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Unit Swell Potential Concept for Expansive Soils and its Simple Evaluation

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Summary Prediction of vertical soil movements and ground heave of expansive soil deposits is an important requirement for taking appropriate measures in the design and construction of structures at such sites. Unit swell potential is a useful and versatile approach in characterising the expansive soils with respect to their degree of expansivity and the swelling behaviour. Besides, it enables easy prediction of soil movements during swelling. This paper outlines a simple method to evaluate the unit swelling potential with the help of easily determinable index property parameters like liquid limit, void ratio at liquid limit, shrinkage index and free swell index. The use of the correlations established from the laboratory investigations for estimation of the ground heave is illustrated by solving a typical field problem. Any field engineer on obtaining simple field data and easily determinable soil parameter values can use the method.

1. INTRODUCTION

The problem of damage to various civil engineering structures caused by expansive foundation soil is of serious concern in civil engineering practice all over the world. Parry's criteria (Ranjan & Rao, 1991) relate the nature and structural distress and damage to the potential ground heave likely to occur at a given site during annual dry-wet seasonal cycles. The prediction of ground heave of expansive sites has therefore assumed importance for designing and constructing damage free structures. Few approaches have been reported in literature for prediction of ground heave under some set of conditions (Ramarao et al 1988; Ramaswamy & Naser, 1984). However, the actual granulometric composition of the natural soil deposit and the environmental conditions, with respect to seasonal water content changes, are seldom taken into account in the available methods. It may be realised that the magnitude of swelling or heaving of a given construction site will be mainly governed by the granulometry of soil with respect to its fine and coarse fractions, cyclic seasonal water content changes, surcharge pressures or overburdens and the overall swellability characteristics of the fine grained ($<75\mu\text{m}$) fraction present in soil. The unit swell potential parameter advocated in recent years (Golait & Khanzode, 1995) is considered as the most rational characterisation of expansive soil mass enabling the prediction of soil movements and ground heave of the natural soil deposit under a given set of geomorphological and environmental conditions. As a further development of this approach and to make it more practice-oriented and simple in its use, even by any practicing civil engineers an attempt has been made to establish the

correlation of unit swell potential with easily determinable index property parameters of soil. The paper highlights this study.

2. DEFINITION OF FIELD PROBLEM

A semi-infinite expansive field soil deposit within the active zone undergoes mainly vertical soil movements during swelling and shrinking caused by water content changes pertaining to wet and dry seasons of the year. The extent of these soil movements and ground heave of the deposit is considered as the index of the 'trouble potential' of the expansive soil site for construction activity. The evaluation of these soil movements is therefore required to be made by simple field investigations and simple laboratory testing of soil samples. During the subsurface exploration, the water contents and bulk unit weights of soil at various depths, up to or slightly beyond the active zone, can be easily determined during the summer season and the rainy season. Thus, the water content profiles and the unit weight profiles for the summer and rainy season for a given site can be developed. This enables one to obtain data on actual water content changes within the depth of the active zone. Undisturbed soil samples taken during the exploration programme can be tested in the laboratory for determining the swelling parameters of the soils. From the information obtained from these field investigations and simple laboratory testing it is required to predict the vertical soil movements and the ground heave for the deposit due to cyclic seasonal environmental conditions. The unit swell potential concept has proved to be a simple, realistic and versatile tool in this respect.

3. UNIT SWELL POTENTIAL

It has been reported earlier (Golait & Kishore, 1990) that the specific volume change of soil from a dry to wet state, and also from the wet to swollen condition, exhibits a linear relationship. It is therefore considered that the vertical swelling of laterally confined soil is linearly proportional to the water content change, Δw within the whole range of Δw from the fully shrunken dry state to the fully swollen condition. The volume change characteristic of soil under given surcharge pressure can thus be appropriately expressed in terms of percentage volumetric strain per unit change in its water content (i.e. $\Delta w = 1\%$). This characteristic is indicated by the parameter 'unit swell potential', P_{su} , which is expressed as;

$$P_{su} = \frac{\Delta h_r}{h \cdot \Delta w} \quad (1)$$

where: h = initial thickness of a laterally confined soil in its fully shrunken dry state;
 Δh_r = increase in height of the sample under given surcharge pressure on its full saturation and swelling; and
 Δw = total change in water content from dry state to fully swollen condition.

