ESTIMATION OF SWELLING PRESSURE OF EXPANSIVE SOILS REINFORCED WITH GRANULAR PILE

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ABSTRACT

Constructing over expansive soils often severely damage the structure due to high swell-shrinkage behaviour and loss of strength owing to fluctuating water content. Due to the above reasons construction on or using expansive soils is considered to be unsafe. The technique of such soil, improvement by installation of granular piles (also known as stone columns) is popular to marshy lands, marine clays, loose sand, silty or clayey sand, and compressible soils. Granular piles improve swelling properties of expansive soil. In the present study six expansive soils were used. The one of them was the naturally available black cotton soil and others were derived from it by mixing bentonite in different proportions. Test beds of these soils were prepared at different initial moisture contents and the granular pile of sand was installed in these beds by the method of removal. Besides initial moisture content, properties of expansive soils, the spacing between the piles (expressed by *s/d* ratio; *s* = spacing between the piles and *d* = diameter of a pile) and the relative density of granular pile forming material were the variables of the study. Multiple linear regression analysis on the test data has been performed and equations for predicting swelling pressure of soil bed without pile and inclusion with granular pile have been developed.

KEYWORDS

Granular pile; S/d ratio; Swelling pressure; Relative density of sand

INTRODUCTION

Expansive soil deposits occur in the arid and semi-arid region of the world and are problematic to engineering structures because of their tendency to heave during wet season and shrink during dry season [1-2,25]. Light structures such as highways, railroads, runways, and other lifeline structures, constructed over such soils often get severely damaged due to high swell-shrinkage behaviour and loss of strength owing to fluctuating water content. Due to the above reasons construction on or using expansive soils is considered to be unsafe. The traditional techniques of ground improvement like lime stabilization, cement stabilization; fly ash stabilization, etc. have difficulty of mixing the stabilizer to the soil properly and are limited to treat the soil to shallow depth only. Ample examples are available which show failure of roads and embankments, boundary walls and uneven settlement of building floors and damage to lightly loaded structures founded on such soils. The annual cost of damage to structures, worldwide, due to construction on such soils is enormous [3-5]. Hence the search for developing a new technique for expansive soil improvement still remains alive and relevant.

Now-a-days, granular pile/stone column (also known as stone column) is one of the soil stabilization technique used in expansive soil [6]. It is also used for improvement of loading bearing capacity in marshy lands, marine clays, loose sand, silty or clayey sand, and compressible soils [7-16,33] and the rate of consolidation [17-20]. Unlike other soils, loss of strength is not the only

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aspect, but swelling and shrinkage is another serious problem with expansive soils; hence effect of inclusion of granular piles on swelling behaviour of expansive soils reinforced with granular pile needs to be studied**.**

In the present study, test beds of expansive soils were prepared at different initial moisture contents and the granular pile of sand was installed in these beds by the method of removal. Granular pile was constructed full length of mould. The initial moisture content, percentage fines, liquid limit, plasticity index and dry density are very important factors which affect the swelling pressure of expansive soils. The spacing between piles is generally expressed by *s/d* ratio, where, '*s*' is the spacing between piles and '*d*' is the effective influence diameter of the granular pile as per unit cell concept [21]. Empirical models were developed for estimating swelling pressure exerted by expansive soils without and with granular pile.

LITERATURE REVIEW

Unit cell concept

Granular piles should be installed preferably in an equilateral triangular pattern which gives the densest packing, although a square pattern may also be used.
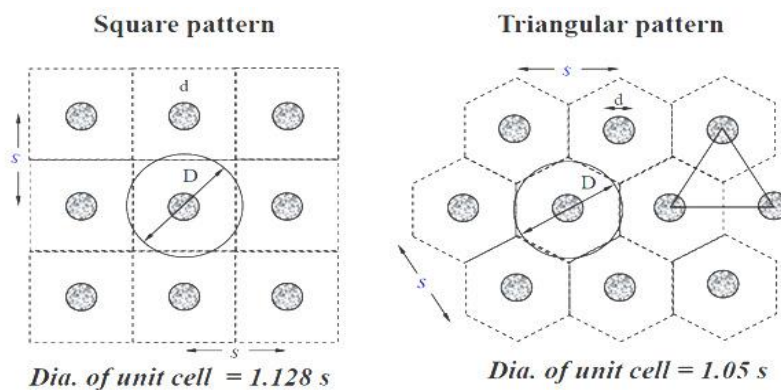

Fig.1- Typical granular piles arrangement (after IS 15284(Part-I): 2003[21])

Where, D_e = effective diameter and "s" is the spacing of granular piles.

