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TECHNICAL PAPER

Innovative natural admixture of calcined clay to improve strength and durability characteristics of expansive soil

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Abstract

Due to urbanization and migration of population to the urban areas are increasing predominantly, the infrastructure development in the available problematic soil is becoming a core importance. The purpose of this study is to improve the strength and durability of the expansive soil, this also an attempt the effect of modified soil by adding calcined clay to the problematic soil on its mechanical properties and strength performances when subjected to freezing and thawing (F–T) action. A series of laboratory tests were done on the untreated and optimum percentage (8%) of calcined clay (CC) treated soil for the sample prepared with optimum moisture content and maximum dry density from standard proctor compaction test. The freezing thawing tests were performed for all the samples from 1 to 15 cycles and the effects were evaluated by analyzing the unconfined compressive strength. The stress–strain characteristics of the untreated and treated soil under 0, 1, 5, 10 and 15th freeze, and thaw indicated an increase in the strength and stiffness for the treated samples with reference to the untreated soil. Unconfined compressive strength decreases around 50%, when compared to its original strength of untreated soil, however, there is no decrease in strength of soil treated with 8% calcined clay after 13th cycle. It was also observed that the durability index of the untreated soil decreases with respect to the number of F–T cycle whereas for the 8% CC treated soil slowly decreases at the beginning and starts to increase from 5th cycle of (F–T) process. The results obtained from the study proves that the calcined clay modified soil samples shows increase in strength of soil by 103%.

Keywords Expansive soil · Calcined clay · OMC · MDD · UCS · Freeze and thaw

Introduction

The rapid growth of urbanization is increasing day by day, the growth of population is almost double in last two decades [1]. The infrastructural development plays a vibrant role in accommodating the growing population with in the available land. Soil is one of the most significant and prime media for any construction work. The strength and durability of any structure depend on the bearing capacity of the soil. To meet the above requirement, it is essential to utilize the problematic soil as well, for example expansive soil. "Expansive soils" are widely seen in many countries and can cause serious damage to infrastructures [2–4]. The soil which possesses low shear strength as well as they are sensitive to change in water content and undergoes drastic variation in shrinkage or swell [5]. In order to improvise the soil property and to utilize it for the construction purpose in the need of the hour. The ground improvement technique [6] is one of the most significant ways of improving the engineering properties of weak soil (shear strength and compressibility) thus making it more stable. Soil stabilization is the most efficient among them particularly for clayey soil, several methods such as are mechanical, chemical and biological stabilization are available to enhance the soil characteristics. The using of cement and lime for soil stabilization considered the most common and traditional methods of stabilization but during the production process, the emission of Co_2 and other greenhouse gases affects the environment. Mechanical stabilization is the physical process changing the soil's physical characteristics [7, 8]. It involves compacting the soil so as to change its resistance, compressibility, permeability, and porosity [9, 10]. The chemical stabilization is been identified as a most effective one, predominantly

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for expansive soil. Chemical stabilization is process of adding admixture to the soil to improve the strength and swell properties. The chemical materials act as binders, compaction aids and water repellents and alter the soil performance [11, 12]. Various admixtures such as agro-waste (rice husk ash, wood ash, bagasse ash, groundnut shell ash) industrial waste (fly ash, pond ash, GGBS, phosphogypsum [13], copper slag, steel slag, Geopolymer [14, 15] etc..) and chemical material, that enhances strength and durability and reduces the swell potential of the soil [16–18], but using this waste is polluting the soil and the ground water quality. Therefore, civil engineering organizations are endlessly on the exploration for the new soil stabilizer, with sustainable substance, low-carbon, and ecofriendly cost-effective material [19–26]. Calcined clay is the suitable material for the replacement of cement. The production cost of cement is much greater than the calcined clay. The economic analysis is already done by previous authors [27], Hence calcined clay was the identified material as a natural admixture with is highly reactive cementitious material which can provide a viable solution for improving the durability of the expansive soil.

