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STABILIZATION OF BLACK COTTON SOIL BY USING ALUMINUM OXIDE

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Abstract - This study investigates the effect of aluminum oxide (Al_2O_3) on the stabilization of black cotton soil (BCS). Laboratory tests including liquid limit, plastic limit, free swell index, modified Proctor test, and direct shear test were conducted on BCS with varying Al_2O_3 contents (0.25%, 0.5%, 0.75%, and 1%). The results aim to assess the potential of Al_2O_3 in improving the engineering properties of BCS for construction applications.

Index Terms - Black cotton soil (BCS), Aluminium oxide(Al_2O_3), Stabilization, Liquid limit, Plastic limit, Plasticity index, Compaction, Shear strength, Bearing capacity.

I. INTRODUCTION

Black cotton soil (BCS) presents a significant challenge for civil engineering projects due to its high shrink-swell behaviour. The presence of montmorillonite clay in BCS causes significant volume changes with fluctuations in moisture content. These changes can lead to foundation failures, pavement cracking, and structural instability. Stabilization techniques are crucial for mitigating these issues and ensuring the long-term performance of infrastructure built on BCS.

Traditional methods for BCS stabilization often rely on cementitious materials like lime or fly ash. These methods offer proven effectiveness but may not always be readily available or cost-effective. Therefore, exploring alternative stabilization methods is crucial.

This research investigates the potential of aluminum oxide (Al_2O_3) as a novel stabilizing agent for BCS. Al_2O_3 possesses several properties that might be beneficial for this purpose. Its high specific surface area and reactivity suggest potential for cation exchange and pozzolanic reactions with clay minerals. These reactions could lead to improved strength and reduced swelling characteristics in BCS.

II. LITERATURE SURVEY

1. **Brajesh Mishra (2015):** Mishra's study delved into the engineering behavior of black cotton soil (BCS) and its stabilization using lime. The research highlighted the effectiveness of lime in modifying the clay behavior within BCS, potentially reducing its swelling. This study contributed to the understanding of lime as a viable option for improving the properties of BCS.
2. **Akshaya Kumar Sabat (2012):** Sabat investigated the geotechnical properties of lime-stabilized expansive soil mixed with quarry dust. His study provided valuable insights into the interaction between cementitious materials and clay minerals in BCS. This research contributed to a deeper understanding of the mechanisms involved in stabilization and the potential benefits of combining different materials.
3. **Ankit Singh Negi et al. (2013):** Negi and his colleagues examined soil stabilization using lime. Their work reinforced the established effectiveness of lime in modifying BCS behavior. This study provided further evidence supporting the use of lime as a reliable stabilization technique.
4. **Rajesh Kumar et al. (2018):** Kumar and his team investigated the use of fly ash and ground granulated blast furnace slag for stabilizing BCS. They found that these materials could significantly improve the strength and reduce the swelling of BCS. This study introduced additional options for stabilizing BCS and demonstrated the potential of industrial byproducts for soil improvement.
5. **S.S. Kumar et al. (2019):** Kumar et al. studied the effect of lime and cement on the shear strength of BCS. Their research concluded that both materials could significantly enhance the shear strength of BCS. This study provided insights into the comparative effectiveness of lime and cement for improving the load-bearing capacity of BCS.

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6. **A.K. Singh et al. (2020):** Singh and his colleagues explored the use of geotextiles for reinforcing BCS. They found that geotextiles could improve the stability of BCS slopes. This study highlighted the potential of geotextiles as a practical solution for mitigating slope instability in areas with BCS.
7. **D.K. Pradhan et al. (2021):** Pradhan et al. investigated the use of bamboo fibers for stabilizing BCS. They found that bamboo fibers could improve the strength and reduce the swelling of BCS. This study introduced a sustainable and locally available material for BCS stabilization, promoting a more environmentally friendly approach.
8. **M.K. Sharma et al. (2022):** Sharma and his team studied the effect of magnesium oxide on the stabilization of BCS. They found that magnesium oxide could improve the strength and reduce the swelling of BCS. This study presented a new material for BCS stabilization and expanded the range of potential options for improving the properties of this challenging soil.

These literature reviews collectively provide a comprehensive overview of the research conducted on BCS stabilization. While traditional methods like lime and fly ash have been extensively studied, recent research has explored the use of alternative materials like geotextiles, bamboo fibers, and magnesium oxide. These studies contribute to the understanding of BCS stabilization and offer potential solutions for improving the performance of infrastructure built on this challenging soil type.