Estimation swelling pressure of expansive soils

Regression models, for estimating swelling pressure of expansive soils were developed by many researchers, are shown in Table 1.

Tab.1 - Empirical relationships for estimating swelling pressure of expansive soils

Investigators	Empirical relationships	Remarks
[26]	Log P_s = -2.132 + 0.0208LL + 0.000565 γ_d - 0.0269w	P_s= kg/cm², γ_d=kg/m³
[27]	Sp = 3.5817 x 10² PI$^{1.12}$ (C²/w^2) + 3.7912	P_s=Psi
[28]	P_s= -227.27 + 2.14 w + 1.54LL + 72.49 γ_d	P_s= N/cm² γ_d=g/cm³
[29]	Log P_s =-4.812 + 0.01405PI + 2.394 γ_d-0.0163 w Log P_s =-5.020 + 0.01383PI + 2.356 γ_d	P_s= kg/cm², γ_d=g/cm³
[30]	Sp = 135 +2(C+PI $-w$)	P_s= kPa
[31]	Log Ps = 0.0276PI - 365.2118 $\gamma_d^{-2.4616}$ - 0.0320 w+ 2.2292 Log Ps = 0.0239PI - 1285.3723 $\gamma_d^{-3.2768}$ - 0.0396 + 2.3238	P_s= kPa γ_d= kN/m³
[32]	S_P= 1.9319 S$^{1.2897}$	S_P ≤ 300 kPa,

S= Swelling in percent, Sp/ P_s/ S_P= Swelling Pressure, LL= Liquid Limit (%), PI= Plasticity Index, γ_d= dry density of soil, w= water/moisture content, C= clay percent,

Most of the test performed for measurement of swelling pressure of expansive soil by Oedometer test. There is no arrangement to construction of granular pile in oedometer test.

In the present work, empirical models were developed for swelling pressure of test beds without pile and reinforced with granular pile.

DATA COLLECTION

The study has been conducted on six different expansive soils in which one was the natural black cotton soil and others were the mixture of black cotton soil with bentonite clay as presented in Table 2.

Tab. 2 - Expansive soils used in the present work

S.N.	Soil samples	Combination	Type of Soil
1	*SS1*	Black Cotton (BC) Soil	Natural
2	*SS2*	BC soil+ 10% Bentonite	Prepared
3	*SS3*	BC soil+ 20% Bentonite	Prepared
4	SS4	BC soil+ 30% Bentonite	Prepared
5	SS5	BC soil+ 40% Bentonite	Prepared
6	*SS6*	BC soil+ 50% Bentonite	Prepared

Liquid limit of these soils in range of 48-77%, plastic limit 22-36%, optimum moisture content 18-24%, and maximum dry density 15.4-14 kN/m³ were measured and procedure adopted to determination of these properties by IS 2720 (Part 5) [24], IS 2720 (Part 7) [23] respectively. The soils were classified as per IS: 1498-1970[22] and all were fall in CH i.e. clay of high plasticity and compressibility group. BC soil and bentonite both soils have expansive nature and check

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performance of granular pile in worst ground condition. So both soils were mixed and made new soils.

The beds of soils were prepared in cylindrical moulds of three different sizes as shown in Table 3.

The consistency of the soils was varied by changing the initial moisture content (w_i=15%, 17% and 20%). In the present study, granular piles were installed in an equilateral triangular pattern as suggested by IS 15284(Part-I): 2003[21]. Piles of three different diameters were installed in moulds of different diameters so as to have variation in *s/d* ratio of 2, 3 and 4 as given in Table 3.

Tab. 3 - Requirement of mould diameter for different s/d ratio

Mould Designation	*s/d* ratio	Pile diameter (mm)	Mould diameter (mm)	Mould Height (mm)
M_1	2	48	100	220
M_2	3	32	100	144
M_3	4	25	105	115

Single pile was installed as full length of mould to reduce the swelling pressure of expansive soils. Constant volume method was adopted for determination of swelling pressure of expansive soils. Sand was used as the granular pile forming material. The piles were formed by filling sand at two relative densities 40% and 60%. For different combinations of pile-soil, and *s/d* ratio, total 108 composite specimens were prepared for swelling pressure determination. Corresponding to three moulds and at three different moisture contents, test beds of six soils without piles were also made for swelling pressure determination. Thus in total 162 swelling pressure tests were conducted. Swelling pressure of soils were estimated for basic soil parameters in case of unreinforced pile test beds, and pile parameters in case of granular pile reinforced clay beds. Summary of model tests conducted for determination of swelling pressure as shown in Table 4.

