Stabilisation of expansive clay bed using calcium chloride solution

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Expansive clays experience cyclic volumetric changes upon moisture fluctuation because of their intrinsic mineralogical behaviour. As these volumetric changes threaten the stability of almost all lightly loaded structures, various remedial techniques have been developed to reduce the damage they cause. Among these measures, chemical stabilisation using multivalent cations is aimed at altering the chemical environment around the clay particles upon which the behaviour of clay depends to a great extent. In the present work, an attempt is made to study the efficacy of calcium chloride ($CaCl_2$), a strong electrolyte, on the plasticity and swell characteristics of an expansive clay bed. One per cent $CaCl_2$ solution was applied to the expansive clay bed by ponding and also through boreholes. The relative influences of lime and calcium chloride on the properties of the clay bed are brought out by using data from a previous study of lime piles on an adjacent site. The plasticity index of the clay bed is decreased by 7–15% and 40–60% with lime and calcium chloride treatments respectively. Similarly, the swell pressure of the clay is decreased by 20–25% and 50–65% respectively. From this study, it is revealed that the modification of clay properties with calcium chloride is several times greater than that for the conventionally used lime.

Keywords: calcium chloride; expansive clay bed; heave measurements; lime; swell pressure

Les argiles expansives connaissent des changements volumétriques cycliques lors des fluctuations d'humidité en raison de leur comportement minéralogique intrinsèque. Comme ces changements volumétriques menacent la stabilité de presque toutes les structures légèrement chargées, on a développé diverses techniques visant à réduire les dégâts ainsi causés. Parmi ces mesures il faut citer la stabilisation chimique qui utilise des cations multivalents pour changer l'environnement chimique autour des particules d'argile dont dépend, dans une grande mesure, le comportement de l'argile. Dans ce travail, nous essayons d'étudier l'efficacité du chlorure de calcium ($CaCl_2$), électrolyte puissant, sur la plasticité et les caractéristiques de gonflement d'un lit d'argile expansive. Nous avons appliqué une solution à un pour cent de $CaCl_2$ au lit d'argile en accumulant l'eau audessus et aussi en l'injectant par des forages. Nous montrons les influences relatives de la chaux et du chlorure de calcium sur les propriétés du lit d'argile en utilisant les données provenant d'une étude précédente sur des piles de chaux dans un site adjacent. L'indice de plasticité du lit d'argile diminue respectivement de 7 à 15% et de 40 à 60% après les traitements à la chaux et au chlorure de calcium. De même, la pression de gonflement de l'argile diminue de 20 à 25% et de 50 à 65% respectivement. Cette étude montre que la modification des propriétés de l'argile provoquée par le chlorure de calcium est de plusieurs fois supérieure à celle provoquée par la chaux utilisée de manière conventionnelle.

Introduction

Expansive clay beds are widespread all over the world, and they are well known to the civil engineering community for their troublesome behaviour caused by their intrinsic cyclic volumetric changes upon moisture fluctuations (Donaldson, 1969; Katti, 1979; Snethen, 1979; Chen, 1988; Petry and Little, 2002; Vu and Fredlund, 2004). Such volumetric changes threaten the stability of most lightly loaded structures, such as single-storey dwellings, pavements, canal linings and railway tracks (Wooltorton, 1936; Holtz and Gibbs, 1956; Livneh and Ishai, 1987; Katti and Katti, 1994). Various remedial measures have been devised to reduce the damage caused by such deposits, including soil replacement, placement of adequate surcharge pressure, stiffening of the superstructure, under-reamed pile foundations (CBRI – Roorkee), mat foundations, the cohesive nonswelling (CNS) layer technique (Katti, 1979), and chemical alteration. These remedial techniques were developed with a view to either absorb the volume changes or resist them. Often, it is not possible to resist volume changes because of inadequate structural loads, and the engineer is left with techniques that control the volumetric changes. It has been universally tried to control volumetric changes by altering the chemical environment around the clay particles using suitable chemical additives (Holtz and Gibbs, 1956; Katti *et al.*, 1966; Ramaiah *et al.*, 1972; Snethen, 1979; Chen, 1988; Petry and Armstrong, 1989; Rao and Subba Rao, 1994; Al-Rawas *et al.*, 2005).