III. OBJECTIVE

The primary objectives of this research are to:

- Investigate the effects of aluminum oxide (Al_2O_3) on the engineering properties of black cotton soil (BCS). This includes assessing changes in plasticity, density, shear strength, and swelling characteristics.
- Determine the optimum percentage of Al_2O_3 addition for achieving the desired improvements in BCS properties. This will involve analyzing the relationship between Al2O3 content and changes in engineering parameters.
- Explore the mechanisms through which Al_2O_3 interacts with BCS to improve its properties. This may involve studying the physical and chemical interactions between the two materials.
- Evaluate the potential of Al_2O_3 as a cost-effective and sustainable stabilization alternative for BCS. This will require comparing the performance of Al_2O_3 to traditional stabilization methods.
- Provide recommendations for the practical application of Al_2O_3 in the stabilization of BCS for various civil engineering projects. This will involve considering factors such as soil conditions, project requirements, and economic feasibility.

IV. EXPERIMENTAL METHODOLOGY

The primary objective of this study was to evaluate the effectiveness of aluminium oxide in enhancing the strength of black cotton soil. To achieve this, a series of compaction and strength tests were conducted on soil samples mixed with varying percentages of aluminium oxide. The table below outlines the specific tests performed and the sample designations corresponding to different aluminium oxide concentrations and curing periods.

Table 4.1. Mix designations for aluminium mixed samples

Sl. No	Sample	% Al_2O_3	Details about mix	Tests conducted
1.	BCS	0	100% BCS	PL, LL, FS, MPT, DST
2.	BCS + Al_2O_3	0.25	99.75% BCS + 0.25% Al_2O_3	PL, LL, FS, MPT, DST
3.	BCS + Al_2O_3	0.5	99.55% BCS + 0.5% Al_2O_3	PL, LL, FS, MPT, DST
4.	BCS + Al_2O_3	0.75	99.25% BCS + 0.75% Al_2O_3	PL, LL, FS, MPT, DST
5.	BCS + Al_2O_3	1.0	99.% BCS + 1% Al_2O_3	PL, LL, FS, MPT, DST

*LL = Liquid Limit, PL = Plastic Limit, FS = Free Swell Index, MPT = Modified Proctor Test, DST = Direct Shear Test

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MATERIALS USED

Black Cotton Soil: A Challenging Substrate for Construction

- Black cotton soil (BCS), also known as expansive soil, was collected from cotton fields in Potladurthi village, Andhra Pradesh, at a depth of 3 feet. This clayey soil type, prevalent in regions with high clay mineral content, presents significant challenges for civil engineering applications.
- Characterized by its low bearing capacity, high swelling, and shrinkage tendencies, BCS poses risks to infrastructure, leading to uplift pressure, heave, and cracking in structures such as foundations, plinth beams, floors, canals, and roads. Despite traditional construction techniques adapted for BCS regions, structural issues persist due to insufficient precautions during construction and maintenance.
- The volume changes in BCS are primarily attributed to the presence of fine clay particles, which absorb and release water, causing fluctuations in soil volume. This behaviour can result in severe damage to structures, necessitating effective stabilization measures before construction.

Aluminium Oxide: A Versatile Additive for Soil Stabilization

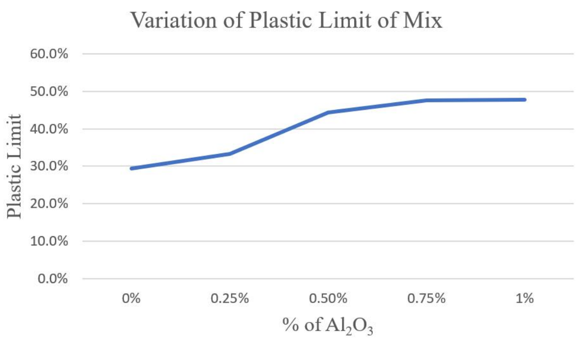
- Aluminium oxide (Al_2O_3) is an amphoteric compound, exhibiting properties of both acids and bases. It occurs naturally in crystalline form, commonly known as corundum, as well as in gemstones like rubies, sapphires, and emeralds. Due to its hardness, Al_2O_3 is widely used in abrasive and cutting tools.
- As a pozzolanic additive, Al_2O_3 undergoes a chemical reaction with hydrated aluminium oxide and the clay mineral montmorillonite. This reaction can modify the physical and chemical properties of black cotton soil, potentially improving its engineering characteristics.

