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Influence of Chemical Admixtures on Geotechnical Properties of Expansive Soil

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ABSTRACT

The present study is to elucidate and efficacy of Ultra-fine slag and Calcium Chloride in improving the Engineering characteristics of expansive soil. An experimental program has evaluated the effects of Ultra-fine slag 3%, 6%, 9% and $CaCl_2$ 0.25%, 0.5%, 1.0%, Free swell index, swelling potential, swell pressure, plasticity, compaction, strength, hydraulic conductivity, Cation Exchange Capacity and microstructural XRD, SEM tests of expansive soil. Both admixtures were added independently and blended to the expansive soil. Mixing of Ultra-fine slag, $CaCl_2$ and expansive soil results have shown that plasticity index, hydraulic conductivity, swelling properties of blends decreased and dry unit weight and unconfined compressive strength is increased in combination of soil +6% of Ultra-fine slag + 1% $CaCl_2$. The unconfined compressive strength (UCS) of the samples is again found to decrease slightly beyond 6% Ultra-fine slag and 1% $CaCl_2$. It was found that the optimum quantity of material for a favorable combination of soil +6% of Ultra-fine slag + 1% $CaCl_2$ was taken for further study in view of its economy due to lower $CaCl_2$ content.

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NOMENCLATURE

W_L	Liquid limit	MDD	Maximum dry density
W_P	Plastic limit	UCS	Unconfined Compressive Strength
W_S	Shrinkage limit	$CaCl_2$	Calcium chloride
FSI	Free swell index	G_s	Specific gravity (g/cc)
W_A	Water absorption	ρ	Bulk Density (kg/m^3)
CEC	Cation Exchange Capacity	PI	Plasticity Index
OMC	Optimum Moisture Content	CNS	Cohesive non-swelling soil

1. INTRODUCTION

Expansive soils are known worldwide for their volume change behaviour due to moisture fluctuation because of their intrinsic mineralogical behaviour [1]. These types of soils are found mainly in the arid and semi-arid regions [2] such as Australia, Canada, China, India, South Africa, and the United States. India has an extensive track of expansive soils known as black cotton soil covers about twenty percentage of the total land area [3]. Due to its black colour which is a result of high iron and magnesium minerals acquire from basalt [4]. Expansive soils are clayey soils are the extensive specific surface area and high cation exchange capacity [5, 6]. Expansive soil contains clayey minerals such as montmorillonite which increases in volume during wetting. This volume change can exert sufficient stress on a building, sidewalk, driveways, basement floors, pipelines, and foundations to cause damages. Since the expansive soils are found worldwide, the challenges to the Civil Engineers in one felt around the globe. If not adequately treated, expansive soils may act as natural hazards resulting in damages to structures [7, 8]. The annual cost of damages to the Civil Engineering structures is estimated at 150 million in the

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United States and many billions of dollars worldwide [9]. Under the moisture ingress and digress, a building founded on expansive soil undergoes differential movements caused by alternate swell/shrink behaviour of soil causing several structural damages. Many reported data are available on the heave profile of soil at the surface, at various depths from the ground surface and on covered areas [10, 11] it is generally observed that the amplitude of soil movement decreases with depth and there is an increase in time lag with movement at depth compared with that at the surface. To date, distress problems related to this type of soils are quite immense to have ensued in the loss of billions of dollars in repairs and rehabilitation [12].

Many Researchers used the strong electrolytes such as potassium Chloride, Magnesium Chloride, Zinc Chloride, Sodium hydroxide, Ferric Chloride, and Calcium Chloride could be tried instead of lime [13]. strong electrolytes are readily soluble in water and hence could supply adequate cations for exchange reactions. Industrial by-product material such as flyash [14], GGBS [15], cement kiln dust, limestone dust [16] as additives are becoming more popular due to their relatively low cost additionally CO_2, emission can be reduced significantly by the increased use of such supplementary cementing materials currently wasted in lagoons and landfill sites. The most important feature in the stabilization of clay soils is the ability of the stabilizer to provide a sufficient amount of Calcium [17]. Stabilizers can be amended with activators like lime or cement to enhance their cementitious and pozzolanic properties.

