Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-341

Evaluation of predicted equations for swelling potential

Evaluation des équations prédîtes pour le gonflement potentiel

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ABSTRACT
Attempts have been made by various researchers to suggest methods for identification and classification of expansive soils. This paper is concerned with the comparison of the predicted equations of swelling potential of expansive soils. A comparison between nine different predicted equations for swell percent was carried out. The results brought from each equation are later compared to experimental results for soil samples obtained from three different site locations chosen according to their swelling potential: moderate, high and very high. A conclusion for the use of the predicted equations based on these comparisons is outlined in this work.
Keywords: expansive soils, swelling potential, clay, predicted equations, Sudan

RÉSUMÉE
Des tentatives ont été faites par plusieurs chercheurs dans le but de suggérer des méthodes pour identifier et classifier des sols expansives: cet article traite la comparaison des équations prédites des gonflement potentiel des sols expansifs. Une comparaison entre neuf équations prédites pour des pourcentages du gonflement a été mené dans ce travail. Le résultats obtenus de chaque équation ont été comparés plus tard à des résultats expérimentés du selon leur potentiel due gonflement : modéré; haut et très haut. Une conclusion pour l'utilisation des équations prédites basée sur ces comparaisons sont données en grande lignes dans ce travail.
Mots clés: sol expansif; gonflement potentiel, argile (terre battue) équations prédites, Soudan.

1 INTRODUCTION

Some clay minerals have a special property which allows them to incorporate water molecules into their structure. This water changes the dimension of the clay particles as it goes into or out of the clay structure. These are called expansive clay soils. Thus, Expansive soils are defined as those clayey materials which exhibit significant volume changes caused by changes in the subsoil moisture. The expansive soil swells if its moisture content increases and it shrinks if its moisture content decreases. This phenomenon depends in first line on the mineralogical combination of the clay soils. These expanding clays are also known as smectites. Montmorillonite is the most prominent member of the smectite group, with other members including nontronite, saponite, hectorite and sauconite (Singer and Munns, 1992).

It is important to identify expansive soils at early stages of a project to allow for appropriate sampling, testing and design in later stages. Hence the soil investigation must comprise two important phases: First is the recognition and identification of the soil as expansive soil and the second is sampling and measurement of material properties to be used as the basis for design predictions.

One of the important aspects of the laboratory testing of expansive soils is to classify them according to their degree of potential expansiveness. There are many different ways to classify the expansive soil based on laboratory testing. The most commonly used system is to classify soil as having a very low, low, medium, high, or very high expansive potential. In engineering practice standard classification results, such as grain size analysis and Atterberg limits, are used as basis for the common identification and classification schemes.

2 IDENTIFICATION OF EXPANSIVE SOILS

The purpose of identification of expansive soil is to provide rational bases for soil characterization, to warn against expected potential hazards and help in foundation selection. Clay minerals can be identified using a variety of techniques. The most commonly employed techniques are: Visual identification, Mineralogy Identification, Indirect Methods (index properties, Potential Volume Change (PVC), Activity (Ac)) and Direct Methods (Laboratory tests), (Nelson et al., 1990).

The visual identification should preferably be done at the field site. The objective of the site visit should be to gain enough information about the history of the site. Investigation of the structures in the vicinity of the site helps a lot in understanding the behaviour of the soil. Shrinkage cracks in the ground surface are a good indicator of the activity of the expansive clay soil. In the dry state, expansive soil is very hard and produces a glazed surface when cut by scraper or shovel. In the case of wetted state, the soil becomes soft, cohesive, and sticky and leaves a powdery residue after moulding with hand. Presence of vegetation can be an indicator of the existence of the expansive soil. Local experiences usually reveal that certain type of plants tend to occur more frequently on soils having either high or low expansion potential.

The minerals comprising clay are hydrated aluminium, iron or magnesium silicates combined in complicated crystalline structures which can be divided into three basic types to give a means of classification. The structure is built up from two basic units, the silica tetrahedron and the octahedral hydroxide of aluminium (or of iron or magnesium). Clay mineralogy is a fundamental factor controlling expansive soil behaviour. The more common recent techniques used to identify clay minerals of expansive soils are: X-Ray diffraction, Differential thermal analysis (DTA), Dye absorption, Chemical analysis and Electron Microscope resolution (Grim, 1968, Chen, 1975).

