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Experimental Investigation on the Combined Effect of Marble Dust Powder and Sodium Silicate on Engineering Properties of Expansive Soil

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Abstract - *Expansive soils such as Black Cotton Soil pose major challenges in geotechnical engineering due to their high swelling–shrinkage behavior, low strength, and moisture sensitivity. This study investigates the combined effect of* ***marble dust powder****, an industrial waste by-product, and* ***sodium silicate****, a chemical binder, on the stabilization of Black Cotton Soil. The primary objective is to evaluate improvements in* ***plasticity characteristics****,* ***swelling potential*** *and* ***engineering strength parameters*** *such as* ***Unconfined Compressive Strength (UCS)*** *and* ***California Bearing Ratio (CBR)****.*

Marble dust powder was added to the soil at varying percentages to utilize its calcium-rich composition for pozzolanic reactions, while sodium silicate was introduced as a liquid stabilizer to enhance bonding and reduce micro-voids. Laboratory tests including Atterberg limits, standard Proctor compaction, free swell index, UCS, and soaked/unsoaked CBR were conducted.

The results indicate a ***significant reduction in plasticity and swell index*** *with increasing marble dust content, while sodium silicate further improved* ***cementation and early strength gain****. The combined treatment produced denser soil matrices, higher maximum dry density, reduced optimum moisture content, and substantial enhancement in load-bearing capacity. Overall, the dual stabilization technique demonstrates an* ***effective, economical, and environmentally friendly*** *method for improving the engineering properties of expansive soils, making it suitable for subgrade and foundation applications.*

Keywords: Expansive Soil (ES), Marble Dust Powder (MDP), Sodium Silicate.

1. INTRODUCTION

Black Cotton Soil, classified as an expansive soil, is one of the most problematic geomaterials encountered in geotechnical engineering. Predominantly found in the central, western, and southern regions of India, this soil is characterized by its dark color and high content of **montmorillonite**, a clay mineral known for its exceptional swelling and shrinkage behavior. When water is absorbed, the soil undergoes substantial **volume expansion**, and during dry seasons, it experiences severe **shrinkage and cracking**. These cyclic volumetric changes pose serious challenges to civil engineering structures, including pavements, foundations, pipe lines, canal linings, and embankments.

1.1 Marble Dust Powder

Marble dust powder is a finely divided waste material generated during the cutting, shaping, polishing, and processing of marble stones in the construction and decorative stone industries. With rapid growth in marble-based industries worldwide, large quantities of this waste are produced, often leading to serious environmental concerns such as soil contamination, air pollution, and improper landfill usage. Due to its high calcium carbonate ($CaCO_3$) content, marble dust possesses physical and chemical characteristics that make it a valuable additive in civil engineering applications.

1.2 Sodium Silicate

Sodium silicate, also known as water glass or liquid glass, is a compound that consists of sodium oxide (Na_2O) and silica (SiO2) in various proportions. It is commonly represented by the formula Na2SiO3. Sodium silicate is a versatile material used in various industrial applications due to its adhesive, binding, and sealant properties. In the present study, Sodium Silicate with the chemical name of Sodium Silicate (Meta) Non-hydrate (i. e $Na_2SiO_3.9H_2O$) from one of non-traditional Loba Chemie Pvt. Ltd, which is stabilizers, has been used.

2. OBJECTIVE OF THIS PRESENT STUDY

- To study the properties of Expansive Soil.
- To investigate the effect of Marble Dust Powder as a stabilizing material.

To access the effect of varying dosage of Sodium Silicate(1%, 2% 3% 4%5% by dry weight of soil) on the strength properties.

3. LITERATURE REVIEW

1.C.C. Ikeagwuani — Emerging trends in expansive soil stabilization: Are view (2019). Good recent review of stabilization techniques and trends.

2. A. K. Jain — Geotechnical behavior and micro-analyses of expansive soils(2020). Useful for microstructural evidence and experimental results on black cotton soils.