Tab. 4 - Summary of model tests conducted

S.N.	Test Series	Parameter measured	Initial Water Content (%)	*s/d* ratio	Granular Pile Diameter(mm)	D_r of Sand	No. of test conducted		
							Without pile	With pile	Total
1	TS1	Swelling pressure	15,17,20	2	48	40%	18	18	54
						60%		18	
2	TS2	Swelling pressure	15,17,20	3	32	40%	18	18	54
						60%		18	
3	TS3	Swelling pressure	15,17,20	4	25	40%	18	18	54
						60%		18	
Grand Total							**54**	**108**	**162**

The test results have been analysed using multivariate regression analysis for estimation of swelling pressure (S_P in kN/m^2) and validation of regression models through 20% data set. The basic soil parameters considered were percentage fines (F), liquid limit (LL in %), plasticity index (PI), initial water content (w_i in %**)**, dry density (γ_d, in kN/m^3) and pile related parameters were *s/d* ratio (α) and relative density of sand (D$_r$, in kN/m^3).

ESTIMATION OF SWELLING PRESSURE OF EXPANSIVE SOILS

In order to estimate swelling pressure (S_P) of expansive soils reinforced with granular pile, multivariate regression analysis (MRA) has been performed on the test data. Swelling pressure of a soil depends on clay content, initial moisture content, density of the soil and the type of mineral present in the soil. Further, in case of an expansive soil reinforced with granular pile, the pile characteristics such as D$_r$ of the pile material, *s/d* ratio will also affect these properties. Hence MRA model for swelling pressure of soil bed without pile and with pile has been developed by taking following basic parameters as input.

(i) **Soil bed without pile**: Input parameters taken were percentage fines (F), liquid limit, (LL), plasticity index (PI), initial water content (w_i), and the dry density of the clay soil (γ_d). For different combinations of input parameters four equations have been developed and listed in Table 5. The performance parameters namely coefficient of correlation (R^2), root mean square error (RMSE) and mean absolute error (MAE) have been determined and listed in Table 6.

Tab. 5 - Regression models for swelling pressure of soil bed without granular pile

S.N.	Equation
(1)	S_P = 82.87+ 1.358 LL -4.802 w_i
(2)	S_P =4702.684 -41.328F -1.428LL + 3.018PI -39.135γ_d
(3)	S_P = 1972.077 -19.523F +1.993LL -0.303PI -4.802w_i
(4)	S_P =2140.064 -20.854F +1.784LL-0.100 PI -4.583w_i-2.389γ_d

Tab. 6 - Performance parameters for swelling pressure of soil bed without granular pile

Equation No.	R^2	RMSE	MAE
(1)	0.710	11.380	7.781
(2)	0.669	12.145	8.789
(3)	0.722	11.139	7.691
(4)	0.722	11.135	7.696

(ii) **Soil bed with pile:** In the case of test beds reinforced with granular pile, besides F, LL, PI, w_i and γ_d of the clay soil, the relative density of granular fill material, D$_r$ and *s/d* ratio (α) were also taken as input parameters. The developed equations, for different combinations of input parameters by MRA analysis, are shown in Table 7 and their performance parameters are given in Table 8.


Tab. 7 - Regression models for swelling pressure of soil bed with granular pile

S.N.	Equation
(5)	$S_P = 1612.817 - 9.691F - 1.657LL + 1.628PI - 30.890\gamma_d + 6.444\alpha - 82.963D_r$
(6)	$S_P = -971.806 + 11.939F + 0.393LL - 3.586w_i + 6.444\alpha - 82.963D_r$
(7)	$S_P = -546.056 + 7.519F + 1.042LL - 0.99PI - 3.586w_i + 6.444\alpha - 82.963D_r$
(8)	$S_P = 21.466 + 3.021F + 0.336LL - 0.307PI - 8.071\gamma_d - 2.846w_i + 6.444\alpha - 82.963D_r$