In cold regions, the soil experience freeze–thaw cycle at least once in an annum. It is evident that the freeze–thaw cycle can influence the structural characteristics of soils significantly, and thus has a substantial effect on the engineering properties and mechanical characteristics of the soil [28–30].The effect of freeze thaw cycle on the performance of expansive soils has been the focus of current research [31–33], and the behavior of expansive soils under chemical impact has also been widely examined [34–38].Furthermore, numerous investigations on the impact of hydro-mechanical factors on the behavior of expansive soils under various temperatures have been conducted [21, 39–42]. However, based on the detailed literature review, the effect of freeze thaw cycle on the strength and durability of expansive soils is very limited. It is well known that freeze thaw cycle is a major cause of soil deterioration in many frozen regions. Freeze thaw cycle cause visible soil cracking on different scales [43–45], which leads to a loss of soil strength [46–49]. Numerous literatures evident that the change in strength characteristics cycles for the expansive clays due to varying climatic conditions cause alternate freeze–thaw cycles [25, 50, 51]. Previous works were done to determine the effect of freezing and thawing on the soil stabilized with different raw and waste material. Also, some investigations on the impact of cement, lime, flyash etc. on the stabilized soil upto ten freeze and thaw cycles. Cement production causes the global warming due to emission of CO. It shows in the below literature review using the traditional admixtures, like cement and gypsum, includes Environmental concerns [52, 53].This research findings differs from the earlier studies and its focuses on the naturally available calcined clay material which possess same cementitious properties as that of cement inorder to overcome the environmental concerns due to carbon emission and also reduce the cement consumption to contribute the sustainable and Ecofriendly construction. Several studies have been concentrated on the strength properties influenced by the freeze–thaw cycles whereas less preference was given to evaluate the failure at strain and Durability index. Thus, the key goal of this study to study the Strain at failure and Indexing the Durability variations of the treated samples comparing with the reference sample upto fifteen number of freeze–thaw cycles. The Main advantageous is usage of naturally available stabilizers acts as a good cementitious material for the assessment of their impact on strength. In cold environments, the migration and accumulation of water in soil influences the strength characteristics due to change in the rate of temperature. Moreover, not much investigation has been performed on the strength properties of the expansive soils improved by the calcined clay in expansive soil under varying climatic conditions. The aim of this study is to identify, the potential use of naturally available material as an admixture to improve the strength and durability of soil, and also the effect on hydro thermo mechanical properties on expansive soil. The strength and durability of the soil are validated by conducting unconfined compressive strength (UCC) test on samples which are subjected to various Freeze and Thaw (F–T) cycle.

Materials and methodology

Material properties

In this study, the soil sample was collected on the site located in Tharamani at a depth of 1.2 m from ground level. The series of test were carried out on the naturally dried and pulverised soil to find out the physical properties and expansive nature of the soil as per bureau of Indian Standards BIS. The specific gravity of the soil is 2.5, The Particle size distribution showed that the more that 50% passes through 75 micron, it range of 4% sand, 9% silt and 87% clay. The Consistency limits of the soil were 65% liquid limit and 22% plastic Limit and 6% shrinkage limit shows the soil is highly plasticity which comes under the category of high compressible clay (CH) as per the IS 1498 (1970) [54]. The free swell index value of the soil is 210% shows the very high expansiveness. From the above test, results shows that the Reference soil is highly expansive and more compressible in nature hence it requires the soil stabilization in order to enhance the behavior of soil.

Admixture property

The additives used for this soil treatment is calcined clay which possess high pozzolanic natural material which is eco-friendly. The calcined clay is the natural admixture obtained from the clayey soil after the calcination process which is highly reactive cementitious material. In this study, the soil is treated with varying proportions of 2, 4, 6, 8 and 10% of calcined clay to enhance the thermal and hydro mechanical properties of the expansive soil. The properties of the Reference soil were given in the Table 1. The chemical composition of the soil and admixture is determined using the X-ray fluorescence (XRF) shown in the Table 2.

