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EFFECT OF STRUCTURE ANISOTROPY AND COMPACTION METHOD ON THE SWELLING BEHAVIOR OF Al-QATIF SOIL

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ABSTRACT: The degree of variation in anisotropy adversely affects the predictability of swell behavior. For this purpose, one dimensional fixed ring oedometer consolidation tests were conducted on Al-Qatif soil, by varying the mode as well as the degree of compaction. The samples were prepared by both dynamic and static compaction techniques. Prior to consolidation testing, the samples were prepared at the respective dry densities for each compaction technique, in order to study the effect of structure anisotropy on the swelling behavior of the soil. Further, in order to check the effect of fabric orientation on the swell behavior, both horizontal and vertical samplings were done from the compaction mold and the resulting degree of swell was determined in both the cases. The studies carried out indicate that, the anisotropy brought by varying the degree and method of compaction as well as orientation has a considerable effect on the swell behavior of Al-Qatif soil.

Keywords: Anisotropy; Compaction; Static; Dynamic; Swell.

1. INTRODUCTION

Understanding the behavior of physical properties of soil is a fundamental step in civil engineering. Due consideration has to be given while testing the samples in disturbed and in undisturbed conditions as it bears significance in the design of engineering projects such as foundation design, slope stability problems, retaining structures, and highways [1]. Prima facie, it has been observed that, the results obtained from both the disturbed as well as undisturbed specimens are vary from than those observed in the actual field conditions. A wealth of literature is available on the effect of disturbance on soil properties due to the changes arising in the structure [2] and [3].

The evaluation of soil characteristics under controlled laboratory conditions is also affected by the imposed initial conditions and the method of preparation of the sample [4] and [5]. The engineering properties like compression index, heave, unconfined compression strength behavior and lime leachability pattern are adversely affected if the drying method is employed [4, 6]. The compaction process in engineering applications still remains a quite complex phenomenon as it affects the compressibility, shear strength and in most cases the permeability too. Proper compaction ensures durability and stability of any earthen structure. Dynamic and static compaction processes are most commonly used in the laboratory. Whilst the first test constitutes a means to control field compaction the later is resorted to produce samples at known densities and water contents. In most of the cases, both these tests do not truly depict the field compaction. The purpose of any laboratory compaction test is to provide a guideline and a basis for the control of compaction in the field, by giving an indication that a certain percentage of the maximum dry density achieved in the laboratory test shall be achieved during construction in-situ. Prima facie, the relative degree of compaction of a soil is characterized by its dry density.

In this study, a typical swelling soil originating from Saudi Arabia was selected and the difference in heave induced due to static and dynamic compaction techniques studied. In order the study the effect of fabric orientation, the soil sampling was carried out in both the horizontal and vertical directions from the compaction molds (for both the static and dynamic cases). Increase in compactive effort or the energy expended is found to result in an increase in the maximum dry density causing a corresponding decrease in the optimum moisture content. However, in the present case, the heave studies have been conducted at fixed water content but at varying compactive energies by resorting to modified proctor compaction.

2. MATERIALS AND METHODS

2.1. Materials

Physical properties of the soil samples collected from Al-Qatif, which is a historic coastal oasis region located on the western shore of the Persian Gulf in the Eastern Province of Saudi Arabia are reported in Table 1. According to Unified Soil Classification System, as per ASTM [7], this soil has been categorized as clay with high plasticity.

2.2. Experimental Procedure

Table 1. Physical Properties of Al – Qatif soil

Physical Property	Value
Liquid Limit (%)	137
Plastic Limit (%)	60
Shrinkage Limit (%)	12
Plasticity Index (%)	77
Linear Shrinkage (%)	77
% Finer than 200 μm	99.1
USCS Classification	CH
Specific Gravity	2.71

***** *'USCS' refers to Unified Soil Classification System;*
'CH' refers to clay with high plasticity

Figure 1 represents particle size analysis based on laser diffraction as per ASTM [8]. This principle relies on the fact that particles passing through a laser beam will scatter light at an angle that is directly related to their size. As the particle size decreases, the observed scattering angle increases logarithmically. Scattering intensity is also dependent on particle size, diminishing with particle volume. Larger particles therefore scatter light at narrow angles with high intensity whereas smaller particles scatter light at wider angles but with low intensity. Major portion of the selected soil has a gradation ranging from 0.1 to 10 µm. This finer fraction is critical to the study as it affects the heave considerably.

