EXPANSIVE SOIL IN AL-QATIF AREA

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الخلاصـــة :

يُبيِّن هذا البحث وجود مشاكل متعلقة بتمدُّد التربة الطينية في مدينة القطيف بالمنطقة الشرقية من المملكة . وتــمَّ في هذه الدراسة استقصاء ميداني للحصول على عيِّنات غير مفككة أُجريت عليها اختبارات معملية لايجاد الخواص الجيوتكنيكية والتركيب المعدني . ولقد أوضحت حدود (اتربرج) والمحتوىٰ المائي والكثافة ونسبة الطين عن قابلية التربة الشديدة للانتفاخ . كذلك فقد أظهرت حيود الأشعة السينية والميكروسكوب الألكتروني عن وجود معدن (المونتموريللونيت) ذي الصفائح الرقيقة المبعثرة . ولقد تَــمَّ الحصول على ضغط ونسبة الانتفاخ بطريقة مباشرة باستخدام مقياس الاندماجية التقليدي ذي الاتجاه الواحد . ولقد أوضحت النتائج عن قابلية تربة القطيف للتمدد الشديد .

ABSTRACT

This paper presents documented evidence of the existence of expansive clay in the Al-Qatif area in the Eastern Province of Saudi Arabia and a description of the problem associated with it. A site investigation was conducted to obtain undisturbed clay samples. Laboratory tests were used to determine geotechnical properties and mineralogical composition. Atterberg limit, natural water content, density, and the clay fraction indicate that the swelling potential of soil is high. X-ray diffraction and the scanning electron microscope analysis showed that Al-Qatif soil contains montmorillonite clay minerals with flaky flocculated particles. The swelling pressure and percentage of swell were obtained by direct measurement, which was achieved by using the conventional one-dimensional consolidometer. The results indicate that Al-Qatif clays can be characterized as highly expansive.

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INTRODUCTION

Certain clay soils exhibit large volumetric deformation upon change in moisture content even when the external load is constant. In the dry state, these soils are quite hard and are often erroneously assumed to be excellent foundation soils. If a structure is built on such a soil deposit and there is a potential source of water, the clay slowly absorbs moisture and thereby expands. In many cases this expansion is more than sufficient to lift buildings and sometimes tear them apart.

Today, there is world-wide interest in expansive clays and shales. Usually, the potentially expansive soils are found in abundance in the semi-arid regions of the tropical and temperate climatic zones, where the annual evapotranspiration exceeds the precipitation [1]. Distribution of swelling soil is generally a result of geologic history, sedimentation, and the local climatic conditions. The arid climate, geology, and the severe weathering conditions in the Arabian peninsula produces a wide distribution of expansive soils in the region [2].

Identification of potentially expansive soils at the outset of an investigation is of paramount importance in the design of highways, building foundations, hydraulic structures, and earth-retaining structures. The problems with foundations on expansive soil have included heaving, cracking, and break-up of pavements, building foundations, and slab-on-grade members. In view of the amount of structural damage caused by expansive soils, engineers in Saudi Arabia are concerned with the study of properties and composition of swelling soils found in the Kingdom, and with their interaction with structures and the extent of the damage they cause [3]. The expansive soil formation was investigated in five different areas in the Kingdom, including Tayma, Tabuk, Al-Ghatt, Madinah, and Al-Hofuf [4].

Recent construction procedures for small structures in Al-Qatif area of the Eastern Province are based primarily on observation and local experience, often without adequate consideration of the soil's characteristics. Neglect of these characteristics is reflected in the numerous documented and non-documented reports of structural damage in the area. Movement of suspended ground slabs and cracks in the ground beams, in the foundation of some walls, and in the lower part of the walls were observed, due to differential swelling [5].

SUBSURFACE SOIL CONDITIONS

A suitable site located in Anak area in Al-Qatif region was chosen for drilling and sampling. This selection was based on reported structural damage in the area, due to expansive soil. The ground conditions of the site appear to correspond to miocene formation, which contains green clay with a cover of eolian dune sand. A typical subsurface profile showing the stratification of the ground is depicted in Figure 1. The ground mainly consists of top soil underlined by greenish silty clay.

Test pits, which are an effective means of exploring and sampling, were used to obtain undisturbed soil samples. Three test pits, as shown in Figure 2, were used in this study. Undisturbed block samples were carefully cut from the bottom as well as from the sides of the test pits. Samples were trimmed to the desired size and painted with warm melted wax in the field. All samples were marked and moved into the laboratory, where they were wrapped with thin plastic tape to hold natural moisture.

