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Study of Compressibility and Hydraulic Conductivity Characteristics of A Chemically Treated Expansive Clay

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Abstract: The paper presents a progression of research facility tests and assesses the impact of lime and fly ash on the compressibility and water powered attributes of a broad soil in Bhubaneswar. The tests were performed at various rates of lime (0–7%) and fly ash (15 and 25%) by dry load of soil, and extra tests were additionally performed on soils treated with 15% fly ash in addition to 3% lime. Recently distributed examination uncovers that couple of information are accessible concerning the com-pressibility and water powered conductivity of lime-treated soils. The consequences of this review demonstrate an increment in the upward viable yield pressure (obvious preconsolidation pressure) and a decline in the compressibility attributes of the treated soils. In addition, in contrast to a portion of the discoveries in the writing, higher pressure driven conductivity esteems were acquired with time. This finding has been validated by the diminished cation trade limit (CEC) values, which demonstrate that the pozzolanic response makes the dirts become more granular in nature, bringing about higher pressure driven conductivity.

Key words: cementation, compressibility, fly ash, hydraulic conductivity, lime.

Introduction

Excessive heave, settlement, low shear strength, and internal erosion of some soils cause damage to many civil engineering structures such as spread footings founded on expansive soils; roads, highways, and airport runways constructed on expansive subgrade; and earth dams constructed with dispersive soils. Expansive soils are usually found in abundance in semiarid regions of tropical and temperate climate zones, where annual evapotranspiration exceeds precipitation (Abduljauwad 1993). Swelling of expansive soils causes more damage to structures, particularly light buildings and pavements, than any other natural hazards, including earthquakes and floods (Jones and Holtz 1973).

In practice, lime has been used as an effective additive to improve the soil engineering properties and prevent damage to structures. Lime treatment in cohesive soils generally reduces swelling and improves soil plasticity, workability, and bearing capacity (El-Rawi and Awad 1981; Locat et al. 1990; Tuncer and Basma 1991; Abduljauwad 1993; Narasimha and Rajasekaran 1996). Lime stabilization has been successfully used in various projects such as erosion control (Machan et al. 1977), dam construction (Perry 1977), lime column foundations (Broms and Boman 1979*a*), and road foundation treatment (National Lime Association 1982). The dredging of ports and harbours often involves fine-grained contaminated sediments which cannot be disposed of in free water. With a growing concern for the environment, lime stabilization has also become of great interest in the fixation of toxic metals in these sediments (Khorasani et al. 1988; Locat et al. 1996).

The island of Cyprus is located in the eastern Mediterranean Sea and has semiarid climate which has produced calcareous expansive soils in some areas. In Degirmenlik village located in the northern part of Cyprus, serious cracks have been observed in many buildings and pavements. In particular, light structures have been badly cracked. This problem has necessitated an investigation of soil stabilization prior to construction. To understand the effect of lime on the physical and mechanical properties of clayey soils, the chemical reactions of soil–lime must be examined.

The improvements in the engineering properties of soils as lime is added can be explained by two basic reactions: short-term reaction, consisting of cation exchange and flocculation, and long-term reaction, involving pozzolanic activity. The first reaction is colloidal and occurs almost immediately after lime is added and tends to modify the soil without producing new secondary minerals (Marks and Haliburton 1972). The pozzolanic reaction is time and temperature dependent; during this process, the high pH in soils causes silica and alumina to be dissolved out of the structure of the clay minerals and combine with calcium to produce the new cementitious compounds, calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH), which are responsible for the long-term strength increase in soils.

Previous findings

In previously published studies, most researchers (Nagaraj 1964; Tuncer and Basma 1991; Nicholson et al. 1994) have concentrated on the effect of lime on the strength and swelling of expansive clays, with little attention given to the compressibility problems in such soils. Few data are available concerning the compressibility and hydraulic conductivity of lime-treated soils. Fossberg (1965) reported that the treated clay behaved like a preconsolidated material because of cementation of particles. Basma and Tuncer (1991) noted an increase in the immediate settlement and a decrease in the primary consolidation with an increase in percent lime and curing time. The findings of hydraulic conductivity studies of lime-treated soils are widely varied and require further investigation. Ghazali et al. (1991) suggested a reduction in the hydraulic conductivity of a chemically treated kaolin clay due to the decreased rate of consolidation. Terashi et al. (1980) and Locat et al. (1996) also recorded a reduction in the hydraulic conductivity of treated soils, whereas Townsend and Kylm (1966), Broms and Boman (1979*b*), and Brandl (1981) concluded that hydraulic conductivity of soils should increase with lime treatment.