Though various chemicals have been investigated for their effectiveness, lime continues to be one of the most widely used chemical admixtures thanks to its abundant availability for large-scale use (Snethen, 1979; Chen, 1988). However, there is considerable controversy over its effectiveness, as reported from several project sites (Holtz, 1969; Snethen, 1979; O'Neill and Poormoayed, 1980; Bell, 1993). It is known that lime is sparingly soluble in water (about 1·2 g/l at

(GI 4199) Paper received 5 February 2004; last revised 21 April 2005; accepted 19 July 2005

1365-781X

21°C), and hence the availability of calcium ions for exchange reactions is meagre in the supernatant solution (Snethen, 1979; Chen, 1988; Bhattacharya and Bhattacharya, 1989; Petry and Armstrong, 1989). When lime can be properly mixed with the clay, the modification is by cation exchange within the available cations and also by equivalent physical dilution of clay mineralogy for the proportion of lime added. However, when lime is applied through boreholes, most of it settles at the bottom, and lateral diffusion depends on the presence of cracks in the ground (Wright, 1973; Snethen, 1979; O'Neill and Poormoayed, 1980). In the absence of cracks, lateral diffusion is very limited through the highly impervious clay bed (Davidson *et al.*, 1965; Thompson and Robnett, 1976; Snethen, 1979).

It has been felt by researchers that strong electrolytes such as potassium chloride, magnesium chloride, zinc chloride, sodium hydroxide, ferric chloride and calcium chloride could be tried instead of lime (Desai and Oza, 1977; Frydman *et al.*, 1977; Yousry and Mowafy, 1985; Petry and Armstrong, 1989; Saha and Saha, 1991; Rao and Subba Rao, 1994; Chandra Sekhar *et al.*, 2001). Strong electrolytes are readily soluble in water and hence could supply adequate cations for exchange reactions. Petry and Armstrong (1989) reported that the reasons why $CaCl_2$ is not being widely used are not clear, although it is readily soluble in water and forms calcium-charged supernatant more easily than lime.

In the present work, an attempt is made to investigate the use and effectiveness of $CaCl_2$ in modifying the plasticity and swell properties of an expansive clay bed by conducting both laboratory and field experiments. The effectiveness of lime piles was investigated in the adjacent site previously (Venkat Reddy, 1987), the results of which were used in this paper for a comparative study between lime and $CaCl_2$ treatments. Recent studies (Ramana Murty *et al.*, 2003) have also revealed that the degree of leaching of $CaCl_2$-treated samples is negligible after the first wash, which is likely to remove the non-adsorbed cations in the clay–water electrolyte system. Even the leaching in the first wash is also nominal, indicating that the effect of leaching in clay deposits is limited because of their imperviousness and the presence of a surface charge, especially below the covered areas where the consequent desiccation cracking is greatly limited.

Materials

Soil

The soil used for pilot testing in the laboratory was a typical black cotton soil collected from 1·2 m below ground level, near the north boundary of National Institute of Technology (NIT) Warangal campus, where field investigations have been carried out since 1985. The properties of the soil are given in Table 1.

Calcium chloride ($CaCl_2$)

Commercial grade calcium chloride was used in this investigation. It consisted of 60% calcium chloride ($CaCl_2$), 22% magnesium chloride ($MgCl_2$) and 18% water (H_2O).

Laboratory study

Preliminary testing was carried out in the laboratory on clay collected from the site under investigation, with different concentrations of commercial-grade $CaCl_2$ solution to understand the influence of $CaCl_2$ on the Atterberg limits, permeability and swell properties of expansive clay. The swell potential and swell pressure of the treated and untreated expansive clay were determined by the free swell method in oedometers at maximum dry unit weight and optimum moisture content. The samples were allowed to swell fully under a surcharge pressure of 5 kPa and then consolidated back to their original volume by incremental loading similar to a conventional consolidation test. The percentage increase in sample thickness upon wetting is reported as swell potential, and the swell pressure values were obtained from e–log p plots, corresponding to the initial void ratio (Sridharan *et al.*, 1986).