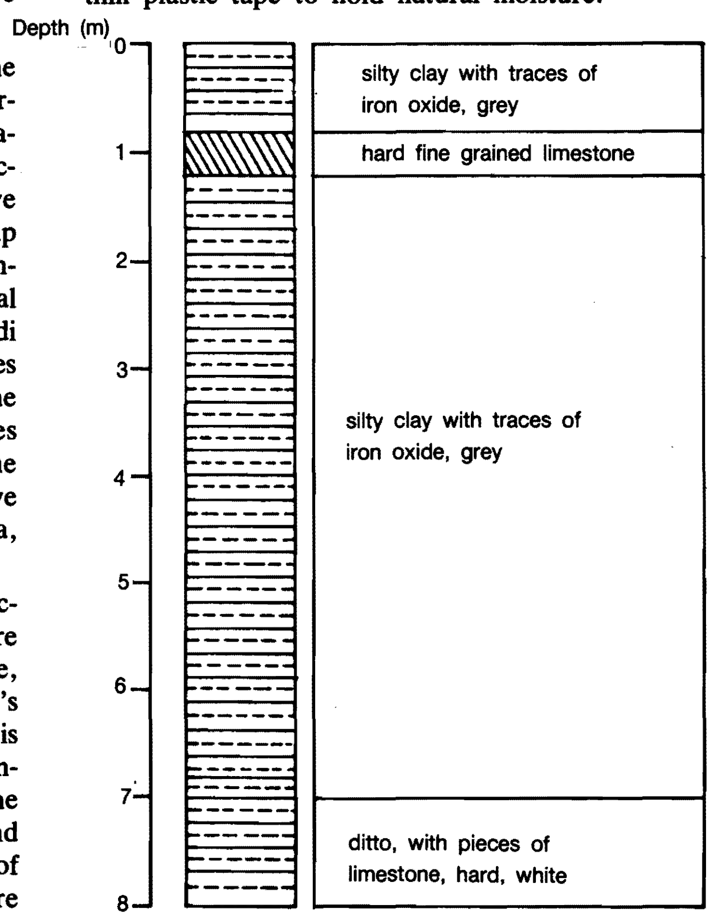

Figure 1. Typical Soil Profile at Al-Qatif.

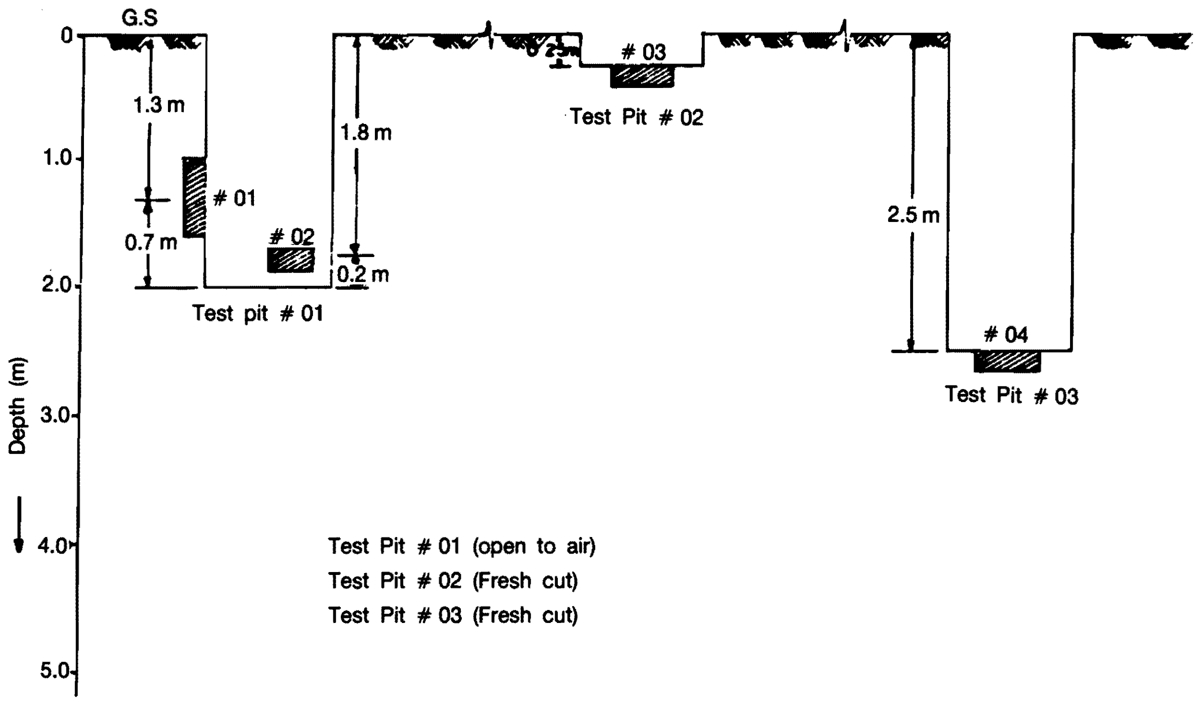

Figure 2. Block Sampling From Excavated Test Pits.