The unit swell potential of soil therefore depends on the surcharge pressure acting on the soil during swelling. It has been found that the effect of the surcharge pressure, p , on the unit swell potential of the soil is given by the expression :

$$P_{su} = (P_{su})_o - 0.275 \cdot \log(p/p_o) \quad (2)$$

Where: $(P_{su})_o$ = value of unit swell potential under a nominal surcharge pressure p_o (a small seating load) of 1 psi or 0.07 kg/cm². This is designated as the 'limiting unit swell potential'.

For a given soil deposit with known unit weight and water content profiles, and with known overburden surcharge pressures, the problem therefore reduces to knowing or determining the limiting unit swell potential value of the soil at various depths. Based on this concept of unit swell potential, Golait & Khanzode (1995) developed the following equation for estimating the total overall ground heave ΔH of insitu deposit:

$$\Delta H = \sum_{i=1}^n (h_i \cdot \Delta w_i (P_{su})_{oi} - 0.275 \cdot \log(p_i/p_o)) \quad (3)$$

where: n = the number of sublayers of soil within the active zone;
 h_i = initial thickness of any i^{th} sublayer;

Δw_i = average water content change in i^{th} layer during the summer - rainy seasonal cycle;
 $(P_{su})_{oi}$ = limiting unit swell potential value for i^{th} sublayer; and
 p_i = average overburden pressure for i^{th} layer.

It is realised that the computation of vertical soil movements and the ground heave of the expansive soil deposit requires determination of the limiting unit swell potential of the soil within various sublayers in the active zone. The test specified to determine directly $(P_{su})_o$ in the laboratory is a very long duration test and it requires careful and skillful preparation of sample, testing, observations, etc. It is therefore thought essential to evaluate the limiting unit swell potential indirectly from the simple index property tests by establishing the correlation between them. The liquid limit, void ratio at liquid limit, shrinkage index and the free swell index are considered as the relevant index property parameters signifying the swellability characteristics in the form of limiting unit swell potential.

4. LABORATORY INVESTIGATIONS

A detailed investigation programme under controlled laboratory conditions was undertaken to establish the correlations of limiting unit swell potential with the main index property parameters of a large number of expansive soil samples falling in a wide range of their degree of expansivity. The samples had coarse-grained fractions from 0 to 40% and the liquid limit ranging from 45 to 125%. The tests were conducted on all the samples to determine the liquid limit w_L , void ratio at liquid limit e_L , free swell index FSI_{OK} and limiting unit swell potential $(P_{su})_o$. Free swell index was determined as per the method suggested by Golait & Kishore (1990) to take into account the volume increase in the soil from the fully shrunken dry state in summer to the unrestrained freely swollen condition. The observed results of the investigation are shown in Table 1.

5. ANALYSIS OF TEST RESULTS

As can be seen from the results given in Table 1, the limiting unit swell potential value, in general, increases with increase in the index property parameters, viz. liquid limit, shrinkage index, void ratio at liquid limit, free swell index and potential specific volume change Δv . Various linear and nonlinear relationships between them were evaluated and it was found that the results plotted on log-log scale showed almost linear variations (Figs. 1, 2, 3, 4 & 5). It is realised that the few samples which belonged to negligible or low expansivity soils had little effect in establishing the general trends. The general correlations between the limiting unit swell potential and the index property parameters can thus be expressed as:

Table 1. Observed index properties and limiting unit swell potential values.

Sample No.	Designation	Liquid Limit (w_L)	Void Ratio at Liquid Limit (e_L)	Shrinkage Index (I_s)	Free Swell Index (FSI_{ck})	Potential Specific Volume Change (Δv) cm^3/g	Limiting Unit Swell Potential ($Psu)_o$
1	F.1 - 0	72.0	194.11	53.5	234.7	1.294	0.674
2	F.1 - 20	59.2	159.19	44.8	204.1	1.104	0.660
3	F.1 - 40	44.8	120.64	30.0	144.9	0.725	0.459
4	F.2 - 0	73.2	196.47	55.4	246.6	1.353	0.648
5	F.3 - 0	74.0	200.98	56.1	254.6	1.358	0.686
6	F.3 - 20	60.6	163.74	46.6	215.2	1.201	0.662
7	F.3 - 40	45.7	123.98	31.9	150.4	0.762	0.485
8	F.5 - 20	61.4	166.68	47.9	245.0	1.147	0.608
9	F.6 - 0	78.6	214.74	66.8	305.3	1.448	0.691
10	F.6 - 20	62.3	170.70	50.1	250.0	1.219	0.627
11	F.6 - 40	46.8	128.84	34.5	182.3	0.865	0.519
12	F.8 - 0	95.0	256.50	83.9	425.4	2.300	0.724
13	F.8 - 20	76.0	207.33	64.7	325.3	1.440	0.698
14	F.8 - 40	58.5	159.94	46.4	209.9	1.230	0.578
15	F.9 - 0	124.5	333.40	112.7	593.6	3.036	0.749
16	F.9 - 20	91.0	247.16	79.5	445.5	2.236	0.701
17	F.9 - 40	66.2	180.06	54.4	267.7	1.445	0.670

