Enhancing Soil Stability: Investigating the Efficacy of Marble Dust and Calcium Chloride for Stabilizing the Expansive Soils.

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Abstract - *This research attempts to investigate the effect of marble dust and Calcium Chloride on the stabilization of expansive soils. Expansive soil, also known as shrink-swell soil, responds to changes in moisture content by exhibiting notable volume fluctuations. Lightly laden civil engineering projects such as residential buildings, pavements, and canal linings suffer significant damage due to this alternate swelling and shrinkage. Therefore, reducing the issues caused by expansive soils is essential. Many creative foundation solutions have been updated to address the issue of expanding swelling soils. Some of them are Foundation design, Mechanical stabilization, and Moisture control. One method of treating expansive soil to make it suitable for construction is stabilization. This study investigates the efficacy of marble dust and calcium chloride as potential stabilizers for mitigating the expansive nature of soils. Geotechnical features of expansive clay including OMC and MDD, CBR, Atterberg limits, DFS, and strength characteristics, were assessed before and after treatment with marble powder and calcium chloride ($CaCl_2$). The study concludes that these properties of expansive soil have significantly improved.*

Key Words: Expansive soil, Marble dust, Calcium Chloride, Maximum Dry density, Optimum Moisture Content, California Bearing Ratio.

1.INTRODUCTION

Expansive soils experience volume changes with moisture fluctuations. When these soils become wet and then dry, they can cause considerable damage to pavements built upon them. Pavements on such soils show distress early, leading to failures. Expansive soils have poor engineering properties like low bearing capacity, instability, and volume change, posing challenges to structures. The minerals found in these soils are mostly clays, especially those belonging to the smectite group, which includes montmorillonite. These clay minerals have a unique crystal structure with a high capacity to absorb water molecules into their interlayer spaces. When expansive soil comes into contact with water, these clay minerals absorb the water molecules, causing them to expand and the soil to swell. Conversely, soil shrinks as clay minerals release water when moisture is lost. This cycle of water absorption and release drives the swelling and shrinking behavior of expansive soil. To address challenges posed by expansive soil, various remedial measures can be taken to enhance the stability and durability of construction projects. Techniques like prewetting, mechanical compaction, and subgrade drainage help manage moisture content and reduce soil swelling. Geosynthetic materials such as geotextiles and geogrids can reinforce soil and provide stability. One effective approach involves soil stabilization techniques utilizing additives such as lime, cement, bitumen, rice husk ash, steel slag, and calcium chloride. Marble dust, a waste product from the marble industry, can also be used to modify the properties of expansive soil, improving its strength, cohesion, and resistance to moisture-induced volume changes. The reason for choosing Marble dust as a stabilizer is due to the fact that Marble dust contains high content of Calcium Carbonate which helps in reacting with the clay minerals present in Expansive soil. In addition, marble powder is environmental friendly and cost-effective. It reduces the disposal of industrial waste and the consumption of natural resources. Calcium chloride, a chemical stabilizer, can enhance soil compaction and reduce its susceptibility to swelling by altering the soil's moisture retention characteristics.

2) LITERATURE REVIEW

Numerous studies have investigated the use of marble dust as a soil stabilizer. Marble dust, a waste product from marble processing industries, possesses pozzolanic properties and fine particle size distribution, which can contribute to improved soil stabilization.

1) Hassan A. M. Abdelkader et al. (2016) have conducted laboratory tests by mixing Marble dust with the expansive soil by different proportions (5%, 10%, 15%, 20%, and 25%). The following conclusions are drawn for the addition of marble dust up to 25%:

- The plasticity index decreases from 17.12% to 10.7%. The rate of decrease is more up to 15%, and after that, the rate of decline is low.

- The swell potential ratios of decrease were reported as 11.17%, 31.67%, 66.67%, 76.67%, and 91% with adding MD by 5%, 10%, 15%, 20%, and 25%, respectively
- MDD increases from 18.72 kN/m³ to 20.2 kN/m³ and the corresponding OMC decreases from 13.1% to 11.2% with increasing the amount of MD up to 25%.
- At the optimum percentage CBR value is obtained as 8.12% at 15% of marble dust.