V. RESULTS

PLASTIC LIMIT

Table 5.1: Plastic limit of mix with different proportions of BCS and Al_2O_3

Sl. No	Proportion of BCS in %	Proportion of Al_2O_3 in %	Plastic Limit in %
1	100	0	29.4
2	99.75	0.25	33.33
3	99.5	0.5	44.29
4	99.25	0.75	47.49
5	99	1	47.66



Graph 5.1: Plastic limit of mix with different proportions of BCS and Al_2O_3

LIQUID LIMIT:

Table 5.2: Liquid limit of mix with different proportions of BCS and Al_2O_3

Sl. No	Proportion of BCS in %	Proportion of Al_2O_3 in %	Liquid Limit in %
1	100	0	58.3
2	99.75	0.25	60
3	99.5	0.5	58.9
4	99.25	0.75	55.5
5	99	1	55.4

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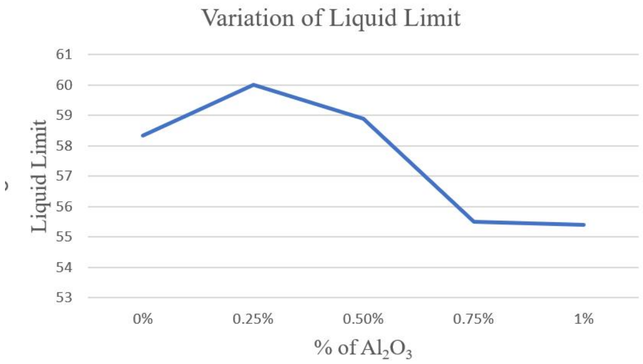

Graph 5.2: Liquid limit of mix with different proportions of BCS and Al_2O_3

FREE SWELL INDEX:

Table 5.3: Free Swell Index of mix with different proportions of BCS and Al_2O_3

Sl. No	Proportion of BCS in %	Proportion of Al_2O_3 in %	Free Swell Index in %
1	100	0	75
2	99.75	0.25	60
3	99.5	0.5	40
4	99.25	0.75	62
5	99	1	68

Graph 5.3: Free Swell Index of mix with different proportions of BCS and Al_2O_3

MODIFIED PROCTOR TEST

Table 5.4: MDD and OMC of mix with different proportions of BCS and Al_2O_3

Sl. No	Proportion of BCS in %	Proportion of Al_2O_3 in %	MDD(g/cc)	OMC (%)
1	100	0	1.62	20.69
2	99.75	0.25	1.71	15.95
3	99.5	0.5	1.743	12.4
4	99.25	0.75	1.63	18.96
5	99	1	1.63	11.1

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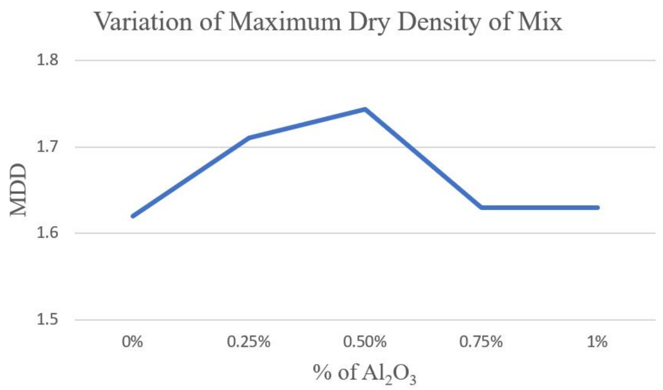
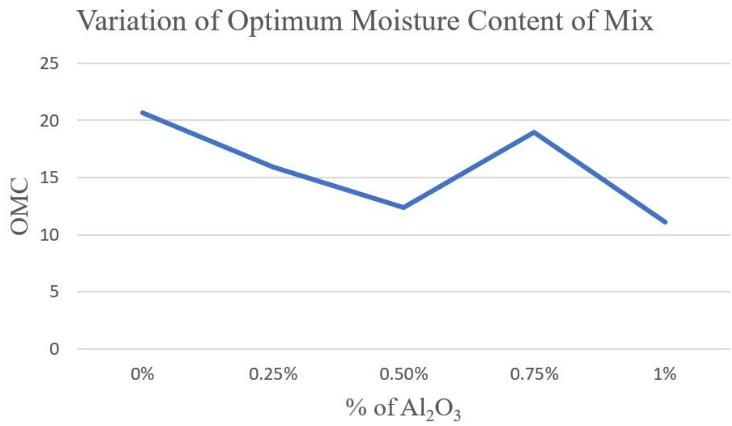