This study presents the compressibility and hydraulic characteristics of Degirmenlik soil treated with lime and fly ash. The effectiveness of lime and fly ash in reducing the plasticity and swell potential of this expansive soil and the possibility of these admixtures improving the compressibility and hydraulic characteristics of Degirmenlik soil were investigated. Furthermore, cation exchange capacity (CEC) values of the treated soils were used to substantiate the qualitative changes occurring in the soil fabric.

Materials used

Degirmenlik soil

The site selected for the investigation was based on the reported structural damage in the area due to expansive soils, which are marine clays of Degirmenlik flysch. The flysch is

Table 1. Physical, chemical, and mineralogical properties of Degirmenlik soil.

Property	Test value
Calcite content (%)	23.0
Quartz content (%)	20.0
Chlorite content (%)	5.0
Illite content (%)	3.0
Plagioclase content (%)	4.0
Dolomite content (%)	7.0
Kaolinite content (%)	21.0
Smectite content (%)	17.0
Liquid limit (%)	68.0
Plastic limit (%)	22.0
Plasticity index (%)	46.0
Clay (< 2 μm) fraction (%)	33.0
Activity	1.38
Swell potential (%)	19.6
CEC (mequiv./100 g)	18.8
Soluble sulfate content, SO_4^{2-} (ppm)	120.0

a Middle Miocene formation which crops out over an area of 1600 km^2 in the north of the island, extending from east to west. The main faces of this Middle Miocene formation consist of turbidites, arenites, lutites, calcilutites, and conglomerates (Dreghorn 1978). The soil deposits derived from this formation give a blue-grey colour in fresh exposures and on hydration produce a khaki colour. Physical, chemical, and mineralogical properties of the soil are shown in Table 1.

Lime and Soma fly ash

In this study, naturally available commercial high-calcium hydrated lime ($Ca(OH)_2$) and Soma fly ash produced in the Manisa power station in Turkey were used as the chemical additives. The fly ash has a fineness of 3818 cm^2/g, and 18% of the ash was coarser than the number 325 sieve. The class C Soma fly ash has a high percentage of lime (16%) which provides an inexpensive source of high-quality soil-stabilizing agent.

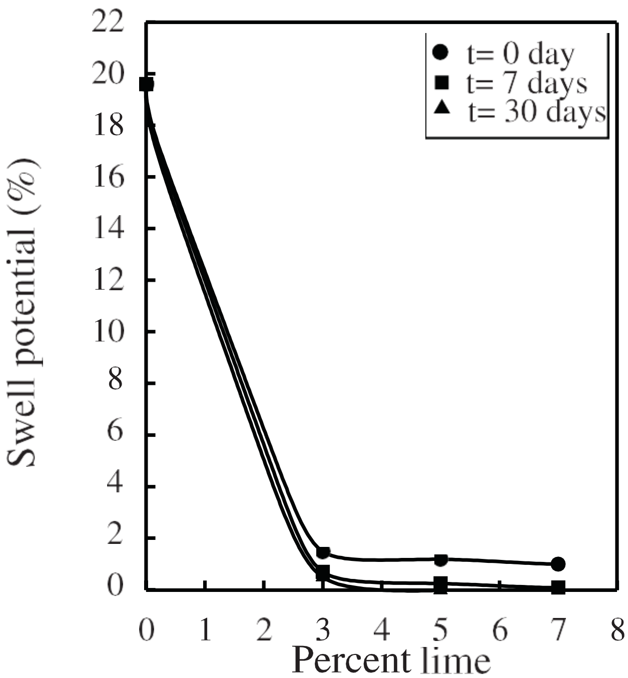
Mixture and specimen preparation

Mixing

An experimental program was performed on Degirmenlik soil specimens collected from a depth of 1.5 m below the ground surface. The soil specimens were stabilized by adding varying percentages of lime or fly ash. Hydrated lime contents of 3, 5, and 7% by dry weight of soil and fly ash contents of 15 and 25% were employed. Further tests were also performed with a mixture of 15% fly ash and 3% lime. In selecting the levels of treatment, previous studies on similar soils were taken into account (Basma and Tuncer 1991; Nicholson et al. 1994). In this study, the tests were performed on specimens which were mixed and stored as follows.