Experimental procedure

The light compaction test was done to determine the optimum moisture content and maximum dry density of the reference soil and soil treated with various percentage of calcined clay as per IS: 2720 (Part 7)-1980 [60]. The sample got prepared using the mould having capacity of 1000 cm^3 with 10 cm diameter and height 12.7 cm using the metal rammer having weight of 2.6 kg and compacted under a free fall of 31 cm. The standard proctor compaction tests were conducted on soil with different percentage of calcined clay from 0 to 10% under increment of 2%.

The unconfined compression test was conducted as per the IS code Specification to obtain the optimum percentage of the admixture needed for the treated soil to obtain the maximum unconfined compressive strength. The Predetermined amount of soil sample passing through 425-micron sieve is mixed with the optimum percentage of water content obtained from the standard proctor compaction test. The mixed wet soil samples were compacted in the mould of standard size 38 mm diameter and 76 mm height to prepare the cylindrical soil specimen. The same procedure of the soil preparation was adopted for the both untreated and treated soil with varying percentages of calcined clay (2, 4, 6, 8 and 10%). After preparing the soil specimen is wrapped in the plastic sheets to maintain the moisture content even after for the several days of curing period. The plastic wrapped soil specimens were maintained in the room temperature under the varying curing period of 1, 3, 7, 14, 28 and 60 days.

In this paper, durability studies were carried out using freeze and thaw test as per the ASTM to study the thermal effect on the strength of the unstabilized and stabilised soil specimen. The soil samples were prepared for the optimum percentage of the calcined clay treated soil sample based on the results obtained from the unconfined compression test. The Prepared samples were kept in the plastic bag to avoid the atmosphere interaction throughout the freeze and thaw tests. It is placed inside the refrigerator for freezing under minus 20 °C for 24 h and thawing under the room temperature of 27 °C for next 24 h in order to complete one F–T cycle (48 h). The analysis was carried out for both reference and 8% CC treated soil sample on every F–T cycles for about 720 h.

Table 1 Properties of reference soil

Properties		Symbol	Value	IS CODE
Free swell index, %		FSI	210	IS-2720-Part 40-1970 [55]
Specific gravity		G	2.65	IS: 2720-Part 3-1980 [56]
Particle size distribution	Sand, %	S	4	IS-2720-Part 4-1985 [57]
	Silt, %	M	9	
	Clay, %	C	87	
Liquid limit, %		W_l	65	IS-2720-Part 5-1985 [58]
Plastic limit, %		W_p	22	
Plasticity index		I_p	43	–
Shrinkage limit, %		Ws	6	IS-2720-Part 6-1972 [59]
Soil classification		CH-Highly compressible Clay		IS 1498-(1970) [54]
Standard proctor compaction		Maximum Dry Density, (kN/m^3)	16.4	IS-2720-Part 7-1980 [60]
		OMC, (%)	18.9	

Table 2 Chemical composition of soil and admixture

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Description
57.62	14.39	6.14	3.58	2.41	0.80	1.93	0.08	Soil
47.83	33.75	3.83	2.55	1.02	0.07	0.23	0.04	CC

Results and discussion

Proctor compaction test

The results are summarized and shown in Fig. 1, from the graph it's been observed that, as the percentage of admixture increases, the optimum moisture content decreases and maximum dry density (MDD) increase rapidly, this signifies the behavior of expansive soil related with the addition of calcined clay. It can be seen from the graph that for the value of optimum moisture content of the modified soil is less than the optimum moisture content of reference soil and it was also evident that the maximum dry density of modified soil is higher than the maximum dry density of virgin soil. The results of standard proctor test of treated soil as compared with the reference soil is shown in plot (Fig. 1). The percentage of optimum moisture content of reference soil is (OMC) is 18.9% and due to the addition of the 8% calcined clay on the soil shows the percentage of decrease in optimum moisture content of 17.1 for the increase in dry density was detected as 1.77 g/cc. From the above analysis, it is clear that the effect of the CC treated soil shows an increase on the density of the specimens, this is because of the calcined clay acts as a filler in the voids of the compacted soil, whereas optimum moisture content of untreated soil was found to be more because of the high compressible characteristics in its nature.