Additionally, calcium chloride has garnered attention for its potential as a soil stabilizer. As a hygroscopic compound, calcium chloride can absorb moisture from the surrounding environment, thereby reducing the water content of expansive soils and mitigating their swelling behavior.

2) Magdi Mohamed Eltayeb Zumrawi et al. (2017) have shown that calcium chloride treatment can enhance soil strength making it a viable option for stabilizing expansive soils in various engineering applications. A series of laboratory experiments were performed to investigate the effect of $CaCl_2$ additive with various percentages of 0%, 2%, 10%, and 15% for improving expansive soil.

- The reduction in plasticity with the addition of 15% $CaCl_2$ was found to be 60%.
- The reduction in free swell value is about 70% with the addition of 15% $CaCl_2$ to expansive clay.
- The addition of 15% $CaCl_2$ resulted in an increase in MDD by 12.5% and also a decrease in OMC by 14%.
- The shear strength increased up to 5% $CaCl_2$addition; beyond this percentage, there is a considerable decrease is observed due to the absorption of more moisture at higher chemical content.

3) Purnanandam. K, Renuka. G (2018) have investigated the effect of marble dust and calcium chloride on expansive soil. Initially, expansive soil samples were treated with varying proportions of marble dust, ranging from 5% to 20%. The results indicated that the optimal improvement in soil properties was achieved at a marble dust content of 15%. further experiments were conducted by treating the expansive soil with 15% marble dust along with different proportions of calcium chloride, ranging from 0.5% to 2%.

- The most effective treatment for stabilizing expansive soil was found to be a combination of 15% marble dust and 1.5% calcium chloride
- This treatment resulted in a significant decrease of 44.81% in the plasticity index.
- It has been shown that adding 15% marble powder and 1.5% $CaCl_2$ to the expanding clay reduced its DFS value by 63.63%.
- The CBR value is increased by 150% with the addition of 15% marble dust while adding 1.5% $CaCl_2$ improved it even more by 349.7%.

3) OBJECTIVE OF THE STUDY

The Objectives of the present experimental study are

- To determine the properties of the Expansive soil.
- To evaluate the properties of expansive soil when treated with percentage variation of marble powder as an admixture.
- To evaluate the properties of expansive soil treated with optimum percentage marble dust on percentage variation of calcium chloride ($CaCl_2$).

4) MATERIALS AND METHODS

4.1 Materials Used

The materials used in conducting the required laboratory investigation are

4.1.1 Expansive soil

The expansive soil used in this study was taken from Amalapuram in the East Godavari District of the Indian state of Andhra Pradesh, at a depth of 1.3 meters below the surface. According to the IS codes of practice, the Index and engineering parameters of the expansive soil are calculated and shown in Table 4. IS codes of practice.

4.1.2 Calcium Chloride ($CaCl_2$)

Calcium chloride ($CaCl_2$) acts as a versatile soil stabilizer in civil engineering and construction, primarily by controlling moisture content, enhancing compaction, improving soil strength, and providing dust control. For this investigation, the Calcium Chloride was collected from Sree Lakshmi Chemicals Kakinada. The properties of $CaCl_2$ are presented in Table 1.

Table-1: Physical Properties of Calcium Chloride

Property	Value
Color	White powder
Odor	Odorless
Density	2.15 g/cm^3
Melting Point	772 – 775 °C
Boiling point	1930 °C

4.1.2 Marble Dust

Marble dust, also known as marble powder, is a byproduct of the marble industry and is typically generated during the cutting, shaping, and polishing processes of marble blocks or slabs. Marble dust, primarily composed of calcium carbonate, along with various mineral impurities, plays a crucial role in stabilizing soil. The fine particle size distribution and pozzolanic properties of marble dust can improve soil properties when used in engineering projects. For this study, the marble dust was collected from Astrra Chemicals Ambattur in Chennai. The physical properties and chemical composition of the marble dust are presented in Table 2 and Table 3, respectively.

