# Amelioration of Expansive Clay Slopes Using Calcium Chloride

V. Ramana Murty[1] and P. Hari Krishna[2]

**Abstract:** Lime continues to be one of the most popular chemical admixtures used to modify expansive clays despite the associated mixing and pulverization problems. In the present investigation, the efficacy of $CaCl_2$ in place of conventionally used lime is studied by conducting laboratory and field tests. These investigations were carried out on the slopes of a trapezoidal trench made in expansive clay bed. Heave measurements were taken on the lime and $CaCl_2$ treated slopes and also on untreated slopes for four consecutive cycles of wetting and drying. The field cyclic seasonal movements and the subsequent laboratory tests on undisturbed and disturbed soil samples revealed that the $CaCl_2$ could be a promising chemical modifier instead of conventionally used lime, not only due to its multifold influence on heave control, plasticity reduction, and swell properties but also its easy application in the form of solution without any need for pulverization and mixing. Though an apparent reduction in unconfined compressive strength of treated samples is observed, the drained triaxial tests on treated and untreated samples revealed that there is an increase in the angle of internal friction of treated samples.

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## Introduction

Expansive soils threaten the stability of most of the lightly loaded civil engineering structures like single storeyed dwellings, pavements, canal linings, and pipe lines due to their peculiar volumetric changes resulting from intrinsic and extrinsic influences (Wooltorton 1936; Holtz and Gibbs 1956; Holtz and Bara 1965; Katti 1979; Snethen 1979; Chen 1988; Erol and Ergun 1994; Subba Rao 1999; Petry and Little 2002) upon moisture fluctuations. Global efforts have been mooted to devise remedial techniques either to counter the volumetric changes or accommodate the movements (Zeitlen 1969; Williams and Donaldson 1980; Chen 1988; Phanikumar et al. 1994; Ramana Murty 2001). When slopes are made in expansive soils for the purposes like running a canal or an embankment, the slopes are highly prone to damage due to large lateral swell pressure coupled with reduced shear strength upon increased void ratio due to volumetric changes. Among the several remedial techniques put forth to combat these damages, chemical alteration is considered to be a more fitting method to counter the volume change, which itself is a physicochemical phenomenon in expansive clays. Chemical alteration is aimed at changing the chemical environment around the clay particles upon which the behavior of clay depends to a great extent (McDowell 1959; Katti et al. 1966; Uppal and Chadda 1969; Snethen et al. 1979; Ramana Sastry et al. 1986; Petry and Armstrong 1989). For this purpose, lime has been widely used all over the world despite the associated mixing and pulverization problems (Holtz 1969; Snethen 1979; O' Neill and Poormoayed 1980; Chen 1988; Boominathan and Raju 1996). Even when lime is applied through boreholes, most of the lime settles at the bottom of boreholes due to its limited solubility in water (about 1.25 g/L of water at 21°C). As lime is sparingly soluble in water, the availability of calcium ions for extensive cation exchange reactions is also meager. It is reported that the lateral diffusion of lime by lime slurry pressure injection away from boreholes is hardly 38–50 mm in 1 to 4 years unless extensive fissures and crack system is present in the ground (Davidson et al. 1965; Wright 1973; Thompson and Robnett 1976; Snethen 1979; Chen 1988; Bhattacharya and Bhattacharya 1989).

In view of the above drawbacks of lime modification, researchers have been simultaneously investigating the feasibility of using strong electrolytes in place of conventionally used lime (Katti et al. 1966; Ho 1968; Desai and Oza 1977; Frydman et al. 1977; Yousry and Mowafy 1985; Rao and Subba Rao 1994; Chandra Sekhar et al. 2001). It is felt that the strong electrolytes due to their ready dissolvability could supply adequate cations for exchange reactions (Katti et al. 1966; Desai and Oza 1977; Hausmann 1990). Further, it is opined that the reasons why $CaCl_2$ is not widely used are not clear, though it can make calcium charged supernatant more easily than lime (Slate and Johnson 1958; Ho 1968; Mitchell and Raad 1973; Petry and Armstrong 1989). Further, the application of $CaCl_2$ to the ground is easy as it can be applied in the form of $CaCl_2$ solution, either by ponding or through boreholes preferably in summer when the ground is subjected to extensive desiccation cracking, without any need for mixing and pulverization. It is also reported that the $CaCl_2$ works not only by cation exchange but also by intercalation whereby $CaCl_2$ as a whole can enter into the intermiscellar spaces of clay minerals which constitute about 90% of the total surface area, thus bringing about significant modification of clay behavior (Van Olphen 1965; Desai and Oza 1977; Jamil and Niranjan 1977; Tan