Table 1. Properties of soil used for laboratory testing

Grain size distribution	
Gravel: %	2
Sand: %	26
Silt: %	23
Clay: %	49
Atterberg limits	
Liquid limit: %	108
Plastic limit: %	26
Shrinkage limit: %	14
Compaction properties	
Optimum moisture content: %	21
Maximum dry unit weight: kN/m^3	1·58
Unconfined compressive strength at optimum moisture content and maximum dry unit weight: kPa	160
Swell properties at optimum moisture content and maximum dry unit weight (by free swell method)	
Swell potential: %	28
Swell pressure: kPa	320

In situ modification of clay bed

In this part of the work, an attempt was made to stabilise the expansive clay bed using 1% commercial-grade $CaCl_2$ solution. The $CaCl_2$ solution was applied through boreholes and also by ponding methods. These studies were carried out on a site near the north boundary of NIT Warangal campus that has been used since 1985 for various field investigations on expansive soils. The general soil profile at this site is a top 1·2–2·0 m thick layer black cotton soil underlain by murrum. The properties of the top clay vary sharply with depth, especially at the clay/murrum interface and at different locations. In view of such natural variability of clay properties, untreated samples were collected separately at each treatment location to obtain individual reference values, rather than make a common reference.

Borehole method

Three boreholes 100 mm in diameter and 1·50 m deep were made by hand auger in a triangular pattern at a spacing of 2 m centre to centre (Fig. 1), and 1% commercial-grade $CaCl_2$ solution was filled in the boreholes and allowed to diffuse laterally in summer. The quantity of $CaCl_2$ solution required to stabilise the soil bed below the triangular area B_1, B_2, B_3 up to 1·5 m depth was estimated based on the porosity of the soil, and this quantity of solution was poured through boreholes to saturate the bed.

Disturbed and undisturbed soil samples were collected from locations S_1, S_2, S_3 and S_4 (Fig. 1) at 0, 0·5, 1·0 and

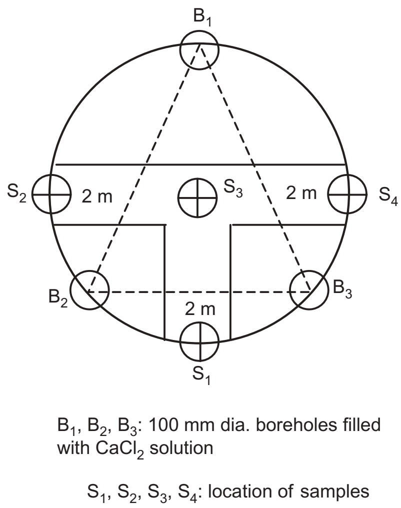

Fig. 1. Application of $CaCl_2$ solution through boreholes

1·5 m depths after 4 months to study their index, swell and strength properties. In order to collect the untreated samples, a separate open pit was excavated a little away from the boreholes.

Ponding

Two test trenches 1·2 m × 3 m × 0·3 m were excavated in the field (Fig. 2) in summer. One trench was used for ponding with water, and in the other trench 1% commercial-grade $CaCl_2$ solution was ponded. The quantity of either water or $CaCl_2$ solution required to saturate the soil bed up to 1·0 m depth was estimated based on the porosity of soil, and filled in the respective trenches. Both the trenches were left for subsequent monsoon rains.

Heave measurements were taken in both ponding trenches by placing 450 mm × 450 mm cement concrete (CC) reference panels in the centre of each trench. The initial reduced levels (RLs) of the top of the CC panels were fixed

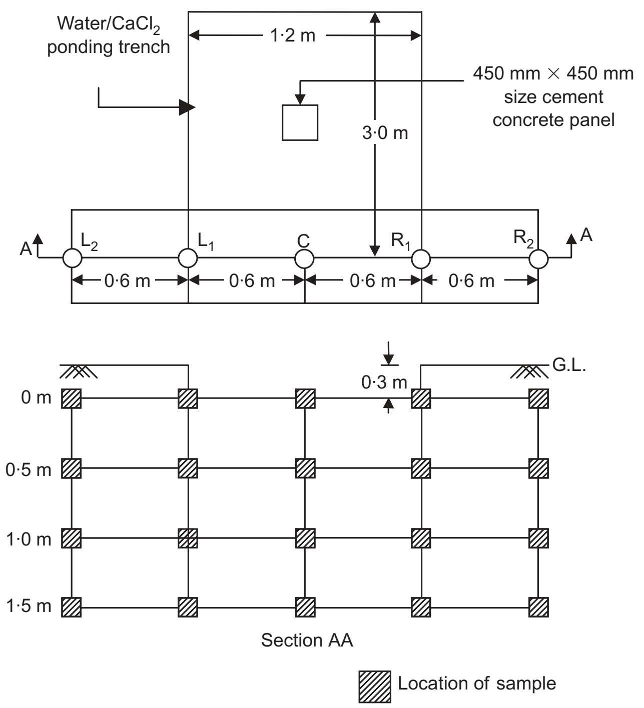

Fig. 2. Application of $CaCl_2$ solution by ponding

prior to ponding, and subsequent heave measurements were taken at regular intervals for about 3 months. These measurements were made using a levelling instrument at up to 1 mm accuracy by sticking plastic scales graduated in millimetres on the levelling staff.