Table-2: Physical properties of Marble dust

Property	Value
Physical state	Fine Powder
Color	Natural white
Odour	Odourless
Specific Gravity	2.6
Density	2.74 g/cm^3
Bulk Density	1118.01kg/m^3

Table-3: Chemical composition of Marble dust

Constituent elements	Content%
Calcium Carbonate (CaCO3)	88.50%
Calcium Oxide (CaO)	45.18%
Silica (SiO2)	11.38%
Magnesium Carbonate (MgCO3)	0.420%
Alumina (Al2O3)	0.230%
Magnesium Oxide (MgO)	0.200%
Ferric Oxide	0.090%
Phosphorous (P2O5)	0.009%
Sulphur (SO3)	0.008%
Loss on Ignition	43.60%

4.2 Methodology

The samples used in the laboratory investigations are

- Expansive clay
- Expansive clay + marble powder
- expansive clay + marble powder + calcium chloride ($CaCl_2$)

4.2.1 Liquid limit

Liquid limit test was conducted using Casagrande's liquid limit apparatus as per the procedures laid down in IS: 2720 Part 5 (1985). The liquid limit test was conducted with Expansive soil, Expansive soil + 20% Marble dust, Expansive soil + 20% marble dust + 1.5% Calcium Chloride.

4.2.2 Plastic limit

The plastic limit test was performed on Expansive Clay, Expansive Clay + 20% Marble Powder, Expansive clay + 20% Marble powder + 1.5% $CaCl_2$ according to IS 2720 Part 4 (1970) requirements.

4.2.3 Plasticity index

The plasticity index is calculated as the difference between its liquid limit and plastic limit

Plasticity index (I_P) = liquid limit (w_L)- plastic limit (w_P)

4.2.4 Specific gravity

The specific gravity test was performed using a Pycnometer under IS 2720 Part 3 (1980).

4.2.5 Differential Free Swell Test

The Differential Free Swell test was conducted as per IS 2720 Part 40 (1977) specifications with samples of Expansive Clay, Expansive Clay + 20% Marble dust, Expansive Clay + 20% Marble dust + 1.5% $CaCl_2$.

$$\text{Differential Free Swell (\%)} = \frac{v_d - v_k}{v_k} * 100$$

Where,

V_d = volume of soil specimen read from the graduated cylinder containing distilled water.

V = volume of soil specimen read from the graduated cylinder containing kerosene.

4.2.6 Proctor's Standard Compaction Test

This test is a method for the determination of the relation between the water content and the dry density of soils using light compaction. In this test, a 2.6 kg rammer falling through a height of 310 mm is used as per the specifications mentioned in IS 2720 Part 7 (1980).

4.2.7 California Bearing Ratio

The ratio expressed in percentage of force per unit area required to penetrate a soil mass with a circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that needed for corresponding penetration in a standard material. This test is conducted by preparing the sample and following the required procedures as per specifications mentioned in IS 2720 Part 16 (1987).

4.2.8 Triaxial Test

The triaxial test, which determines the shear strength and stiffness of soil, is conducted as per the requirements mentioned in IS 2720 Part 11 (1993).

5) RESULTS AND DISCUSSIONS

Initially Expansive soil is treated with various percentages of Marble dust (10%, 15%, 20%, and 25%) . After analyzing the properties of soil further the expansive soil and Marble dust are treated with varying percentages of calcium Chloride (0.5%, 1%, 1.5%, 1.7%, 2%).

The Index & Engineering properties were obtained as per the IS code of practice for

- Expansive soil
- Expansive soil when treated with optimum percentage of Marble dust.
- Expansive soil and Marble dust when treated with optimum percentage of Calcium Chloride .

5.1 Expansive Soil

The Index & Engineering properties for expansive soil are obtained from the laboratory investigations. Table 4 shows the properties of Expansive soil obtained during this study.

Table-4: Index & Engineering Properties of Expansive Soil

Property	Symbol	Value
Liquid Limit	w_L	61.23%
Plastic Limit	w_P	26.84%
Plasticity Index	I_p	34.39%
Soil Classification		CH
Differential Free Swell	DFS	110%
Specific Gravity	G	2.517
Optimum Moisture Content	OMC	27.79%
Maximum Dry Density(g/cc)	MDD	1.602
Cohesion (kg/cm2)	C	1.22
Angle of Internal Friction (°)	ϕ	2°
California Bearing Ratio (%)	CBR	1.80%

5.2 Expansive Soil treated with various proportions of Marble Dust

To evaluate the effectiveness of marble Dust for stabilization of Expansive soil, various percentages of Marble Dust (10%, 15%, 20%, 25%) were added to the soil. Laboratory tests were undertaken to determine the soil's basic properties.