The effect of the freeze–thaw cycles on the stress–strain behavior

To study, the influence of the freezing and thawing cycle on the mechanical properties of expansive soils, unconfined compression test was performed on the untreated and treated expansive soilsamplesfor1 to 15 F–T cycle. The optimum percentage of the treated calcined clay as 8% is fixed from the test results of the unconfined compression test conducted on the series of sample prepared for the different percentage of admixture at varying curing period. The typical stress–strain characteristics curve for the untreated and 8% CC treated soil is shown in Fig. 2. The stress–strain characteristics of the untreated soil under 0, 1, 5, 10 and 15th freeze and thaw cycle is shown in Fig. 3. From this figure, it is observed that the pattern is similar to the strain softening nature [18, 61]. This pattern represents the reduction in the strain and stress value for the increment of the number of the freeze and thaw cycles with respect to the 0th cycle. It shows that the strength and stiffness of the soil got affected due to the alternate change in the temperature. The stress and strain behaviour of the 8% CC treated soil are shown in the Fig. 4 shows the increase in the strength and stiffness with reference to the untreated soil. The stress–strain behavior of calcined clay treated expansive soils tends to exhibit strain-hardening [2, 10, 12, 62]. Also it is observed that the stress strain pattern changes is more ductile in the earlier days of

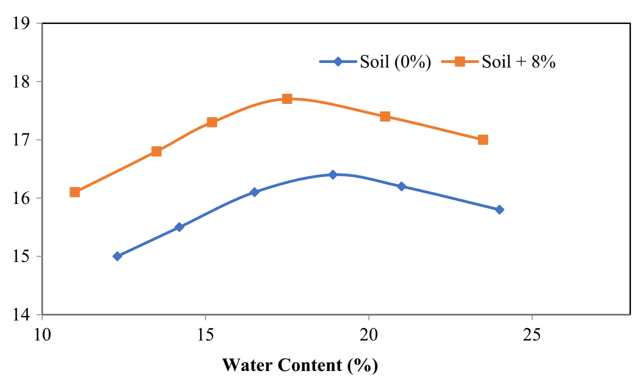

Fig. 1 Compaction characteristics of reference soil and soil treated with 8% calcined clay

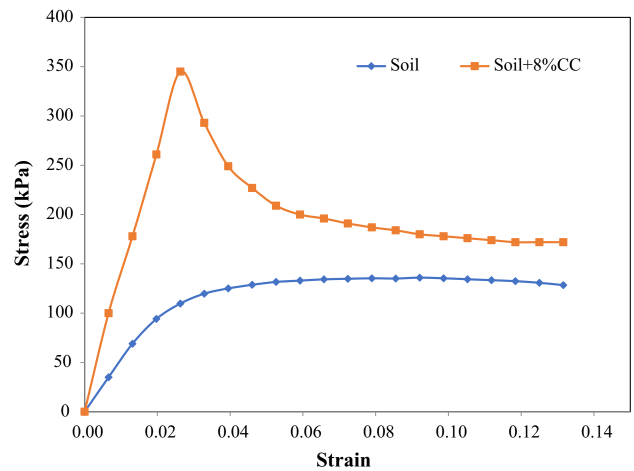

Fig. 2 Stress strain characteristics of untreated and 8% calcined clay treated soil under 28 days curing period