The soil, oven-dried for 4 days at 50°C, was mixed with a calculated amount of stabilizer and then water was added. The soil–stabilizer–water was thoroughly mixed for 5 min using a mechanical mixer at 140 rpm. After mixing, the specimens were tightly encased in a plastic bag and stored in a humidity- and temperature-controlled room for 24 h, after

Fig. 1. Variation of swell potential with percent lime and curing time (*t*).



which they were subjected to compaction in a standard Proctor mould using standard Proctor compaction effort at standard optimum water content. The compacted specimens were then subjected to various tests at different curing periods (0, 7, 30, and 100 days).

Specimen preparation

The swell, compressibility, and hydraulic conductivity tests were performed on specimens extruded from a soil compacted in a standard Proctor mould as described in the previous section. The prepared specimens were sealed in waxed paper and then dipped in hot paraffin to provide an airtight seal and allowed to cure at 22°C and 70% relative humidity for 7, 30, and 100 days. In the tests, cylinders 20 mm high and 76 mm diameter were used. After moulding and curing, natural and treated specimens were placed in a standard oedometer device with a seating pressure of 6.9 kPa. The samples were then submerged in water and allowed to expand until equilibrium was reached, after which a one-dimensional consolidation test with the load increment ratio equal to unity was conducted on the specimens. The hydraulic conductivity of the natural and treated specimens was also determined from the one-dimensional consolidation test. This type of testing has been adopted by many investigators (Mesri and Olson 1971; Narasimha and Mathew 1995).

Discussion

Effect of lime and fly ash on swell potential

The effect of lime and fly ash on the swell potential of the natural and treated soils is shown in Figs. 1 and 2, which indicate that lime and fly ash are effective in reducing the swell potential of the treated soils. A decrease in the swell potential values was obtained with an increase in the per-

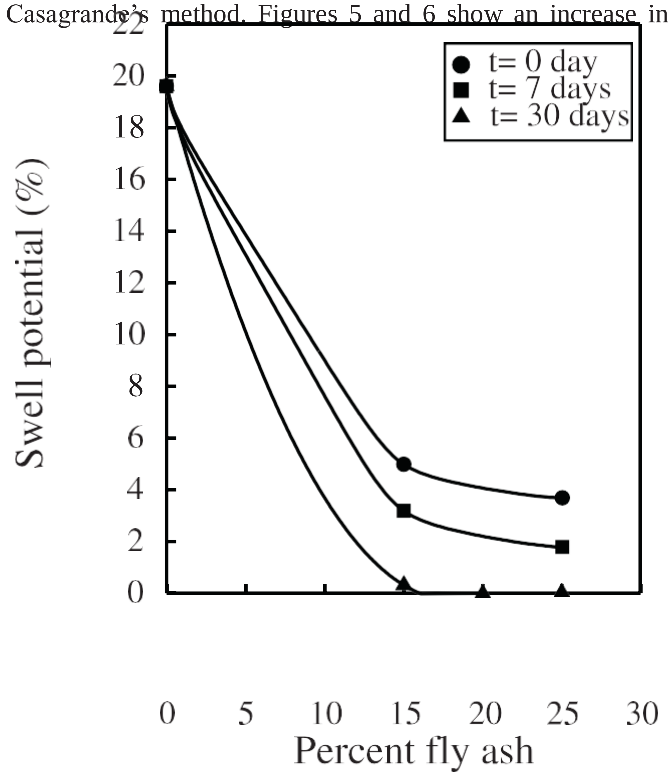


Fig. 2. Variation of swell potential with percent fly ash and curing time.

centage of lime and fly ash. The specimen treated with 15% fly ash plus 3% lime gives a swell potential of 0.9%; with curing times of 7 and 30 days, this value of swell drops to zero.

Vertical effective yield stress (apparent preconsolidation pressure) and compressibility characteristics

A review of the present state of the art of lime and fly ash stabilization reveals that little work has been done on the compressibility and hydraulic conductivity of stabilized clay soil mixes. This study investigates the effect of lime and fly ash on the compressibility characteristics and hydraulic conductivity of Degirmenlik soil. Figures 3 and 4 give the void ratio versus logarithmic pressure diagram obtained from the one-dimensional consolidation test at zero curing time.

The results indicate that lime and fly ash treatments decrease the compressibility characteristics of the treated soils. A reduction in the slope of the virgin curve was obtained at all treatment levels. Due to cation exchange reaction, an increase in the flocculation and aggregation causes a chemically induced preconsolidation effect which increases the vertical effective yield stress and reduces the compressibility characteristics.