5.2.1 Proctor Compaction Test Results

Table-5: OMC and MDD values of untreated and treated expansive soil on percentage variation of marble dust

S.No	Property	OMC (%)	MDD (g/cc)
1	Untreated Expansive soil	27.79%	1.602
2	90% ES+ 10% MD	26.23%	1.686
3	85% ES + 15% MD	25.01%	1.711
4	**80% ES + 20% MD**	**23.40%**	**1.786**
5	75% ES + 25% MD	24.23%	1.732

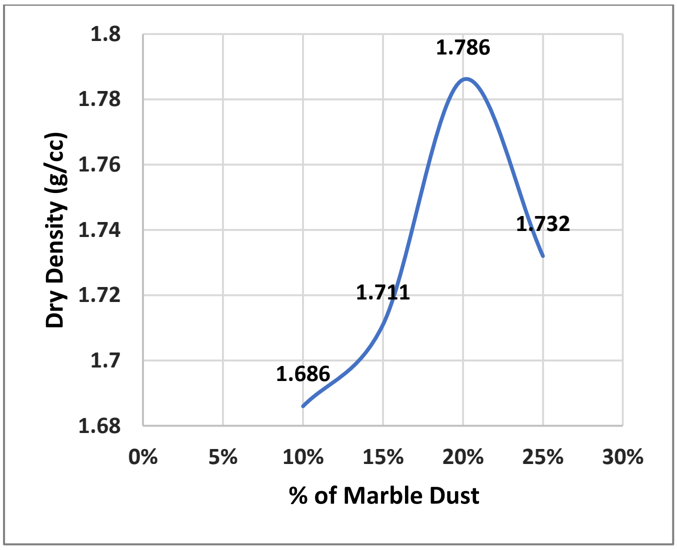

Chart-1: MDD values of Expansive Soil treated with percentage variation of Marble Dust

5.2.2 CBR Test results for Expansive Clay treated with various percentages of Marble Powder

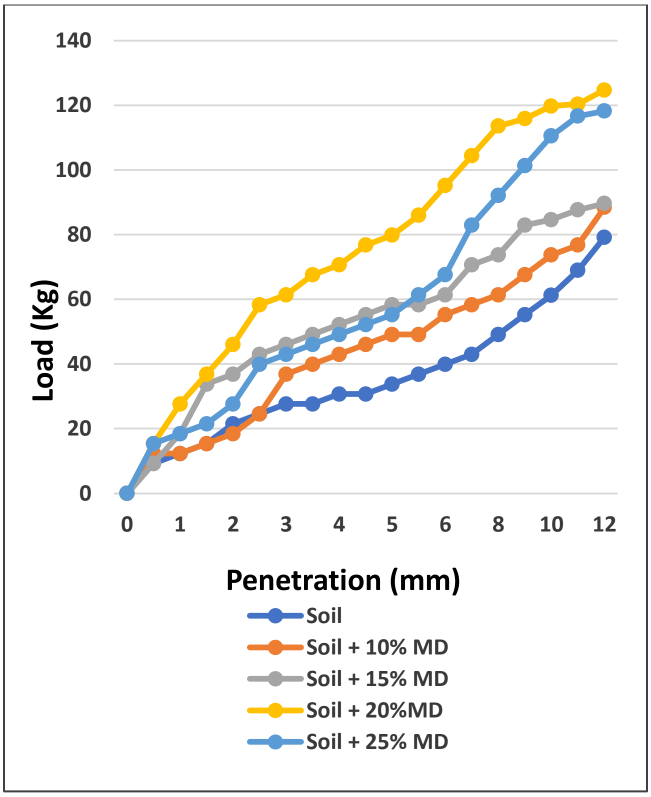

Chart-2: CBR values of Expansive Soil treated with percentage variation of Marble Dust

Table-6: Variation of soaked CBR with Marble Dust

Property	Soaked CBR (%)
Untreated Expansive Soil	1.80%
90% ES + 10% MD	2.69%
85% ES + 15% MD	3.14%
80% ES + 20% MD	**4.26%**
75% ES + 25% MD	3.42%