SOIL CHARACTERISTICS

The physical and chemical characteristics of the collected samples were investigated to evaluate the swelling potential. Soil samples were subjected to the following test programs:

1. Determination of the following geotechnical properties of soils: grading, Atterberg limits, density, and water content.
2. Determination of mineralogical composition by X-ray diffraction.
3. Determination of soil fabric by scanning electron microscope (SEM).
4. Determination of organic content.
5. Determination of pH and cation exchange capacity.

Geotechnical Properties

The sieve washing analysis and hydrometer analysis were conducted to determine the grain size distribution as depicted in Figure 3. The gradation curve indicates a narrow range with a high percentage of silt and clay. The dry unit weight, natural water content, Atterberg limits, and plasticity index are shown in Table 1. Gromko in 1974 [6] has classified expansive soil based on their index properties as shown in Table 2. According to this classification, Al-Qatif clay can be characterized as highly expansive since the values of Atterberg limits for all samples fall within the range of very high expansion. A plasticity chart shown in Figure 4 [7, 8] was used for classification of degree of swelling. This chart indicates the high swelling potential of Al-Qatif clay.

Table 1. Geotechnical Properties of Expansive Soils in Al-Qatif*

Properties	Block No. 1	Block No. 2	Block No. 3	Block No. 4
Dry unit weight $g\,cm^{-3}$	1.37	1.19	1.24	1.17
Natural water content, %	30.7	52.4	51.9	58.6
Clay fraction, %	54	73	64	42
Liquid limit, %	136.5	140.2	140.2	131.5
Plastic limit, %	49.6	50.7	51.0	44.7
Plasticity index, %	86.9	89.5	89.2	86.8
Shrinkage limit, %	10.5	11.9	8.5	11.8

*All values are average of four tests.

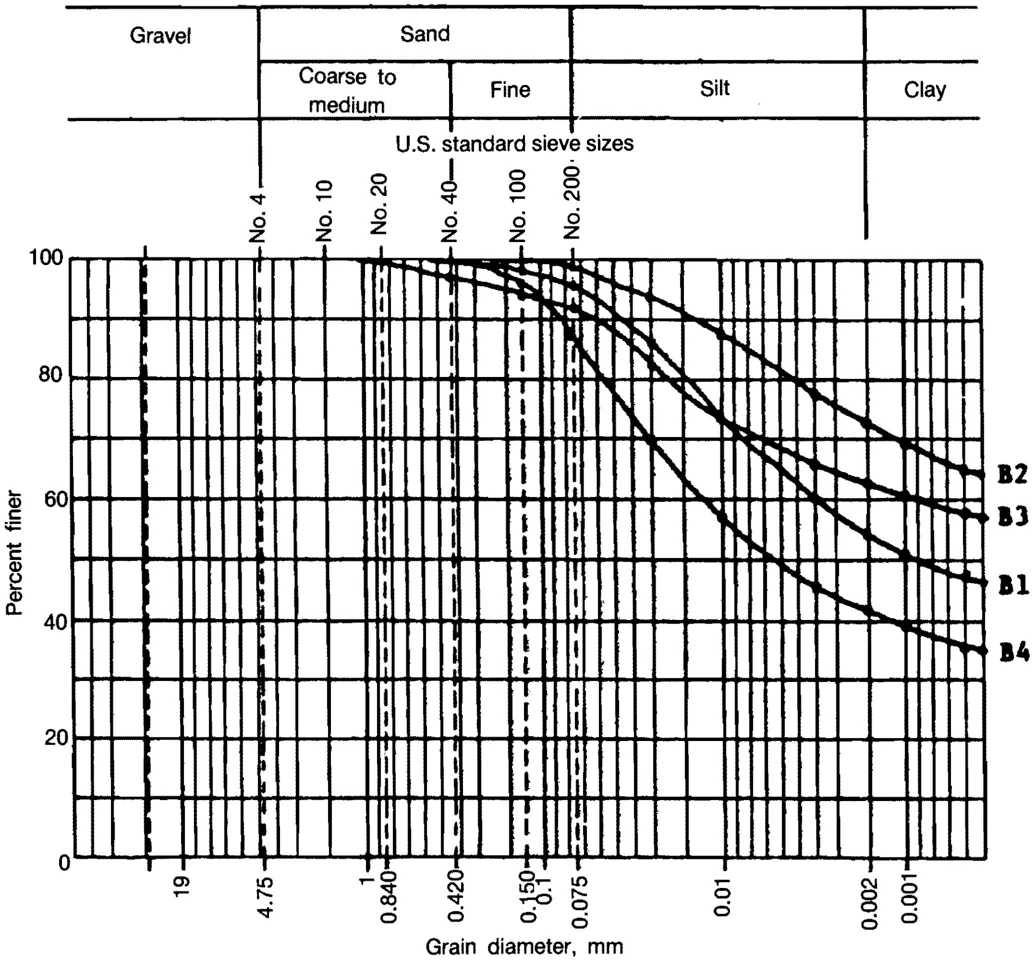

Figure 3. Typical Grain Size Distribution of Al-Qatif Soils.