3.Akash & Ahsan Rabbani — Swell–shrink characteristics of expansive soil: are view(2019). A compact review focused on swelling–shrinkage mechanisms and testing.

4. I. H. Umar — Marble Powder as a Soil Stabilizer: An Experimental Study(MDPI,2024).Laboratory study showing UCS / CBR improvements and temporal strength trends with MDP.

5. N. W. Jassim — Utilization of waste marble powder as sustainable stabilizer (2022).Discusses optimal low percentages (e.g., ~3%) and environmental advantages.

6.W. Fathonah — Sustainable soil stabilization using marble dust waste on high plasticity soils (2023/24). Good empirical results on PI reduction and CBR increase; useful for mix percentages.

7. C. H. Hurley — Sodium Silicate Stabilization of Soils (TRB annotated bibliography, classic reference).
8. Studies on sodium-silicate grout systems & organic soil stabilization — e.g., stabilization of organic soil using sodium silicate system grout (research gate). Useful for grouting methods and gelation chemistry.

9. V. G. Kiuna et al. — Effect of sodium silicate and cement on soil improvement(2023).Recent experimental paper showing combined sodium silicate + cement effects on strength of problematic soils.

10.W. Hou et al. (2025) — Experimental study on mechanical properties of sodium-silicate activated slag / soils.
Shows high strength gains with silicate-activated binders — useful for advanced chemical stabilization routes.

4. METHODOLOGY

The experimental program was carried out in several stages to evaluate the performance of black cotton soil stabilized with marble dust powder and Sodium silicate the overall procedure included soil collection, material preparation, proportioning of mixes, laboratory testing, and analysis of results.

4.1Soil Collection

Expansive Soil required for the study was collected from peapod,, East Godavari district, Andhra Pradesh. at a depth of about 2 m below ground level to avoid surface contamination. The soil samples were carefully excavated, transported to the laboratory, and air-dried under shade to preserve their natural properties.

4.2 Materials

1. **Expansive Soil:** The collected soil sample was used as the base material for the stabilization study. Preliminary tests were conducted to determine its index and engineering properties, which served as the foundation for further stabilization analysis.

2. **Bagasse Ash:** This ***ash***, a by-product of sugar and power plants, is rich in amorphous silica and has pozzolanic properties.

3. **Sodium Silicate:** Sodium silicate, also known as water glass or liquid glass, is a compound that consists of sodium oxide (Na_2O) and silica (SiO2) in various proportions. Sodium silicate is a versatile material used in various industrial applications.

4.3Mix Proportions

The stabilization process involved preparing soil samples with different proportions of marble dust powder and Sodium Silicate, mix ratios were considered, with 5%, 10%, 15%,20%, 25% for marble dust powder and 1%, 2%, 3%,4% and 5% for Sodium Silicate (by dry weight of soil) added to Expansive soil. For each percentage, two sets of samples were prepared: one with only marble dust powder and another with combined with Sodium Silicate . This allowed a comparison between mechanical stabilization and combined mechanical–chemical stabilization.

Table -1: Mix Proportions for testing Soil

S.NO	Stabilizing Agent	Mix proportions
1	Marble Dust Powder	5,10,15,20,25
2	Sodium Silicate	1,2,3,4,5

4.4 Laboratory Testing

To assess the influence of marble dust powder and Sodium Silicate on the properties of Expansive soil, a series of laboratory tests were carried out in accordance with relevant IS codes. The tests conducted are as follows:

- **Specific Gravity Test (IS: 2720 Part 3 – 1980)**

  This test determines the specific gravity of soil solids, which helps in identifying the type and classification of soil. It is an essential property used in calculating various soil parameters such as void ratio, degree of saturation, and unit weight relationships.

- **Differential Free Swell (DFS) Test (IS 2720 – Part 40):**The free swell behavior of the untreated and treated Expansive Soil was studied to evaluate the reduction in expansiveness after stabilization. The DFS value was obtained by immersing oven-dried soil samples in kerosene and distilled water separately, and calculating the difference in swell percentage. This testing is provided to reflect the potential of the soil to swell under different conditions.