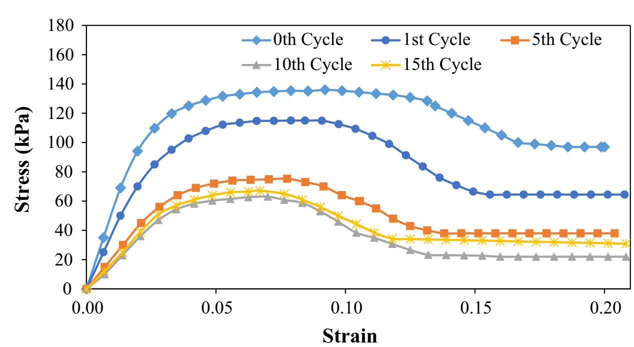

Fig. 3 Stress strain characteristics of untreated soil at 0, 1, 5, 10 and 15 freeze and thaw cycles

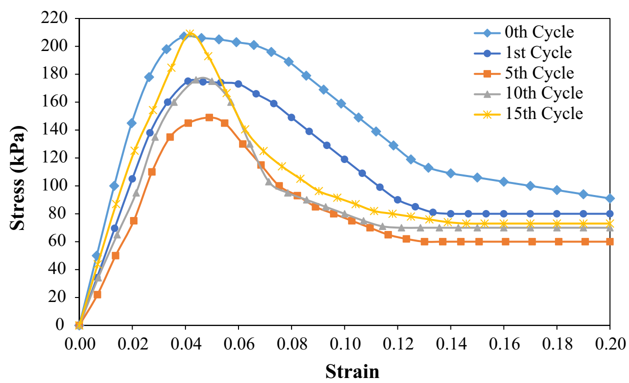

Fig. 4 Stress strain characteristics of 8% calcined clay treated soil at 0, 1, 5, 10 and 15 freeze and thaw cycles

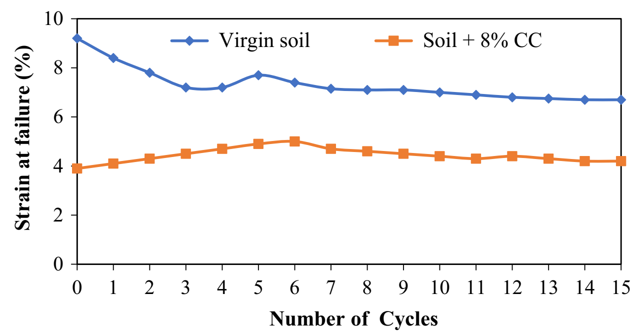

Fig. 6 Strain at failure of reference and 8% calcined clay treated soil under different freeze and thaw cycles

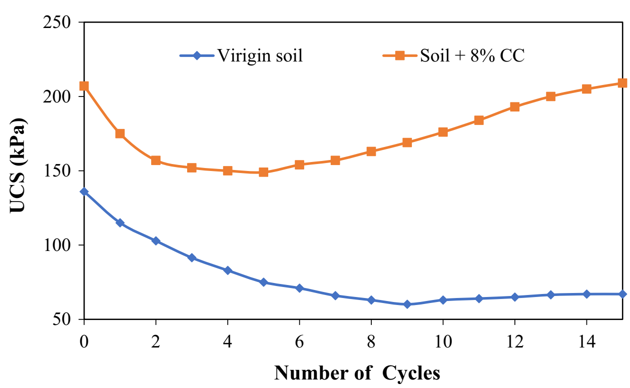

Fig. 5 Unconfined compressive strength of reference and 8% calcined clay treated soil under different freeze and thaw cycles