Table 2. Classification of Swelling Soils Based on Index Tests.

Percentage Passing #200	Liquid Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)	Degree of Expansion
<30	<30	<18	>15	Low
30–60	30–40	15–28	10–16	Medium
60–95	40–60	25–41	7–12	High
>95	>60	>35	<11	Very High

Mineralogical Identification

The mineralogical composition has an important effect on the engineering behavior of soils. The proportion of the various minerals present in a soil sample was determined by using X-ray diffraction. The samples were dried and were reduced to a powdered form, and the diffraction pattern was established by a vertical goniometer and the X-ray diffractometer. The diffraction patterns for samples are shown in Figure 5. The ratios of the intensities of diffraction lines were compared with the intensities of lines from a standard substance [9]. Table 3 summarizes the clay and non-clay mineral composition of Al-Qatif samples together with their percentages.

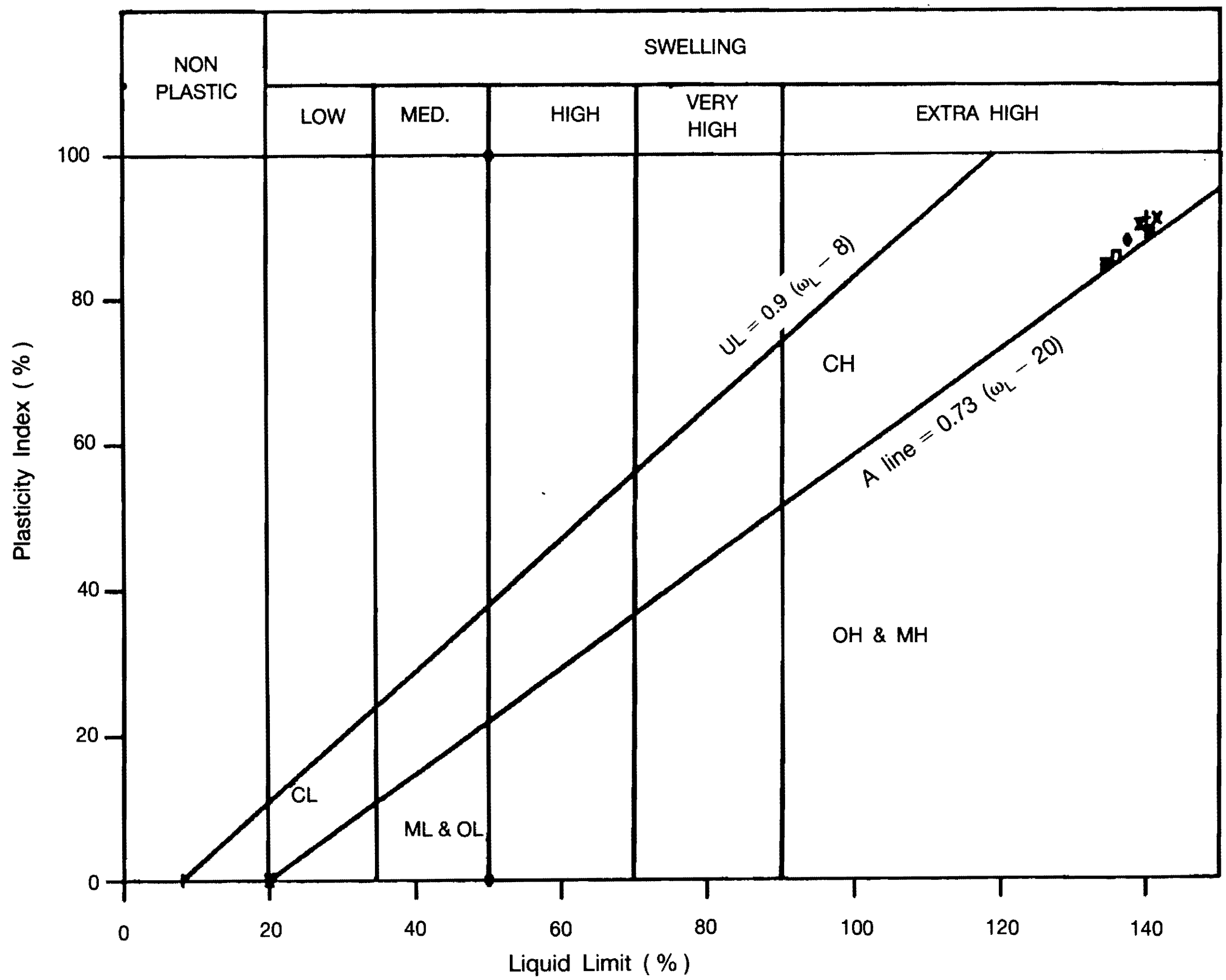

Figure 4. Classification of Al-Qatif Clays According to Dakshanamurthy and Raman Chart.

