Use of Chemically Stabilized Soil as Cushion Material below Light Weight Structures Founded on Expansive Soils

V. Ramana Murty[1] and G. V. Praveen[2]

Abstract: Among the several remedial techniques suggested to combat the damages caused by expansive soils, the use of sand cushion and cohesive nonswelling (CNS) soil cushion were widely accepted, especially for light weight structures such as floorings, pavements, and canal linings, which cover large areas. CNS cushion is preferred to sand cushion in view of the sceptical performance of sand cushion at several work sites. However, various investigators have reported the nonavailability of suitable CNS materials at many project sites and in such circumstances, it is also suggested to prepare the artificial CNS materials by mixing suitable admixtures to the native clay. The present work deals with the modification of black cotton soil using $CaCl_2$ and rice-husk-ash (RHA), which resulted in two favorable combinations of soil +0.5% $CaCl_2$+8% RHA and soil +1% $CaCl_2$+6% RHA with nonswelling properties, while retaining high unconfined compressive strength values. The mix of soil +0.5% $CaCl_2$+8% RHA was taken for further study in view of its economy due to lower $CaCl_2$ content. The field heave measurements of footings, pavement slabs, and canal lining panels cushioned with the proposed chemically stabilized soil (CSS) mix revealed that the CSS cushion can effectively reduce their heave and hence it can be recommended as an alternative to conventional CNS cushion in localities of scarcity for suitable CNS materials.

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CE Database subject headings: Expansive soils; Swelling; Soil stabilization; Footings; Pavements; Slabs; Panels.

Introduction

The problems posed by expansive soils to the stability of civil engineering structures have received the universal attention in view of the serious economic losses at the national levels of many world nations (Petry and Little 2002; Puppala et al. 2005; Rojas et al. 2006a,b). The synergic research efforts carried out all over the globe enabled the engineering community to devise certain remedial techniques to alleviate or reduce the damages caused by these deposits (Snethen 1979; Pathak and Kate 1987; Petry and Little 2002). The prominent remedial techniques such as soil replacement (Zeitlen 1969; Chen 1988), applying adequate surcharge pressure (Chen 1988), stiffening the super structure (Kassiff et al. 1965; Winnfread 1969; Mohan et al. 1973), moisture control (Mohan and Rao 1965; Rojas et al. 2006a,b), physical and chemical alteration of soil (Snethen 1979; Cokca 2001; Puppala et al. 2003), provision of sand cushion (Burov 1977; Boominathan 1987) and CNS cushion (Katti 1979), underreamed piles (Mohan et al. 1973), belled pier foundation (Chen 1975; Garcia-Iturbe et al. 1980), mat foundation (Lytton and Woodburn 1973; Williams and Pellissier 1992), and recently piled footings (Murty 2001) and anchored granular piles (Phanikumar et al. 2004; Krishna et al. 2004) were developed.

Among these remedial techniques, the use of cushion materials below footings, pavements, linings, and other lightly loaded facilities has got prominence in view of its effectiveness and adoptability, especially where other forms of treatments cannot be economically adopted (Burov 1977; Katti and Katti 1994). Previously, sand cushion and later cohesive nonswelling (CNS) soil cushion were suggested to accommodate or alleviate the heave of structures resting on expansive soils. In view of the paradoxical behavior of sand cushion under varied site conditions, a CNS layer technique was promulgated. However, nonavailability of CNS materials is reported at several work sites (Nagarkar et al. 1987; Rao et al. 1994), making the technique unadoptable in many instances.

It has been felt by the researchers (Sastry 1989; Gurumurthy 1993; Katti and Katti 1994) that the CNS material can be prepared artificially using the native black cotton soil itself by mixing with it suitable admixtures. Indian black cotton soils are expansive in nature with the presence of montmorillonite clay mineral (Katti 1979; Rao et al. 1994; Murty and Krishna 2006). It is reported that $CaCl_2$ is a promising chemical stabilizer to alter the expansive soil properties (Vaisanen et al. 1995; Murty et al. 2000; Chandrasekhar et al. 2002). Rice-husk-ash (RHA) is abundantly available in all paddy grown areas in India as waste material and various investigators have reported its effectiveness to stabilize expansive soils (Sastry 1989; Montgomery and Chmeisse 1991; Chandra et al. 2005). During the preliminary investigations on the use of $CaCl_2$ and RHA to modify the properties of black cotton soil, two favorable combinations of soil—$CaCl_2$-RHA mixes with nullified swell properties, while retaining high unconfined compressive strength values were obtained. Katti (1979) reported that the thickness of CNS cushion depends on the allowable value of heave and for a given value of heave, the

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Table 1. Influence of Calcium Chloride and Rice-Husk-Ash on Index and Engineering Properties of Black Cotton Soil