*Tab. 8 - Performance parameters for swelling pressure of soil bed with granular pile*

Equation No.	R^2	RMSE	MAE
(5)	0.892	4.073	3.396
(6)	0.933	3.211	2.529
(7)	0.945	2.890	2.280
(8)	0.951	2.742	2.237

From above mentioned regression models, it is found that equation (4), the incorporate parameters are percentage fines (F), liquid limit, (LL), plasticity index (PI), initial water content w_i, and the dry density of the clay soil (γ_d), gives the best correlation for estimation of swelling pressure (S_P) of the plain soil, shown in Figure 2(a).
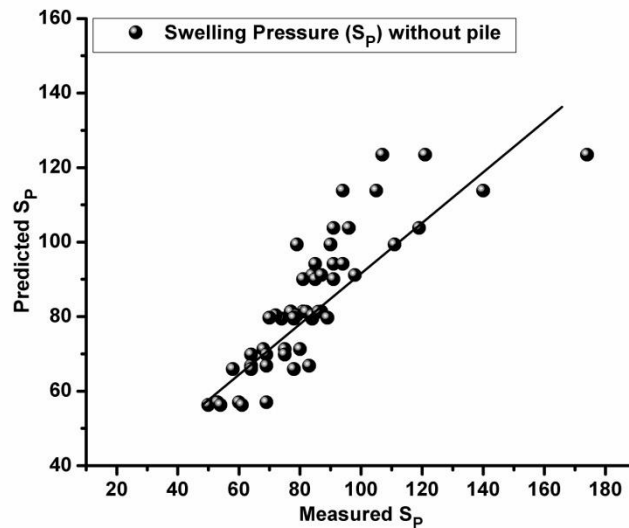
(a)

Fig.2 - Relationship between measured and predicted swelling pressure for (a) without pile and (b) with pile

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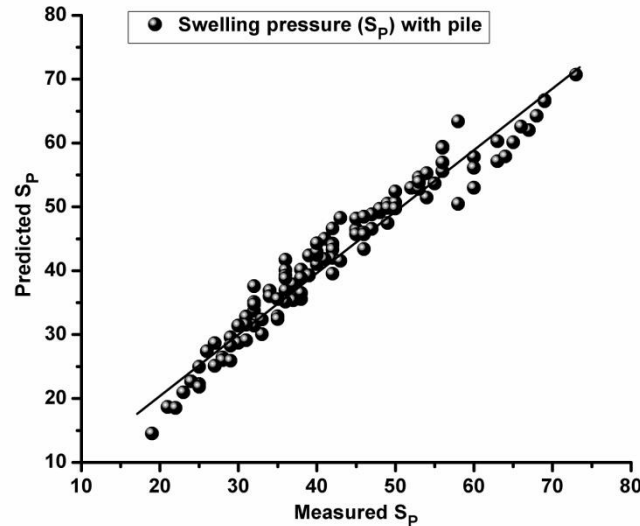
(b)

Fig.2 - Relationship between measured and predicted swelling pressure for (a) without pile; and (b) with pile

In case of expansive soil reinforced with granular pile, equation (8) estimate swelling pressure with high R^2= 0.951, and low RMSE=2.742, MAE= 2.237, shown in Fig. 2(b).

Therefore, Equation (4) and (8) may be used to estimate swelling pressure of soil alone and that reinforced with granular pile.

CONCLUSIONS

Six expansive soils having variation in liquid limit and plasticity index and expansiveness have been taken in the present study. These soils were prepared for installation of a pile for different combinations of *s/d* ratio, D_r of pile material and initial moisture content, w_i for the soils. The test data has been analysed and models for predicting swelling pressure of soils unreinforced and reinforced with granular material (pile) have been developed. Based on the analysis following conclusions are drawn:

1. Granular pile technique is promising technique for reducing the swelling pressure of expansive soil and it may install successfully at any season.

2. Regression equations that have high R^2, least RMSE and MAE values are:

(i)For test beds without pile

S_P =2140.064 -20.854F +1.784LL-0.100 PI -4.583w_i-2.389γ_d

R^2 =0.722, RMSE=11.135, MAE=7.696

(ii)For test beds without pile

S_P= 21.466+3.021F+0.336LL-0.307PI-8.071γ_d -2.846w_i +6.444α- 82.963 D_r

R^2 =0.951, RMSE=2.742, MAE=2.237

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