The purpose of this study is to investigate the influence of the inclusion of Ultra-fine slag in conjunction with Calcium Chloride ($CaCl_2$) in the stabilization of expansive soils. In India, an industrial by-product Ultra-fine slag material is manufactured by Ambuja cement private limited. The majority of Ultra-fine slag material is utilized in the high-performance concrete structures either as a cement replacement or as an additive to improve concrete properties in both fresh and hardened states and soil stabilization purpose [18], while $CaCl_2$ is mainly used to reduce the swelling and increase the shear strength of expansive soil for soil stabilization. These Ultra-fine slag and $CaCl_2$ have also great potential to be used as stabilizing agents. The main reason for their underutilization is the lack of pozzolanic reactivity [19].

Ultra-fine slag is ultrafine ground granulated blast furnace slag, performs a superior to all other mineral admixtures used in India [20–22]. On the other hand, $CaCl_2$ is the hygroscopic material and hence is pre-eminently suited for stabilization of expansive soils, because it absorbs water from the atmosphere and prevents shrinkage cracks occurring in expansive soils during summer season. The combination of the two materials can be more beneficial when used as a stabilizing agent than using the individual. However, no studies on the joint activation of Ultra-fine slag and $CaCl_2$ as stabilizing agents for expansive soils have been published to date.

2. MATERIALS

2. 1. Expansive Soil The expansive clay soil is collected from Kirumambakkam, is located in Puducherry, India. The soil is collected in a dry condition at a depth of 1 meter below the ground level and preserved in the laboratory. Identified the index and engineering properties of expansive soils as shown in Table 1.

2. 2. Alccofine-1203 Alccofine-1203 is ultrafine slag, manufactured by Ambuja cement private limited in India. Ultra-fine slag and Ultra-fine slag-1101 are two types with low calcium silicate and high calcium silicate respectively. Ultra-fine slag has the lime binder 34% and average particle size of 4 microns (Range 0-17microns). Chemical composition and physical properties are tested by Ultra-fine slag micro materials, Pissurlem, Goa. Ultra-fine slag properties are given in Table 2.

2. 3. Calcium Chloride The chemical formula of Calcium Chloride is $CaCl_2$. It is a hygroscopic material and hence, it is pre-eminently suited for stabilization of

TABLE 1. Physical properties of soil

Properties of soil	Results
Sand (%)	12
Silt (%)	30
Clay (%)	58
Specific gravity	2.60
Liquid limit (W_L)	59%
Plastic limit (W_P)	34.5%
Shrinkage limit (W_S)	12.5%
Free swell index (FSI)	25%
Water absorption (W_A)	53.69%
Cation exchange capacity (CEC) meq/100g	55
Unified soil classification (USCS)	CH
OMC (%)	18.19
MDD (kN/m^3)	15.73
UCS (kPa)	157
Swell potential (%)	5.29
Swell pressure (kPa)	150
Hydraulic conductivity cm/sec	1.58×10^{-6}

TABLE 2. Physical and chemical properties of Ultra-fine slag

Properties	Results
Physical properties	
Particle size Distribution(mm)	
D10	1.5
D50	4.3
D90	9.0
Specific gravity (g/cc)	2.88
Bulk density (kg/m^3)	680
Chemical properties	
SiO_2	35.6%
Al_2O_3	21.4%
Fe_2O_3	1.3%
CaO	33.6%
SO_3	0.12%
MgO	7.98%

black cotton soil (expansive soil), because it absorbs water from the atmosphere and releases heat when it is dissolved in water. Calcium Chloride is obtained from Sri Rajendra Scientific and Surgicals Pvt Ltd. Pondicherry, India.