							Unconfined compressive strength (kPa)			Swell characteristics (in 60 mm diameter oedometer)	
$CaCl_2$ (%)	RHA (%)	w_L	w_P	w_S	MDD (Mg/m^3) (standard Proctor)	OMC (%)	0 days	7 days	14 days	Swell potential (%)	Swell pressure (kPa)
0	0	108	26	14.5	1.58	24.0	186	—	—	24	370
0	2	99	28	15.4	1.56	25.9	224	—	—	11	300
	4	86	30	17.4	1.54	26.5	276	—	—	9.5	260
	6	72	29	19.7	1.52	27.2	321	—	—	6.7	220
	8	63	31	22.3	1.50	28.3	279	—	—	5.5	190
0.25	0	80	29	15.0	1.57	25.5	188	240	257	13.2	240
	2	76	29	17.0	1.56	26.2	219	302	383	6.0	230
	4	71	29	18.5	1.54	26.9	272	410	481	3.8	180
	6	63	29	21.0	1.52	27.9	326	350	429	3.5	150
	8	55	29	24.0	1.51	28.9	292	245	317	2.1	80
0.50	0	76	28	16.0	1.56	26.0	204	187	202	9.5	180
	2	72	29	17.5	1.54	26.7	227	225	303	5.8	170
	4	62	29	20.5	1.52	28.0	281	268	315	1.0	110
	6	54	29	22.5	1.50	28.0	312	276	347	0.45	45
	8	49	29	25.5	1.49	29.0	299	288	344	0	0
1.00	0	65	30	17.0	1.57	26.4	212	181	192	6.50	120
	2	60	29	19.0	1.58	26.3	240	196	240	4.70	90
	4	55	30	22.0	1.54	28.4	294	214	284	0.40	50
	6	49	29	24.0	1.52	28.8	340	254	273	0	0
	8	44	30	27.0	1.48	29.4	312	281	341	0	0

cushion thickness decreases with increasing cohesion value of CNS cushion. This prompted the authors to study the effectiveness of chemically stabilized soil (CSS), using one of the favorable soil—$CaCl_2$-RHA mix as a cushion material.

Brief Review of Background Work

In view of the dearth for the suitable CNS materials, efforts have been made by several investigators to prepare artificial cushion materials. Sastry (1989) carried out the detailed laboratory studies to investigate the engineering properties of soil—lime, soil—lime-flyash, soil—lime-RHA, and soil—lime-cinder ash mixes and recommended the use of these stabilized mixes in lieu of conventional CNS cushions in deltaic areas where natural CNS materials are scarcely available. Naresh et al. (1989) used soil +4% lime and soil +4% lime +35% sand mixes as CNS cushions below foundations of various structures of Anta Power Plant in Rajasthan state, India. Gurumurthy (1993) carried out extensive laboratory studies in oedometers using lime or cement stabilized RHA as artificial CNS material and reported that this material performed even better than some of the natural CNS materials. Katti and Katti (1994) recommended to prepare artificial CNS material by mixing 2% commercial lime/gypsum or 60% sand with the native expansive soil.

Murty (2001) studied the use of $CaCl_2$ with the abundantly available RHA in India, in different combinations to get a mix with nonswelling properties. $CaCl_2$ was found to be a very useful chemical stabilizer of expansive clays (Vaisanen et al. 1995; Murty et al. 2000). The Atterberg limits, compaction properties (standard Proctor), unconfined compressive strength (UCS), and swell properties (IS: 2720-Part 41) (IS 1987) of the mixes were determined. The UCS of the mixes is determined on samples of 38 mm diameter and 76 mm height samples molded at their corresponding optimum moisture content (OMC) and maximum dry density (MDD) and cured by sealing them in plastic bags, which in turn were kept in a desiccator. The results obtained from these tests are presented in Table 1.

A perusal of Table 1 indicates that though the addition of either $CaCl_2$ or RHA would reduce the plasticity and swell properties of black cotton soil substantially, their combination is found to be superior to their individual influences. The reduction in plasticity and swell properties could be attributed to the cation exchange reactions by $CaCl_2$ (Murty et al. 2000) and change in the soil matrix by the bulk volume of RHA in proportion to its content by dry weight of soil due to its lower specific gravity. Further, the RHA promotes the pozzolanic reactions, which can be evidenced from the gain in UCS values with curing period.