- **Atterberg Limits Test (IS 2720 – Part 5):** This test was conducted to determine the liquid limit, plastic limit, and plasticity index of both untreated and stabilized soil samples. The Atterberg Limits test helps to identify the critical water contents of fine-grained soils, particularly clays and silts, which define their consistency states and plastic behavior.

  Modified Proctor Compaction Test (IS 2720 – Part 7): Compaction tests were carried out to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for each mix proportion. These tests were used to evaluate the effect of marble dust powder Ash and Sodium Silicate on the densification characteristics and moisture requirements of the soil.

- **California Bearing Ratio (CBR) Test (IS 2720 – Part 16):** Both soaked and unsoaked California Bearing Ratio (CBR) tests were conducted to evaluate the load-bearing capacity of the stabilized soil. The results provided valuable insight into the improvement in strength characteristics and the potential suitability of the stabilized expansive soil for use as a foundation or subgrade material in pavement construction.

- **Triaxial Compression Test (IS: 2720 Part 11 – 1993)**

  The triaxial compression test was conducted to determine the shear strength parameters of the soil, namely cohesion (c) and the angle of internal friction (ϕ), under varying drainage and loading conditions. This test provides a realistic simulation of in-situ stress conditions by subjecting the soil specimen to both confining and axial pressures. It aids in understanding the stress–strain behavior of soil under controlled conditions and is widely used for the analysis and design of slopes, foundations, and embankments.

Table -2: Properties of Expansive Soil

S.NO	NAME OF THE EXPERIMENT	VALUE
1	**Particle size distribution**	
	Sand (%)	11.58
	Silt (%)	20.56
	Clay (%)	67.88
2	**Atterberg's Limit**	
	Liquid Limit (%)	73.23
	Plastic Limit (%)	28.3
	Plastic Index (%)	44.93
3	**Modified Compaction Results**	
	Optimum Moisture Content (%)	29.42
	Maximum Dry Density (g/cc)	1.52
4	Differential Free Swell (%)	95
5	Specific gravity	2.48
6	IS Classification	CH
7	CBR(%)	1.54
8	Cohesion (KN/m^2)	130
9	Angle of Internal friction (^{0})	2.2

5. RESULTS AND DISCUSSION

5.1 Differential free swell

Table -3: Results of Free swell index test

S.NO	MIX PROPORTION	DFS
1	80%ES+20%MDP	50
2	80%ES+20%MDP+1%SS	45
3	80%ES+20%MDP+2%SS	40
4	80%ES+20%MDP+3%SS	34
5	80%ES+20%MDP+4%SS	29
6	80%ES+20%MDP+5%SS	20

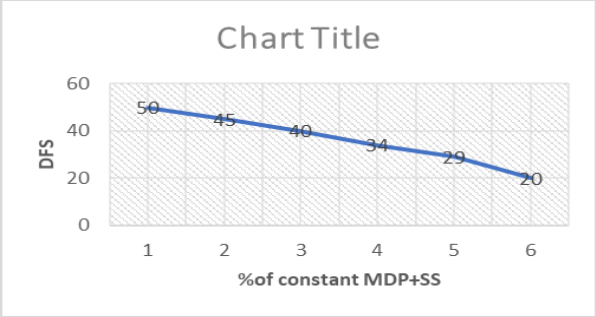

Fig -1: Variation in DFS of Expansive soil and marble dust powder treated with percentage of Sodium Silicate.