The intensity of the diffraction pattern of a particular phase in a mixture of phases depends on the concentration of that phase in the mixture. This principle is exploited by software for the quantitative analysis. The weight fraction is calculated by comparing the intensity of the peaks of that phase in the mixture, with the intensity of the peaks of the pure phase. The X-ray powder diffraction results showed that the most abundant minerals are quartz, polygorskite, and montmorillonite. Quartz is a non-clay mineral which is common in the clay size grade and is inherited mainly from sandstone [10]. Polygorskite has a wide range of crystallinity and has been recorded as hydrothermal alteration product of pyroxenes and amphiboles. It is mostly found in marine deposits of Miocene age. The presence of montmorillonite is a good indicator that the soil has an expansive potential. Montmorillonite is the most active 2:1 layer clay mineral in which a sheet of octahedral units is sandwiched between two oppositely oriented sheets of tetrahedral units. This minerals is characterized by the interlayer water bond which is very weak and unstable, so it exhibits very high water absorption and very high swelling characteristics.

Soil Fabrics

This term describes the physical nature of soil according to the geometrical arrangement of particles and pore space between the grains. The scanning electron microscope (SEM) was used for the examination and analysis of the microstructure characteristics of soil. The SEM analysis was carried out on JEOL JSM-840, which enables morphological observations of a very fine structure and full elemental