It can also be observed from Table 1 that there is an increase in UCS values of mixes immediately after the addition of admixtures to the soil, but a reduction in strength is recorded at 7 days curing period, and thereafter, strength gain is noticed except for 0.25% $CaCl_2$ content for which, the UCS is observed to increase with curing period. Such deviations in strength gain were also reported previously (Anandakrishnan and Dhaliwal 1966; Sivanna 1976). It is evident from this table that for the soil +1% $CaCl_2$+6% RHA or soil +0.5% $CaCl_2$+8% RHA, both the swell potential and swell pressure are nullified while retaining high UCS values. In view of the higher cost of $CaCl_2$, the latter mix of soil +0.5% $CaCl_2$+8% RHA was taken for further study for its possible use as cushion material. Most of the previous studies were confined to laboratory testing and the field performance evaluation studies are still wanting. In order to study the performance of the proposed artificial CSS cushion material in controlling the swell properties of expansive soil and also the heave of the light weight structures founded in/on them, a detailed laboratory and field investigation were taken up. The possible mechanisms for effective control of volume changes using CSS cushion

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Table 2. Properties of Materials Used in Experimental Work

Property	B.C. soil	CSS cushion (soil+0.5% $CaCl_2$+8% RHA)	Sand	Murrum	Stone dust (from granite quarry)
Grain size distribution					
Gravel (%)	2	2	0	9	8
Sand (%)	26	27	97	65	76
Silt (%)	23	25	3	15	16
Clay (%)	49	46	0	11	—
Specific gravity	2.70	2.67	2.65	2.68	2.69
Atterberg limits (%)					
Liquid limit (w_L)	108	48	—	36	Nonplastic
Plastic limit (w_P)	26	29		15	
Shrinkage limit (w_S)	14	25		14	
Unified soil classification	CH	CI	SP	SC	SM
Compaction properties (standard Proctor)					
OMC (%)	24	28	8	14	6
MDD (Mg/m^3)	1.58	1.50	1.65	1.89	1.86
UCS (kPa) (after 14 days curing period)	160	344	—	92	—
Swell properties					
Swell potential (%)	24	0	—	0	—
Swell pressure (kPa)	370	0		0	
Coefficient of permeability, cm/sec	2.2×10^{-7}	6.3×10^{-5}	4.26×10^{-2}	5.3×10^{-5}	8.2×10^{-3}

were explained in the light of the concept of CNS layer technique postulated by Katti (1979). The studies were also focused to bring out the relative performance of the proposed CSS cushion and the conventional CNS cushion based on the laboratory and field investigations.

Experimental Program

The experimental studies were carried out both in the laboratory and field. Laboratory studies were taken up to understand the effectiveness of CSS cushion in controlling the swell properties of expansive clay. Field investigations were carried out by providing different thicknesses of the proposed CSS cushion and the conventional CNS cushion below the footings, pavement slabs, and canal linings to study the relative performance of these cushion materials in controlling the heave.

Materials. For the proposed experimental program, the following materials were used.

Soil. The expansive soil, which is well known by the term black cotton (B.C.) soil in India, was used in the present work for both the laboratory and field studies. For the laboratory study, the soil was collected from a site near the north boundary of NIT, Warangal campus where highly expansive clay bed is available.

CSS Cushion. The mix of B.C. soil +0.5% $CaCl_2$+8% RHA is designated as CSS. To prepare the CSS mix, 0.5% $CaCl_2$ by dry weight of soil was dissolved in water equivalent to its OMC and mixed with dry soil +8% RHA. The cushion made up of CSS mix is termed as CSS cushion.

Sand. Locally available river sand classified as poorly graded sand (SP) with D_{10}=0.23 mm, C_u=3.5, and C_c=1.34 was used in this study.

Murrum. Locally available murrum soil was used as conventional CNS cushion both in the laboratory and field experimental work.

Stone Dust. Stone dust from the local granite quarry was used as cushion material below the canal lining panels.

The properties of the above materials are given in Table 2.

Rice-Husk-Ash (RHA). Well-burnt rice-husk-ash obtained from a brick kiln was used as an admixture with clay. The properties of RHA are given in Table 3. The chemical composition of RHA is obtained from the Indian Institute of Chemical Technology, Hyderabad, India.

Calcium Chloride ($CaCl_2$). Commercial grade $CaCl_2$ having the composition of 60% $CaCl_2$, 22% $MgCl_2$, and 18% H_2O was used along with RHA.

Table 3. Properties of Rice-Husk-Ash

Property	Value
Grain size distribution (percent finer than)	
425μ	93
212μ	79
150μ	46
75μ	17
Specific gravity	1.91
Chemical composition (Percentage of)	
Silica	89.32
Alumina	2.73
Ferric oxide	0.81
Calcium oxide	4.22
Magnesium oxide	0.87

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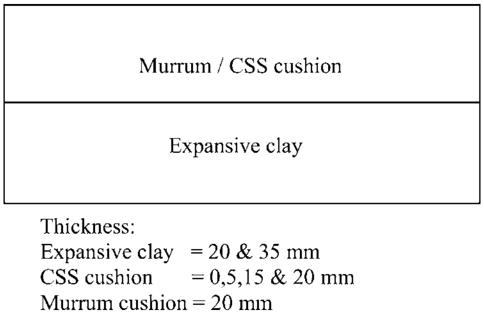

Fig. 1. Variables in oedometer testing

Studies on CSS Cushion

The studies on the performance of CSS cushion were carried out both in the laboratory and field.