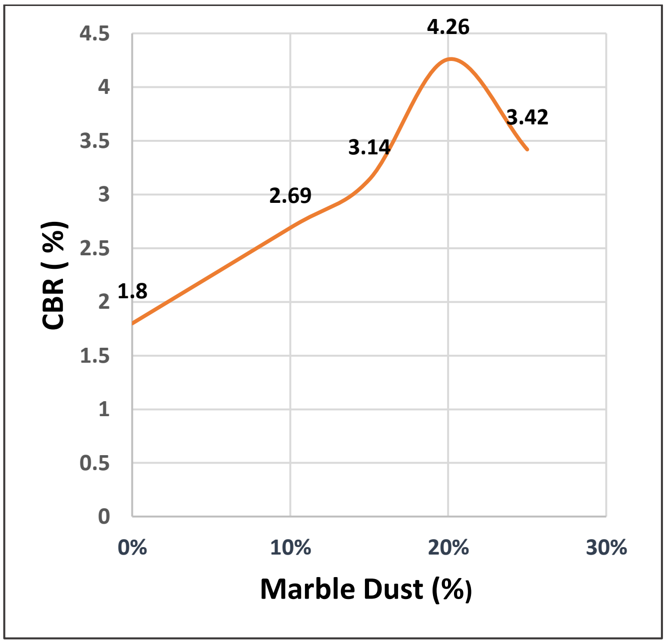

Chart-3: CBR values of Expansive Soil treated with Percentage variation of Marble Powder

Based on the results presented above, we can conclude that 20% Marble Dust produces the best outcome for expansive soil.

The Engineering properties of the soil for 80% Expansive Soil + 20% Marble Dust are obtained as below.

Table-7: Index & Engineering Properties of Expansive Soil treated with the optimum percentage of Marble Dust

Property	Symbol	80% Soil + 20% MD
Liquid Limit	w_L	47.23%
Plastic Limit	w_P	22.66%
Plasticity Index	I_p	24.66%
Soil Classification		CI
Differential Free	DFS	40%

Swell		
Specific Gravity	G	2.651
Optimum Moisture Content	OMC	23.40%
Maximum Dry Density (g/cc)	MDD	1.786
Cohesion (kg/cm^2)	C	0.912
Angle of Internal Friction (°)	ϕ	8°
California Bearing Ratio (%)	CBR	4.26%

Discussion 1: As per IRC 37-2012, The Subgrade soil should possess a minimum CBR value of 8%.

In the present study, The Expansive Soil treated with an optimum of 20% Marble Dust has exhibited the CBR value of 4.26%. Hence, this treated Expansive soil is not suitable as subgrade for flexible pavements. Therefore, an attempt has been taken further for improving the CBR value of treated Expansive soil by using chemical admixture viz. $CaCl_2$.

5.3 Expansive soil and optimum percentage of Marble Dust treated with various proportions of calcium Chloride ($CaCl_2$)

To assess the efficiency of Calcium Chloride for soil stabilization in expansive soil, various percentages of $CaCl_2$ (0.5%, 1%, 1.5%, 1.7%, 2) were mixed with the Expansive soil and Marble dust.

5.3.1 Proctor Compaction Test Results

Table-8: Variation of MDD and OMC with % of Calcium Chloride

Property	OMC (%)	MDD (g/cc)
79.5% ES + 20% MD + 0.5% $CaCl_2$	25.00%	1.620
79% ES + 20% MD + 1% $CaCl_2$	23.45%	1.659
78.5% ES + 20% MD + 1.5% $CaCl_2$	**19.34%**	**1.866**
78.3% ES + 20% MD + 1.7% $CaCl_2$	24.45%	1.710
78% ES + 20% MD + 2% $CaCl_2$	25.08%	1.630

