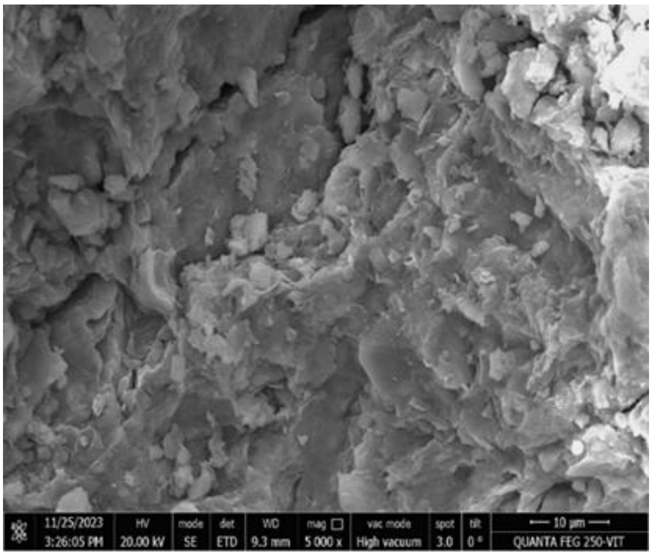

Fig 27. SEM Image of (CH Soil-15% GGBS) Mix

SEM produces high-resolution images of the surface of the sample, providing detailed information about its topography, texture, and features at a microscopic scale. These images can reveal surface defects, cracks, grain boundaries, and other structural characteristics. The microstructure of GGBS-treated soils may exhibit changes compared to untreated soils. Based on the SEM graphs it can be observed that formation of cementitious compounds and hydration products resulting from the interaction between GGBS particles and soil constituents. These compounds contribute to soil stabilization by binding soil particles together and reducing their susceptibility to volume changes.

IV. CONCLUSIONS

The settlement studies on an expansive soil slope were conducted with and without admixture. Based on the test results, the soil is classified as Highly Plasticity Clay (CH soil). When soil is admixed with GGBS, the Liquid Limit and Plasticity Index decreased, whereas the Plastic Limit increased. Regarding Compaction Characteristics, the Optimum Moisture Content (OMC) decreased, and Maximum Dry Density (MDD) increased at 15% GGBS, crucial for resisting settlement. The test results showed a decrease in Compression Index and Swelling Pressure, indicating reduced settlement potential and swelling behaviour, further enhancing slope stability. From Triaxial shear test it is observed Shear strength increased with addition of varying % of GGBS and Angle of internal Friction is decreased. This investigation reveals significant changes in suction and moisture content, which play pivotal roles in determining settlement behaviour. In unsaturated soil slopes, suction increased while moisture content decreased, contributing to reduced settlement, whereas in saturated soil slopes, Suction decreased and Moisture Content increased. Microstructural studies, through SEM analysis, indicate the formation of C-S-H gel and C-A-S-H gel when GGBS is added to selected soil, improving strength, durability, reducing permeability, and enhancing workability. Overall, the findings demonstrate that the addition of GGBS significantly reduces settlement in soil slopes, irrespective of saturation conditions. This highlights the effectiveness of GGBS additives in improving the stability and performance of soil slopes, making them a promising solution for engineering applications requiring slope stabilization.

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