Laboratory Tests

The laboratory swell tests were carried out both in the oedometers and also in a bigger size test tank. The tests in a bigger size tank were intended to overcome the effect of sample confinement, which is inevitable in the case of oedometer testing and to cover a wider range of thickness variations of cushion materials that could further substantiate the test results, but not merely for the purpose of comparison between these methods.

Oedometer Tests (IS: 2720-(Part 41) (IS 1987)

The influence of CSS mix on swell potential and swell pressure of black cotton soil was studied in 100 mm diameter and 45 mm high oedometers with 5,15, and 20 mm thick CSS cushion over 20 mm thick black cotton soil layer (Fig. 1). The swell potential of clay is calculated as the percentage increase in thickness of the sample with respect to its original thickness upon inundation with water under 5 kPa surcharge pressure. Swell pressure is taken as the pressure required to bring back the swollen sample to its original thickness. Silicon grease was applied on the inner side of oedometers to reduce the side friction. Tests were also carried out using 20 mm thick murrum (commonly used CNS material) cushion over 20 mm thick black cotton soil layer in order to compare the effectiveness of CSS cushion with conventional CNS cushion. One more test was conducted by separating the CSS cushion and black cotton soil using a thin aluminum foil to understand the interface cohesion mechanism as explained by Katti (1979). The clay and the cushion materials were compacted to their respective MDD at their OMC.

Tests in Bigger Size Tank

These tests were carried out in 500 mm diameter and 600 mm high steel tank (Fig. 2). The test tank was placed on the pedestal of a compression testing machine with a 40 mm thick metal plate placed below it to ensure adequate support at its base. Four strips of graph paper were stuck to the sides of the test tank to guide the compaction of soil and cushion materials in 20 mm thick layers. A 20 mm thick sand layer was placed at the bottom of the test tank to facilitate saturation and a filter paper was placed over it. The black cotton soil was mixed at OMC and compacted to its MDD in 20 mm thick layers after 24 h of mellowing period. Each layer was scarified before the next layer was placed. The thickness of clay layer was varied as 100 and 200 mm over which the desired CSS cushion was provided by compacting the CSS mix to its MDD at OMC similar to the clay layer. In order to facilitate the process of wetting of the system, vertical sand drains were provided at the inlet and outlet ends of the test tank connecting to a circular groove filled with sand at the clay—CSS cushion interface (Fig. 2). A filter paper was placed on the top of the CSS layer, over which a 300 mm diameter footing plate with extension rod was placed. Sand (passing 2 mm sieve) was compacted over the footing plate to its MDD of 1.65 Mg/m^3. The extension rod was brought in contact with 3 ton capacity proving ring and two dial gauges of least count 0.01 mm were placed on the metal flats welded to the extension rod. The swell pressure was measured by constant volume method, in which the system was allowed to absorb moisture from a water reservoir with a head of 1.2 m above the inlet level and the increase in volume was compensated by applying additional load through the proving ring within 0.10 mm displacement. The process was continued until no volume change was observed and the equilibrium load was recorded. One test was carried out by placing 100 mm thick murrum cushion over 100 mm thick expansive clay bed. To measure the percent swell, a similar test setup was used except connecting the extension rod of the footing to the proving ring and maximum dial gauge readings were taken under a surcharge pressure of 7 kPa imposed by the backfill sand over the footing.

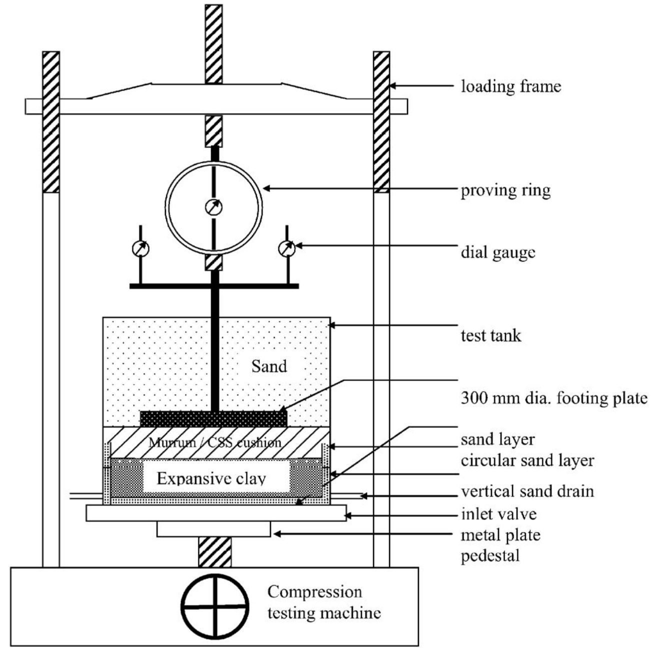

Fig. 2. Schematic diagram of experimental setup for swell tests in a 500 mm diameter and 600 mm high test tank

Field Tests Using CSS Cushion

The effectiveness of CSS cushion in controlling the heave of light weight structures was investigated by placing it below footings, pavement slabs, and behind canal lining panels.