Graph 5.4: MDD of mix with different proportions of BCS and Al_2O_3

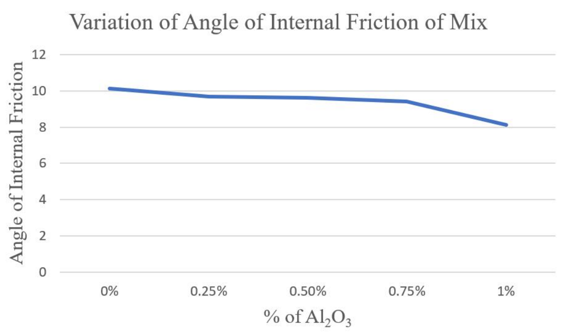


Graph 5.5: OMC of mix with different proportions of BCS and Al_2O_3

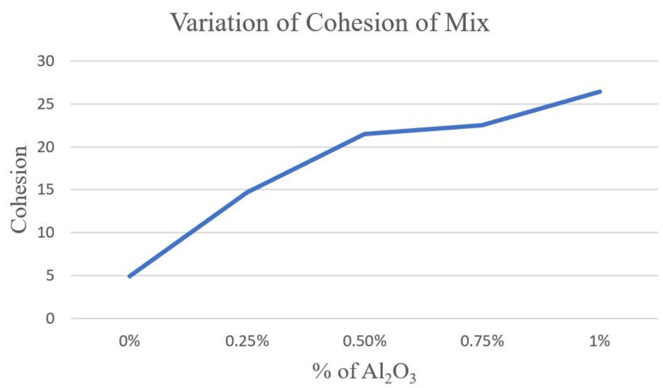
DIRECT SHEAR TEST

Table 5.5: Angle of Internal Friction, Cohesion and SBC of mix with different proportions of BCS and Al_2O_3

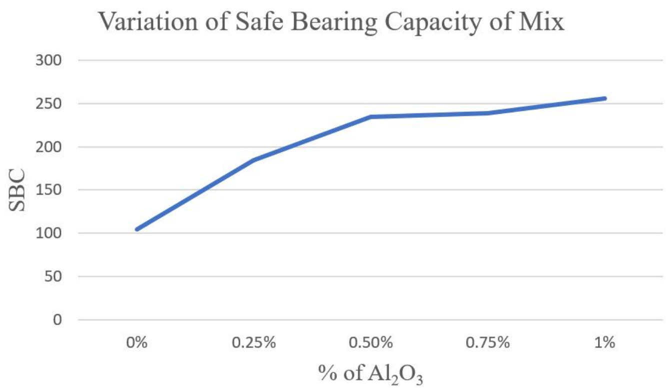
Sl. No	Proportion of BCS in %	Proportion of Al_2O_3 in %	Angle of Internal Friction (ϕ)	Cohesion (c) in kN/m^2	SBC of Mix in kN/m^2
1	100	0	10.1	4.9	104.5
2	99.75	0.25	9.7	14.7	184.2
3	99.5	0.5	9.6	21.5	234.8
4	99.25	0.75	9.4	22.5	238.3
5	99	1	8.1	26.4	255.4



Graph 5.6: Angle of Internal Friction of mix with different proportions of BCS and Al_2O_3



Graph 5.7: Cohesion of mix with different proportions of BCS and Al_2O_3



Graph 5.8: SBC of mix with different proportions of BCS and Al_2O_3

VI. CONCLUSIONS

The addition of aluminium oxide to black cotton soil significantly influenced its engineering properties. Key findings from the study include:

- **Plasticity:** Aluminium oxide addition decreased the liquid limit and increased the plastic limit, resulting in a decrease in plasticity index. However, excessive addition beyond the optimum level led to a reduction in overall plasticity index.
- **Density:** The addition of aluminium oxide increased both the maximum dry unit weight and optimum moisture content of the soil. This suggests an improvement in compaction characteristics.
- **Shear Strength:** The inclination angle of the soil decreased with increasing aluminium oxide content. Concurrently, the cohesion (C) value increased, indicating improved shear strength.
- **Bearing Capacity:** The soil bearing capacity increased with the addition of aluminium oxide, with a notable improvement of 2.43% compared to the original value.
- **Swelling and Shrinkage:** The free swell index of black cotton soil decreased with aluminium oxide addition, indicating a reduction in swelling and shrinkage tendencies. The optimum percentage of aluminium oxide for minimizing swelling was determined to be 0.5%.

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