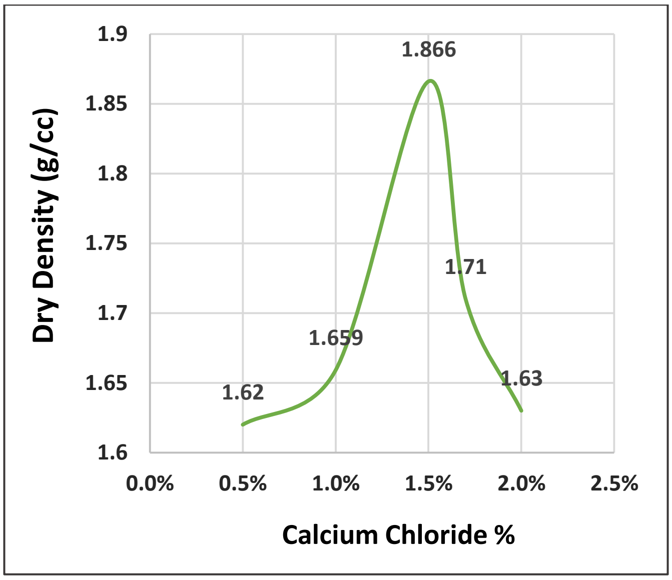

Chart-4: Influence of $CaCl_2$ on Max Dry Density

5.3.2 CBR Test results for Expansive Clay treated & Marble Dust treated with various percentages of Calcium Chloride ($CaCl_2$).

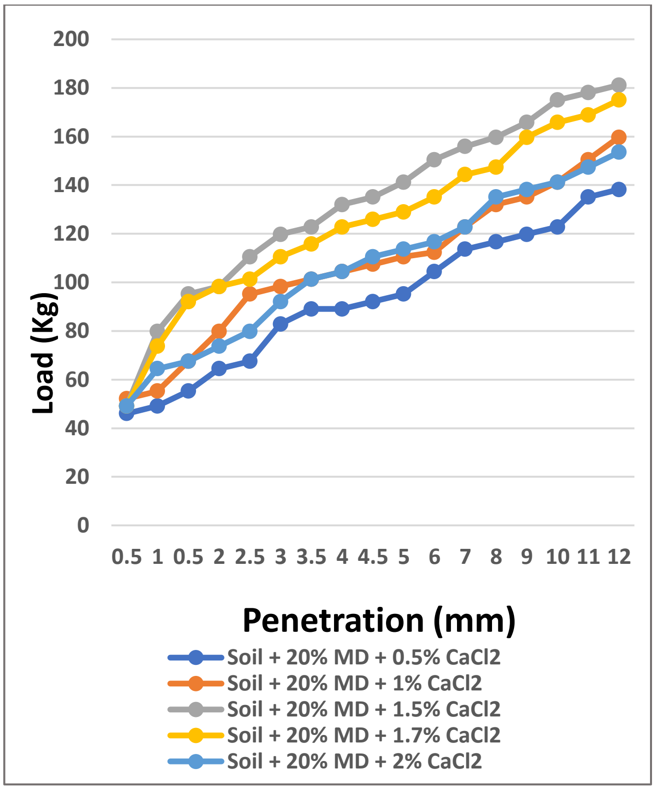

Chart-5: Influence of various percentages of calcium chloride with the marble powder and expansive clay of CBR values

Table-9: Variation of soaked CBR with Calcium Chloride

Property	Soaked CBR (%)
79.5% ES + 20% MD + 0.5% $CaCl_2$	4.93
79% ES + 20% MD + 1% $CaCl_2$	6.95
78.5% ES + 20% MD + 1.5% $CaCl_2$	**8.07**
78.3% ES + 20% MD + 1.7% $CaCl_2$	7.39
78% ES + 20% MD + 2% $CaCl_2$	5.83

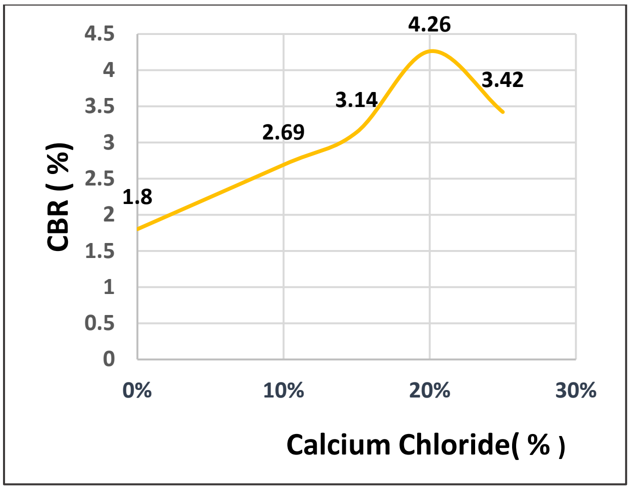

Chart-6: Influence of $CaCl_2$ on CBR values

Based on the findings above, we can infer that 1.5% Calcium Chloride offers the greatest outcomes for expansive soil mixed with 20% Marble Dust. The soil parameters for 78.5% Expansive soil, 20% Marble Dust, and 1.5% $CaCl_2$are obtained as below.