Index Properties are generally used for identification of expansive soils. Referring to the investigations carried out on the expansive soils, many empirical correlations between the simple physical and mechanical properties of the expansive soils and their swelling characteristics are available. These properties include Atterberg limits, linear shrinkage and colloid content. Because this type of identification is related to great extend to the parameter used in classification of the soil, more details of these correlation are presented in the next sections

3 EVALUATION OF SWELLING POTENTIAL

The purpose of an identification and classification system for expansive soils is to qualitatively characterise the potential volume change behaviour and to forewarn the engineer in the planning stage about the problems associated with these soils. Approaches suggested for identification and classification of expansive soils are related to experience and/or direct measured volume change behaviour with Atterberg limits. However, few methods also involve other properties such as colloidal content, specific surface area, etc. Various methods have been proposed for characterizing the expansive soil behaviour. These methods can be divided broadly in two main types namely: direct and indirect methods.

3.1 *Direct methods*

In this method the swell percent and the swelling pressure are directly measured in the laboratory. There are two main "common" methods proposed to measure the values of swell percent and swelling pressure: swell-consolidation method and constant volume method.

3.2 *Indirect method*

This group includes all the method in which a measured soil property is related to either the swell percent or swelling pressure of the soil by a simple empirical or semi empirical mathematical expression or graphical illustration. The value of the measured soil properties can then be substituted to estimate the swelling percent or pressure. A large number of research works concerned with the classification of expansive soil are available in literature. The researchers used in these methods one or more of the Atterberg limits as well as the shrinkage index, linear shrinkage, initial moisture content and clay fraction.

4 EXPERIMENTAL WORK

Three disturbed soil samples were taken from three different areas in Sudan namely: AlGadarif (in east Sudan), Malakal (south Sudan), and Alnishishiba (central Sudan). The samples were taken within the active zone at depths 1.0m, 1.0m, and 0.5m respectively. Different experimental tests in laboratory were carried out on these samples including sieve analysis, hydrometer, Atterberg limits, compaction, specific gravity, consolidated undrained Triaxial Compression, constant volume, swell and reload tests. The experimental data produced from these tests are presented in Table (1). This data is used later in the predicted equations of swelling potential suggested by various researchers.

The most reliable approach for predicting behaviour of potentially expansive soils is the direct measurement of swelling. The swelling pressure and the swell percent are the most commonly used methods to evaluate potentiality of swelling clays. Many laboratory procedures have been proposed to estimate these two parameters. The most common ones are the constant volume and swell and reload method. The results of swell percent for the three collected samples are presented in Table (2).

Based on Hamadto and Van Der Merrwe (1964) the three samples can be classified as:

Algadarif medium potential expansiveness.
Malakal high potential expansiveness.
Alnishishiba very high potential expansiveness.

Table (1): Experimental data for the three sides

Soil Location / Properties	AlGadarif	Malakal	Alnishishiba
Depth of sample (m)	1	1	0.5
Liquid limit (L.L.) %	47	58	64
Plastic limit (P.L.) %	26	24	31
Plastic Index (P.I.) %	21	34	33
Shrinkage limit (S.L.) %	11.75	9.75	8.25
Shrinkage index (S.I.) %	35.25	48.25	33.75
Optimum moisture content (O.M.C.) %	19.75	14.5	21
Maximum dry density (γ_d) gm/cm3	1.554	1.67	1.43
Clay content (C) %	34	44	27
Specific gravity (SG)	2.696	2.695	2.79
Angle of internal friction (ϕ')	3	22	2
Cohesion (c)	1.1	0.7	2.05
Void ratio (e)	.66	0.67	0.5859

Table (2): Measured values of swell percent and swelling pressure

Location	Swell percent (%)	Potential swell
AlGdarif	2.5	Medium
Malakal	7.6	High
Alnishishiba	12.5	Very high

5 PREDICTION OF SWELLING POTENTIAL

Many investigations studied intensively the behaviour of expansive soil and developed different techniques for predicting soil heave. These methods are used aiming to arrive at easy and simplified procedures to be convincingly utilized in heave prediction, and preserving the time required to perform Oedometer tests for estimating soil volume change. In this study nine different empirical predicted equations for swell percent were chosen.