The calcium ion is accepted to be a flocculating agent in soils (Tuncer et al. 1989). Since some cation exchange occurs on addition of additives, this causes the replacement of the exchangeable sodium, magnesium, or other cations previously held by the soil clay by calcium cations (Abduljauwad 1993). This is believed to produce a soil with a more flocculated fabric and result in a reduction in the compressibility characteristics. The effects of lime and fly ash on the vertical effective yield stress at zero curing time are given in Figs. 5 and 6. The vertical effective yield stress of the natural and treated soils was determined by

Casagrande's method. Figures 5 and 6 show an increase in

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Fig. 3. Void ratio – pressure curves for natural soil and soil treated with lime – fly ash.

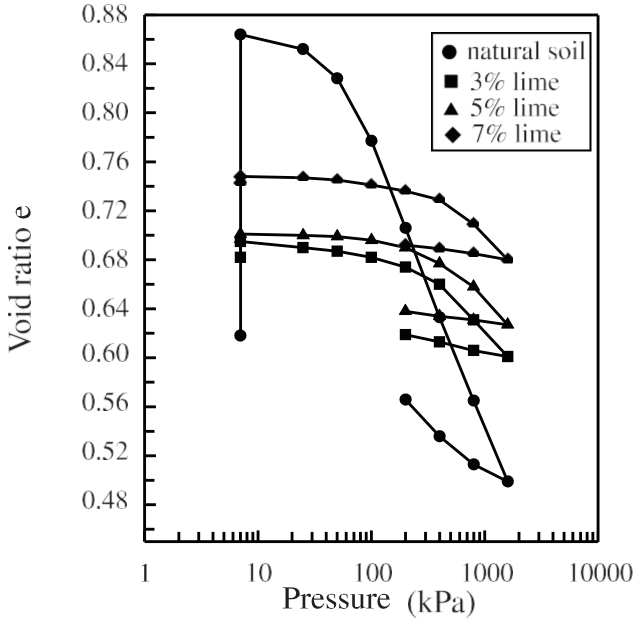
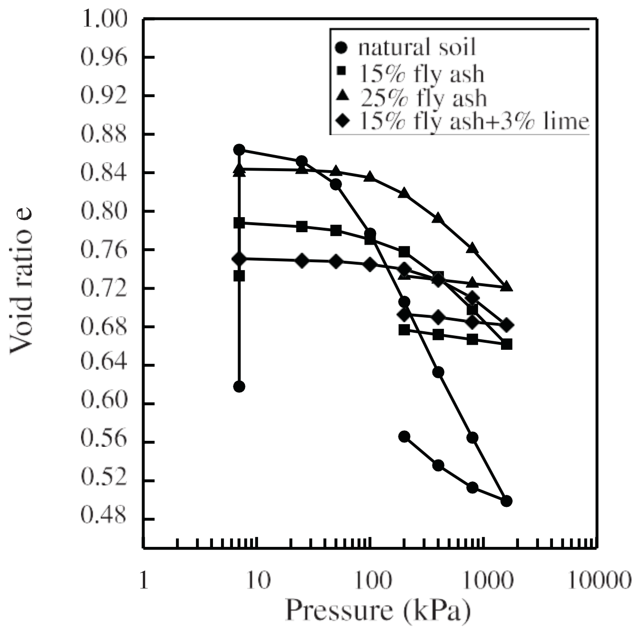


Fig. 4. Void ratio – pressure curves for natural soil and soil treated with fly ash and lime – fly ash.



the vertical effective yield stress with an increase in the percent lime and fly ash.

In Figs. 7 and 8 the compression and rebound indices (C_c and C_r) obtained from the one-dimensional consolidation test data are plotted against percent lime and fly ash, respectively. The figures show a dramatic decrease in C_c and C_r with an increase in the percent lime and fly ash. This indicates the increased tendency of soils treated with lime and fly ash to resist compression and expansion. The highest reduction in C_c and C_r values is obtained for the soil treated with 3% lime plus 15% fly ash.

Fig. 5. The increase in the vertical effective yield stress with an increase in percent lime.