After 4 months, both the disturbed and undisturbed soil samples were collected (Fig. 2) from stabilised and unstabilised ground at 0, 0·5, 1·0 and 1·5 m depths. The reference samples were collected separately, away from the trench.

Results and discussion

Laboratory study

The results obtained from the pilot testing are presented in Table 2. It can be seen that $CaCl_2$ has a profound influence on the liquid limit, and a marginal influence on the plastic limit and shrinkage limit. The liquid limit is decreased by about 41%, and the swell potential and swell pressure are decreased by 90% and 51% respectively after 1% $CaCl_2$ treatment. The average coefficient of permeability of the clay samples collected from 1·2–1·5 m depth is increased from $3{\cdot}45 \times 10^{-9}$ cm/s to $2{\cdot}18 \times 10^{-6}$ cm/s for 1% $CaCl_2$ treatment, indicating an approximately 630-fold increase. The significant modification of clay properties with $CaCl_2$ treatment could be attributed to depressed double layer thickness upon cation exchange by calcium ions and increased electrolyte concentration, whereby the repulsive forces between clay particles decrease.

Field study

Based on the promising performance of $CaCl_2$ in clay stabilisation as observed from the laboratory study, its efficacy for ground modification was studied by applying 1% $CaCl_2$ solution to the ground by ponding and also through boreholes. The soil profile at the testing site is a top 1·2–2·0 m thick layer of expansive clay underlain by murrum. The results of the field investigations are presented below.

Borehole method

Atterberg limits It can be observed from Table 3 that the liquid limit of samples collected along the depth at the centroid (S_3) of the triangular area between boreholes (where the maximum influence of calcium chloride is felt) is decreased by 30–42%. However, the influence of calcium chloride on the plastic limit and shrinkage limit is marginal. The plasticity index of the soil is reduced by 40–60% at location S_3. The considerable reduction in plasticity of the clay could be attributed to reduced double-layer thickness due to adsorption of calcium ions, increased ionic concentration, and a reduction in clay size fraction by about 10–15% with the corresponding increase in silt size fraction.

Swell properties The influence of $CaCl_2$ on the swell characteristics of the ground is also shown in Table 3. The swell potential is reduced by more than 90% at sample location S_3. It can also be observed from this table that the swell pressure is decreased by 30–65% for samples collected at location S_3, where the beneficial influence is maximum.

This modification of clay could be attributed to reduced repulsive forces between clay particles due to adsorption of calcium ions and subsequent decrease in double-layer thickness. Further, it is felt that $CaCl_2$ reacts not only by cation exchange but also by intercalation where it occupies the intermiscellar spaces of clay minerals with expanding lattice

Table 2. Effect of calcium chloride on index and swell properties of expansive clay in laboratory testing

Sample no.	Percent $CaCl_2$ solution	Liquid limit: %	Plastic limit: %	Shrinkage limit: %	Coefficient of permeability: cm/s	Swell potential: %	Swell pressure: kPa
1	0·00	108	30	14·7	$3{\cdot}45 \times 10^{-9}$	28	320
2	0·25	80	29	14·9	–	15	220
3	0·50	76	31	15·5	–	7·5	182
4	1·00	65	33	17·2	$2{\cdot}18 \times 10^{-6}$	2·7	156

Note: Swell potential and swell pressures are determined by free swell method in oedometers

Table 3. Influence of $CaCl_2$ solution applied through boreholes on index and swell properties of in situ clay bed