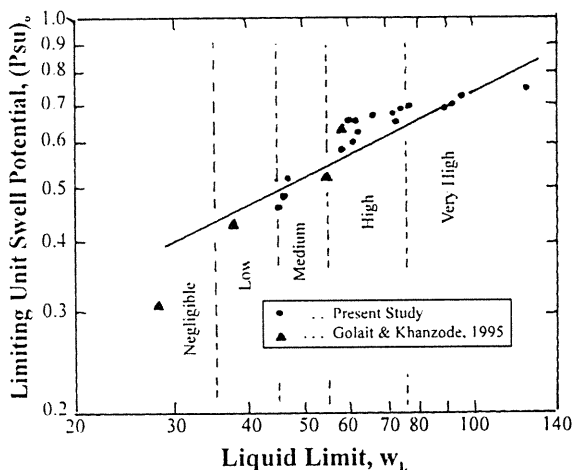


Figure 1. Variation of $(Psu)_o$ with w_L

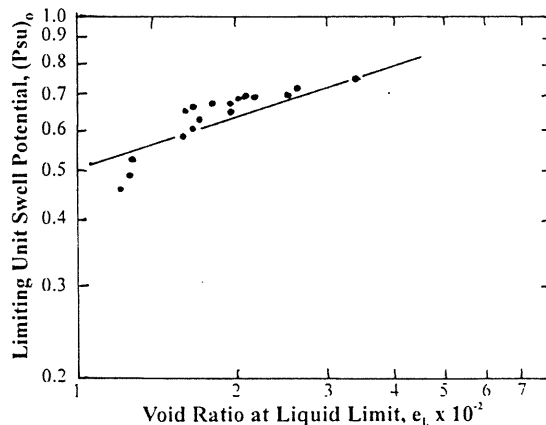


Figure 3. Variation of $(Psu)_o$ with e_L .

