SWELL AND SWELL-PRESSURE ASSESSMENT OF FIVE COMPACTED CLAYS

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ABSTRACT
The problem of expansive soils is wide spared in all over the world. Partially saturated highly plastic and active clays are likely to volume change when their natural water content change. Increment of natural water content of compacted clays can lead to heave in presence of stable structure otherwise collapse may occur. Lightly loaded expansive clays will cause differential heave in the surface and severe problems to the structures on top.
In the present work, free-swell index and swell-pressure of five compacted clays have been investigated. The selected materials cover low and high plastic clays and X-ray and atomic absorption analyses have been done on them to show the effects of soil mineralogy and chemistry on swelling behavior. Samples were prepared by static compaction method at dry, optimum and wet conditions by a hydraulic jack. Results of experiments were utilized to train two Artificial Neural Networks to model both free-swell index and swelling pressure of such compacted clays based on their clay size fraction, liquid limit, plastic limit, at compaction degree of saturation and void ratio.

RÉSUMÉ
Le problème des sols expansibles est au loin épargné dedans partout dans le monde. Les argiles fortement en plastique et actifs partiellement saturés sont probables au changement de volume quand leur changement normal de teneur en eau. L'incrément de la teneur en eau normale des argiles compacts peut mener à soulever en présence de l'effondrement stable de structure autrement peut se produire. Les argiles expansibles légèrement chargés causeront la poussée différentielle dans les problèmes extérieurs et graves aux structures sur le dessus. Dans le travail actuel, libre-gonflez l'index et de la gonfler-pression de cinq argiles compacts ont été étudiées. Les matériaux choisis couvrent bas et de hauts argiles en plastique et des analyses de rayon X et d'absorption atomique ont été faits sur elles pour montrer les effets de la minéralogie et de la chimie de sol sur le comportement de gonflement. Des échantillons ont été préparés par la méthode statique de tassement aux conditions sèches, optimas et humides par un cric hydraulique. Des résultats des expériences ont été utilisés pour former deux réseaux neurologiques artificiels pour modeler libre-gonflent l'index et la pression de gonflement de tels argiles compacts basés sur leur fraction de taille d'argile, limite de liquidité, limite de plasticité, au degré de tassement de saturation et de rapport vide.

1. INTRODUCTION

Compacted clays are widely used in various geotechnical projects and mostly as hydraulic barriers in dams or landfills. Naturally compacted clays are also available in various depths under ground. Such soils can be either saturated or unsaturated related to their position and ground water level. Changes in ground water level and also infiltrated water or humidity from surface as a result of seasonal precipitation or absorption of water by upper and drier layers can alter the natural water content of the soil layer. Highly plastic clays have shown volume changes in these conditions. Increment in the water content can lead to heave and expansion in presence of stable structure otherwise collapse may occur. Lightly loaded expansive clays will cause differential heave and severe problems to the structures on top.

In the present study, free-swell index and swell-pressure of five compacted clays have been investigated in different compaction states. The selected materials cover low and high plastic clays and X-ray and atomic absorption analyses have been done to understand mineralogical and chemical characteristics of them. It was aimed to obtain better insight into effects of physico-chemical and compaction parameters of clay soils on their volume change behavior. Results of experiments were utilized to train two Artificial Neural Networks (ANNs), and to model both free-swell index and swelling pressure of such compacted clays, based on their clay size fraction, liquid limit, plasticity index, and at compaction degree of saturation and void ratio.

2. EXPANSION INDICES AND DOMINATING FACTORS

Swelling behavior of compacted clays are measured with two parameters, free-swell index and swell-pressure, which are the percentage of heave to initial height in one dimensional condition and the amount of pressure that prevents soil from swelling respectively. Expansion indices are dominated by a combination of factors including soil composition and environmental conditions. Several studies have been done on correlating clay content and Atterberg limits to swelling potential of compacted soils (Seed et al 1962; Bandyopadhyay 1981; Chen 1988; Basma 1993). All the investigation indicates on the available correlation between the containing minerals or soil activity and swelling potential. Montmorillonite has shown the highest tendency to expand and as the fraction of clay size particles (finer than 2μm) increases the swelling potential will increase.