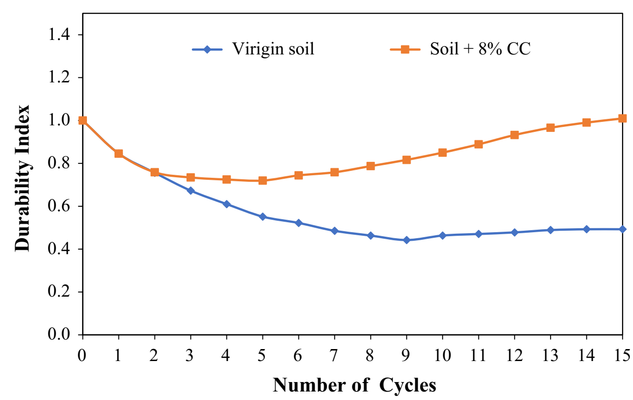

Fig. 7 Durability index of the natural and 8% calcined clay treated soil

the freeze and thaw cycles changes its behavior slightly with increase in the number of cycles and after 10th cycle start to acts as brittle due to the effect of calcined clay in the treated soil absorbs the hydroxyl components and stabilizing the rearrangement of particles. It leads to the increase in the strength and improve the hydro mechanical properties of the soil.

The Effect of the freeze–thaw cycle on the unconfined compression strength and the strain at the failure of the untreated and treated soil are shown in Fig. 5 and 6. The result shows that the influence of calcined clay plays a major role on the strength and stiffness of the soil. During the freezing process, due to the generation of ice lenses, the soil particles get separated and there will be a disrupting interlocking of soil grains and this may affect the mechanical behavior of the expansive soil [14, 63–65]. While comparing the UCS value of natural and treated soil, the natural soil starts to loosening its strength with increase in the number of Freeze and thaw cycle and reaches the threshold value after large number of cycles. In case of 8% CC treated soil, Starts to loses its strength at the initial stage of F–T cycle upto the 5th cycle and thereafter it get stabilize and improve the hydro- thermo mechanical properties mainly due to the admixture acts as a binder by absorbing the moisture and gain its strength during the Freeze and thaw cycles. It also justifies from the durability index of the untreated and 8% CC treated soil shows in the Fig. 7. Durability index is the parameter to identify the durability nature of the material. It is defined as the unconfined compressive strength of the soil at corresponding number of cycles with reference to the original initial strength. From the results, it was observed that the durability index of the untreated soil decreases with respect to the number of F–T cycle whereas for the 8% CC treated soil slowly decreases at the beginning and starts to increase from 5th cycle of (F–T) process. It increases the durability nature of the treated soil compared to that of the natural soil because of the effect of the pore water pressure is reduced due to the admixture acts as a filler and binder [66, 67].

Conclusion

In this study, the influence of the calcined clay on the thermo mechanical and durability properties of the expansive soil was concluded by the Light compaction and freeze and thaw test on the natural and treated soil shows the following.

1. The compaction characteristics show the increase in the percentage of the admixture increases the maximum dry density and reduces the optimum moisture content of the soil.
2. The optimum percentage of calcined clay was obtained as 8% using the Unconfined compression test based on the strength characteristics of treated soil is 2.5 times more with respect to the natural expansive soil for the 28 days of curing period.
3. The stress–strain characteristics pattern changes from ductile to brittle under increase in the F–T cycle and also exhibits more strength and stiffness compared to the natural soil. Moreover, minimal change in the stress–strain behaviors was found after 5 freeze–thaw cycles, indicating that the mechanical properties of the treated expansive soil remain stable when the number of freeze–thaw cycles exceeds a threshold value.
4. Unconfined compressive strength decreases around 50% from its strength of 136 kPa at 15th cycle. However the soil treated with 8% calcined clay, the strength slowly decreases at the beginning and reaches 149 kPa at 5th cycle and starts to increase and reaches the Strength value of 204 kPa at 15th cycle.
5. Strain at failure shows drastic reduction in the strain value for the expansive soil whereas for 8% CC treated soil it increases initially and decreases gradually after the 5th cycle upto 15th cycle.
6. Hence calcined clay was the suitable material effectively on the expansive soil as a natural admixture which is highly reactive cementitious material which can cost effective and ecofriendly.
7. Furthermore the study can be carried out to know the influence of climatic change on treated and untreated soil with minor variation of temperature.

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Declarations

Conflict of interest There are no conflicts of interest declared by the authors.

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