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1982; Yousry and Mowafy 1985; Mitchell 1993). Further, it is realized that the modification of slopes by conventional lime treatment involving pulverization, mixing, and compaction processes is a tedious one and hence, instead of adopting such a cumbersome method, in the present investigation, lime slurry and $CaCl_2$ solution are simply applied through boreholes made in the ponding trenches excavated at the top of the slope. The relative diffusion of lime and $CaCl_2$ and their influence on heave of lining panels and the properties of clay are brought out through field and laboratory investigations.

## Materials Used

### *Lime*

Commercial lime locally known as Madras lime was used in this investigation. The lime consists of CaO=75%, MgO=6%, coal dust=17%, and moisture content=2%.

### *Calcium Chloride*

Based on the preliminary investigations carried out in the laboratory, 1% commercial grade $CaCl_2$ solution was found to be optimum in terms of swell control and economics. The chemical composition of commercial grade calcium chloride used is $CaCl_2$ =60%, $MgCl_2$=22%, and $H_2O$=18%.

### *Water*

Potable water from a well was used to make either lime slurry or $CaCl_2$ solution.

## Experimental Study

A trapezoidal trench (bottom width=0.60 m, bottom length =3.0 m, depth=0.75 m, and side slopes=1 1/2:1) was made in the field (Fig. 1) for the purpose of the present investigation. Narrow trenches of 0.30 m width and 0.30 m depth were made along the two long side slopes and one short side slope. Fifty mm diameter boreholes were made in the narrow trenches at 0.50 m c/c up to 1.5 m depth using hand auger to increase the depth of influence and accelerate the process of improvement. About 1.0 m length of the trench was lined with concrete to preserve the slopes for measurement of heave for a relatively longer time period. Polished stone slabs were placed in mortar on all the side slopes including on the lined portion to measure the vertical heave (Fig. 2). The initial reduced levels (RLs) of top of stone slabs were fixed using levelling instrument upto an accuracy of 1 mm.

One long side slope was treated by filling the narrow trench with 1% commercial grade $CaCl_2$ solution and the quantity of solution required for improvement was determined based on the estimated porosity of soil to saturate the portion of slope up to 1 m away from it. Similarly, the opposite long side slope was treated by filling the narrow trench, with 20% lime slurry. 20% lime slurry was used to enable its flow under gravity as against the conventionally recommended 25–30% slurry for lime slurry pressure injection (Snethen 1979). One short slope was prewetted with water by ponding in the trench, which is supplemented by 50 mm diameter boreholes to increase the depth of wetting, and the corresponding opposite slope was left for natural (environmental) wetting. The trench was completely flooded by subsequent monsoon rains.