5.2 Atterberg's Limit Test

Table -4: Results of Atterberg's limit test

S.NO	MIX PROPORTION	LL%	PL%	IP%
1	80%ES+20%MDP	46.92	32.44	14.48
2	80%ES+20%MDP+1%SS	45.72	31.86	13.78
3	80%ES+20%MDP+2%SS	44.92	31.36	13.48
4	80%ES+20%MDP+3%SS	44.12	30.54	13.18
5	80%ES+20%MDP+4%SS	43.32	30.12	12.88
6	80%ES+20%MDP+5%SS	41.52	29.24	11.43

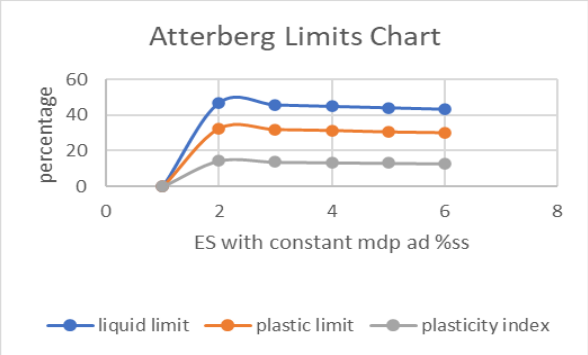

Fig -2: Variation in liquid limit, plastic limit, plasticity index of Expansive soil and constant marble dust powder treated with percentage of Sodium Silicate.

5.3 Modified Proctor Compaction Test

Table -5: Results of Modified Proctor Compaction test

S.NO	MIX PROPORTION	OMC	MDD
1	80%ES+20%MDP	24.78	1.67
2	80%ES+20%MDP+1%SS	24.00	1.71
3	80%ES+20%MDP+2%SS	23.76	1.76
4	80%ES+20%MDP+3%SS	22.40	1.80
5	80%ES+20%MDP+4%SS	21.10	1.62
6	80%ES+20%MDP+5%SS	19.86	1.48

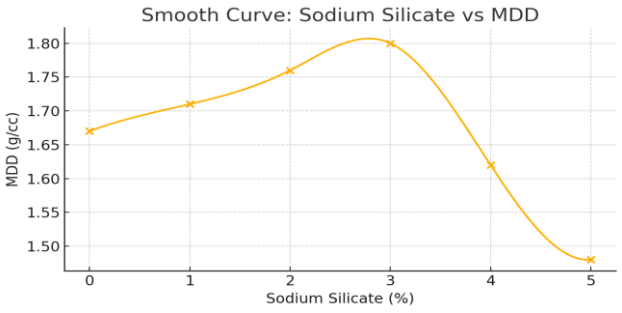

Fig -3: Variation of mdd in Expansive soil and constant marble dust powder treated with percentage of sodium silicate.

5.4 California Bearing Ratio (CBR) Test

Table -6: Results of CBR test

S.NO	MIX PROPORTIONS	SOAKED CBR
1	80%ES+20%MDP	**5.65**
2	80%ES+20%MDP+1%SS	**6.67**
3	80%ES+20%MDP+2%SS	**7.20**
4	80%ES+20%MDP+3%SS	**9.30**
5	80%ES+20%MDP+4%SS	**10.50**
6	80%ES+20%MDP+5%SS	**8.76**

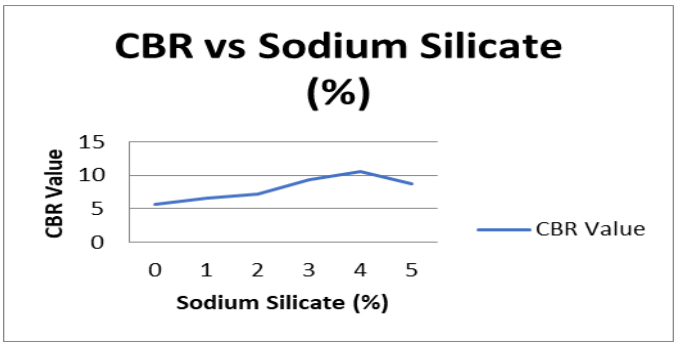

Fig -4: Variation in CBR test Black Cotton Soil and constant Marble Dust Powder and %of Sodium Silicate used.

6. CONCLUSIONS

The following conclusions were based on the laboratory studies carried out of Marble Dust Powder and Sodium Silicate found through the laboratory on this study. From the laboratory investigations the Optimum percentage research is 20% and 4% respectively.