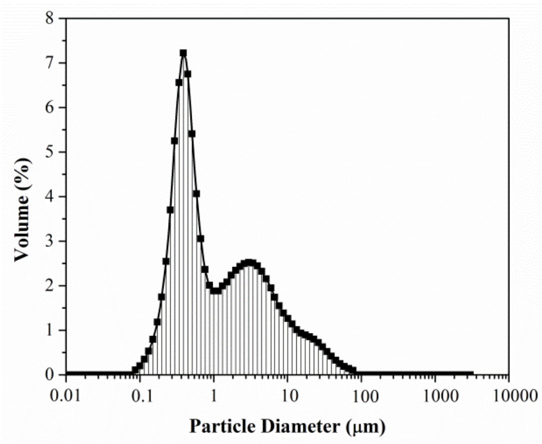
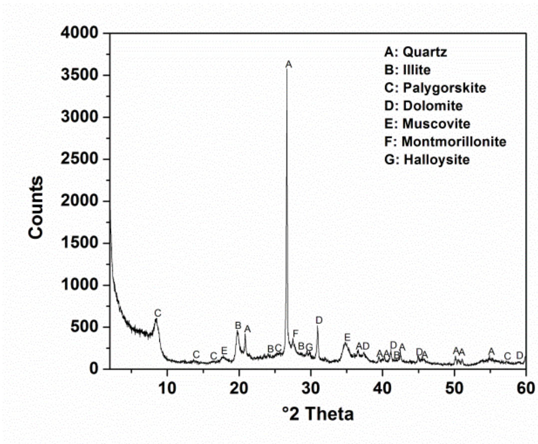


Fig.1. Particle Size Distribution Curve by Laser Diffraction Analysis

The predominant minerals were determined by carrying out XRD using Bruker D8 Advance system. Samples were scanned from 2° to 60° (2θ) using 2.2kW Cu anode long fine focus ceramic X-ray tube at a scanning rate of 1 degree per minute. XRD patterns of samples were then compared with standard patterns (JCPDS, Powder Diffraction File [9]). Figure 2 depicts comprehensive X-Ray diffraction analysis. In addition to Quartz, Dolomite, Illite, Muscovite, and Palygorskite, the presence of Montmorillonite (a smectite group mineral known to induce significant swelling upon interaction with water) is noteworthy.

Fig. 2. X - Ray Diffraction Analysis



The dry density – moisture content relationship of Al-Qatif soil, determined by the standard proctor test as per ASTM D [10], is shown in Figure 3. The shape of the curve is bell shaped, which is typical to that of highly plastic clay. The initial decrease of dry unit weight with increase in moisture content may be due to the capillary tension effect.

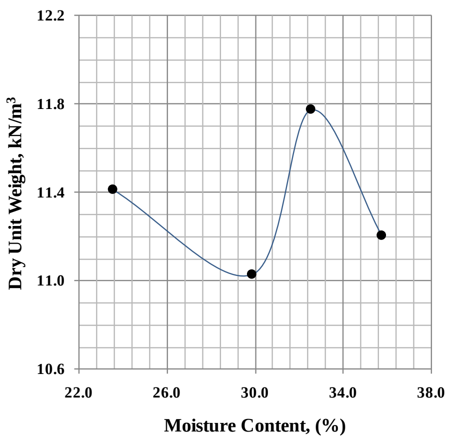


Fig. 3. Moisture Content – Dry Density Relationship

Since, at lower moisture contents the induced capillary tension in the pore water inhibits the tendency of soil particles to move around and be densely compacted. The maximum dry density and the corresponding moisture content are found to be 11.8 kN/m^3 and 32.5%, respectively.