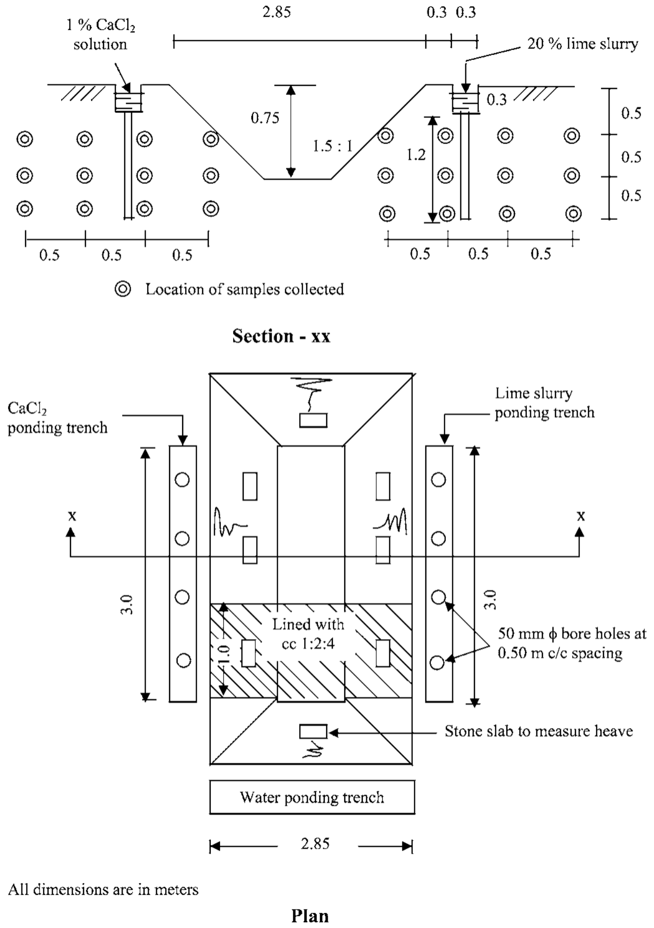



**Fig. 1.** Details of trapezoidal trench made in expansive clay bed

Heave measurements were continued until maximum heave was attained and then both disturbed and undisturbed samples were collected from 0, 0.5, 1.0, and 1.5 m lateral distances at 0.5, 1.0, and 1.5 m depths (Fig. 1) on calcium chloride, lime, and artificially wetted sides to test them for their index, swell, and strength properties. On water saturated side, the samples were

**Fig. 2.** Heave measurements on slopes of trapezoidal trench

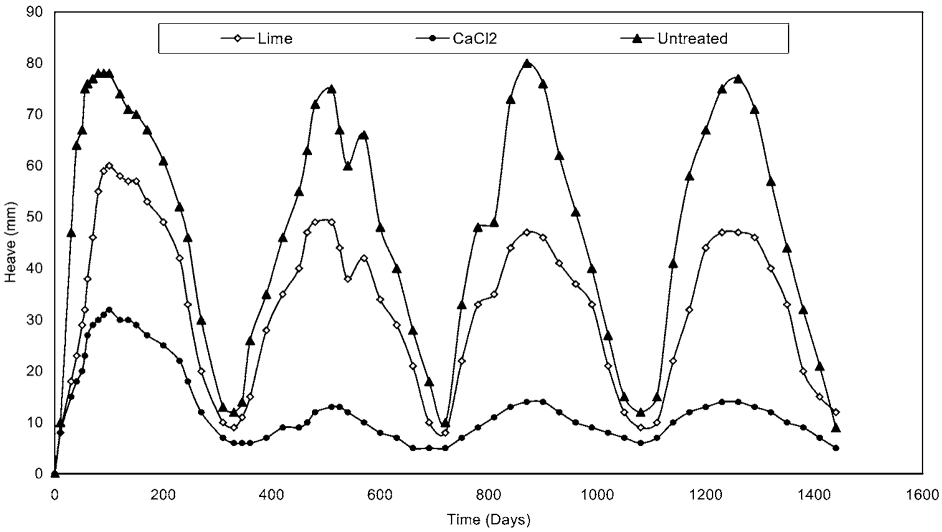



**Fig. 3.** Cyclic seasonal movements of treated and untreated expansive clay slopes

collected from 0.5, 1.0, and 1.5 m depths below ground level at the center of the slope. The soil samples were collected by open pit excavation after two months of application of lime and $CaCl_2$ solutions to the slopes without disturbing the lined portion of the trench for subsequent heave measurements upon cycles of wetting and drying. One shorter side slope is also preserved for long time heave measurements.

## Discussion on Test Results

### *In Situ Heave—Time Plots*

Fig. 3 shows the in situ heave—time plots of lining panels laid on expansive soil slopes treated with $CaCl_2$ and $Ca(OH)_2$, respectively, along with that for untreated slope. It can be observed from this figure that the heave of lining panel laid on the slope improved by $CaCl_2$ solution is about half of that improved by lime slurry. The time required to attain maximum heave is almost the same for both the lime and $CaCl_2$ treatments. Heave measurements were continued for four consecutive cycles of wetting and drying. It can be observed that the heave of lining panel laid on lime treated slope is only marginally controlled in all the seasonal cycles of wetting and drying whereas the movements of lining panel on $CaCl_2$ treated slope are nominal. The substantial heave control on $CaCl_2$ side could be attributed to its promising reactivity with clay by cation exchange and possible intercalation (Desai and Oza 1977; Yousry and Mowafy 1985), whereby the chemical environment around the clay particles changes, which helps to reduce the thickness of double layer. During the subsequent sample collection at different depths and lateral distances, it is observed that the lime slurry has passed only through the desiccation cracks and formed its seams with negligible diffusion into the clay clods, leaving large part of the clay bed unmodified which resulted in uncontrolled heave.