Influence of gravel content also has been studied by Day (1991). He noted on reduction of swell percent by increasing the gravel content. On the other hand effects of environmental conditions have been focused on effects of cyclic drying and wetting on expansion (Dif and Bluemel 1991; Day 1994; Al-Homoud et al 1995; Tripathy et al 2002) and fewer attentions paid to influences of initial soil structure on the swelling characteristics of compacted clays (Seed et al 1962). The studies on swell-shrink cycles have shown that after about three to five cycles, soils reach an equilibrium condition where the vertical deformation due to swelling and shrinkage are the same. Since the swelling potential in the previous studies was considered as the percent of heave to initial height for optimum compacted samples under standard compaction condition, the influence of initial water content and dry density of the samples compacted at dry and wet side of optimum water content received less attention. Swelling potential of the samples along a typical compaction curve reaches their maximum value for the sample compacted 2 to 3 percent off-line of optimum water content point (Figure 1) (Basma 1993).

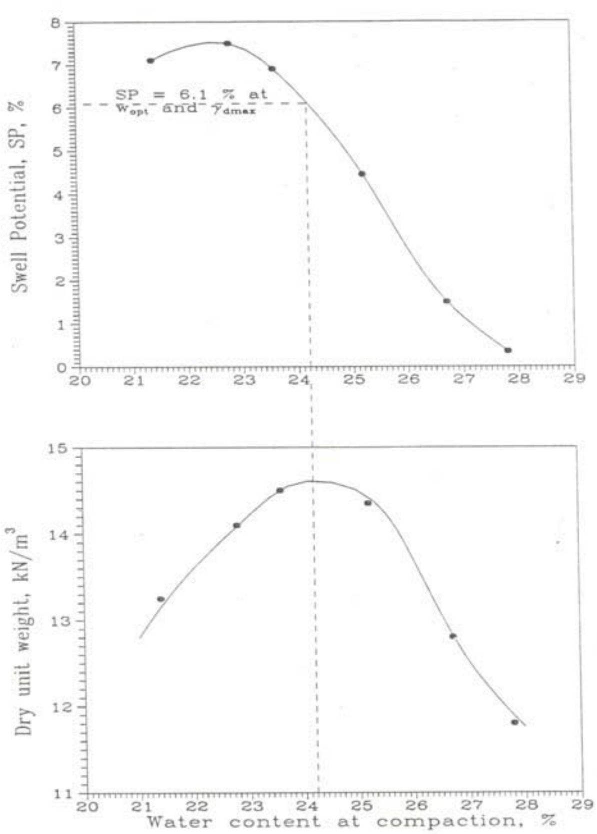

Figure 1. Swelling potential at different compaction state (after Basma 1993.)

3. TESTING PROGRAM AND MATERIALS

Free-swell and constant volume swell-pressure tests were done according to ASTM D-4546. Five different clayey soils were used in this study the physico-chemical properties of them are presented in Table 1. Soluble cations were measured in saturation extract of soils by atomic absorption method and X-ray analyses were done on S3, S4 and S5. Figures 2 to 4 present the results. From these tests S1 and S2 are considered as low plastic clays with low activity, S3 is low plastic silty clay and rich in Ca^{2+}, containing montmorilonite, illite, and kaolinite S4 is considered as highly plastic Ca-Montmorillonite, and S5 as Na,K-Montmorillonite with the highest plasticity index.

Soils were sieved to finer than 4.75 mm (gravels were removed) and standard and modified proctor compaction curves for soil samples obtained from ASTM D-698 and D-1557 respectively then compacted samples were prepared based on the compaction curves information to the desired water content and dry density by static compaction. The compacted samples then were placed in the oedometer cell and were inundated. Swell tests performed under 1 kpa surcharge (the minimum surcharge recommended in ASTM D-4546), and the vertical deformation of the samples recorded to at least 2 days after completion of primary swelling. In the swell-pressure tests samples kept in constant volume conditions and the pressure needed to prevent the sample from swelling recorded after equilibrium.

