Stabilization of alluvial soil with fly ash and GGBS as a subgrade for pavement construction

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Abstract: With the significant increase of construction activities in the road sector, the scenario has awakened the need for typical good quality soils for subgrade construction which are deficient in supply at many locations for numerous reasons. In this research activity, comprehensive study in the laboratory has been carried out to examine the use of fly ash and GGBS (Ground Granulated Blast Furnace Slag) to stabilize alluvial soils. Multiple influential properties such as UCS, CBR, Permeability, swelling potential, Compaction characteristics, and Atterberg limits were found for control samples and compared with the samples of distinct sequences of different percentages of Fly ash and GGBS ratio and on different curing periods. All the tests are performed by varying the Fly ash content to 5%,15%,25%,35% and 45% while keeping the GGBS content constant at 5% to the weight of dry soil. There is a remarkable change in the shear strength of the soil as the UCS value increased by 150% and the CBR value increased by 389% when the control sample is compared with those of treated samples with 35% Flyash+5% GGBS

Keywords: Fly Ash, GGBS, California Bearing Ratio, Unconfined Compressive Strength, Permeability

1 INTRODUCTION

Because of the rapid development in the industrial sectors, enormous quantities of waste are being produced and this waste must be above the discharge areas in the vicinity of the plants. In this case, these wastes not only require land for disposal, but they also create build-up risks for hazard accumulation and pollute the environment around the facilities. As we know the electricity demand is increasing progressively everywhere and to meet this demand, many coal-based power stations are in operation. However, these coal-based power stations around the world face severe problems in handling and disposing of ash. India's production of fly ash escalated from 106 million tons in the first half of 2020-2021 to 133.90 million tons in the first half of 2021-2022 (Suman.S. K., et.al (2017)). Thus only 40% to 50 % of ash generated is being utilized for beneficial purposes and the remaining material is disposed of as waste product.

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The main intention of this research paper is to identify and examine the influence of fly ash &GGBS on engineering properties of alluvial soil. Though there wasn't much information with respect to literature about the strength and durability of soils treated with Fly ash and GGBS. The intention of this study is to confirm the engineering effectiveness and efficiency of soil treated with Fly ash. To determine the strengthening properties of alluvial soil treated with a mixture of Fly ash and GGBS, laboratory tests were conducted. To confirm the viability and sustainability of soil treated with Fly ash and GGBS, long-term durability was examined (Malikzada, A., ET.AL(2021)). The effect on samples of alluvial soil, with respect to GGBS (5%), based on literature, and Fly ash (5%, 15%, 25%, 35% and 45%) were examined.

1.1 Materials

1.1.1 *Alluvial Soil*

In this research activity, a soil sample was collected from Krishna Riverbank, Potharlanka, Andhra Pradesh. The soil was collected at 3m depth to eliminate unnecessary gravel, debris, or waste, and it was transported to the laboratory for various tests like Atterberg limits, permeability, strength tests, CBR in test, and UCS test. The collected soil samples were air-dried for 24 hours, processed in accordance with IS 2720: BIS, I. (1983) (Part I) [25], and then tested in a lab. The unified soil classification system classifies soil obtained from the sample site was Intermediate Plastic Clay (CI).

The particle size distribution of the soil utilized in this investigation is shown in figure 1 and was determined using a sieve and hydrometer examination. The soil's primary physical and geotechnical characteristics, including its sand, silt, and clay percentages, are stated in table 1.

Table 1: Properties of Alluvial Soil.

Properties	**Value**
Gravel	3%
Sand	37%
Clay and silt	60%
Specific gravity	2.61
Liquid limit	35%
Plastic limit	23%
Shrinkage limit	19%
Plasticity index	12%
Type of soil	**CI**
Optimum moisture content	15.65
Maximum dry density	1.649 g/cc
California bearing ratio. a. Soaked cbr b. Unsoaked cbr	 3.89% 4.32%
Unconfined compressive test	13.9812kpa
Permeability	1.45* 10^{-7} cm/sec

1.1.2. *GGBS (Ground Granulated Blast-furnace Slag):*

GGBS (Ground Granulated Blast-furnace Slag) is a cementitious material and its by-product from the blast-furnaces used to make the iron in the manufacturing industry. Blast-furnaces operate at temperatures of about 1,500°C.

Table 2: Properties Of GGBS.