### *Index Properties*

The influence of lime and calcium chloride on index properties of clay is shown in Table 1 and Fig. 4. It can be seen from Fig. 4 that the liquid limit of clay is decreased by 30 to 35% for 1% $CaCl_2$ treatment with insignificant modification for lime treatment beyond 1 m depth. At 0.5 m depth, the liquid limit of clay on lime treated slope is decreased by 22%. From this observation, it is understood that the influence of lime is limited to only shallow depth of about 0.5 m. From Table 1, it can be observed that the variation of plastic limit and shrinkage limit is only marginal after chemical treatment. Further, it can be seen that the clay size fraction is reduced by 7–9% on the $CaCl_2$ treated slope with a very little change on lime treated slope except at 0.5 m depth. The high efficiency of calcium chloride could be attributed to its complete solubility and effective diffusion into the soil compared to sparingly soluble lime. Further, there is substantial replacement of monovalent $Na^+$ ions by divalent $Ca^{++}$ ions by cation exchange on calcium chloride side with little exchange between sodium and calcium on lime treated side as observed from atomic absorption spectroscopy analysis (Table 2).

### *Swell Properties*

The swell potential and swell pressure values of samples were determined by free swell method in oedometers. The influence of lime and calcium chloride on swell properties of soil is shown in Table 3 and Figs. 5 and 6. The swell potential of soil is almost nullified at 0.5 m depth and it is decreased by 80 to 90% at 1.5 m depth (Fig. 5). On lime treated slope, the swell potential is reduced by 49% at 0.5 m depth and 10 to 30% below 1.0 m depth.

Fig. 6 shows the variation of swell pressure with depth at different lateral distances. The swell pressure of clay is decreased by more than 60% at all the lateral distances up to 1.5 m depth in case of calcium chloride treatment, whereas it is only 10–20% for lime treatment below 1 m depth. At 0.5 and 1.0 m lateral distances from the slope, lime treatment reduced the swell pressure by about 40–60% at 0.5 m depth. This also indicates that the lime treatment can be adopted for treating only shallow depths of clay bed of about 0.5 m. The greater influence of calcium chloride over the entire thickness of clay bed compared to lime is due to its complete solubility in water and relatively easy diffusion into the clay bed. The coefficient of permeability is increased by about 600 times with $CaCl_2$ treatment as measured in the laboratory. The $CaCl_2$ treated clay samples and virgin samples collected from

**Table 1.** Relative Influence of Calcium Chloride and Lime on Index Properties of Expansive Soil

| S.No. | Property | Depth below G.L.(m) | Before Treatment | Calcium chloride Treatment | | | | Lime Treatment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.5 m | 0.5 m | 0.5 m | | | 0.5 m | 0.5 m | 0.5 m |
| 1 | Liquid Limit (%) | 0.5 | 66.0 | 44.0 | 43.0 | 45.0 | 48.0 | 53.0 | 43.0 | 53.5 | 54.0 |
| | | 1.0 | 79.0 | 55.0 | 57.0 | 54.0 | 53.0 | 76.0 | 73.5 | 70.0 | 77.5 |
| | | 1.5 | 102.0 | 76.0 | 73.0 | 72.0 | 71.5 | 94.0 | 96.5 | 97.0 | 98.0 |
| 2 | Plastic Limit (%) | 0.5 | 22.5 | 23.5 | 22.7 | 23.0 | 24.4 | 23.5 | 23.5 | 24.0 | 23.0 |
| | | 1.0 | 26.0 | 25.6 | 28.0 | 26.8 | 28.0 | 24.3 | 26.8 | 25.0 | 26.3 |
| | | 1.5 | 27.0 | 28.0 | 26.5 | 29.0 | 28.0 | 27.0 | 27.4 | 27.2 | 27.4 |
| 3 | Shrinkage Limit (%) | 0.5 | 14.5 | 14.3 | 15.0 | 15.2 | 15.7 | 14.6 | 14.3 | 14.8 | 14.7 |
| | | 1.0 | 15.0 | 15.2 | 17.8 | 17.5 | 16.9 | 14.9 | 15.2 | 15.6 | 15.1 |
| | | 1.5 | 15.0 | 16.1 | 17.8 | 17.8 | 17.8 | 15.5 | 16.3 | 15.2 | 16.0 |
| 4 | Clay Size Fraction (%) | 0.5 | 42.0 | 35.0 | 34.0 | 33.0 | 34.0 | 35.0 | 33.5 | 34.0 | 35.0 |
| | | 1.0 | 47.0 | 41.0 | 39.0 | 40.0 | 39.5 | 44.0 | 42.5 | 43.0 | 46.0 |
| | | 1.5 | 53.0 | 47.0 | 44.0 | 44.0 | 46.0 | 51.0 | 50.5 | 51.5 | 52.0 |