Table -7: Optimum Percentages of MDP and SS, observed the laboratory investigations

S.NO	Additives	Optimum percentage addition
1	Marble Dust powder	20%
2	Sodium Silicate.	4%

- is noticed from the laboratory test results that the Differential Free Swell Index of Expansive soil has been reduced from 90% to 50% on the addition of 20% MDP and it has been further reduced from 50% to 20% with and addition of 5% Sodium Silicate. When compared with untreated Expansive soil.

- It is observed from the laboratory test results that the Liquid limit of Expansive Soil has been decreased from 73.23%% to 46.92% on the addition of 20% MDP and it has been further decreased from 46.92% to 41.12% with an addition of 5% Sodium Silicate.
- It is observed from the laboratory test results that the Plastic limit has been increased from 28.3% to 32.44% in addition to 20%.
- It is noticed that the Plasticity Index has been decreased from 44.93% to 14.48% in addition to 20% MDP and it has been further decreased from adding Sodium Silicate.
- It is observed from the laboratory tests that the OMC of the Expansive soil has been decreased from 29.42% to 24.78% on the addition of 20% MDP and it has been further decreased from 24.78% to 19.86% with addition of 5%Sodium silicate.
- It is observed from the laboratory tests that the MDD of the Expansive Soil has been increased from 1.52/cc to 1.67 g/cc on the addition of 20% MDP and it has been further increased from 1.67g/cc to 1.8g/cc with addition of 3%Sodium silicate.
- It is observed that the CBR of the Expansive soil has been increased from 1.54% to 5.65% on the addition of 20% MDP and it has been further increased from 5.65% to 10.5% with addition of 4%Sodium silicate.
- It is observed that the Cohesion of the soil is 130·
- It is observed that the Angle of Internal Friction of the Expansive soil is 2.2^{0}.
- It is also observed that MDD is decreased after adding 4%,5%.

7. REFERENCES

[1] Abbas J. Al-Taie, Abeer F. Hussein, Ahmed S Ali (2019), "A Review on Stabilization of Expansive Soil Using Different Methods." Journal of Geotechnical Engineering. Vol 6, Iss: 3, pp 32-40.

[2] Abdul Shukoor (2017), "Stabilization of Expansive Clay Using RHA and TSP." International Journal for Research in Applied Science and Engineering Technology (IJRASET), pp 2833-2837.

[3] Adunoye G. O., Yinusa I., Chibuogwu D E (2024), "Effects of Lime on Bagasse Ash- It Stabilised Expansive Soils" African journal of environment and natural science research. ISSN 2689-9434.

[4] Ahmed SA. Al-Gharbawi, Ahmed M Najemalden, Mohammed Y. Fattah (2022), "Expansive Soil Stabilization with Lime, Cement, and Silica Fume" Applied Sciences, Vol 13, Iss: 1, pp 436-436.

[5] Al-Swaidani, A., Hammoud, 1. Meziab, A Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil. J. Rock Mech. Geotech. Eng 2016, 8, 714-725.

[6] Anil Kumar Singhai (2014), "Laboratory study on soil stabilization using fly ash and rice husk ash." International Journal of Research in Engineering and Technology. Vol. 03, Iss: 11, pp 348-351.

[7] Anggraini, V.; Asadi, A., Farzadnia, N, Jahangırıan, H., Huat, B.B.K. Effect of coir fibres modified Ca(OH)2 and Mg (OH)2 nanoparticles on mechanical properties of lime- treated marine clay. Geosynth. Int 2016, 23, 206-218

[8] Kharade Amit S., Suryavanshi Vishal V., Gujar Bhikaji S.; Deshmukh Rohankit R.: (2014) "Waste product bagasse ash from sugar industry can be used as stabilizing material for expansive soils" IJRET, ISSN: 2321- 7308.

[9] Shambamaheshwari,and s.s.goliya.stabilization of black cotton soil for pavement using flay ash and lime.international journal of engineering development and research 2016.

BIOGRAPHIES

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