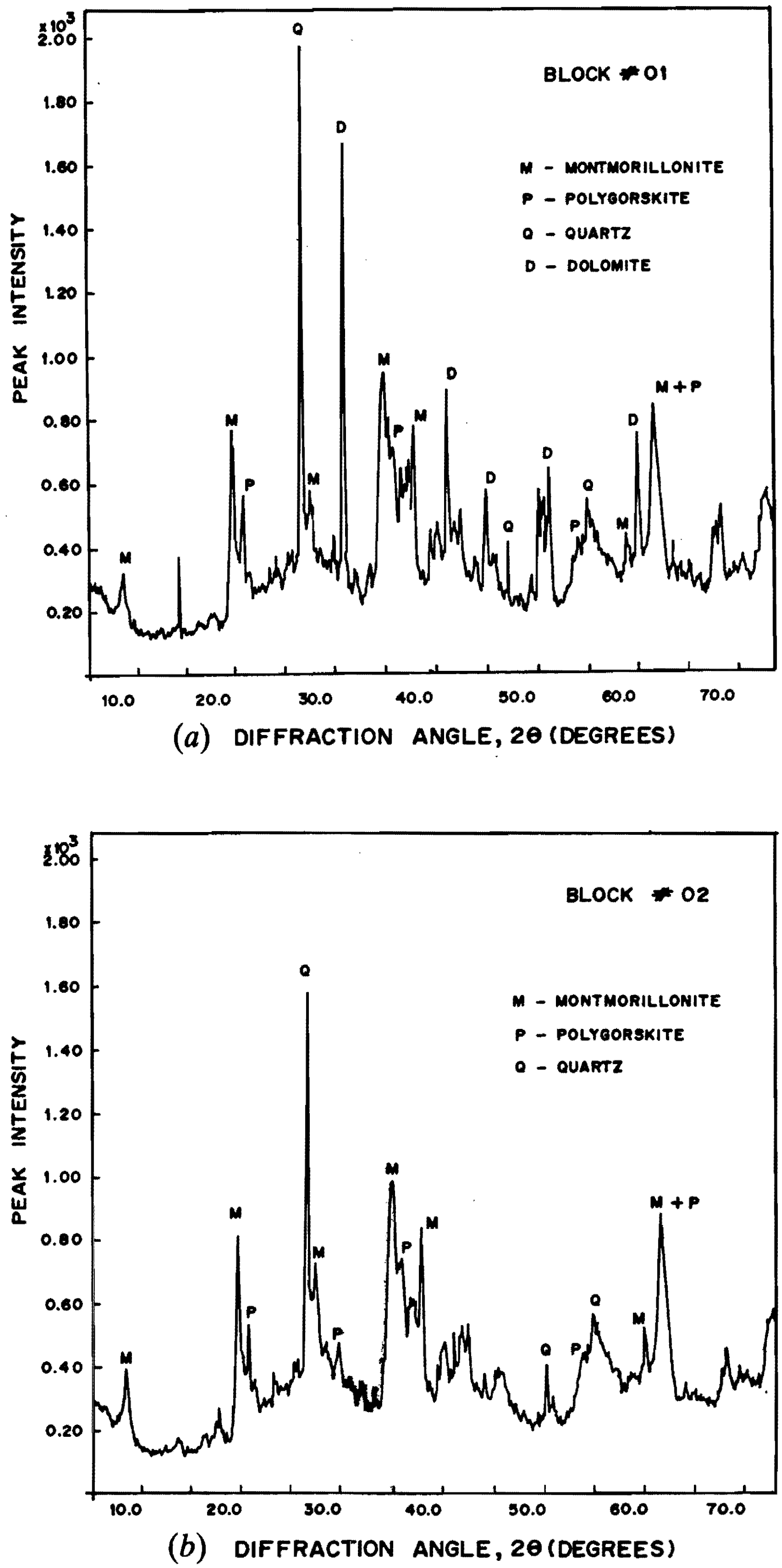

Figure 5. X-Ray Pattern for Sample From: (a) *Block No. 1;* (b) *Block No. 2.*

Table 3. Minerals Present in Al-Qatif Soil Samples.

Minerals		Sample 1	Sample 2
Samples from Block #01			
Quartz	SiO_2	45%	45%
Palygorskite	$Mg_5Si_8O_{20}(OH)_2.8H_2O$	7%	7%
Dolomite	$CaMg(CO_3)_2$	43%	43%
Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2.xH_2O$	5%	5%
Samples from Block #02			
Quartz	SiO_2	53%	53%
Palygorskite	$Mg_5Si_8O_{20}(OH)_2.8H_2O$	25%	27%
Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2.xH_2O$	22%	20%
Samples from Block #03			
Quartz	SiO_2	70%	70%
Palygorskite	$Mg_5Si_8O_{20}(OH)_2.8H_2O$	18%	15%
Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2.xH_2O$	12%	15%
Samples from Block #04			
Quartz	SiO_2	60%	60%
Palygorskite	$Mg_5Si_8O_{20}(OH)_2.8H_2O$	28%	29%
Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2.xH_2O$	12%	11%

analysis using the Energy Dispersive Spectrometer System. Clay samples from the four blocks were analyzed. To fully understand the formation and distribution of pore, each sample was fractured into transverse and longitudinal sections. Figures 6 and 7 show the selected microstructure of samples taken from blocks No. 2 and No. 4 respectively. Figure 6 depicts the flocculated flaky particles of montmorillonite with contamination of polygorskite in a needle form. The face to face structure of montmorillonite with accumulation of quartz particles is well displayed in Figure 7.

Table 4. Chemical Engineering Properties of Al-Qatif Soils.

Samples	Organic matter, %	Cation exchange capacity (meq/100 g)	pH
Block No. 1	0.349	24.05	7.91
Block No. 2	0.052	23.62	7.90
Block No. 3	0.763	24.09	7.91
Block No. 4	0.517	22.59	7.89

Organic Matter

This embraces the whole non-mineral fraction of soil and any decayed vegetable or animal matter. Organic matter contributes to the physical condition of soil by holding moisture and by affecting structure. Organic matter may cause high plasticity, high shrinkage, high compressibility, low permeability, and low strength [11]. The ASTM D-2974-34 procedure was used to determine the organic matter. Test results as shown in Table 4 indicate that Al-Qatif soil samples have a low percentage of organic matter. The closes sample to the ground surface taken from block No. 3 has the largest organic content. No fossils or presence of any other organism were detected. The most probable source of this small amount of organic matter was plant debris. It may have been derived from vegetation growing in these areas during periodic cycles of non-deposition.

pH and Cation Exchange Capacity

pH is equivalent to the common logarithm of the reciprocal of the hydrogen concentration in a solution. It is used to determine the acidity or alkalinity of soil. There is evidence that the clay particles are charged negatively on their edges under a high (pH >7, basic) pH environment [11]. pH values for tested soil samples were determined by using a calibrated pH meter. Test results shown in Table 4 indicate that the pH value of Al-Qatif soils are between 7.89 to 7.91, which is in the alkaline range.