Properties	Value
Calcium Oxide	43%
Silica	34%
Alumina	14%
Magnesia	9%
Density	1.30g/cc

1.1.3 Fly Ash:

Fly ash is the residue produced during the process of burning powdered coal, which ranges in size between 10 to 100 micrometres. Fineness is one of the governing factors contributing to the pozzolanic reactivity of fly ash.
There are no harmful consequences that will arise after the soil is treated.The fly ash required for the study was collected from Delhi. The fly as oven dried, to eradicate the moisture content. Precautions were taken not to overheat the Fly ash. The impurities such as underdone coal etc were removed

Table 3: Physical properties of fly ash

Properties	Value
Specific Gravity	2.19
Sand size mm (0.075-4.5) (%)	7.4
Silt Size mm (0.002-0.075) (%)	87.0
Clay size mm (<0.002 mm) (%)	5.0
Maximum Dry Density (KN/m^3)	1.601
Optimum Moisture Content (%)	15.62
Liquid Limit (%)	41.0
Plastic limit	NP

2 METHODOLOGY

Ample tests were performed in the laboratory to examine the properties of both natural soil and the soil mixed with respect to various proportions of GGBS (5%) & Fly Ash (5%,15%,25%,35% and 45%). Various laboratory procedures were performed identify the properties of stabilized subgrade soil: Atterberg's limit test, Standard Proctor test, Unconfined compressive strength test, and CBR test, permeability test.

2.1 Atterberg Limit (IS:2720-part 5,1985)

Atterberg limit tests are conducted in the laboratory to determine the moisture content of soil and to differentiate between types of silts and clays. Test will be conducted on the soil sample passing through a 425µm sieve.

2.2 Standard Proctor Test (IS:2720-part 8, 1983)

The Standard Proctor compaction test is a laboratory test which is used to determine the optimal moisture content where the provided soil type will become densified and achieve its maximum dry density.

2.3. California Bearing Ratio (CBR) IS: 2720 (Part 16) - 1987

To determine the subgrade's strength, the CBR test is performed. Both soaked and unsoaked soil mix proportion specimens were tested, and the laboratory test was carried out in conformance with IS: 2720 (Part 16) – 1987with a load of 1.25mm per minute.

2.4. Unconfined Compressive Strength (UCS) (IS:2720-Part 16, 1987)

The most similarpractice for determining the soil's shear strength for both mixed soil proportions and untreated soil is the UCC test. According to IS: 2720 (Part 10) - 1991, the test was performed on a specimen of the requisite size to evaluate its strength at zero confining pressures with an axial strain of 0.5 to 2 percent per minute.

2.5. PermeabilityTest IS: 2720 (Part 17)-1986

The permeability of the soil is assessed using set permeability apparatus of the falling head type. IS: 2720 (Part 17)-1986 is followed when the soil is well compacted in the mould and water is passed through the soil to determine the coefficient of permeability.

3. RESULTS AND DISCUSSIONS

3.1 Standard Proctor Test

For the laboratory test analysis, the various combinations of 5%GGBS as a constant and 5%,15%,25%,35% and 45% of Fly ash is utilised. These values mentioned below express the variation of Optimum moisture content and dry density with the percentage of Fly ash and GGBS. The compaction characteristics of the soil are the key parameters which play an major role in determining the strength and durability of pavements built on subgrades. Any subgrade soil is designed at the optimum moisture content (OMC) can attain and maintain the sufficient stability over the required time span with respect to the action of various types of loads acting on it. The compaction specifications are very crucial for attaining the required sustainability for the pavement as shown in figure 1 and tabulated in table 4.

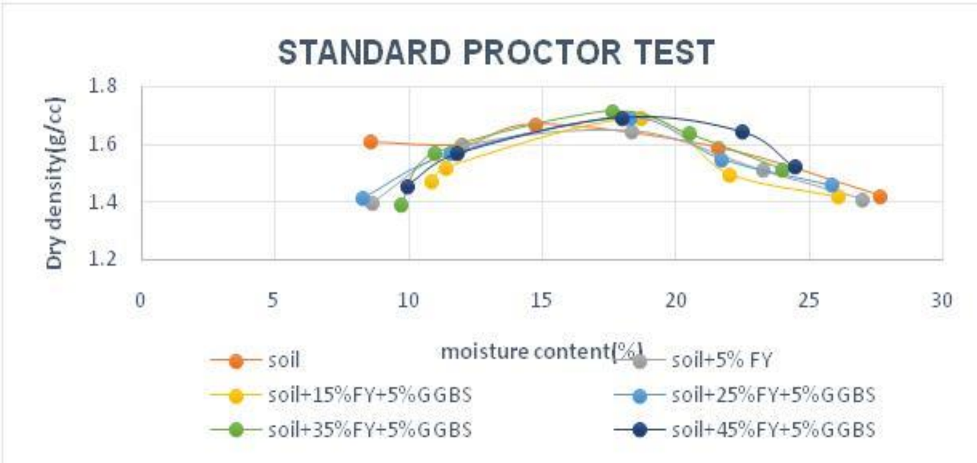

Fig. 1: Standard Proctor value for treated and untreated soil.