Below Footings

This study was carried out at the north boundary of NIT—Warangal campus—where the soil profile is the top 2–2.4 m thick black cotton soil followed by murrum stratum. The moisture-density fluctuations of the clay bed are shown in Fig. 3. Two numbers of 0.5 m × 0.5 m size of pits were dug out in which 150 and 300 mm thick CSS cushion was compacted, respectively,

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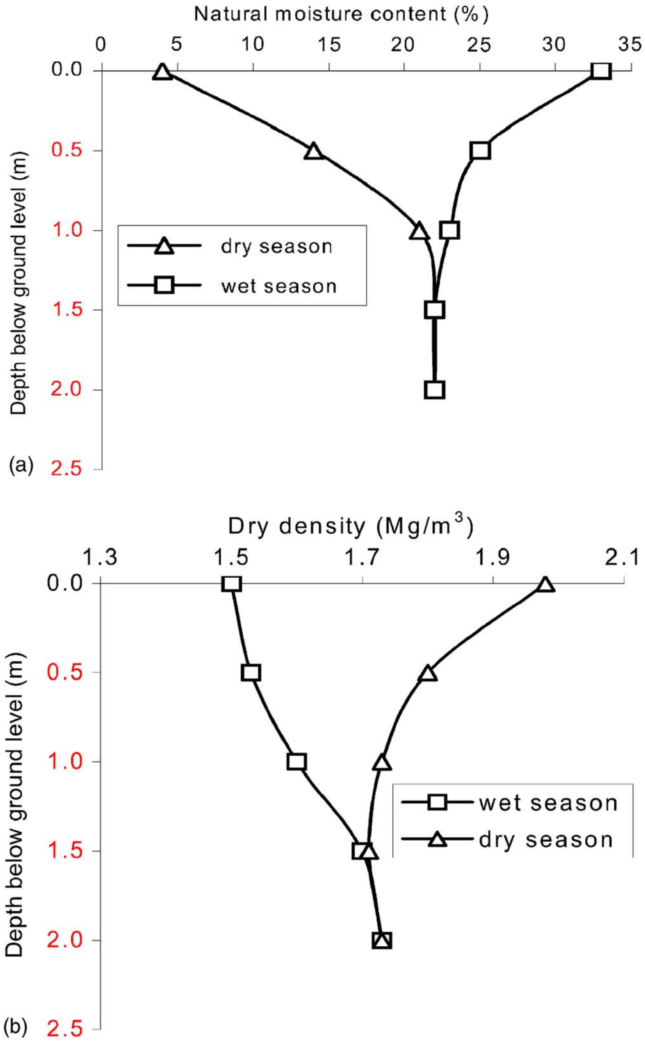

Fig. 3. (a) Variation of seasonal moisture content with depth; (b) variation of dry density with depth in dry and wet seasons

using a hand hammer, over which 300 mm × 300 mm × 50 mm size of concrete panels were placed centrally. The tops of these model-footing panels were kept 100 mm below the ground surface to pond with water. In order to compare the behavior of CSS cushion with CNS cushion, two more footings were provided with the similar thicknesses of murrum soil cushion, the conventionally used CNS material. One more footing was placed at 100 mm depth below ground level without any cushion for reference. The initial reduced levels of top surfaces of footing panels were fixed by using a leveling instrument and heave measurements were taken after flooding the pits with water.

Below Pavement Slabs

This part of the study was also carried out at the same site where the footings were laid. Four numbers of 100 mm thick cement concrete (CC) slabs of size 1 m × 1.6 m were cast with 0, 200, 300, and 500 mm thick CSS cushion below them, respectively (Fig. 4). A CSS cushion was accommodated in the respective pits dug out for the purpose. The pavement panel without CSS layer was placed at 100 mm depth below ground level. Two more slabs of size 1 m × 2 m and 1 m × 2.5 m were cast with 300 mm thick CSS cushion below them to observe the influence of size of slab on heave. The required CSS material was prepared by pulverizing

Fig. 4. Pavement slabs with CSS cushion

the sun dried black cotton soil using a 2 ton stone roller and mixing with it the other admixtures mentioned previously. The CSS mix was compacted in the excavated pits using the same stone roller. In order to observe the possible differential heave of slabs, a 25 mm wide joint was left centrally along the length of each slab. Polished stones were fixed on these slabs to take heave measurements. Subsequently, the pavement slabs were flooded with water, and heave measurements were taken using a leveling instrument up to an accuracy of 1 mm by affixing plastic scales to the leveling staff.