Table 1. Physico-chemical properties of materials

Property	S1	S2	S3	S4	S5
Fc (%)	75	94	79	70	69
CSF (%)	21	26	28	29	38
LL (%)	28	36	48	68	76
PI (%)	8	16	19	39	50
Activity	0.4	0.6	0.7	1.3	1.3
Gs	2.83	2.84	2.72	2.51	2.65
USCS	CL	CL	ML	CH	CH
Soluble Cations (meq/lit)					
Ca^{2+}	2	40	40	25	0.03
Mg^{2+}	0.5	12.5	0.25	0.8	1.7
Na^{+}	0.43	6.1	0.35	2.2	9.1
K^{+}	0.1	0.15	0.51	0.3	5.6
SAR $(meq/lit)^{1/2}$	0.38	1.2	0.1	0.6	9.8

Fc= Fine content, CSF= Clay Size Fraction, Activity=PI/CSF, SAR= Sodium Absorption Ratio

Results of free-swell and swell-pressure tests are shown in tables 2 and 3. Different compaction efforts were used for S1 and S2 in order to see the effects of higher dry density on expansion indices. Results of these tests confirms that samples compacted at low water content and low dry density has smaller values of free-swell and swell-pressure than samples compacted next to optimum water content and optimum compacted samples don't represent the maximum expected heave or swelling pressure of compacted samples.

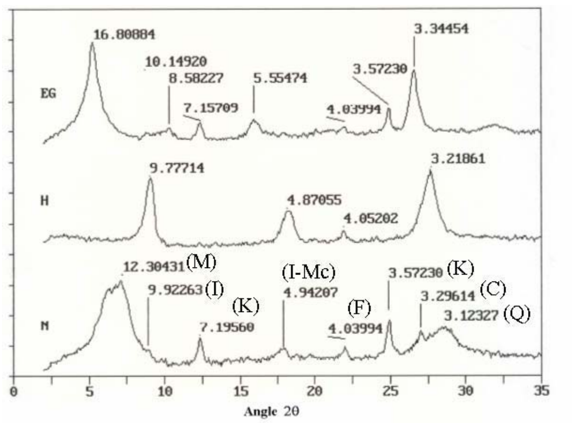

Figure 2. X-ray analysis for S3

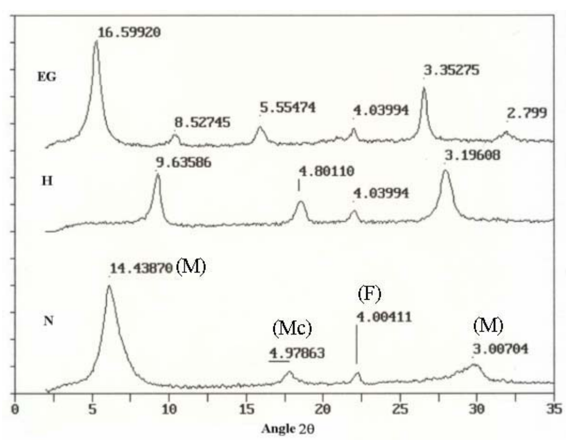

Figure 3. X-ray analysis for S4

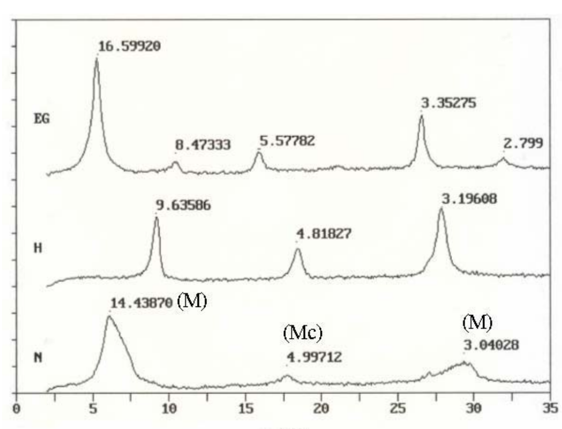

Figure 4. X-ray analysis for S5

M: Montmorillonite, K: Kaolinite, I: Illite

Mc: Mica, F: Feldspar, C: Carbonate, Q: Quartz

4. MODELING FREE-SWELL AND SWELLING PRESSURE

Neural networks were utilized for modeling free-swell and swell-pressure changes of compacted clays due to five parameters. Those five parameters are; clay size fraction (material finer than 2 μm in percent), Liquid Limit,