3. RESULTS AND DISCUSSION

3. 1. Index and Compaction Tests The influence of Ultra-fine slag and $CaCl_2$ on Atterberg limits (liquid limit, plastic limit, and shrinkage limit) of expansive soil is shown in Table 3. Results show that liquid limit decreases and plastic limit increases; hence, the difference between liquid limit and plastic limit is the plasticity index. The plasticity index is reduced by about 67% when the soil is blended with 6% Ultra-fine slag + $CaCl_2$ 1%.

The compaction characteristics of untreated and treated soils are shown in Table 3. The results of compaction show that the maximum dry density is increased from 15.73 kN/m^3 to 16.92 kN/m^3 and optimum moisture content is reduced from 18.19% to 16.5% with an increase of 6% Ultra-fine slag and 1% $CaCl_2$ binder; that is, for sample which shows maximum strength.

3.2. Unconfined Compression Strength Unconfined compressive strength (UCS) tests were conducted with Ultra-fine slag and $CaCl_2$ was added. Independently and blended to the expansive soil samples. UCS tests were performed on both intrinsic soil and chemically treated soil. The UCS value for intrinsic soil is 157 kPa. The percentage of Ultra-fine slag (3, 6 and 9%) and $CaCl_2$ (0.25, 0.5 and 1.0%) were added by dry weight of the soil. The UCS values are shown in Table. 3. The optimum increase was noticed at 6% Ultra-fine slag and 1% $CaCl_2$. The UCS strength was an increase from 157 kPa to 418 kPa. Beyond 6% of Ultra-fine slag with 1%, $CaCl_2$ resulted in a slight decrease in UCS values.

3. 3. Swell Behavior The swell behavior of soil and mixed with different percentages of Ultra-fine slag and $CaCl_2$ is presented in Table. 3. The maximum swell potential of intrinsic soil is 5.29% and swell pressure is 150 kPa. The swell of intrinsic soil is mainly due to the presence of montmorillonite mineral. With the addition of various percentages of Ultra-fine slag and $CaCl_2$, the swell of the soil decreases gradually and completely brings to halt beyond the addition of Ultra-fine slag 6% with 1% of $CaCl_2$. Beyond Ultra-fine slag 6% with 1% of $CaCl_2$, complete elimination of swell is due to the availability of adequate calcium, not only for cation exchange reaction but also for the formation of pozzolanic reaction compounds. Pozzolanic reaction binds the flocculated soil particles, and thereby, the formation of strong flocculated fabric, leading to the reduction in a swell of soil.

3. 4. Mineralogical and Microstructural Analysis

3. 4. 1. SEM Analysis Changes in surface matrix and chemical composition due to reaction between minerals of soil-Ultra-fine slag-$CaCl_2$ were performed with SEM and EDAX techniques, respectively. EVO 18 Carl Zeiss is used for the SEM and EDAX studies. The analysis for clay soil, Ultra-fine slag and clay soil + Ultra-fine slag 6% + $CaCl_2$ 1% are shown in Figure 1 (a, b, c).

These studies were carried out in order to observe the individually and changes in the soil are blended with an admixture of 0 days. Eminent peaks Fe, Au, Al are observed in 1(a) and Fe, Au, Al, Si are observed in clay soil. In Ultra-fine slag (1b) Ca, Mg, Si, Al eminent peaks are observed. In combination of soil blended with admixture (1c) is observed eminent peaks are Fe, Au, Si, O, Al. The test was performed mainly for the identification of the various cementations compounds on the soil stabilized with 6% Ultra-fine slag + $CaCl_2$ 1% binder; that is, for sample which shows maximum strength. The formation of aggregation or flocs is mainly responsible for the reduction of the swelling in expansive soil [8]. Cement hydration materials such as C-S-H gel is mixed with calcium hydroxide, aggregation can be observed in the SEM-micrograph. The hydration products are usually intermixed with pore spaces that are not empty but occupied by hardened epoxy resin [22].