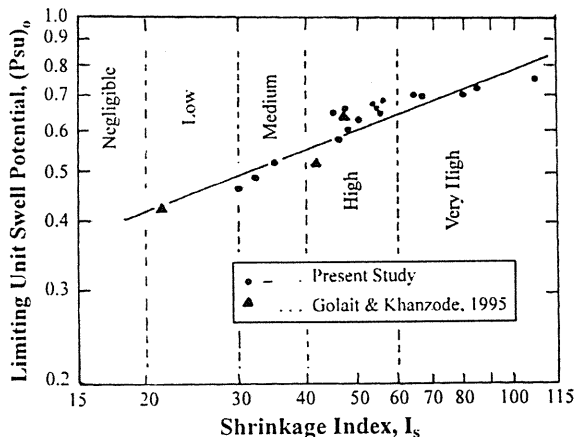


Figure 2. Variation of $(Psu)_o$ with I_s

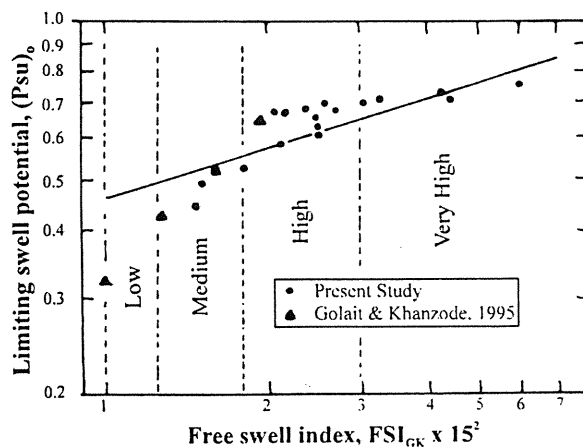


Figure 4. Variation of $(Psu)_o$ with FSI_{ck}

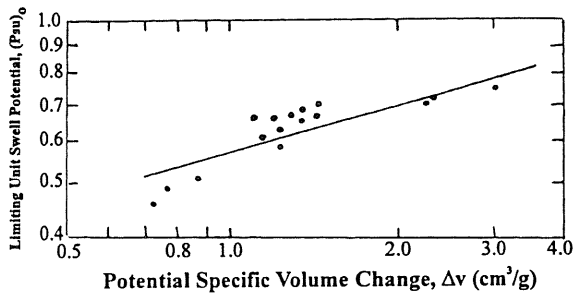


Figure 5. Variation of $(P_{su})_o$ with Δv

$$(P_{su})_o = 0.068 (w_L)^{0.522} \quad (4)$$

$$(P_{su})_o = 0.133 (I_s)^{0.385} \quad (5)$$

$$(P_{su})_o = 0.109 (e_L)^{0.330} \quad (6)$$

$$(P_{su})_o = 0.111 (FSI_{GK})^{0.310} \quad (7)$$

In order to determine the degree of accuracy in predicting the swelling property of expansive soil from the above correlations, the values of $(P_{su})_o$ of all 17 samples were calculated from their known values of index property parameters and the estimated $(P_{su})_o$ of a sample was taken as the average of its four calculated $(P_{su})_o$ values. In a similar way the percentage error in estimating $(P_{su})_o$ with respect to actual or observed $(P_{su})_o$ was determined for all the samples and the distribution is shown in Fig. 6. It is seen that in most of the cases the error is in the range of 0 to $\pm 10\%$.

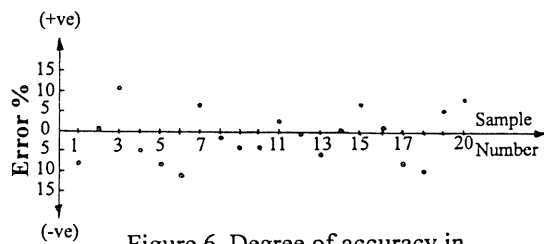


Figure 6. Degree of accuracy in estimation of $(P_{su})_o$

6. CLASSIFICATION OF EXPANSIVE SOIL

The classification of expansive soils with respect to their degree of expansivity is reported in the literature and is mainly based on shrinkage limit, soil activity, shrinkage index, etc. (Holtz & Gibbs, 1956; Seed et al., 1962; Ranganatham & Satyanarayana, 1965; Merwe, 1975). The liquid limit, shrinkage index, free swell index and the limiting unit swell potential are considered by the authors to be more rational parameters for characterising the degree of expansivity of soil. Considering the degree of expansivity of field deposits in five categories, viz. negligible, low, medium, high and very high, the suggested classification based on the present study and the earlier work (Golait & Khanzode, 1995) is

shown in Table 2. The sample data (17 samples from the present study and 4 samples from previous study by Golait & Khanzode, 1995) considered in the analysis indicates realistically the number of samples in negligible, low, medium, high and very high categories as 1, 3, 3, 8 & 6 respectively.

Table 2. Proposed classification of expansive soil.

Degree of Expansivity	Limiting Unit Swell Potential $(P_{su})_n$	Liquid Limit (w_L)	Shrinkage Index I_s	Free Swell Index FSI_{GK}
Negligible	<0.400	<35	<20	<100
Low	0.40-0.50	35-45	20-30	100-125
Medium	0.50-0.59	45-55	30-40	125-175
High	0.59-0.68	55-75	40-60	175-300
Very High	>0.68	>75	>60	>300

7. SUGGESTED PROCEDURE FOR ESTIMATING GROUND HEAVE

A very simple method for predicting the ground heave of an expansive soil site is suggested by making use of the results of the present study and the earlier investigations by Golait & Khanzode (1995) and Golait et al (1998). The various stages in the procedure are given below:

- i. Obtain the water content profile and the unit weight profile of soil deposit up to or slightly below the depth of active zone of expansive soil site, both for the dry summer season and for the rainy season.
- ii. During site exploration, obtain the soil samples from various depths (conveniently at every 0.5m interval) and determine, by wet sieving the sample through 75 μ m sieve, the percentage of fine active fraction (F) and the coarse grained content (I).
- iii. Conduct the index property tests on the fine fraction of the sample and determine the parameters, viz. liquid limit (w_{Lr}) , shrinkage index I_{sr} and free swell index $(FSI_{GK})_r$.
- iv. For a field soil with granulometry of known F & I, the actual index properties (suppressed values due to the presence of coarse particles content I) are estimated from the following equations (Golait et al., 1998):

$$w_L = w_{Lr} (1.0 - 0.012 \cdot I) + 0.20 \cdot I \quad (8)$$

$$I_s = I_{sr} (1.0 - 0.012 \cdot I) + 0.08 \cdot I \quad (9)$$

$$FSI_{GK} = (FSI_{GK})_r (1.0 - 0.0175 \cdot I) + 1.95 \cdot I \quad (10)$$

The e_L is determined from w_L and specific gravity of solids G .