The soil after mixing with water content corresponding to optimum conditions was left over night for homogenization. It was then compacted using the dynamic compaction technique in a cylindrical standard proctor mold of 101.3 mm diameter and 116.8 mm height as per ASTM [10] in three different layers. Upon compaction, the compacted specimen was extruded using a hydraulic jack and an oedometer consolidation ring was pressed into the middle portion. Figure 4 shows the method adopted in sampling the specimen in both the vertical and horizontal directions. For each testing condition, the sample was prepared independently. The excess sample was trimmed out and the magnitude of heave at an overburden pressure of 40 kPa (equivalent to the overburden pressure experienced at foundation depth by the soil underneath light weighted structure) was determined as per ASTM [11]. The sample was then loaded up to 800 kPa using load increment ratio of unity, and coefficient of compressibility (Cc) was determined (slope of linear part of the (Δh/h – Log P) curve during loading after wetting). The sample was reloaded and the swell index (Cs) was determined (slope of linear part of the (Δh/h – Log P) curve during unloading after wetting). In the case of horizontal sampling, the consolidation ring was pressed into the extruded compacted specimen at the central portion in the perpendicular direction. The entire procedure was repeated for modified compactive efforts keeping the moisture content constant around 30 %. For the static compaction series, the sample was compacted using hydraulic jack to reach the same dry unit weight. For compactive effort corresponding to standard proctor, the sample was compacted statically in three layers, whilst for modified proctor; the sample was statically compacted in five layers.

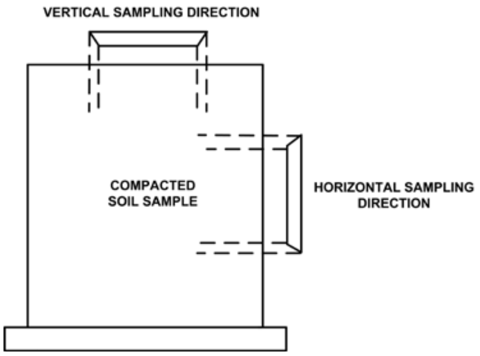


Fig. 4. Schematic diagram of horizontal and vertical sampling

2.3. Notations used

In this study, the prefixes ‘ST’ and ‘DY’ denote static and dynamic compaction techniques; ‘E1’ and ‘E2’ correspond to standard compactive effort of 600 kN-m/m^3 [10] and 2700 kN-m/m^3 [12] of soil respectively; while ‘H’ and ‘V’, correspond to horizontal and vertical sampling directions.

3. RESULTS AND DISCUSSION

Generally, it is observed that, higher compactive energies tend to be effective for greater depths and the compressibility characteristics are observed to be negligible. However, the magnitude of heave induced under such scenarios dictates the safety of light weighted structures founded on them. Hence, the effect of density on the swell characteristics assumes paramount importance. In the following sections, the effect of sampling direction and compactive energy on the heave are discussed.

3.1. Part A: Vertical Sampling Effect on Heave and Swelling Pressure

The tests reported in this section were intended to verify whether the anisotropy induced due to vertical sampling has any bearing on the heave induced in the compacted specimen. Figure 5 shows the relationship between the heave percentage and the compaction method employed. It is noteworthy that, the heave is found to be predominantly more for the modified compactive energy rather than standard compactive energy. With increase in density at a given water content, the particles are densely packed and the negatively charged clay particles tend to oppose each other upon saturation. The physico-chemical interactions, due to intrusion of water into the clay matrix medium, are more pronounced at higher density levels. Hence the magnitude of heave observed is more in case of specimens compacted using the modified proctor method.

The effects of compactive energy swell pressure in case of vertical samplings are shown in Figure 6. As the release of effective stress is more in case of modified compactive energy, an increase in the swelling pressure is observed. The soil fabric which refers to the arrangement, size, shape and frequency of the individual solid soil components within the soil, contributes to the increased swell pressure intensities as seen in Fig. 6. Also as is evident from Fig. 2, the presence of Montmorillonite too contributes to the increased swell pressures. A maximum percentage heave of

24.4% was observed in the case of dynamic compaction at compactive energy level E2 as observed from Table 2.