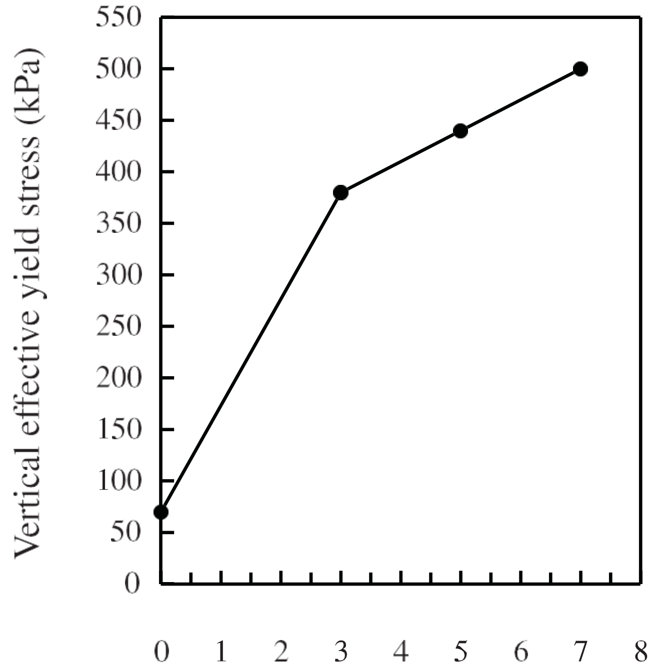
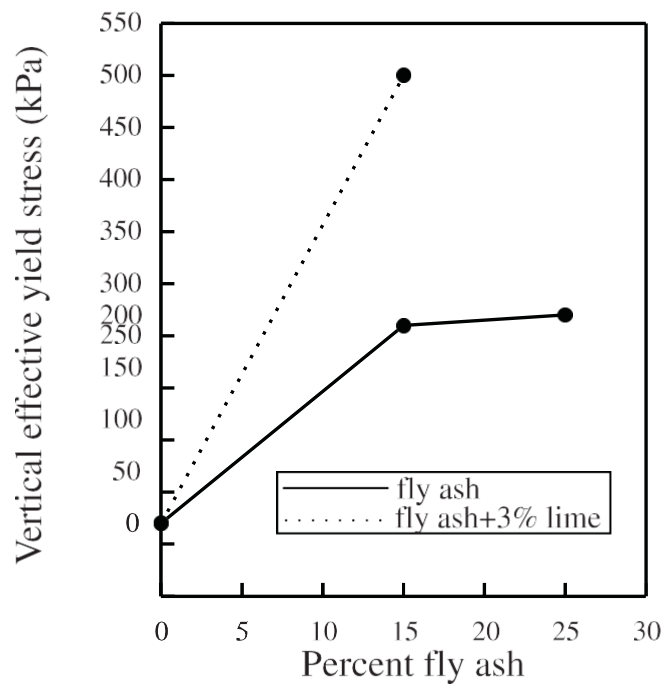


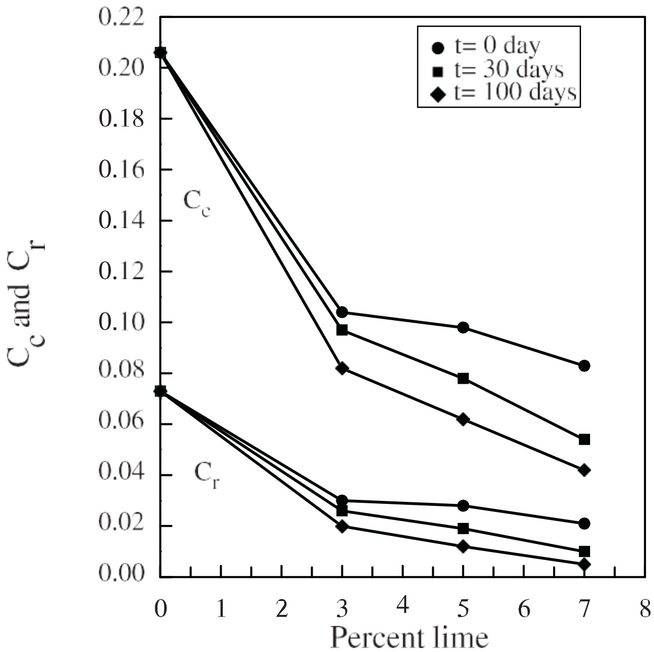
Fig. 6. The increase in the vertical effective yield stress with an increase in percent fly ash and lime – fly ash.



Flocculation and aggregation of soils treated with lime and fly ash cause a decrease in plasticity and an increase in the vertical effective yield stress. The correlation between the plasticity index values and the vertical effective yield stress is given in Fig. 9, which shows the increase in vertical effective yield stress with a decrease in the plasticity index.