- v. Consider the active zone (where changes in water content during summer and rainy seasons become almost zero) to be of n number of sublayers (say of 0.5m thick) and for each such sublayer the following computations are carried out:

- determine the limiting unit swell potential values from Equations 4, 5, 6 & 7 and take their average as $(P_{su})_o$ for further computations.
- calculate the average water content change Δw and the average overburden pressure p .
- calculate the predicted vertical movement (heave) by:

$$\Delta h = (h \cdot \Delta w \cdot (P_{su})_o - 0.275 \log(p/p_o)) \quad (11)$$

- vi. Calculate the ground heave at the surface of deposit from Equation (3).

8. A TYPICAL PROBLEM OF GROUND HEAVE ESTIMATION

This simplified procedure is illustrated by solving a typical problem of ground heave estimation for an expansive soil site found generally in the Vidarbha region of Maharashtra in India. The known data, in a generalised form, are given in Fig. 7 (Katti & Katti, 1994) and Table 3. For a sublayer 1, the values of liquid limit w_L , shrinkage index I_s , and free swell index FSI_{GK} as calculated from Equations 8, 9 & 10 are 53.1, 37.8 & 181.5 respectively. The void ratio at liquid limit, with known G , works out to be 1.43. Using Equations 4, 5, 6 & 7, the limiting unit swell potential values are computed as 0.5409, 0.5385, 0.5566 & 0.5612. Their average value of 0.5475 is thus considered as $(P_{su})_o$ for computation of vertical soil movement, Δh of sublayer 1. From the data in Fig. 7, the average overburden pressure, p , is 0.0903 kg/cm^2 and by taking p_o as 0.07 kg/cm^2 , the vertical soil movement due to swelling of sublayer 1 (Eqn. 11) works out to be 9.48 cm. Similar computations are made for all the sublayers. The computational summary is shown in Table 4. The resulting nature of vertical soil movement at various depths and the total ground heave for the expansive soil site are indicated in Fig. 8.

Table 3. Known data for a typical expansive site.

Sublayer No.	Thickness h (cm)	Specific Gravity G	Coarse Fraction I (%)	Index Properties of Fine Fraction		
				Liquid Limit w_{Lr}	Shrinkage Index I_{sr}	Free Swell Index $(FSI_{GK})_r$
1	50	2.70	29.3	72.9	54.7	255.3
2	50	2.65	20.1	73.2	49.9	256.1
3	50	2.69	16.8	78.5	66.8	310.5
4	50	2.72	8.5	69.0	53.1	248.0
5	50	2.75	24.0	50.2	34.6	180.1
6	50	2.69	19.6	58.4	45.8	209.2
7	50	2.68	5.20	79.1	68.3	308.7

Table 4. Summary of computations.

Sublayer No.	Av. Water content change, Δw	Av. overburden pressure p (kg/cm^2)	Natural Soil Properties			Limiting unit swell Potential $(P_{su})_o$	Δh (cm)	Soil movement at top level of layer (cm)
			w_L	I_s	FSI_{GK}			
1	34.75	0.0903	53.10	37.80	181.50	0.5475	9.4825	24.0523
2	22.00	0.1810	59.56	33.50	205.20	0.5700	6.1565	14.5698
3	13.75	0.2725	66.03	54.67	251.97	0.6125	4.0486	8.4133
4	8.75	0.3626	63.66	48.36	227.68	0.5950	2.4067	4.3647
5	5.50	0.4517	40.54	26.56	151.26	0.4900	1.1248	1.9580
6	3.50	0.5404	48.58	36.60	175.66	0.5350	0.6922	0.8332
7	1.25	0.6284	75.20	64.45	290.75	0.6450	0.1410	0.1410