Table-10: Index & Engineering Properties of Expansive Soil treated with the optimum percentage of Marble Dust & Calcium Chloride.

Property	Symbol	78.5% Soil + 20% MD + 1.5% $CaCl_2$
Liquid Limit	w_L	34.12%
Plastic Limit	w_P	18.19%
Plasticity Index	I_p	15.22%
Soil Classification		CL
Differential Free Swell	DFS	10%
Specific Gravity	G	2.716
Optimum Moisture Content	OMC	19.34%
Maximum Dry Density (g/cc)	MDD	1.866
Cohesion (kg/cm²)	C	0.752
Angle of Internal Friction (°)	ϕ	11°
California Bearing Ratio (%)	CBR	8.07%

Discussion 2: As per IRC 37-2012, The Subgrade soil should possess a minimum CBR value of 8%.

In the present study, The Expansive Soil treated with 20% of Marble Dust and 1.5% $CaCl_2$ has exhibited the CBR value of 8.07%. Hence, the treated Expansive soil is suitable as subgrade for flexible pavements.

6) CONCLUSIONS

- It is noticed that the Liquid Limit of expansive clay has been decreased by 22.86% with the addition of 20% marble powder and further, it has been decreased by 44.27% with the addition of 1.5% $CaCl_2$when compared with untreated expansive soil.

- It is found that the Plastic Limit of the expansive clay has been decreased by 15.57% with the addition of 20% marble powder and further, it has been decreased by 32.22% with the addition of 1.5% $CaCl_2$ when compared with untreated expansive soil.

- It is observed that the Plasticity Index of the clay has been decreased by 28.29 with the addition of 20% marble powder and further, it has been decreased by 55.74% with the addition of 1.5% $CaCl_2$when compared with untreated expansive soil.

- It is found that the OMC of the expansive clay has been decreased by 15.79% with the addition of 20% marble powder and further, it has been decreased by 30.40% with the addition of 1.5% $CaCl_2$when compared with untreated expansive soil.

The reason for such behavior is due to the replacement of soil particles (fine particles) with MD particles (coarser particles) and thus increases the coarser particles in the mix, leading to the decrease of total surface activity and therefore lesser water-adsorptive capacity.

- The addition of 20% marble powder enhanced the MDD of the expanding clay by 11.48%, whereas the addition of 1.5% $CaCl_2$ improved it by 16.47%.

The reason behind the increase of MDD is due to the occupation of the void spaces of waste marble dust by the clay soil particles and the cementitious effect of CaO present in the MD and also the replacement of MD particles having high specific gravity with soil particles having a low specific gravity of mixes.

The improvement in compaction parameters with the addition of Calcium Chloride can be attributed to the cation exchange between mineral layers.

- It has been noted that adding 20% marble powder to the expanding clay enhanced its CBR value by 135% while adding 1.5% $CaCl_2$improved it even more by 347.77%.

The improvement can be attributed to filling voids between expansive soil grains by MD and also improvement in gradation and thereby an increase in MDD of soil; consequently, CBR values were increased.

- The results show that adding 20% marble powder to the expanding clay reduced its DFS value by 63.63% while adding 1.5% $CaCl_2$reduced it by 90.90%.

This happened due to the replacement of the swelling particles of the soil with the non-swelling particles of MD that works as an inert material.

This result can also be supported by the fact that the double layer thickness is depressed with cation exchange with calcium ions present in Calcium Chloride.

- It is noticed that the Cohesion of expansive Clay has been decreased by 25.24% on the addition of 15% marble powder and it has been further decreased by 17.54% when 1.5% $CaCl_2$is added.
- It is noticed that the Angle Internal Friction of expansive clay has been improved by 300% with the addition of 15% marble powder and it has been further improved by 450% when 1.5% $CaCl_2$is added.

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