Behind Canal Linings

This part of the study was carried out on a tail channel of Kakatiya canal of Sriramsagar project at 257.902 km (Fig. 5) in Andrapradesh state. The moisture-density fluctuations at this site are similar to the site where footings and pavement slabs were laid except that the depth of active zone is extended up to 1.65 m. The soil profile at this site is top 4.8 m thick clay bed followed by murrum stratum. The relative influence of CSS, CNS, and stone dust cushions on the heave of 100 mm thick concrete lining panels was studied by providing different cushion thicknesses of these materials behind the panels. Two numbers of 1 m × 1 m size cement concrete panels were provided with 0.5 m and 1 m thick stone dust as cushion material. Two more panels of the same size were provided with similar thickness of murrum cushion, the conventionally accepted CNS material. Four CC panels of 1 m × 1 m size were provided with 0.3, 0.5, 0.75, and 1 m thick CSS cushion, respectively. In order to accommodate the respective

Fig. 5. Lining panels with CSS cushion

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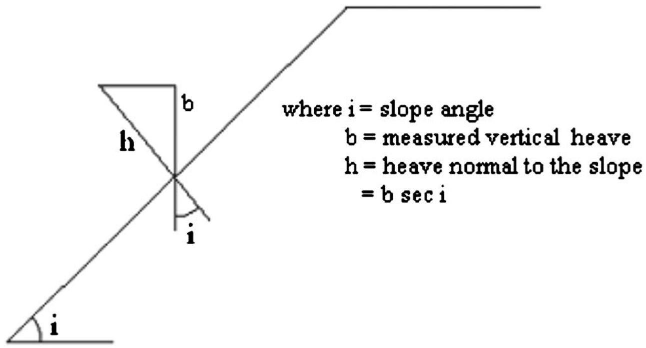

Fig. 6. Heave calculation for lining panels on canal slope

cushion thicknesses, the pits were excavated normal to the slope. The slope was flooded with water by filling the cross trenches cut for the purpose, and heave measurements were taken for about 6 months. The vertical heave was measured using the leveling instrument and the heave normal to the slope is deduced by using the relation $h=b$ sec i, where "h"=heave normal to the slope; "b"=measured vertical heave; and "i"=slope angle (Fig. 6).

Results and Discussion

The results obtained from laboratory and field studies are presented and discussed below.

Laboratory Test Results

Swell Studies

The results obtained from the swell tests carried out in 100 mm diameter oedometers and 500 mm diameter test tank using different thicknesses of murrum and CSS cushions over the black cotton soil layer are presented in Table 4. It can be observed from this table that both the swell potential and swell pressure values of clay tested in oedometers and bigger size test tank even with a nominal thickness of CSS cushion are significantly decreased. The substantial reduction in swell properties can be supported by the high cohesion value of CSS mix, whereby the soil-CSS system attains an equilibrium electrical environment at and below the interface between soil and a CSS cushion. Further, $CaCl_2$ present in a CSS cushion helps to chemically stabilize the clay at the interface. The effectiveness of a CSS cushion could also be supported by the concept of CNS layer technique (Katti 1979). The CNS layer technique was proposed based on the field observations that only a limited thickness of clay bed near the surface is subjected to volumetric changes upon moisture fluctuations while protecting the underneath clay from volume changes, and if this top layer is replaced by a CNS layer, it helps to restore the initial electrical environment at the interface and below. Further, it is corroborated that the replacement by cohesionless soils breaks the cohesive bonds at the interface due to their different surface properties, which is believed to cause swelling. The placement of a CNS cushion is believed to help the moisture films to first surround the clay mineral particles that help to develop self-stabilizing cohesive bonds, rather than allowing the moisture from entering into the interlayer space that causes swelling. It was also reported that the higher cohesion value of the CNS material helps to restore the initial stable environment effectively, for which the proposed CSS cushion has a good amount of cohesion. The interface cohesion mechanism can be supported by the present experimental findings that when a CSS layer and soil were separated by a thin aluminum foil, the swell pressure is almost raised to its original value, as can be observed from Table 4. The interface separation by aluminum foil having different surface properties is believed to break the cohesive bonds, which causes it to exert the swelling pressure.

It is also evident from Table 4 that the oedometer method overestimates the swell properties of clay due to lateral confinement of the sample, and it can be observed that the value of swell

Table 4. Laboratory Study on Influence of Cushion Materials on Swell and Swell Pressure of Expansive Soil

			Percent swell/swell potential (%) at OMC and MDD		Swell pressure (kPa) at OMC and MDD	
Type of cushion material	Thickness of B.C. soil (mm)	Thickness of cushion material (mm)	In 100 mm diameter and 45 mm high oedometer	In 500 mm diameter and 600 mm high steel tank for 300 mm diameter footing	In 100 mm diameter and 45 mm height oedometer	In 500 mm diameter and 600 mm high steel tank for 300 mm diameter footing
—	20	0	26	—	400	—
CSS layer	20	5	4.6	—	95	—
CSS layer	20	15	3.95	—	51	—
CSS layer	20	20	1.95	—	51	—
CSS layer[a]	20	20	23.1	—	385	—
CSS layer	35	5	5.25	—	95	—
Murrum	20	20	7.6	—	320	—
CSS layer	100	0	—	9.2	—	232
CSS layer	100	20	—	2	—	96
CSS layer	100	50	—	2.25	—	65
CSS layer	100	100	—	2.02	—	62
Murrum	100	100	—	4.2	—	197
CSS layer	200	20	—	2.46	—	97
CSS layer	200	50	—	2.32	—	68

[a]CSS layer is separated by a thin aluminum foil in order to have an idea of interface cohesion mechanism.