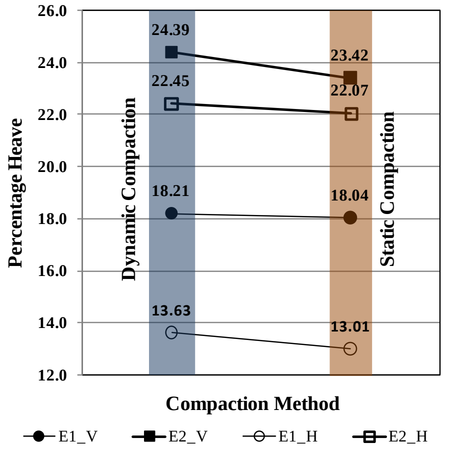


Fig. 5. Percentage Heave versus Compaction Method

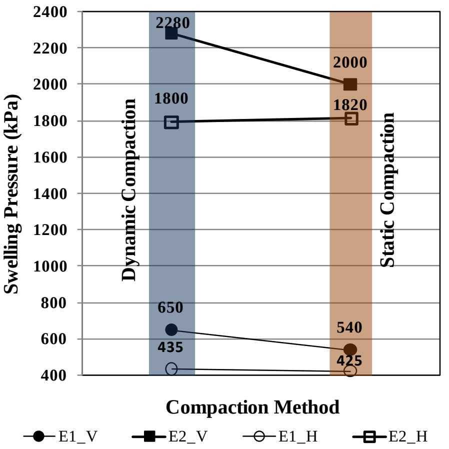


Fig. 6. Swelling Pressure versus Compaction Method

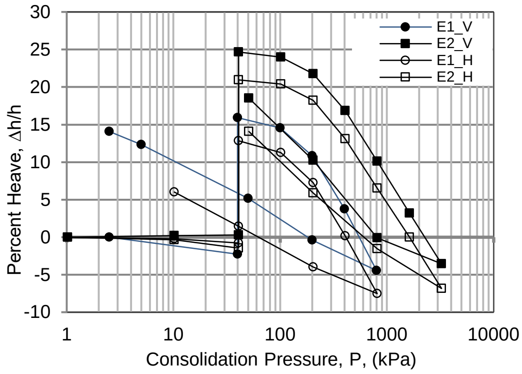


Fig. 7. Percent Heave versus Consolidation Pressure for Dynamic Compaction

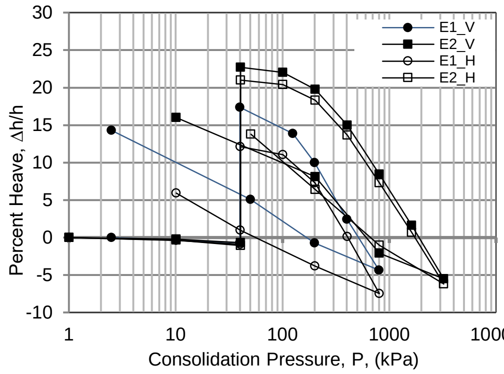


Fig. 8. Percent Heave versus Consolidation Pressure for Static Compaction

3.2. Part B: Horizontal Sampling Effect on Heave and Swelling Pressure

In order to study the effect of induced anisotropy due to orientation of soil fabric perpendicular to the direction of compaction, horizontal sampling was taken out from the proctor molds compacted at both standard and modified proctor at a fixed water content value of 30%. The samples were then used for determining the magnitudes of heave and swelling pressure and are shown in Figs. 5 and 6 respectively.

The gradation and arrangement of soil particles and bonding agents along with the specific interactions developed between particles through associated electrical forces play a definite part in the horizontal direction. However, the magnitudes of values obtained are less than those obtained from vertical sampling direction. The heave values obtained from samples prepared by dynamic compaction technique were considerably high. However, no significant change was noticed in swelling pressure values obtained for dynamic and static compaction conditions. For horizontal sampling, the maximum percentage of heave was 22.5% as observed in the case of dynamic compaction at compactive energy level E2 (Table 2). The increase in compactive effort resulted in higher maximum dry density values.

3.3. Effect of Sampling Direction on the Compression and Swell Index Values

The values of compression index were computed from one-dimensional consolidation tests and the percent heave – consolidation pressure relationship graphs were plotted under both static and dynamic compaction conditions (Figs. 7 and 8). The compression is observed to be more as expected in case of vertical sampling condition pertaining to standard proctor compaction.