Sample no.	Description	Depth below ground level: m	Before stabilisation	After stabilisation at different locations			
				S_1	S_2	S_3	S_4
1	Liquid limit: %	0·0	64·0	49·0	46·5	45·0	53·0
		0·5	68·0	51·0	47·0	45·0	54·0
		1·0	89·0	64·0	68·0	64·5	72·0
		1·5	98·5	68·5	61·0	57·0	70·0
2	Plastic limit: %	0·0	23·0	25·5	24·3	26·0	24·0
		0·5	23·5	24·0	26·0	26·5	25·0
		1·0	25·2	25·8	27·0	28·0	26·0
		1·5	26·0	27·0	29·0	29·0	28·0
3	Shrinkage limit: %	0·0	16·6	17·2	18·0	18·1	17·0
		0·5	15·7	16·8	18·3	17·9	16·8
		1·0	15·3	17·1	17·4	17·7	16·0
		1·5	16·3	16·6	18·4	18·9	16·7
4	Swell potential: %	0·0	11·2	3·8	4·1	0·8	6·7
		0·5	18·4	3·6	4·6	0·7	7·2
		1·0	23·3	6·1	4·4	2·6	11·8
		1·5	27·3	2·0	2·3	1·4	6·0
5	Swell pressure: kPa	0·0	210 (15·3, 27·1)	150 (15·8, 23·9)	160 (16·0, 23·2)	145 (16·0, 22·8)	160 (15·7, 24·1)
		0·5	290 (16·0, 24·0)	152 (16·5, 21·9)	160 (16·4, 22·1)	150 (16·6, 21·4)	230 (16·3, 22·7)
		1·0	380 (16·3, 22·1)	184 (16·6, 21·7)	160 (16·5, 22·0)	143 (16·5, 22·8)	270 (16·4, 21·4)
		1·5	410 (16·6, 21·7)	150 (16·6, 22·1)	152 (16·5, 22·9)	140 (16·6, 23·0)	250 (16·6, 21·8)

Note: The values in parentheses indicate dry unit weight (kN/m^3) and moisture content (%)
The properties of untreated soil at this location are separately determined in view of the inherent variation of the soil properties with depth over the selected site

structure (Desai and Oza, 1977; Tan, 1982; Yousry and Mowafy, 1985), which is considered to be more effective than mere cation exchange in modifying the soil properties.

Ponding

The results obtained from this part of the study are presented in Table 3 and Figs 3 and 4.

Heave–time plots Figure 3 shows the in situ heave–time plots for water and calcium chloride ponding. It can be observed from this figure that the maximum pre-monsoon heave in the calcium chloride ponding trench is about half and the maximum post-monsoon heave is nearly a quarter of that in the water ponding trench. Moreover, the time required to attain the ultimate heave for calcium chloride ponding is about half of that for water ponding. This can be attributed to improved permeability and simultaneous stabilisation of the soil due to chemical treatment. The coefficient of permeability of the soil is increased by about 630 times with 1% calcium chloride solution compared with ordinary water as determined in the laboratory. The average value of the coefficient of permeability of untreated samples collected