These equations are useful in distinguishing between soils of different potential swelling. They use the basic engineering soil indices such as liquid limit, plasticity index or clay content in evaluating the soil percent. Some of the correlations between swell percent, liquid limit, plasticity index, and initial water contents established by various research workers are presented in this section. The following notations are used in these equations

S = Swell percent
w = Initial water content
LL = Liquid limit
SL = shrinkage limit
PI = Plasticity index

Seed, Woodward and Lundgren (11) used only the plastic index to predict the swell percent:

$$S = 0.00216\ PI^{2.44} \tag{1}$$

Ranganatham and Satyanarayana(1965):

$$S = 0.00413\ SI^{2.67} \tag{2}$$

Where
SI shrinkage index = $LL - SL$
SL shrinkage limit

Nayak and Christensen(1971):

$$S = 0.0229\ PI^{1.45}\ c/w + 6.38 \tag{3}$$

Where
c clay content
w initial moisture content
PI Plasticity Index

This equation was derived from analysis of test data from 18 artificial soil samples compacted at optimum moisture content by the standard proctor method and allowed to swell under a surcharge load of 1 psi (7kPa).

Vijayvergiya and Ghazzaly equation (1973) was based on density:

$$LogSP = \frac{1}{19.5}\left[\delta_d + 0.65LL - 130.5\right] \quad (4)$$

δ_d dry density lb/ft^3

Vijayvergiya and Ghazzaly equation(1973) based on moisture content:

$$LogSP = \frac{1}{12}\left[0.4LL - W + 5.5\right] \quad (5)$$

Equation (4) and (5) were based on test swell under a surcharge load of 1.5psi (10.5kPa)

Schneider and Poor equation(1974):

$$S = 0.66x\,10^{(0.9\,PI/w - 1.19)} \quad (6)$$

Brackley equation (1975):

This equation was developed from results of oedometer test on compacted residual black clay (Onderstepoort, South Africa). Samples under a surcharge load of 1kPa.

$$SP = \left[5.3 - \frac{147e}{PI} - \log P\right] * \left[0.525PI + 4.1 - 0.85w\right] \quad (7)$$

e void ratio
P applied load kPa

Chen equation (1975):

$$S = 0.2558\ e^{0.08381\,PI} \quad (8)$$

Weston equation (1980):

$$S = 0.000195\,LL^{4.17}\,w^{-2.33} \quad (9)$$

Data for this equation are collected from undisturbed residual black clay soil samples with very wide ranges of engineering indices and this method therefore may be proved to be very useful for predicting the swelling of both natural and compacted soils. Samples were tested under a surcharge load of 1kPa.

6 COMPARISON OF THE PREDICTED AND EXPERIMENTAL RESULTS

The results of the laboratory testing on samples collected from AlGadarif, Malakal and Alnishishiba site, Table(1) is used to evaluate the prediction equations for Swell percent. The computed values of swell percent and swelling pressure according to these parameters using the prediction equations are presented in Table (3) and (4) respectively.

Table (3): Swell Percent values from predicted equations

Equations	Values of Swell Percent		
	Al Gadarif	Malakal	Alnishishiba
Equation (1)	3.636	11.783	10.96
Equation (2)	1.36	3.139	4.62
Equation (3)	9.638	17.93	11.46
Equation (4)	0.707	3.867	1.045
Equation (5)	3.434	23.805	11.35
Equation (6)	0.383	5.494	1.106
Equation (7)	0.8503	13.703	6.565
Equation (8)	1.487	4.42	4.065
Equation (9)	1.754	8.661	5.509

6.1 *Equation used for predicting Swell Percent*

1. Seed Wood Equation:
   In this equation the plasticity index is the only variable used. The values of swell percent deduced from this equation are range of (87% - 155%) of the measured ones, Table(5), (6) and (7).
   This equation seems to have good results in soil with medium and high expansion potential (AlGadarif and Malakal), but in the very high expansion potential (Alnishishiba) unacceptable results are obtained although a high plastic index value is deduced.
2. Rangatham and Satyanavayana equation:
   This equation is based on shrinkage index. The predicted values of swell percent with this equation are small due to the small values of shrinkage limit measured at the three locations. The values of swell percent are ranged from(37%-54%) of the measured ones.
3. Nayak and Chirsten equation:
   This equation depends on plasticity index, clay content and moisture content. The results obtained by this equation compared to the measured ones indicate that it has no stable trends. It may give high values of swell percent in case of moderate and high expansion potential soils and low ones in case of very high expansion potential.