Table 2. Results of free-swell tests

Sample	Sr_i (%)	e_i	S_{wp} (%)
S1-S-1	39	0.62	10.5
S1-S-2	76	0.5	8
S1-S-3	82	0.56	5
S1-M-1	50	0.45	16.8
S1-M-2	64	0.43	15.3
S1-M-3	86	0.44	9.2
S1-M-4	89	0.5	4.4
S2-S-1	31	0.77	13.3
S2-S-2	44	0.65	15.3
S2-S-3	56	0.61	15.6
S2-S-4	67	0.58	13.6
S2-S-5	86	0.56	6.6
S2-S-6	87	0.62	3.2
S2-M-1	33	0.69	19
S2-M-2	42	0.6	20.3
S2-M-3	50	0.56	19.5
S2-M-4	70	0.52	17.9
S2-M-5	83	0.48	15.4
S2-M-6	87	0.57	3.8
S3-1	36	0.69	21
S3-2	43	0.67	20.6
S3-3	66	0.61	21.4
S3-4	73	0.6	20
S3-5	86	0.64	14.7
S3-6	86	0.74	8.2
S4-1	38	0.7	23.5
S4-2	53	0.65	22.7
S4-3	73	0.55	24.4
S4-4	89	0.54	24.4
S4-5	93	0.57	17.7
S4-6	92	0.65	10.4
S5-1	35	0.67	29.3
S5-2	48	0.61	32.1
S5-3	67	0.55	34.4
S5-4	67	0.6	32.2
S5-5	82	0.55	30
S5-6	90	0.6	22.1

S=Standard proctor, M=Modified proctor, Swp=primary swelling

Plasticity Index, at compaction degree of saturation, and at compaction void ratio. Conventional volume-mass relations were used to calculate initial degree of saturation and void ratio of the samples. About 75 percent of experimental data was used to train two ANNs for free-swell and swell-pressure respectively. Multilayer feed forward structure was used for both models and neural networks were trained using error back propagation algorithm (Haykin 1994). Models contain one hidden layer with 5 processing neurons. Final correlation obtained for free-swell model (FS-Model) and swell-pressure (SP-Model) was 0.95 and 0.99 in training phase respectively.

Table 3. Results of swell-pressure tests

Sample	Sr_i (%)	e_i	S_p (kPa)
S1-S-1	42	0.6	28.6
S1-S-2	79	0.47	16.7
S1-S-3	86	0.56	8.5
S1-M-1	64	0.44	62.6
S1-M-2	85	0.45	25.5
S1-M-3	84	0.53	10.3
S2-S-1	29	0.7	35.5
S2-S-2	40	0.68	32.7
S2-S-3	57	0.6	56.6
S2-S-4	74	0.54	53
S2-S-5	85	0.56	23.2
S2-S-6	87	0.65	7.2
S2-M-1	36	0.63	109
S2-M-2	42	0.63	111
S2-M-3	53	0.55	113
S2-M-4	88	0.48	60
S2-M-5	86	0.58	17
S3-1	35	0.68	238.1
S3-2	50	0.66	292.4
S3-3	70	0.56	261.3
S3-4	77	0.56	184.4
S3-5	85	0.64	72.1
S3-6	87	0.73	29.6
S4-1	40	0.68	180.3
S4-2	53	0.66	302.7
S4-3	79	0.51	308.2
S4-4	88	0.53	150
S4-5	96	0.55	98.4
S4-6	92	0.64	46.1
S5-1	24	0.79	153
S5-2	34	0.68	199.5
S5-3	48	0.61	250.4
S5-4	76	0.51	319.9
S5-5	86	0.52	211.9
S5-6	91	0.61	75.7