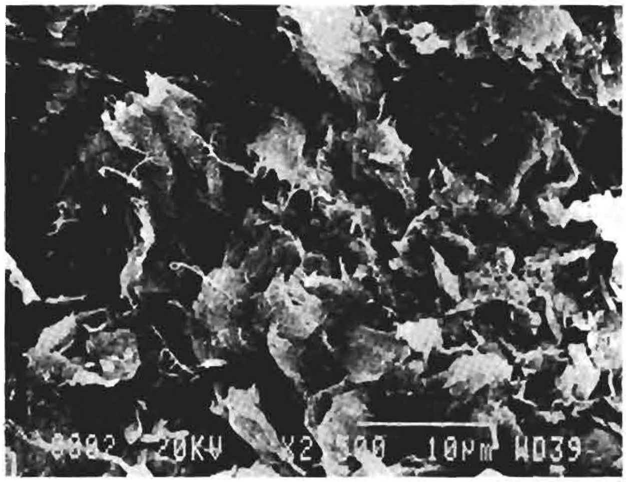

Figure 6. SEM Micrograph of Soil Sample From Block No. 2.

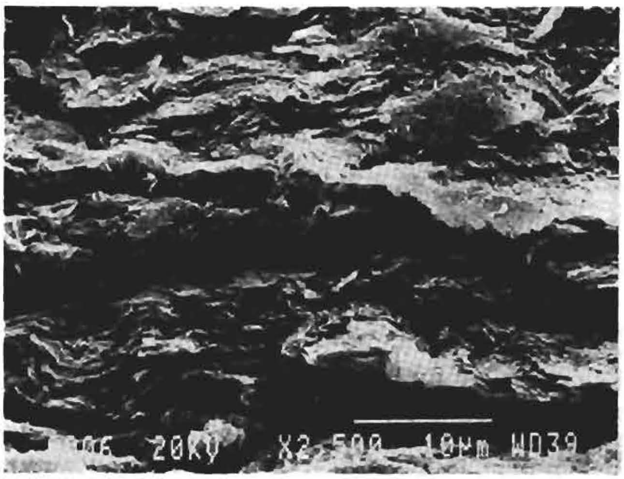

Figure 7. SEM Micrograph of Soil Sample From Block No. 4.

Cation exchange capacity (CEC) is the quantity of exchangeable cations required to balance the charge deficiency of clay and is usually expressed as milliequivalent per 100 gm of dry clay. Cation exchange capacity has a major effect on the properties of clay minerals, particularly the double layer interactions. The CEC has been determined according to Polemio and Rhoades method [12]. The values vary from 22.59 to 24.09 meq/100 g, as shown in Table 4. They are in the high range because of the existence of montmorillonite and the alkalinity of the soil (pH >7).

SWELLING TESTS

These tests include all methods which quantitatively assess the volume change characteristics of expansive soils. The characteristics which are measured are swell and swelling pressure. In this study, direct measurement was achieved by two different methods using the conventional one-dimensional consolidometer.

Swelling Pressure Test

The sample is placed in the consolidometer between two porous stones. Vertical expansion of the sample upon access to water is prevented. The force required to prevent expansion is measured as a function of time by a load cell connected with a portable data logger. The swelling pressure ultimately approached is a measure of the maximum force per unit area that can be exerted by the soil under extreme swelling conditions. A line diagram for the swell pressure test setup is shown in Figure 8.

Figure 9 shows the results of swell pressure *versus* time for samples taken from the four soil blocks collected from Al-Qatif. Figure 10 shows the same data but is drawn on a semi-logarithmic plot which depicts the process of swell with time more clearly. Each curve can be divided into three distinct stages representing the instantaneous, primary and secondary swelling. The maximum swelling pressure of 3.25 kg cm^{-2} was exerted by the sample from block No. 3. This high value of swelling pressure can be attributed to its high plasticity index, low shrinkage limit, high clay fraction, and high percentage of montmorillonite. The sample from block No. 4 has a very similar mineralogical composition to the sample from block No. 3, but exhibits the lower swelling pressure of 0.73 kg cm^{-2}. This happens in sample No. 4 because of its low clay fraction (42%) and its natural water content is greater than the plastic limit. The sample from block No. 2 has the highest percentage of clay fraction (73%) and the highest percentage of montmorillonite (22%), but the recorded swelling pressure of 2.31 kg cm^{-2} was less than the swelling pressure for sample No. 3 because of the low density, high natural water content, and the flocculated arrangement of particles. Sample from block No. 1 exhibits the low swelling pressure of 1.5 kg cm^{-2} due to the low percentage of montmorillonite.