Table 2. Variations of Percent Heave, Swell Pressure, Compression Index and Swell Index Values under Different Conditions

Notation	Water Content (%)	Dry unit Weight kN/m^3	Percentage Heave at 40 kPa	Swelling Pressure kPa	Compression Index, Cc	Swell Index, Cs
DY_E1_V	29.40	11.98	18.21	650	0.60	0.17
ST_E1_V	31.39	11.70	18.04	540	0.51	0.18
DY_E2_V	30.40	14.74	24.39	2280	0.41	0.22
ST_E2_V	31.45	14.42	23.42	2000	0.40	0.16
DY_E1_H	30.00	11.52	13.63	435	0.59	0.16
ST_E1_H	28.34	12.26	13.01	425	0.54	0.14
DY_E2_H	31.38	14.77	22.45	1400	0.40	0.16
ST_E2_H	29.91	14.22	22.07	1850	0.42	0.20

***** ***'DY' and 'ST' refer to Dynamic and static compaction conditions; 'E1' and 'E2' refer to compaction energies corresponding to Standard Proctor (600 kN/m^3) and Modified Proctor (2700 kN/m^3); 'V' and 'H' refer to vertical and horizontal sampling directions respectively.***

These values reduced further as the compaction energy was increased from standard proctor E1 to heavy compaction pertaining to compaction energy level E2 as could be seen from Table 2. The swell index values (rebound index) increased with increase in compaction energy level. Compared to static compaction, this increase in swell index was significantly more in case of dynamic compaction. The highest swell pressure value of 2280 kPa was obtained in the case of vertical sampling corresponding to dynamic compaction at compactive energy level (E2).

3.4. Static and Dynamic Compaction Techniques - A Comparative Study

In the case of dynamic compaction, the rapid tamping induces both punching shear and displacement, as the momentum of the falling weight decays inside the proctor compaction mold. For vertically sampled specimens, soil fabric orientation is parallel and hence, lower compressibility index values were obtained contrary to horizontal sampling.

Also, the degree of anisotropy induced is more in case of vertically sampled specimens which result in higher swell and compression index values, particularly at compactive energy levels corresponding to E2. At higher compactive energy levels, the soils grains are in a state of total dispersion which allows the particles to move independently with respect to each other. Hence, the specimens compacted at higher energy levels corresponding to E2, exhibit greater swelling and compression characteristics. In the case of static compaction, the individual soil grains wedge against each other and resist movement. Hence, with increase in compactive effort, this phenomenon is altogether more pronounced which results in relatively lower heave levels, due to lesser stress relaxation effect. But in case of dynamic compaction, the soil grains are momentarily freed, and hence it is quite effective in forcing the soil particles into a more dense arrangement. However, at higher compactive energy levels, the swell pressure intensities recorded are higher for dynamic compaction particularly for vertical sampling condition as seen from Table 2.

3.5. Practical Importance of the study

During tunneling operations, the approach ends have to be constructed in such a way that, the difference in relative density levels at approach end is minimal. Else, the approach ends would experience heave upon tunneling due to stress relaxation effect. In the present study, the horizontal sampling perpendicular to the compaction direction simulates alike condition. Whereas, the heave and settlement findings from vertical sampling direction would lay insight for similar conditions encountered during the construction phase of an embankment. These studies are of prime importance as the degree of anisotropy affects the geotechnical properties like compression and swell indices. An account of these physiological parameters beforehand is of paramount significance to practicing and field engineers in Saudi Arabia.

4. CONCLUSIONS

In the present study, an expansive soil sample originating from Al-Qatif terrain of Saudi Arabia was compacted at varying densities corresponding to standard and modified energy levels in standard proctor mold at a fixed moisture content value. Both dynamic and static compaction techniques were employed to compact the soil at each energy level. The sampling was then done in both horizontal and vertical directions and swell potential tests were conducted on them. The effect of sampling direction has pronounced effect on both the heave and compressibility characteristics.

Due to the physical structure of the Al-Qatif soil, the temporary bonds formed between particles due to compaction are extremely brittle and are particularly sensitive to any strain which might destroy them and is extremely significant in the horizontal sampling direction.

The rebound index values were significantly more in case of dynamic condition. Further, the dynamic compaction at modified energy level, E2, yielded lower compression and higher swell values compared to standard energy level, E1. In the field, it is recommended to carry out the tests in both sampling directions and the critical value arrived at should be considered in the design calculations for the approach ends in case of tunnels and in embankments.

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