The reduction in the compressibility characteristics is explained by the aggregation formations of soils treated with

Fig. 7. Effect of lime and curing time on the compression and rebound indices C_c and C_r .



lime and fly ash which result in stronger lime particle aggregates and give higher resistance to compression. The formation of these lime particle aggregates produces a soil with a more open fabric and suggests an increase in hydraulic conductivity.

Hydraulic conductivity

To assess the hypothesis that the addition of lime or fly ash increases the hydraulic conductivity of the soil, the hydraulic conductivity of the natural and treated soils obtained from the standard one-dimensional consolidation test was considered. A pressure level of 800 kPa at large strains was chosen to indicate the increase in hydraulic conductivity, and the following expression was used in the calculations:

[1] $$k = \frac{a_v c_v \gamma_w}{1 + e}$$

where k is the hydraulic conductivity, c_v is the coefficient of consolidation, a_v is the coefficient of compressibility, γ_w is the unit weight of water, and e is the void ratio. The results are plotted in Figs. 10 and 11, which show an increase in hydraulic conductivity with an increase in the percent lime, fly ash, and lime – fly ash added to the soils and with an increase in curing time.

The increase in hydraulic conductivity with an increase in curing time is explained by the development of the cementitious matrix due to pozzolanic reaction. The formation of stronger lime particle aggregates results in the soil becoming more granular in nature and results in higher resistance to compression at similar stress levels. This produces a soil with a more open fabric and results in an increase in hydraulic conductivity.

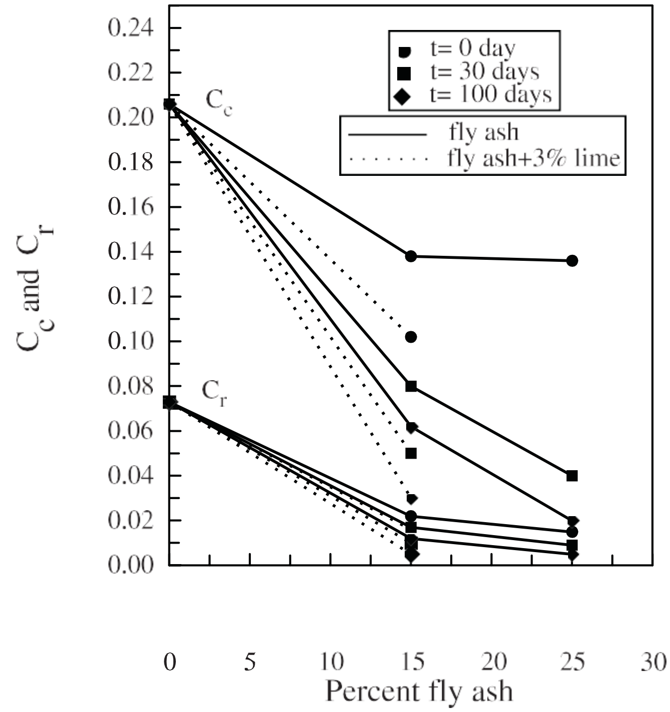


Fig. 8. Effect of fly ash, lime – fly ash, and curing time on the compression and rebound indices C_c and C_r .

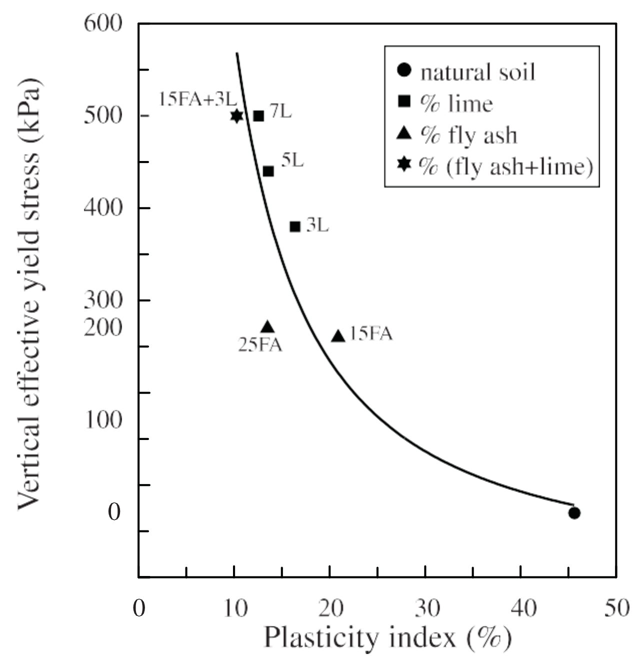


Fig. 9. Variation of the vertical effective yield stress of soils treated with lime, fly ash, and lime – fly ash with the change in plasticity index values.