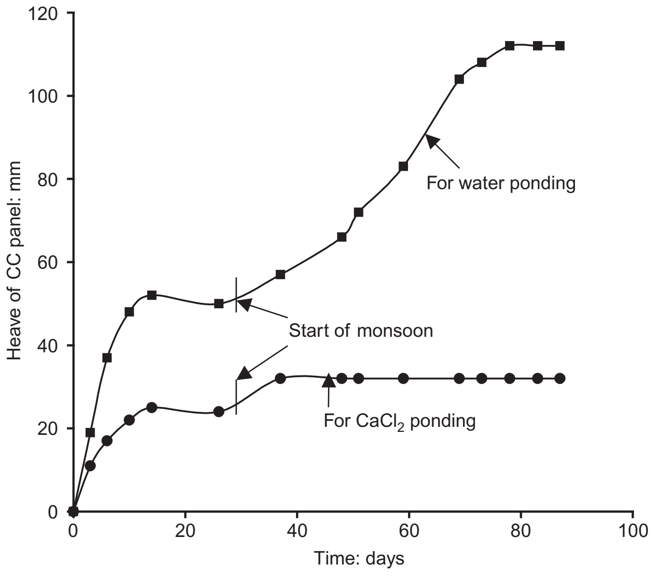

Fig. 3. In situ heave–time plots for water and $CaCl_2$ ponding

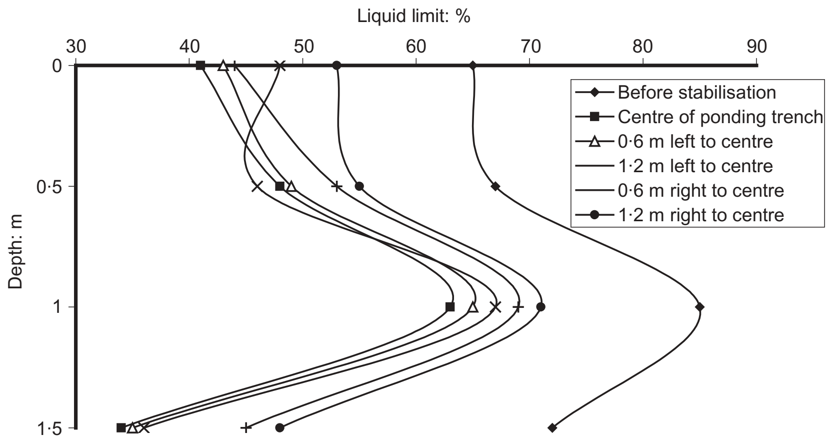

Fig. 4. Variation of liquid limit with depth before and after stabilisation for ponding with $CaCl_2$ solution

from 1·2 m depth is $3{\cdot}45 \times 10^{-9}$ cm/s, and that for the 1% $CaCl_2$ treated sample obtained from a similar depth is $2{\cdot}18 \times 10^{-6}$ cm/s.

Atterberg limits The influence of calcium chloride on the liquid limit of the soil bed with depth for different sample locations is shown in Fig. 4. The liquid limit is decreased by about 26–50% below the centre of the trench, with reduced influence laterally. This decrease could be attributed to cation exchange by divalent calcium ions and increased ionic concentration around the soil particles whereby the thickness of the double layer depresses. It is also found that the clay size fraction is decreased by 10–15% with the corresponding increase in silt size fraction owing to flocculation of clay particles in all the studies carried out under this investigation. However, X-ray diffraction analysis of samples revealed that there are no changes in clay mineralogy (Fig. 5) due to stabilisation; it alters only the surface properties. From Table 4 it can be observed that calcium chloride has marginal influence on plastic limit and shrinkage limit, which can be attributed to its nominal influence on expansive clay structure and stiffness, upon which the plastic and shrinkage limits of a clay largely depend. This can be supported by the fact that $CaCl_2$ is not a binding material, and hence its contribution to soil stiffness will be due to flocculation of clay particles upon cation exchange without any cementation. Further, it is known that expansive clay minerals obey predominantly a double-layer phenomenon compared with clay structural changes, whereas non-expansive clay minerals such as kaolinite obey structural changes by flocculation rather than the double layer phenomenon, upon environmental changes around the clay particles (Sridharan, 1991).

Swell properties It can be seen from Table 4 that the swell potential of the soil bed is almost nullified below the centre of the ponding trench, with reduced influence away from the centre. It can also be seen that the swell pressure is decreased by 60–90% at the centre of the ponding trench. Murrum is encountered at 1·5 m depth below the trench, and hence the maximum influence of the chemical solution is felt at this depth owing to the reduced clay content. As the ground slope is towards the left side, the effect at location R_2 is less. The substantial reduction in swell properties can be attributed to a decrease in repulsive forces between the depressed double layers due to the calcium chloride treatment.

Comparison between borehole and ponding methods

A perusal of Tables 3 and 4 indicates that the beneficial influence of $CaCl_2$ is almost the same in the ponding and borehole methods, indicating that the spread of chemical solution is similar in both methods. However, it should be kept in mind that the $CaCl_2$ solution was applied in hot

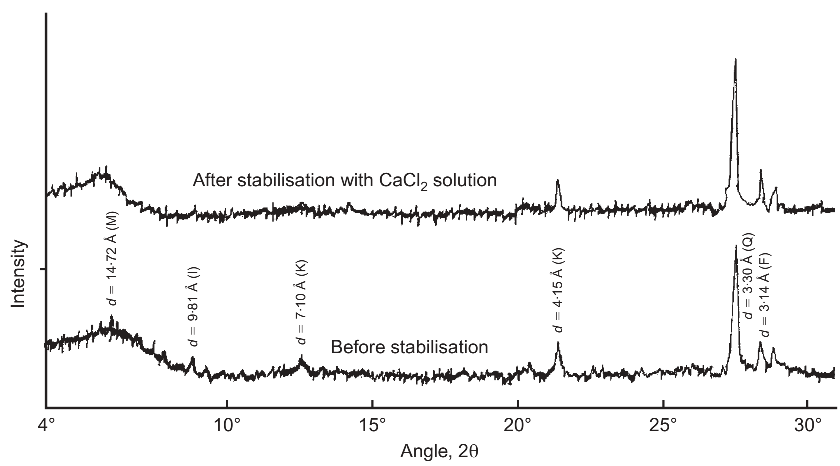

Fig. 5. X-ray diffraction patterns for samples collected from 1 m depth before and after stabilisation with $CaCl_2$ solution. M, montmorillonite; I, illite; K, kaolinite; Q, quartz; F, feldspar. Radiation C_u Kα; $\lambda = 1{\cdot}54$ Å; MA = 10; speed = 2°/min