TABLE 3. Effects of soil-admixtures blended on Index and Engineering properties

$CaCl_2$ (%)	Ultra-fine slag (%)	Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)	Plasticity index (%)	MDD (%)	OMC (%)	UCS (kPa) 0 days	Swell characteristics		W_A (%)
									Swell potential (%)	Swell pressure (kPa)	
0	0	59.0	34.5	12.5	24.5	15.73	18.19	157	5.29	150	53.69
	3	55.0	35.0	13.3	20.0	15.85	17.75	216	3.22	120	50.05
	6	49.0	35.5	16.0	13.5	15.95	17.45	245	1.23	095	44.59
	9	47.0	36.0	22.5	11.0	16.15	17.24	241	0.75	075	42.77
0.25	0	54.0	37.0	14.0	17.0	15.85	18.05	245	2.17	115	49.14
	3	51.0	38.5	15.0	12.5	16.05	17.76	300	1.02	098	46.41
	6	49.0	39.0	19.0	10.0	16.30	17.25	327	0.59	065	44.59
	9	48.0	39.0	24.5	9.0	16.45	17.10	324	0.46	096	43.68
0.5	0	52.5	38.0	14.5	14.5	15.90	17.65	306	1.47	045	47.77
	3	50.4	38.5	16.0	11.9	16.34	17.34	359	0.90	038	45.86
	6	48.0	40.0	18.8	8.0	16.70	16.80	384	0.34	022	43.68
	9	49.0	41.0	24.0	8.0	16.90	16.40	376	0.11	018	44.59
1.0	0	51.0	39.0	18.0	12.0	15.80	17.40	352	0.78	032	45.68
	3	49.0	41.0	21.0	8.0	16.30	16.80	401	0.17	012	44.59
	6	47.0	39.0	22.5	8.0	16.92	16.50	418	0	0	42.77
	9	49.0	42.0	22.8	7.0	16.95	16.24	406	0	0	44.59

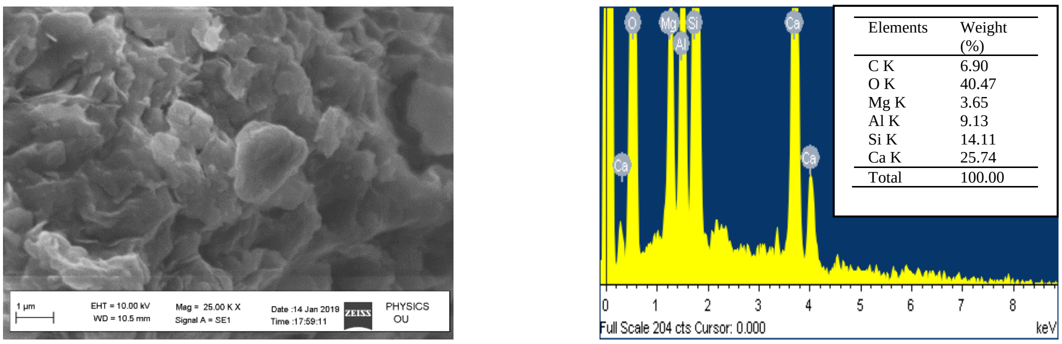
Note: W_L = Liquid limit; W_P = Plastic limit; W_S = Shrinkage limit; PI = Plasticity index; MDD = Maximum dry density; OMC = Optimum moisture content; UCS = Unconfined compressive strength; W_A = Absorption water content.