S=Standard proctor, M=Modified proctor, Sp=swelling pressure

5. INFLUENCE OF SOIL COMPOSITION ON SWELLING AND SWELL-PRESSURE

Although materials used in this study cover wide range of clayey soils, specific conclusions can not be made on the effects of soil composition on swelling because of the number of parameters included such as available minerals, absorbed cations, and clay content in the mixture. Figures 5 and 6 present the free-swell and swell-pressure for optimum compacted samples under modified compaction energy versus their plasticity index. As it is expected, both free-swell and swell-pressure increase when the soil plasticity increase. Generally parent soil activity and availability of enough clay content provide the potential for expansion. The occurrence of heave and the amount of swell-pressure is mostly related to the arrangements of clay sheets and distances between in soil fabric. In contrast, results of free-swell tests of S4 and S5 which have the same mineralogy but different absorbed cations show monovalent cations provide more potential than divalent one.

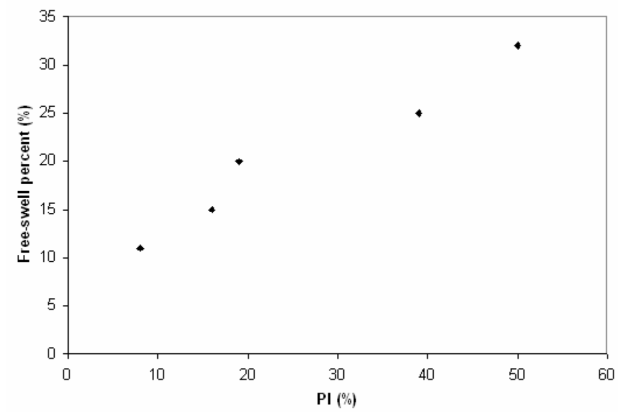

Figure 5. Free-swell versus PI for optimum compacted samples.

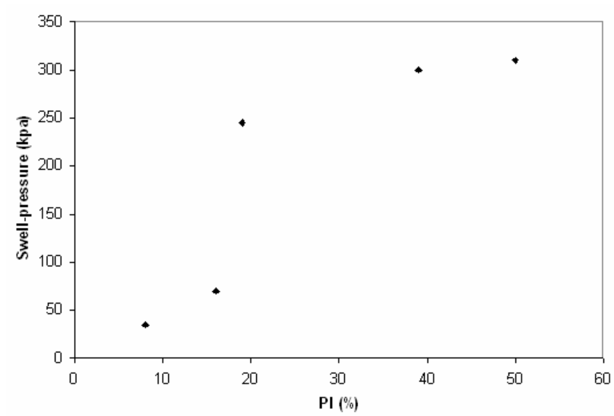

Figure 6. Swell-pressure versus PI for optimum compacted samples.

6. EFFECTS OF INITIAL STRUCTURE ON SWELLING AND SWELL-PRESSURE

As mentioned by several investigators (Lambe 1958, Olsen 1962, Benson and Daniel 1990), at compaction water content and dry density can represent the arrangements of particles or the size of clods, formed during compaction in compacted clays. Larger values of initial dry unit weight of the samples means smaller distances between clay sheets and smaller pores in soil fabric and consequently, more potential for heave by water absorption. In this study at compaction water content and dry unit weight were assigned to their corresponding degree of saturation and void ratio and the variations of free-swell and swell-pressure respect to at compaction degree of saturation and void ratio were observed from the results of neural network models. Figures 7 and 8 show results of models for free-swell percent and swell-pressure versus void ratio and degree of saturation for S3.

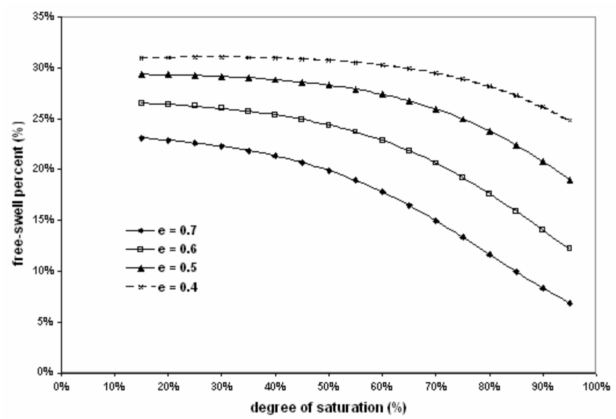

Figure 7. Free-swell versus at compaction degree of saturation in various void ratios from FS-model for S3.