Table 4. Influence of ponding with 1% $CaCl_2$ solution on index and swell properties of in situ clay

Sample no.	Description	Depth below ground level: m	Before stabilisation	After stabilisation at different locations				
				L_2	L_1	C	R_1	R_2
1	Liquid limit: %	0·0	65·0	48·0	42·5	41·0	43·5	53·0
		0·5	67·0	46·0	49·0	48·0	53·0	55·0
		1·0	84·5	67·0	65·0	62·5	69·5	70·5
		1·5	71·5	37·0	35·5	35·0	45·0	47·5
2	Plastic limit: %	0·0	28·5	29·0	29·5	29·0	29·0	28·4
		0·5	28·0	29·4	28·0	29·0	27·4	31·5
		1·0	30·0	31·0	30·5	31·0	28·0	30·2
		1·5	18·5	24·0	23·0	20·5	24·3	20·5
3	Shrinkage limit: %	0·0	16·9	16·2	18·3	18·3	18·6	17·1
		0·5	16·0	17·4	18·2	18·4	18·2	16·9
		1·0	14·8	17·3	18·0	17·8	16·8	16·4
		1·5	18·2	20·5	20·3	20·3	21·1	20·5
4	Swell potential: %	0·0	21·0	2·70	0·35	0·35	2·20	14·3
		0·5	20·0	2·90	0·40	1·50	0·50	11·1
		1·0	23·0	7·90	2·50	1·50	2·65	8·85
		1·5	3·80	0·25	0·10	0·20	0·25	2·70
5	Swell pressure: kPa	0·0	160 (15·4, 26·3)	60 (16·0, 23·5)	20 (16·0, 22·4)	40 (16·0, 22·0)	70 (15·9, 22·5)	160 (15·7, 23·0)
		0·5	230 (15·8, 24·5)	80 (16·0, 21·8)	40 (16·4, 22·7)	90 (16·5, 21·5)	160 (16·4, 22·2)	210 (16·7, 21·2)
		1·0	320 (16·3, 22·3)	320 (16·5, 21·25)	175 (16·6, 21·0)	80 (16·5, 21·4)	155 (16·4, 21·9)	285 (16·6, 21·2)
		1·5	220 (16·8, 17·2)	45 (16·7, 16·3)	20 (16·8, 16·8)	20 (16·5, 17·0)	120 (16·5, 17·2)	230 (16·9, 16·1)

Note: Values in parentheses indicate field dry unit weight (kN/m^3) and moisture content (%)
The properties of untreated soil at this location are separately determined in view of the inherent variation of the soil properties with depth over the selected site

summer, when extreme map-pattern cracks are present in the ground, making the difference between the methods of application insignificant. In the case of moderate cracking of the ground, ponding combined with boreholes is likely to wet the ground more uniformly up to the required depth. The variation in the influence of $CaCl_2$ at different locations vanishes if the total area is subjected to treatment.

Comparison of calcium chloride stabilisation with previous data on lime stabilisation

The data from previous studies (Venkat Reddy, 1987) on lime piles in the adjacent location of this site are taken for the purpose of comparison between lime stabilisation and calcium chloride stabilisation. Comprehensive field investigations on expansive soils have been carried out at this site since 1985. The relative influence of lime and calcium chloride on the plasticity index, swell potential and swell pressure of clay is shown in Figs 6 to 8. From these figures it can be readily seen that calcium chloride is capable of modifying the plasticity index and swell properties of clay to a substantial level; there is relatively less improvement with lime stabilisation. This discrepancy between calcium chloride and lime in stabilising the clay bed arises from the fact that calcium chloride is readily soluble in water and can supply calcium ions for ready cation exchange reactions, whereas lime is sparingly soluble in water (about 1·2 g/l at 21°C), and hence it cannot make Ca^{++}-charged supernatant easily. Subsequent studies (Babu Shanker *et al.*, 1998) have also supported the effectiveness of $CaCl_2$ treatment over lime treatment.