Reduced CEC values substantiating the increase in hydraulic conductivity

In soil improvement studies, CEC values have been used to a limited extent to explain the stabilized soil behavior. However, in this study CEC values have been used to explain the increase in hydraulic conductivity of the treated soils with an increase in curing time. CEC values of soils treated with lime and fly ash measured after 100 days of

Fig. 10. Variation of hydraulic conductivity with percent lime and curing time for pressure p = 800 kPa.

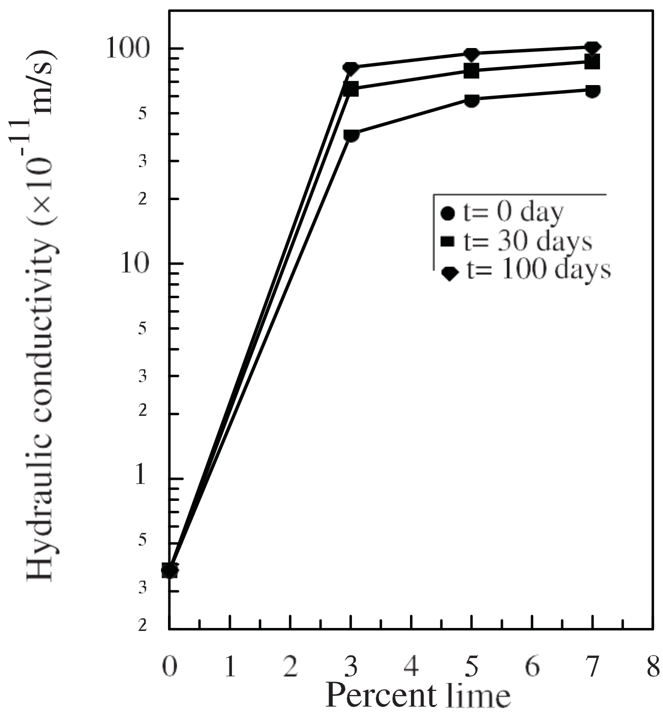
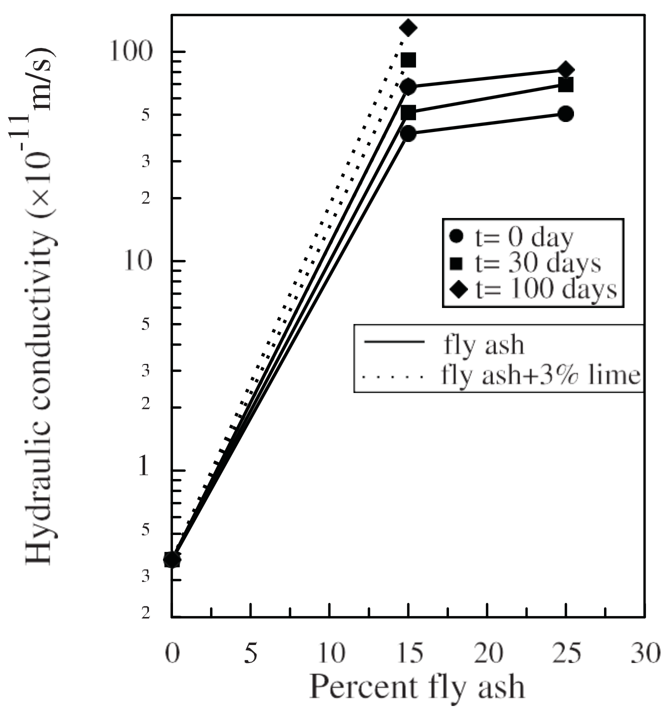


Fig. 11. Variation of hydraulic conductivity with percent fly ash, lime – fly ash, and curing time for pressure p = 800 kPa.



curing are given in Figs. 12 and 13, respectively. CEC is the quantity of exchangable cations required to balance the charge deficiency on the surface of the clay particles (Mitchell 1993). Clays with larger specific surface area usually have a higher CEC, higher surface activity, and consequently higher water absorption potential. Figures 12 and 13 show