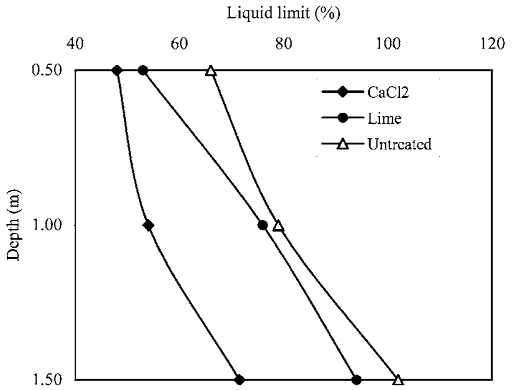



**Fig. 4.** Variation of liquid limit with depth for treated and untreated samples

1.5 m depth have given the average values of coefficient of permeability as $2.18 \times 10^{-6}$ and $3.45 \times 10^{-9}$ cm/s, respectively.

From the above discussion, it is evident that in the presence of extensive cracking of ground, calcium chloride can improve the clay bed by mere ponding or ponding supplemented by boreholes without any need for mixing and pulverization. Further, 1% $CaCl_2$ solution is highly cost effective compared to the generally recommended 25–30% lime slurry for the modification of expansive clay bed.

### *Unconfined Compressive Strength*

The unconfined compressive strength (UCS) of samples collected from lime and $CaCl_2$ treated sides and also from untreated side are presented in Table 4. It can be seen from this table that the UCS values of lime and $CaCl_2$ treated samples are decreased

**Table 2.** Major Exchangeable Cation Contents for Lime and $CaCl_2$ Treated Samples (meq/100 g)

| | Before treatment | | | | After treatment | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | For lime | | | | For calcium chloride | | | |
| | Depth (m) | | | | Depth (m) | | | | Depth (m) | | | |
| Cation | 0 | 0.5 | 1.0 | 1.5 | 0 | 0.5 | 1.0 | 1.5 | 0 | 0.5 | 1.0 | 1.5 |
| Na | 27.33 | 31.52 | 38.26 | 53.82 | 20.13 | 21.30 | 37.00 | 52.48 | 7.01 | 7.04 | 24.65 | 39.70 |
| Ca | 14.18 | 16.06 | 27.60 | 32.19 | 20.35 | 24.56 | 29.92 | 32.64 | 34.98 | 38.15 | 42.10 | 48.38 |
| K | 2.49 | 2.54 | 2.76 | 2.69 | 2.50 | 2.49 | 2.76 | 2.71 | 2.52 | 2.52 | 2.78 | 2.15 |
| Mg | 5.30 | 8.23 | 9.67 | 9.56 | 5.88 | 8.95 | 9.75 | 9.56 | 5.00 | 9.80 | 10.24 | 10.00 |
| Fe | 0.60 | 0.75 | 0.73 | 0.70 | 0.68 | 0.73 | 0.76 | 0.71 | 0.68 | 0.74 | 0.78 | 0.75 |