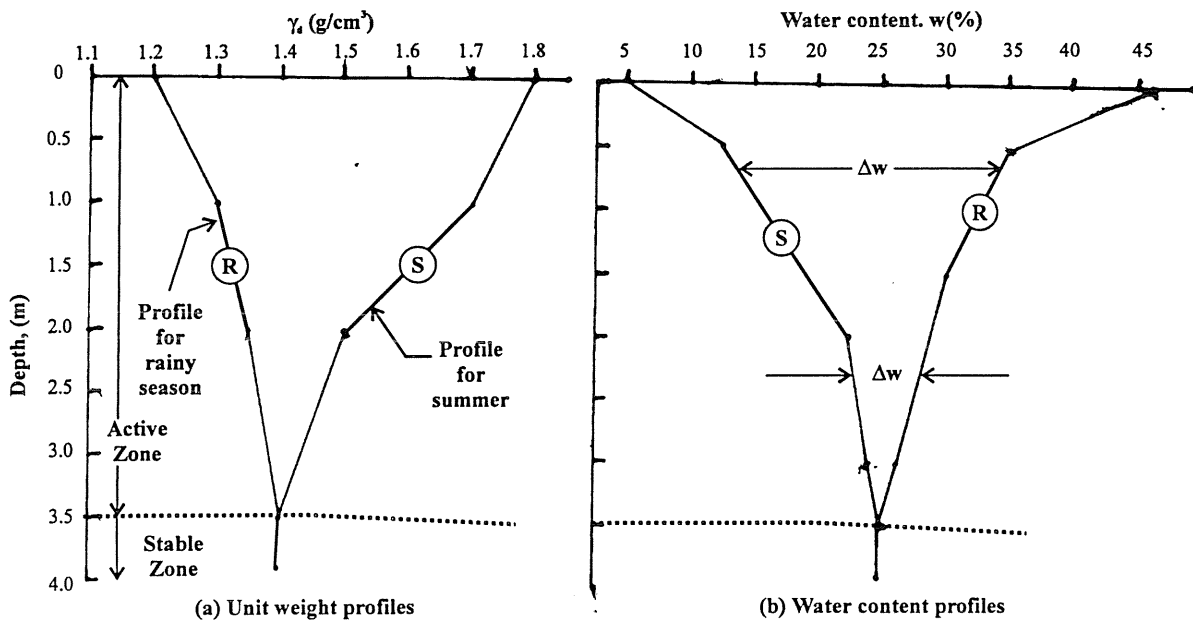


Figure 7. Typical profiles for water contents and unit weights

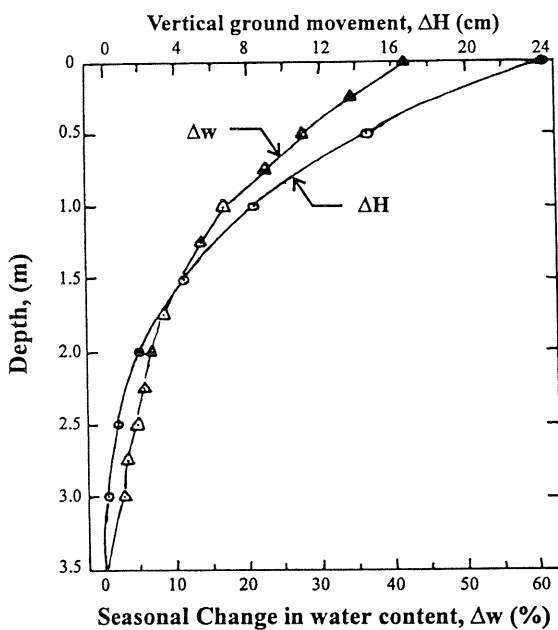


Figure 8. Predicted soil movements & ground heave

CONCLUSIONS

The ‘unit swell potential’ is a useful and rational concept for characterising expansive soils and it enables easy prediction of vertical soil movements and the ground heave of the deposit. The correlations established from the present study (Eqns. 4, 5, 6 & 7) help in evaluating the limiting unit swell potential from the simple and easily determinable index property parameters, viz. liquid limit, shrinkage index, void ratio at liquid limit and free swell index. The proposed method of ground heave estimation takes into account the dilution effect of coarse particles content, the electrochemical activity of fine

(<75 μ m) active fraction in soil, the in-situ water content changes at site, the effect of overburden pressure etc. As most of the important field situations – both geomorphological and environmental – are simulated in the development of the concept, the ‘unit swell potential’ is considered to be a versatile parameter in evaluating the characteristics and behaviour of natural expansive soil deposits.

9. ACKNOWLEDGEMENTS

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