TABLE 4. Properties Obtained for Optimum Soil-Ultra-fine slag-$CaCl_2$ Mix

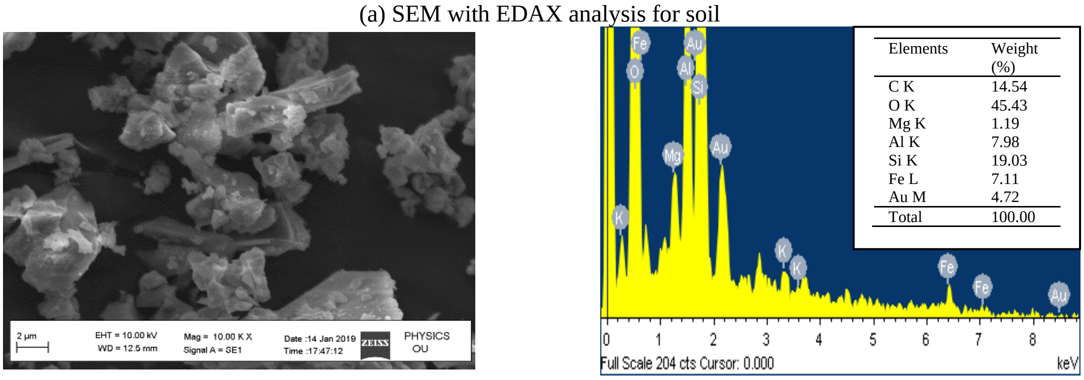
Properties	Soil	93% soil+1% $CaCl_2$+6% Ultra-fine slag
Sand (%)	12	10.30
Silt (%)	30	35.20
Clay (%)	58	54.50
Specific gravity	2.60	2.72
Liquid limit (W_L)	59%	47%
Plastic limit (W_P)	34.5%	39%
Shrinkage limit (W_S)	12.5%	22.50%
Plasticity Index (PI)	25%	8%
Water absorption (W_A)	53.69%	42.77%
Cation exchange capacity (CEC) meq/100g	55	18
Unified soil classification	CH	CI
OMC (%)	18.19	16.50
MDD (kN/m^3)	15.73	16.92
UCC (kPa)	157	418
Free swell index (FSI)	25%	0
Swell potential (%)	5.29	0
Swell pressure (kPa)	150	0
Hydraulic conductivity cm/sec	$1.58x10^{-6}$	$4.3x10^{-5}$

3. 4. 2. XRD The results of experimental and XRD analysis that most of the Calcium is consumed to alter the physical behavior of soil by short-term process. However, peaks related to clay soil are [d = 3.38Å, 2.29Å, and 2.96Å]. The X-ray diffraction peaks identify for clay soil, Ultra-fine slag and clay soil + Ultra-fine slag 6% + $CaCl_2$ 1%. The most important peak traced was related to CH, which was identified at 2ϴ =26° to 36° [20].

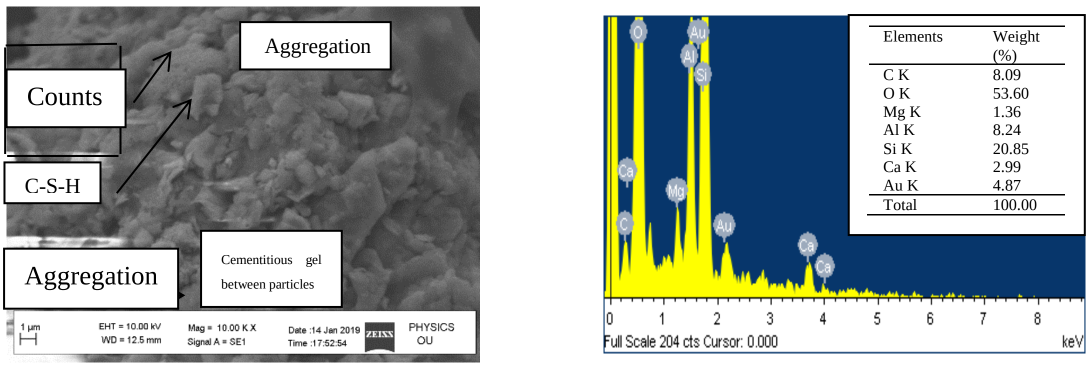
As can be seen from Figure 2 (a, b, c); the addition of Ultra-fine slag and $CaCl_2$ in the soil causes CH related peaks to appear at the aforementioned 2ϴ. It has been carried out to confirm the formation of new minerals, which can play a significant role in strength improvement behavior Calcium stabilized for soil admixture. The intensity has increased for Calcium Chloride and Ultra-fine slag materials treated when compared with the clay soil, which is all-evident from X-ray data. The hydration products as a result of pozzolanic reactions primarily consist of C-S-H gel and calcium hydroxide (CH) [21]. The most important peak traced was related to CH which were identified at 2ϴ=26° to 36° [22].