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Table 5. Maximum Heave of Cushioned Footings

Type of cushion material	Thickness of cushion material (mm)	Maximum heave (mm)
Without cushion	0	106
Murrum	150	51
Murrum	300	43
CSS	150	22
CSS	300	18

pressure obtained on 300 mm diameter model footing tested in a bigger size test tank is almost half of that obtained from oedometer tests. Such findings were also reported by others (Chen 1988; Murty and Krishna 2005). Further, it can be noted from this table that the murrum, which is a conventionally used CNS material could reduce the swell potential of clay, but the reduction in swell pressure is only nominal. This could be explained by the fact that for no volume change condition under CNS cushion, its cohesion characteristics and thickness are critical, which in the present laboratory test conditions may not be sufficient, leading to its sceptical performance. Further, it is also reported that the swell pressure is the intrinsic property of expansive clay, independent of sample thickness, initial water content, and initial surcharge pressure and except under zero volume change environment, the swell pressure could be equal to its original value, even under the controlled volume change condition (Chen 1988). These tests were repeated twice to confirm the test results.

Field Test Results

Cushioned Footings

The heave values of footings cushioned with different thicknesses of cushion materials are presented in Table 5. It can be seen from this table that the heave of footings is decreased by 59 and 83%, when 300 mm thick murrum and CSS cushions are provided below them, respectively. Even a cushion thickness of 150 mm could reduce the heave values by 51 and 79% for murrum and CSS cushions, respectively. The reasons for the reduction in heave could be attributed to controlled wetting of the underneath clay in the presence of cushion materials, which helps the clay to absorb necessary moisture content and develop self-stabilizing cohesive bonds, and the higher effectiveness of CSS cushion compared to murrum cushion could be due to its higher cohesion value and the possible stabilization of clay at the interface by $CaCl_2$.

Cushioned Pavement Slabs

The heave-time plots for different pavement slabs provided with different thicknesses of CSS cushion are shown in Fig. 7. It can be observed from these plots that the heave of pavement slabs is decreasing with increasing cushion thickness, which could be attributed to the surcharge effect and improved facilitation of slow moisture migration. The maximum values of heave as obtained from heave-time plots for different test conditions are given in Table 6. The heave of pavement slab is decreased by 83%, when cushioned with 0.5 m thick CSS layer and as can be observed from Table 6 that the heave is the same for different sizes of pavement slabs under study when cushioned with similar thickness of CSS layer.