**Table 3.** Relative Influence of Calcium Chloride and Lime Treatments on Swell Properties of Expansive Soil

| Sample number | Property | Depth (m) | Before treatment | Calcium chloride treatment | | | | Lime treatment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Differential free swell index (%) | 0.5 | 110 | 75 | 60 | 70 | 70 | 81 | 82 | 110 | 113 |
| | | 1.0 | 192 | 72 | 71 | 75 | 58 | 156 | 149 | 181 | 188 |
| | | 1.5 | 130 | 120 | 117 | 125 | 130 | 166 | 193 | 220 | 230 |
| 2 | Swell potential (%) | 0.5 | 21.9 | 0.7 | 0.4 | 0.2 | 0.1 | 11.3 | 4.9 | 14.9 | 13.4 |
| | | 1.0 | 25.8 | 6.3 | 9.7 | 3.2 | 2.8 | 18.6 | 17.3 | 23.8 | 24.9 |
| | | 1.5 | 36.3 | 5.7 | 2.2 | 3.2 | 3.5 | 21.1 | 19.5 | 29.0 | 30.2 |
| 3 | Swell pressure (kPa) | 0.5 | 280 (15.3, 26.72) | 62 (16.4, 21.98) | 40 (16.3, 22.96) | 20 (16.3, 22.82) | 20 (16.2, 23.04) | 227 (15.5, 26.15) | 80 (15.2, 27.22) | 160 (15.4, 26.96) | 260 (15.6, 25.89) |
| | | 1.0 | 380 (16.1, 24.28) | 160 (16.5, 22.95) | 113 (16.4, 23.20) | 144 (16.5, 22.58) | 40 (16.5, 22.52) | 340 (16.4, 23.16) | 320 (16.5, 23.90) | 380 (16.7, 21.78) | 380 (16.6, 21.46) |
| | | 1.5 | 460 (16.9, 21.48) | 140 (16.8, 21.91) | 143 (16.6, 23.08) | 80 (16.8, 23.08) | 85 (16.7, 22.86) | 360 (16.6, 23.82) | 320 (16.5, 24.08) | 420 (16.8, 22.06) | 430 (16.8, 22.61) |

Note: Values in parentheses indicate field dry unit weight ($kN/m^3$) and moisture content (%).

despite the reduction in heave. The reduction in UCS is more on $CaCl_2$ treated side compared to that on the lime side. The reduction in strength with $CaCl_2$ treatment could be attributed to depressed double layer thickness upon increased electrolyte concentration, which in turn reduces the viscous resistance for the same water content under undrained condition. Such a reasoning was also given by Sivapullaiah et al. (1994). The marginal reduction in strength on the lime treated side could be due to a slight decrease in double layer thickness upon meagre clay-lime reactions with limited diffusion and absence of cementation by puzzolanic reactions as it is a long term process under favorable alkaline environment.

In order to clearly understand the influence of chemical additives on shear strength parameters, drained triaxial shear tests were also carried out on treated and untreated samples collected at 0.5 m away from the slope at 1 m depth. The results are presented in Table 5. It can be seen from this table that there is an increase of angle of internal friction by about 4° upon $CaCl_2$ treatment and by 2° in case of lime treatment. The increase in angle of internal friction due to $CaCl_2$ treatment could be attributed to the possible formation of flocculated structure by cation exchange reactions with calcium ions whereby, the soil becomes friable and workable with reduced plasticity. On the other hand, only a marginal modification of soil is observed on the lime treated side in terms of index and engineering properties due to its meager diffusion. However, the strength gain by $CaCl_2$ modification is only nominal as $CaCl_2$ is not a binding material. Previous investigators (Kezdi 1979; Sivapullaiah et al. 1994) also reported similar trends in strength gain with $CaCl_2$ treatment.