(a) SEM with EDAX analysis for soil

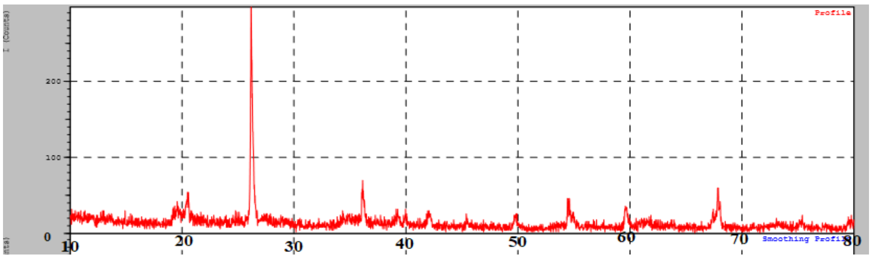


(b) SEM with EDAX analysis for Ultra-fine slag

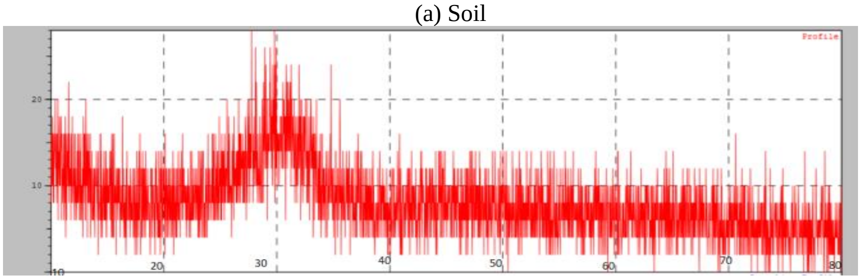


(c) SEM with EDAX analysis for soil + Ultra-fine slag1203+ CaCl2 0 day

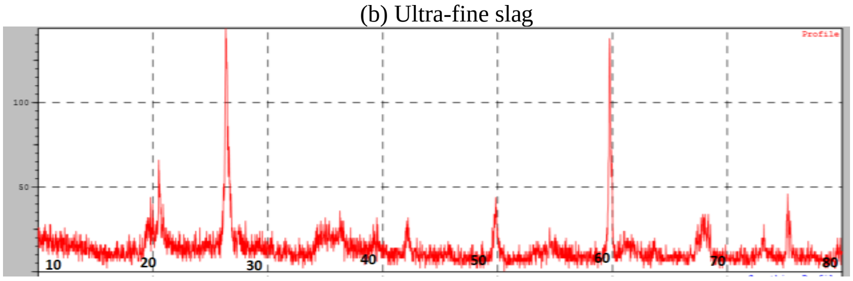
Figure 1. (a) SEM with EDAX analysis for soil; (b) SEM with EDAX analysis for ultra-fine slag 1203; (c) SEM with EDAX analysis for soil + Ultra-fine slag1203+$CaCl_2$ 0 days



Position (º2 Theta)
(a) Soil



Position (º2 Theta)
(b) Ultra-fine slag



Position (º2 Theta)
(c) soil+6%Ultra-fine slag+1%$CaCl_2$

Figure 2. XRD analysis for(a)soil;(b) Ultra-fine slag;(c)soil+6%Ultra-fine slag+1%$CaCl_2$