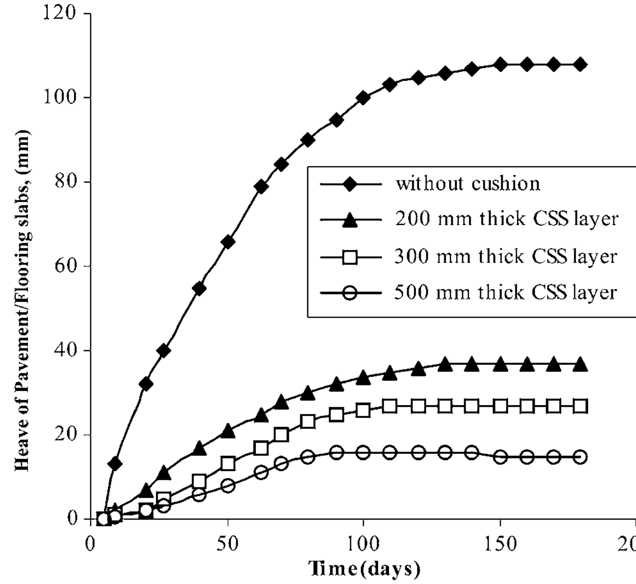

Fig. 7. Heave-time plots for pavement slabs of size 1 m × 1.6 m with CSS cushion

Cushioned Canal Lining Panels

Concrete lining panels of 1 m × 1 m size were cast on the slope of tail channel of Kakatiya canal by providing different types and thicknesses of cushion materials behind them. The heave-time plots for these panels are shown in Fig. 8. As can be seen from this figure, the initial slackness in heave is due to slow migration of water from the cut trenches made across the slope for the purpose of ponding with water. It can be seen from this figure that the panels cushioned with CSS layer attained ultimate heave in a relatively short time (60–70 days), whereas the panels with murrum (conventional CNS material) and stone dust took about 120–130 days, and the panels without any cushion, took about 140–150 days. It can further be observed from this figure that the heave of lining panel could not be controlled using stone dust as a cushion material, which could be due to its high permeability, whereby the underneath clay gets quick access to water with little scope for the development of self-stabilizing cohesive bonds, as explained previously between clay particles. The nominal reduction in heave with this cushion is due to its surcharge effect as heave is sensitive to it. The canal lining adjacent to the test site has shown wide longitudinal cracks for about 2 km length when provided with 1 m thick stone dust cushion in view of the dearth for suitable CNS material at the site. The murrum (conventional CNS material) cushion could reduce the heave by 37–48% and CSS cushion by 65–77% with 0.5–1 m thickness. From these

Table 6. Maximum Heave of Pavement Slabs Cushioned with CSS Layer

Size of slab	Thickness of cushion material (mm)	Maximum heave (mm)
1.0 m × 1.6 m	0	109
1.0 m × 1.6 m	200	40
1.0 m × 1.6 m	300	31
1.0 m × 1.6 m	500	18
1.0 m × 2.0 m	300	30
1.0 m × 2.5 m	300	30

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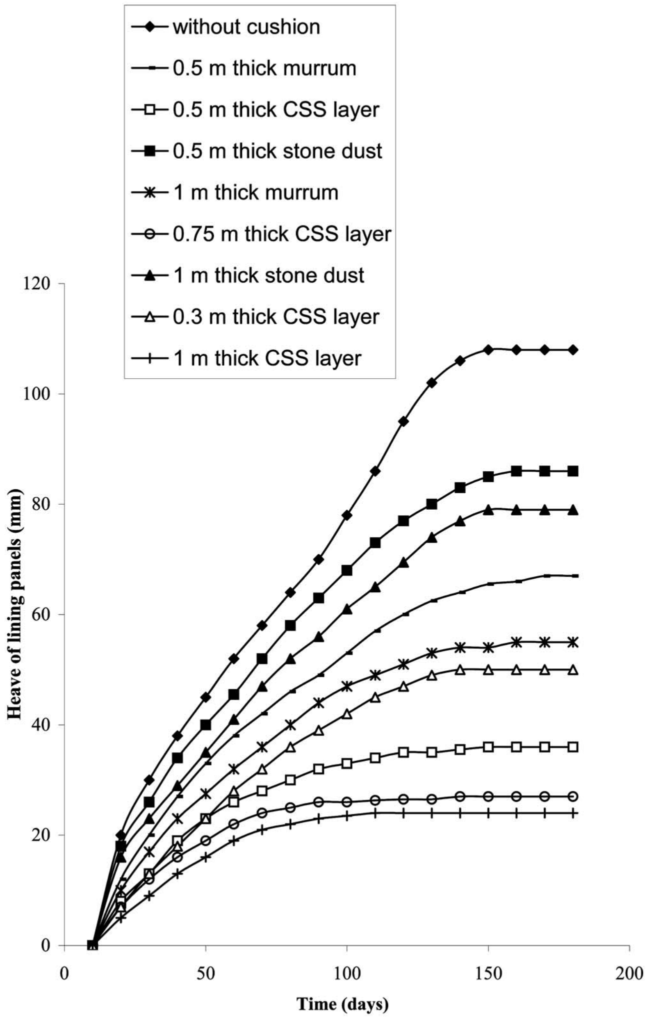

Fig. 8. Heave-time plots for canal lining panels with different cushion materials

observations, it is felt that the proposed CSS cushion can be used as an effective alternative to scarcely available CNS materials at several project sites.

Conclusions

The use of cohesive nonswelling soil (CNS) cushions below the light weight structures is well accepted, especially when the structures cover large areas such as floorings, pavements, and canal linings. In view of severe scarcity for suitable CNS materials at several project sites, an alternative cushion material is proposed to be prepared at the site using the native black cotton soil (expansive soil) by admixing with it 0.5% $CaCl_2$ and 8% RHA by dry weight of soil designating the mix as chemically stabilized soil (CSS). The effectiveness of a CSS cushion is studied by placing different thicknesses of it below the footings, pavements slabs, and behind canal lining panels, the heave measurements of which indicated that the CSS cushion could be used as an effective alternative to conventional CNS cushion whenever there is dearth for suitable CNS materials. The performance of CSS cushion is found to be superior to conventional CNS cushion, which could be attributed to its higher cohesion value while being nonswelling and possible clay-CSS cushion interface stabilization in the presence of $CaCl_2$. The use of cohesionless cushion materials, such as stone dust is found to be ineffective in controlling heave. The heave of lining panels and pavement slabs is decreased by about 66–83% for 0.5 m thick CSS cushion.

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