Table (5): Comparison of predicted equations results and measured values at AlGadarif

Predicted equation for	Equation No.	Ratio P/M	Error (%)
Swell Percent	(1)	1.4544	+ 43.6
	(2)	0.544	- 45.6
	(3)	3.85	+ 285.5
	(4)	0.28	- 71.7
	(5)	1.37	+ 37.4
	(6)	0.15	- 84.6
	(7)	0.34	- 66.0
	(8)	0.594	- 40.5
	(9)	0.7	- 29.8

P/M =Predicted value/measured value Error= 100 x (P-M)/M

Table (6): Comparison of predicted equations results and measured values at Malakal

Predicted equation for	Equation No.	Ratio P/M	Error
Swell Percent	(1)	1.55	+ 55.0
	(2)	0.415	- 58.7
	(3)	2.359	+ 135.9
	(4)	0.509	- 49.1
	(5)	3.132	+ 213.2
	(6)	0.723	- 27.7
	(7)	1.803	+ 80.3
	(8)	0.58	- 41.8
	(9)	1.139	+ 13.9

Table(7): Comparison of predicted equations results and measured values at Alnishishiba

Predicted equation for	Equation No.	Ratio P/M	Error
Swell Percent	(1)	0.876	- 12.4
	(2)	0.3696	- 63.8
	(3)	0.9168	- 8.3
	(4)	0.0836	- 91.6
	(5)	0.908	- 9.2
	(6)	0.088	- 91.2
	(7)	0.525	- 47.5
	(8)	0.325	- 67.5
	(9)	0.441	- 55.9

4. Vijiayrergiya and Ghazzaly equation
   It depends on dry density and liquid limit. It underestimated the values of percent swell in all tested cases.
5. Vijiayrergiya and Ghazzaly equation
   This equation based on moisture content. In this equation the values of predicted swell percent are ranged between (91% - 313%) of the measured ones.
6. Schneider and Poor equation
   It depends on the plasticity index and water content. It doesn't give good results for the three locations. The results ranged between (9% - 72%) of the measured ones.
7. Barckely equation
   This equation underestimated the values of swell percent in cases of moderate and very high expansion potential. The predicted swell percent in high expansion soils (Malakal) is 180% of the measured ones.
8. Chen equation
   This equation depends on plasticity index. All the values of swell percent are underestimated. The results ranged between (33% - 59%) of the measured ones.
9. Weston equation
   This equation depends on liquid limit and water content. It gives good estimate for the swell percent of high expansion potential locations(Malakal). It gives unacceptable results, in spite of the high value of liquid limit, in the very high expansion potential.

6.2 *General Discussion*

Most of the studied predicted equations were based on correlating the effects of one or two variable on the swelling behaviour of the soil. Thus each equation while seeming adequate for known conditions in the area where it was developed showed several limitations when used as universal method. Most of the studied equations are not suitable for the samples taken from Sudan. This may be due to the reason that Sudan is located in semi arid region where the annual potential evapotranspiration is about 1800 mm and mean annual precipitation is about 179 mm. The values obtained for Malakal region appear to be closer to the measured values due to weather conditions in south Sudan. The difference in the type of clay soil, which is not considered in all equations, may also affect the results.

The values of swell percent obtained from all equations increased according to increase in the potential expansions of the samples. The most suitable equations for predicting swell percent in medium swelling potential in Sudan (i.e. AlGadarif) is Vijayvergiya and Ghazzaly equation based on moisture content. For high swelling potential (Malakal) Weston equation for swell precent gives adequate results compare to the measured ones. All the examined equations underestimated the values of swell percent for sites of very high swelling potential (Alnishishiba).

7 CONCLUSION

Several prediction equations for swell percent of expansive soil were examined. Many of them were developed to reflect specific project and site condition under investigation. The obtained results from the different predicted equations varied and also in many cases appeared to be far of the measured values. This may be as a result of the procedures used by researchers which reflect their innovativeness, the frequency of test carried, environmental conditions of the site and the stress history of the soil.

The results obtained in this study show that most of the predicted equations do not obtain reasonable values. This indicates that these equations are suitable only for the locations where they were developed. A general equation which is valid for all types of clay and local conditions may be very difficult to reach due to the nature of these soils and the conditions surrounding testing.

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