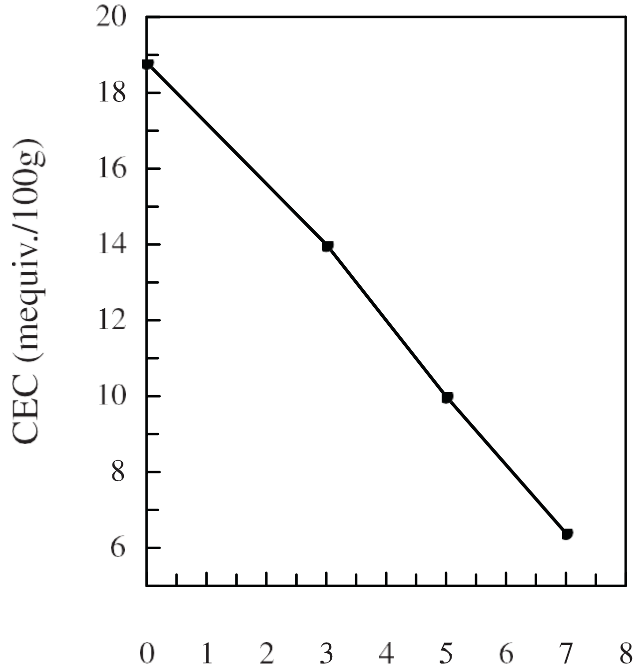


Fig. 12. Variation of cation exchange capacity (CEC) values of soils treated with lime.

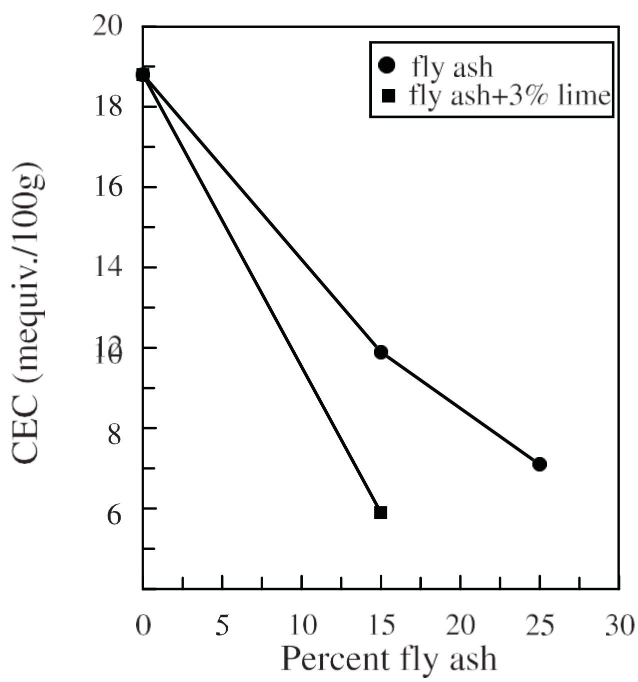


Fig. 13. Variation of cation exchange capacity values of soils treated with fly ash and lime – fly ash.

the decrease in CEC values of the soils treated with lime, fly ash, and lime – fly ash. The reduction in CEC values indicates a change in the crystal structure of the treated soil, which then is no longer representative of the untreated soil. The decrease in CEC values in Figs. 12 and 13 supports the idea that new mineral phases are formed and produce a soil with coarser particles, resulting in an increase in hydraulic conductivity.

Conclusions

This study demonstrates the influence of lime and fly ash on the swelling, compressibility, and hydraulic characteristics of Degirmenlik soil. The main conclusions from this work are as follows:

(1) Lime and fly ash treatments are very effective in reducing the swell potential of the treated soils. With an increase in percent lime or fly ash, a reduction in the swell potential of the treated soils was obtained. The addition of additives results in an increase in the vertical effective yield stress and a decrease in the compressibility characteristics of the treated soils. The stronger lime particle aggregates formed due to pozzolanic reaction give higher resistance to compression and produce a soil with a more open fabric, resulting in an increase in hydraulic conductivity.

(2) The reduced CEC values of the treated soils measured after a curing period of 100 days support the idea that new mineral phases are formed and produce a soil with a more granular nature, resulting in an increase in hydraulic conductivity.

(3) The use of fly ash with a small percentage of lime produces even more dramatic results: the addition of 3% lime plus 15% fly ash resulted in the highest vertical effective yield stress, the lowest slope of the virgin curve, the greatest reduction in C_c, and the highest hydraulic conductivity values.

The study has shown that treatment of soils using lime or fly ash can be used effectively in the stabilization of problematic soils. More importantly, it offers an interesting potential for making use of an industrial waste.

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