4. CONCLUSION

In this study, based on the laboratory investigation, a series of tests were performed to study the effect of $CaCl_2$ and Ultra-fine slag on the swelling properties and strength behavior of soils. Based on the results presented in this paper, the following conclusions are made:

1. The optimum moisture content (OMC) was found to decrease 18.19% to 16.5% while the maximum dry density (MDD) increases from 15.73kN/m^3 to 16.92kN/m^3 with binding content.
2. The unconfined compressive strength (UCS) tests were conducted with Ultra-fine slag and $CaCl_2$ were added independently and blended to the expansive soil samples. The UCS strength was an increase from 157 kPa to 418 kPa. Beyond 6% of Ultra-fine slag with 1% $CaCl_2$ resulted in a slight decreased in UCS values.
3. The swell behaviour of soil; the swell potential is reduced from 5.29% to zero and swell pressure is reduced from 150kPa to completely bring to halt beyond addition of Ultra-fine slag 6% with 1% of $CaCl_2$.
4. SEM and XRD studies confirm the formation of reaction products such as Ca, Mg and Si to contribute to strength significantly. In XRD the addition of Ultra-fine slag and $CaCl_2$ in the soil causes CH related peaks to appear at the aforementioned 2Θ.

In the view of severe scarcity for suitable cohesive non-swelling soils (CNS) at several project sites, an alternative cushion material is proposed to be prepared at the site using the intrinsic soil (expansive soil) by admixing with it 6% Ultra-fine slag and 1% $CaCl_2$ by dry weight of the soil. Based on the favorable results obtained, it can be concluded that the expansive soil with Ultra-fine slag and $CaCl_2$ can be considered as an effective cohesive non-swelling soil (CNS) for pavements, sidewalks, and floorings.

5. Funding

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Persian Abstract

چکیده

مطالعه حاضر برای روشن‌سازی و کارایی سرباره فوق‌العاده ریز و کلرید کلسیم در بهبود خصوصیات مهندسی خاک گسترده است. یک برنامه آزمایشی اثرات سرباره فوق‌العاده ریز ۳ ٪ ، ۶ ٪، ۹ ٪ و $CaCl_2$ ۰/۲۵ ٪، ۰/۵ ٪، ۱/۰ ٪، شاخص تورم آزاد، پتانسیل تورم، فشار تورم، خاصیت انعطاف‌پذیری، تراکم، مقاومت، هدایت هیدرولیکی، ظرفیت تبادل کاتیونی و آزمایشات XRD، SEM ریزساختاری خاک گسترده و همچنین از یک ابزار آماری برای پیش‌بینی مقادیر آزمایشی مقاومت فشاری غیر محدود خاک استفاده شد. هر دو مواد افزودنی به طور مستقل اضافه شده و به خاک وسیع مخلوط می‌شوند. اختلاط سرباره فوق‌العاده ریز، $CaCl_2$ و نتایج گسترده خاک نشان داد که شاخص پلاستیکی، هدایت هیدرولیکی، خصوصیات تورم مخلوط کاهش یافته و وزن واحد خشک و مقاومت فشاری غیر محدود در ترکیب خاک ۶٪+ سرباره فوق العاده ریز ۱٪+ $CaCl_2$ افزایش می یابد. مقاومت فشاری نامشخص (UCS) نمونه‌ها مجدداً کمی فراتر از ۶٪ سرباره فوق العاده ریز و ۱٪ $CaCl_2$ کاهش می‌یابد. مشخص شد که مقدار مطلوب مواد برای ترکیبی مطلوب از خاک ۶٪+ سرباره فوق العاده ریز ۱٪+ $CaCl_2$ برای مطالعه بیشتر با توجه به اقتصاد آن به دلیل محتوای کم $CaCl_2$ مورد بررسی قرار گرفت.