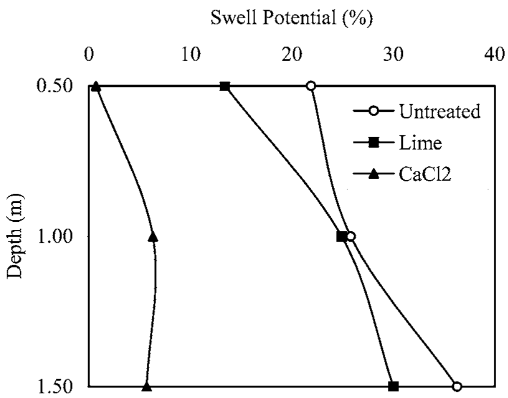



**Fig. 5.** Variation of swell potential with depth for treated and untreated samples

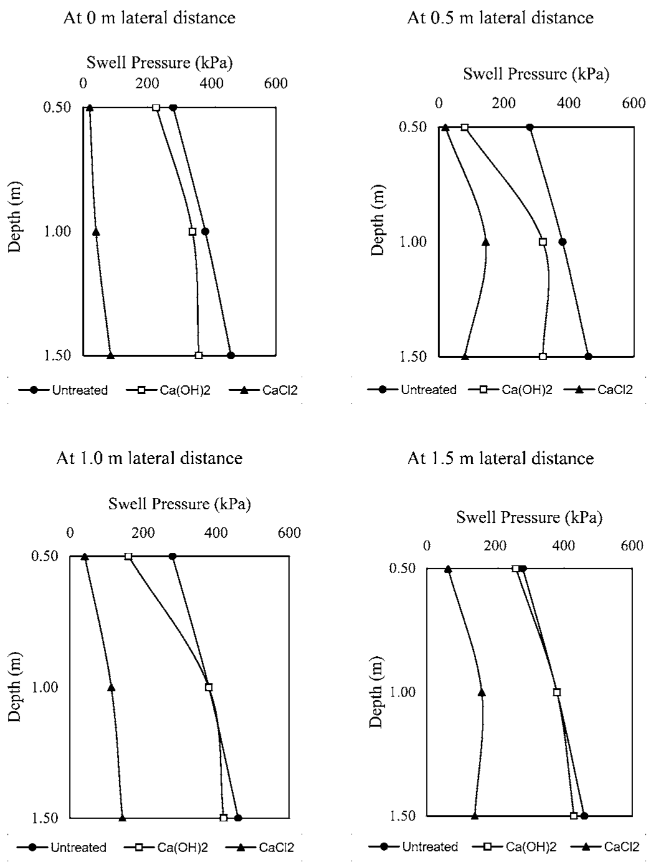
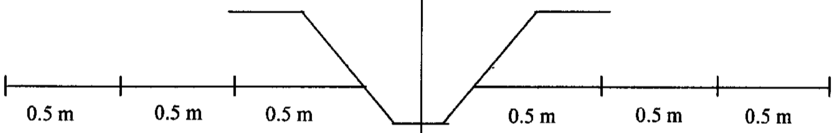



**Fig. 6.** Variation of swell pressure with depth for treated and untreated samples at different lateral distances away from slope

**Table 4.** Unconfined Compressive Strength Values of Treated and Untreated Soil Samples




| Depth below G.L. (m) | Property of soil | Treated with $CaCl_2$ | | | | Treated with lime | | | | Untreated soil |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | Unconfined compressive strength $q_u$ (kPa) | 104 | 110 | 98 | 97 | 99 | 104 | 155 | 106 | 106 |
| 1.0 | | 157 | 161 | 153 | 145 | 280 | 265 | 292 | 304 | 302 |
| 1.5 | | 212 | 196 | 184 | 180 | 321 | 312 | 308 | 316 | 325 |

## Conclusions

The field observations and laboratory findings in the present investigation resulted in the following conclusions:

1. The heave of lining panels is significantly controlled by modifying the expansive clay slope using $CaCl_2$ solution. The lining panels placed on $CaCl_2$ treated slope would be subjected to only nominal movements upon cycles of wetting and drying. The effectiveness of conventionally used lime in controlling heave of lining panels is found to be questionable in view of its limited diffusion into the clay bed;
2. The liquid limit of clay is decreased by 30–35% upon $CaCl_2$ treatment with marginal influence on plastic limit and shrinkage limit values. Although lime modification is expected to increase the plastic limit and shrinkage limit, it has not happened, perhaps due to meager diffusion of lime into the soil;
3. The degree of swelling as reflected from swell potential and differential free swell index is decreased to the extent of 80–90% upon $CaCl_2$ modification due to extensive chemical modification of clay as observed from atomic absorption spectroscopy analysis and only a marginal reduction in swell potential is recorded on lime treated side below 1 m depth. A similar trend is also observed in controlling the swell pressure of clay for lime and $CaCl_2$ treatments; and
4. The $CaCl_2$ treatment caused an apparent reduction in unconfined compressive strength of clay, which could be attributed to truncated double layer thickness due to the changed chemical environment around the clay particles that reduces the viscous resistance for the same water content. However, from drained triaxial testing, it is observed that there is an increase of about 4° in the angle of internal friction of clay for $CaCl_2$ treatment. The reduction in unconfined compressive strength is marginal with lime modification and an increase of 2° in the angle of internal friction is obtained from drained triaxial tests.

**Table 5.** Shear Strength Parameters from Drained Triaxial Testing for $CaCl_2$ and Lime Treated Soil Samples Collected at 1 m Depth and 0.5 m away from Slopes

| Sample number | Description of sample | Effective cohesion $c'$ (kPa) | Effective angle of internal friction $\phi'$ (degrees) |
|---|---|---|---|
| 1 | From untreated slope | 20 | 23 |
| 2 | From $CaCl_2$ treated slope | 22 | 27 |
| 3 | From lime treated slope | 21 | 25 |

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