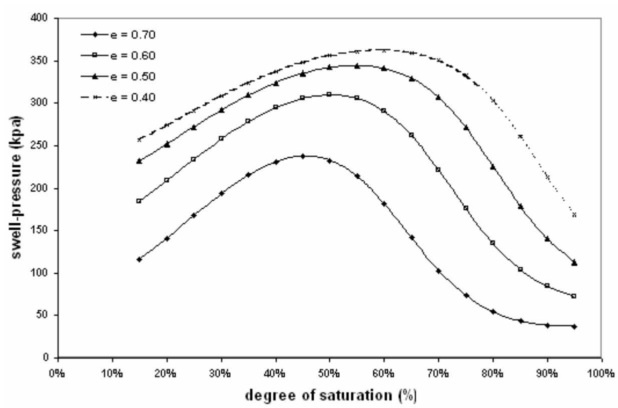

Figure 8. Swell-pressure versus at compaction degree of saturation in various void ratios from SP-model for S3.

In each void ratio, samples that are compacted in larger degree of saturation have smaller free-swell percent, and as the initial degree of saturation decreases the free-swell increases but the rate of increment falls down. The behavior related to swell-pressure shows two opposite trend for the samples compacted with less and more than a critical degree of saturation (Fig.8). Samples compacted at lower degree of saturation have more collapsible or metastable structure, so by increasing capillary forces between weakly bonded particles, they will loss stability and collapse occurs. Since low water content compacted samples have more porous fabric and metastable structure then the amount of pressure required to prevent the sample from swelling will be smaller than the samples which have more stable structure due to stronger interparticle bonding forces formed at higher degrees of saturation.

On the other hand, for the samples those are compacted at higher degree of saturation than the critical value, generally there is no weak bonding and no collapse will occur in such situation and also availability of enough water between particles provides easier movement of particles and increases compressibility of the soil structure, so smaller values of swelling pressure is observed.

7. SUMMARY AND CONCLUSION

Number of free-swell and constant volume swelling pressure tests were done on five compacted clays. Samples were prepared in different initial structure due to their compaction state in order to observe the effects of compacted clay's initial structure on swelling potential. Experimental data from these tests were assisted to train two ANNs for modeling the free-swell index and swelling pressure of compacted clays based on their physical composition and initial degree of saturation and void ratio. Results of neural network models were verified by experimental data and used to obtain correlations representing the possible swell and swell pressure of compacted clays versus their at compaction degree of saturation and void ratio.
The following conclusions are made out of this study:

1. In the range of materials studied in this paper, no correlation was observed between swelling indices and the amount of fine content in the mixture. For materials classified as low plastic to high plastic clays swelling behaviors is dominated by activity of available minerals, absorbed cations to clay sheets and the amount of clay particle available in the mixture.

2. The swelling pressure of compacted clays is mostly related to their initial structure and arrangements of particles. Availability of enough active clay particles with suitable fraction of silt and sand in the mixture in which can provide both stable structure and expansion potential will result in high swelling pressure. In an identical sample swelling indices are directly related to the initial dry unit weight.

3. Results of ANNs model show good correlations abtained between the amount of free-swell and swell-pressure, predicted from CSF, LL, PI, Sr_i, and e_i and their laboratory measured values.

4. Results from the SP-model show in each void ratio there is a critical degree of saturation that result in the maximum swelling pressure. This critical degree of saturation was in the range of 45 to 65 percent for the materials tested in the present work and is smaller in larger void ratios.

5. Constant volume swell-pressure tests and the critical degree of saturation gave a better understanding of swell and collapse behavior of compacted clays at low density and water content conditions.

8. REFERENCES

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