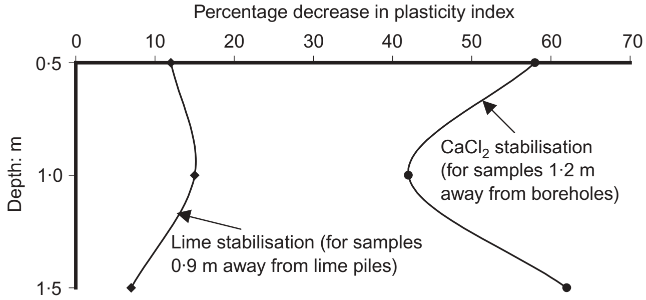

Fig. 6. Percentage decrease in plasticity index with depth for lime and $CaCl_2$ stabilisation by borehole method

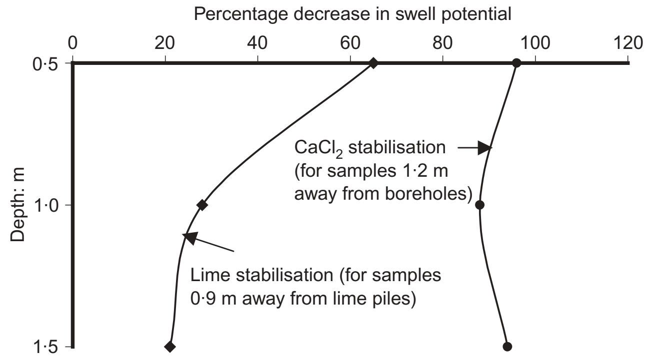

Fig. 7. Percentage decrease in swell potential with depth for lime and $CaCl_2$ stabilisation by borehole method

Conclusions

The following conclusions are drawn, based on the laboratory and field investigations carried out on the

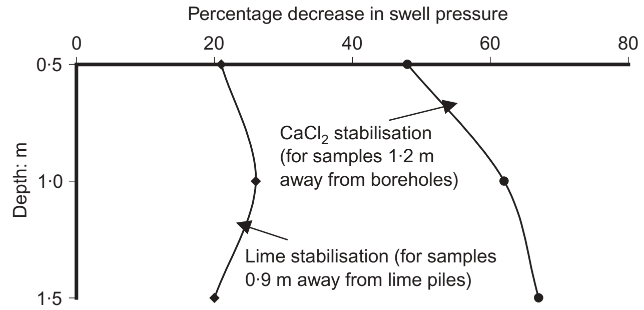

Fig. 8. Percentage decrease in swell pressure with depth for lime and $CaCl_2$ stabilisation by borehole method

influence of $CaCl_2$ solution in modifying an expansive clay bed.

(*a*) Preliminary testing in the laboratory using calcium chloride solution revealed that even low concentrations of 0·5–1·0% $CaCl_2$ could effectively control the plasticity and swell characteristics of expansive clay. They are decreased by 41% and 51% respectively for treatment with 1% $CaCl_2$ solution.

(*b*) The maximum ground heave observed in the test trench ponded with 1% $CaCl_2$ solution is only a quarter of that in the water ponding trench. Further, the time required to attain the ultimate heave with $CaCl_2$ ponding is about half that for water ponding, which can be attributed to its simultaneous wetting and stabilisation effects.

(*c*) The maximum range of reduction in plasticity index and swell pressure of an expansive clay bed for both methods of $CaCl_2$ application is 40–65% and 30–65% respectively. Ground modification, even up to 1·5–2·0 m depth, is possible by mere ponding of $CaCl_2$ solution in summer, when the ground is subjected to extreme desiccation cracks. The discrepancy of the influence of chemical solution at different lateral distances vanishes once the total area of construction is subjected to treatment.

(*d*) A marked difference in the performance of lime and $CaCl_2$ treatments is observed in terms of plasticity and swell control. The range of reduction in plasticity index is 7–15% and 40–60% for 20% lime treatment and 1% $CaCl_2$ treatment respectively. Similarly, the swell potential and swell pressure of the clay bed are decreased by 20–25% and 50–65% respectively for lime and $CaCl_2$ treatments.

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Discussion contributions on this paper should reach the editor by 3 July 2006