Table 4: Effect of Fly ash and GGBS w.r.t MDD and OMC

SOIL	MDD (g/cc)	OMC (%)
UNTREATED SOIL	1.649	14.65
SOIL+5% FLY ASH	1.69	18.69
SOIL+15% FLY ASH+5%GGBS	1.70	18.49
SOIL+25% FLY ASH+5%GGBS	1.72	18.27
SOIL+35% FLY ASH+5%GGBS	1.740	16.8
SOIL+45% FLY ASH+5%GGBS	1.692	17.7

As shown in the results i.e. in graph also there is an increment in the fly ash percentage of 5% to 35%, increases the MDD value from 1.649g/cc to 1.740g/cc, and we can see that further increase in the fly ash from 35% to 45% the MDD value is decreased from 1.740g/cc to 1.662g/ and also the OMC of the soil is changed from 18.69% to 16.8%.

3.2 California Bearing Ratio Test

For the laboratory test analysis, the various combinations of 5%GGBS as a constant and 5%,15%,25%,35% and 45% of Fly ash is utilised. The subgrade's California bearing ratio (CBR) is an important strength characteristic for predicting the thickness of the pavement's subgrade. According to IS: 2720 (Part 16) – 1987 the CBR values for clay subgrades are low. Different admixtures must be used to enhance the CBR of the clay subgrade. The California bearing ratio test was engaged for both soaked and unsoaked states for standard compaction results with the proportions of constant 5 %GGBS with 15%,25%,35% and 45% of fly ash content as tabulated in table 5.

Table 5: Relationship between load and penetration for various fly ash and GGBS content

SOIL	SOAKED CBR (%)	UNSOAKED CBR (%)
UNTREATED SOIL	3.89	4.32
SOIL+5% FLY ASH	3.54	4.9
SOIL+15% FLY ASH+5%GGBS	4.08	5.32
SOIL+25% FLY ASH+5%GGBS	9.65	6.42
SOIL+35% FLY ASH+5%GGBS	12.79	9.06
SOIL+45% FLY ASH+5%GGBS	10.40	8.34

The CBR values for the soaked and unsoaked values are shown in the tables. The CBR values are enhanced with the percentage of the fly ash content up to 35% and decrease after further increasing the percentage ratio. The CBR value for the soaked value increases from 3.89% to 12.79%,it is 3.28 times higher than untreated soil, and also for unsoaked conditions, the CBR value increased by 2.097 times than the untreated soil was 9.06% to 4.32%. The increase in the CBR value with increasing proportion offly ash and GGBS is because the shear resistance was increased in soil to resisting the loading which is caused by the penetration.

3.3 Unconfined Compressive Test

For the laboratory test analysis, the various combinations of 5%GGBS as a constant and 5%,15%,25%,35% and 45% of Fly ash is utilised. As per IS:2720(part-10), the UCS test was performed on both unreinforced &reinforced soil specimen samples at a constant strain of 0.125mm/minute. The results of the unconfined compressive strength parameters of various combinations are being tested under a compressive force and final values are shown in Figure 2 and tabulated in table 6.

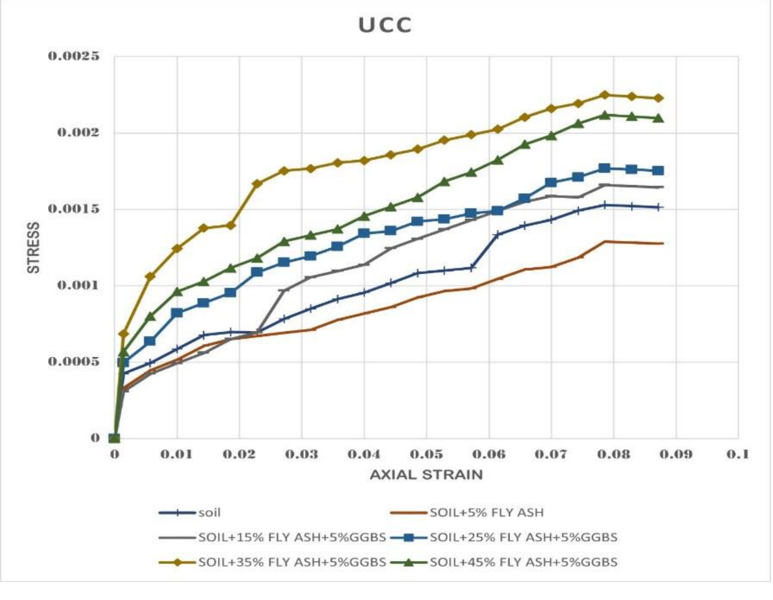

Fig.2: Stress-strain relationship of Untreated soil and Treated soil.

Table 6: Fly ash and GGBS effect on shear strength of soil.

SOIL	UCC (Kpa)
UNTREATED SOIL	14.1972
SOIL+5% FLY ASH	12.6404
SOIL+15% FLY ASH+5%GGBS	16.2826
SOIL+25% FLY ASH+5%GGBS	17.3538
SOIL+35% FLY ASH+5%GGBS	22.0672
SOIL+45% FLY ASH+5%GGBS	20.7818

From the results obtained, it can observed that the UCS for reinforced soil is 1.5 times higher than the unreinforced soil occurs at the combination of soil+5% GGBS+35% fly ash. The UCS value was enhanced from 14.1972kpa to 22.0672kpa and further increase in fly ash content up to 45% the UCS got decreased from 22.0672kpa to 20.7818kpa.

3.4 Permeability Test

For the laboratory test analysis, the various combinations of 5%GGBS as a constant and 5%,15%,25%,35% and 45% of Fly ash is utilized. The voids of the soil are filled with both fly ash and GGBS and it forms a strong mix especially with the help of fly ash nano particle mechanism it helps in creating a stable bond between the particles due its ability of forming an nano particle of higher quality. Thus, the permeability of the soil gets desired value.

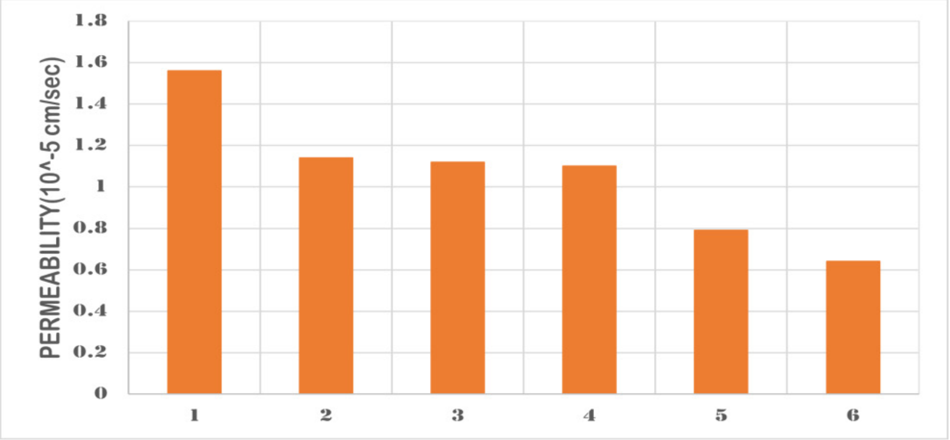

Fig.3: Permeability of Untreated and Treated soil.

Table 7: Fly ash and GGBS impact on permeability

SOIL	Permeability (10^-7 cm/s)
UNTREATED SOIL	1.45
SOIL+5% FLY ASH	1.18
SOIL+15% FLY ASH+5%GGBS	1.14
SOIL+25% FLY ASH+5%GGBS	1.12
SOIL+35% FLY ASH+5%GGBS	0.81
SOIL+45% FLY ASH+5%GGBS	0.72

The values displayed in the table show the increment in the fly ash content reduces permeability nature from $1.45*10^{-7}$ to $0.72*10^{-7}$..The optimal values for the permeability were observed for both percentages of soil with SOIL+ 35% FLY ASH+5% GGBS & SOIL+45% FLY ASH+5% GGBS.

4 CONCLUSIONS

The required quantity of Fly ash and GGBS needed for this study is based on the properties of the soil and to get successful stabilization results. The conclusions reached because of the findings are mentioned below:

1. With the addition of Fly ash and GGGBS up to 35%+5%, it was shown that the OMC was reduced and the MDD increased; however, this sequence was found to be reversed with the addition of 45%Fly ash to 5% GGBS. This happened because ofnano particle mechanism of Fly ash and the replacement of soil by lightweight material, which impacts in lowering the MDD.
2. The CBR value is increased up to 3.89 times compared to the untreated soil with the addition of 35%Fly ash + 5% GGBS for both soaked and unsoaked conditions because the shear resistance in the soil increased which results in increase of resistance to the loading that is brought on by the penetration. This is the main reason for the improvement in the CBR value when the proportion of Fly ash and GGBS was at a required level.
3. At the end, it was determined that the treated soil's UCS increased up to 35%Fly ash + 5% GGBS content and decreased with 45%Flyash+ 5% GGBS. While comparing the untreated soil, treated soil has a UCS value that is 1.5 times higher.
4. A tenuis layer of Fly ash and GGBS is needed for the pavement because the CBR value is strengthened with the addition of Fly ash and GGBS.
5. The results depict that by using Fly ash in the soil stabilization process there is increase in the workability of the soil.
6. The addition of the Fly ash to the soil hasn't shown any adverse effects. We can conclude that by adding Fly ash the cohesion of the clay soil was significantly improved.

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