Swell Percentage Test

The sample is placed in a consolidometer under a small surcharge of about 6.9 kN m^{-2} (1 psi). Water is then added to the sample, and the expansion of the

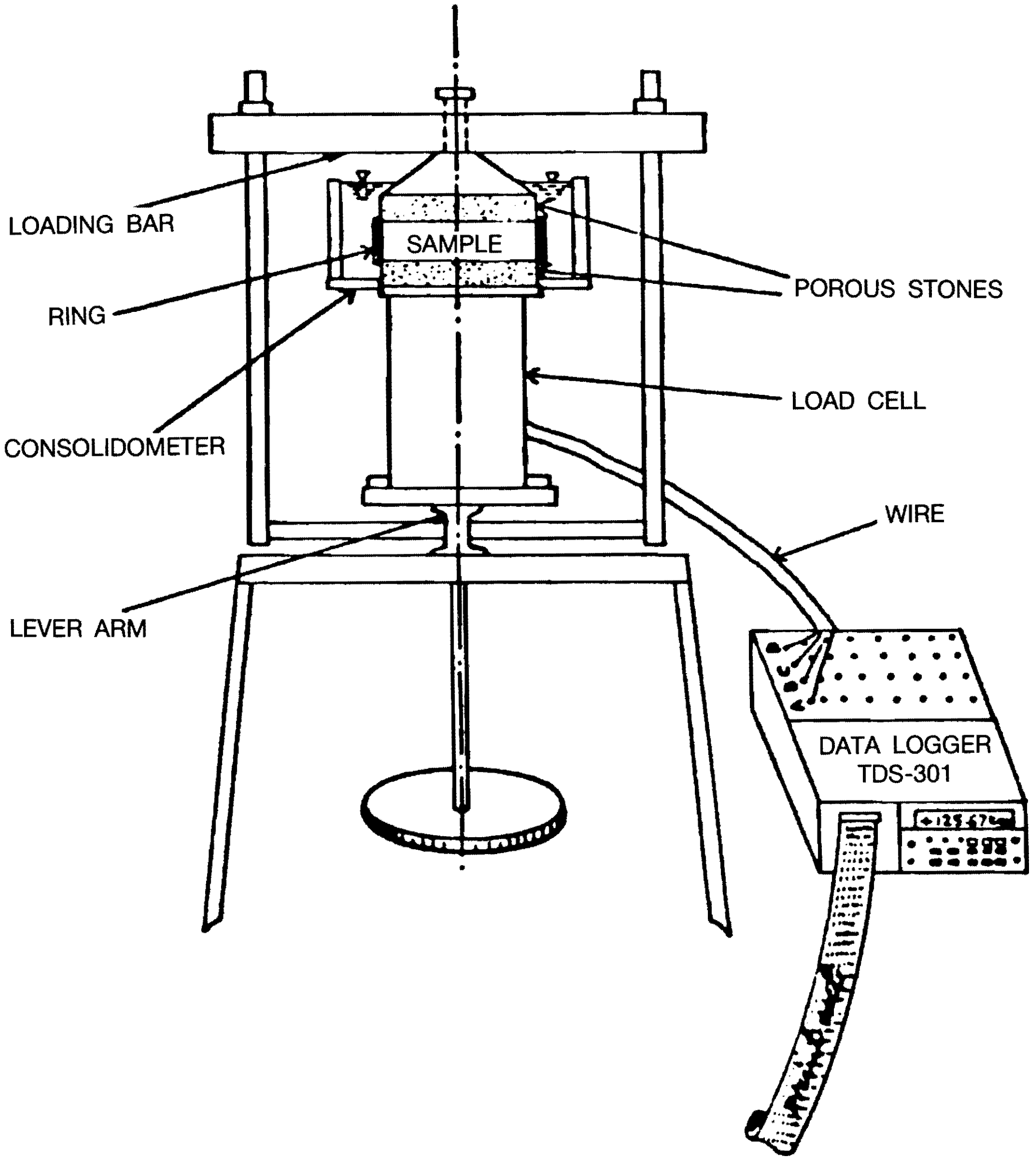

Figure 8. Swell Pressure Test Apparatus.

volume of the sample is measured until equilibrium is reached. The increase in thickness expressed as a percentage of the original thickness is designated as the percentage of swell. Figure 11 shows the results of tests conducted on undisturbed soil samples taken from the same blocks. The maximum percentage of swell of 14% was recorded for the sample taken from block No. 3. After reaching the maximum volume change under 1 psi, samples were loaded in small increments. The loading was continued until the samples attained their original height. The swelling pressure shown in Figure 12 was calculated from the sum of the loads increments divided by the cross-sectional area of the sample.

The calculated values of the swelling pressure from the swell percentage test are somewhat smaller than those obtained for corresponding samples in the swelling pressure tests. This is because the samples in swelling pressure tests are restrained completely against expansion, while in swell percentage tests the samples are tested in unrestrained conditions. The unrestrained conditions and the swelling pressure tests give useful indication of extreme behavior. In most instances, swelling is partly restrained. Consequently, the magnitude of swell and swelling pressure is likely to be intermediate between that determined by the two tests. Comparison of swelling pressure and the percentage of swell for Al-Qatif

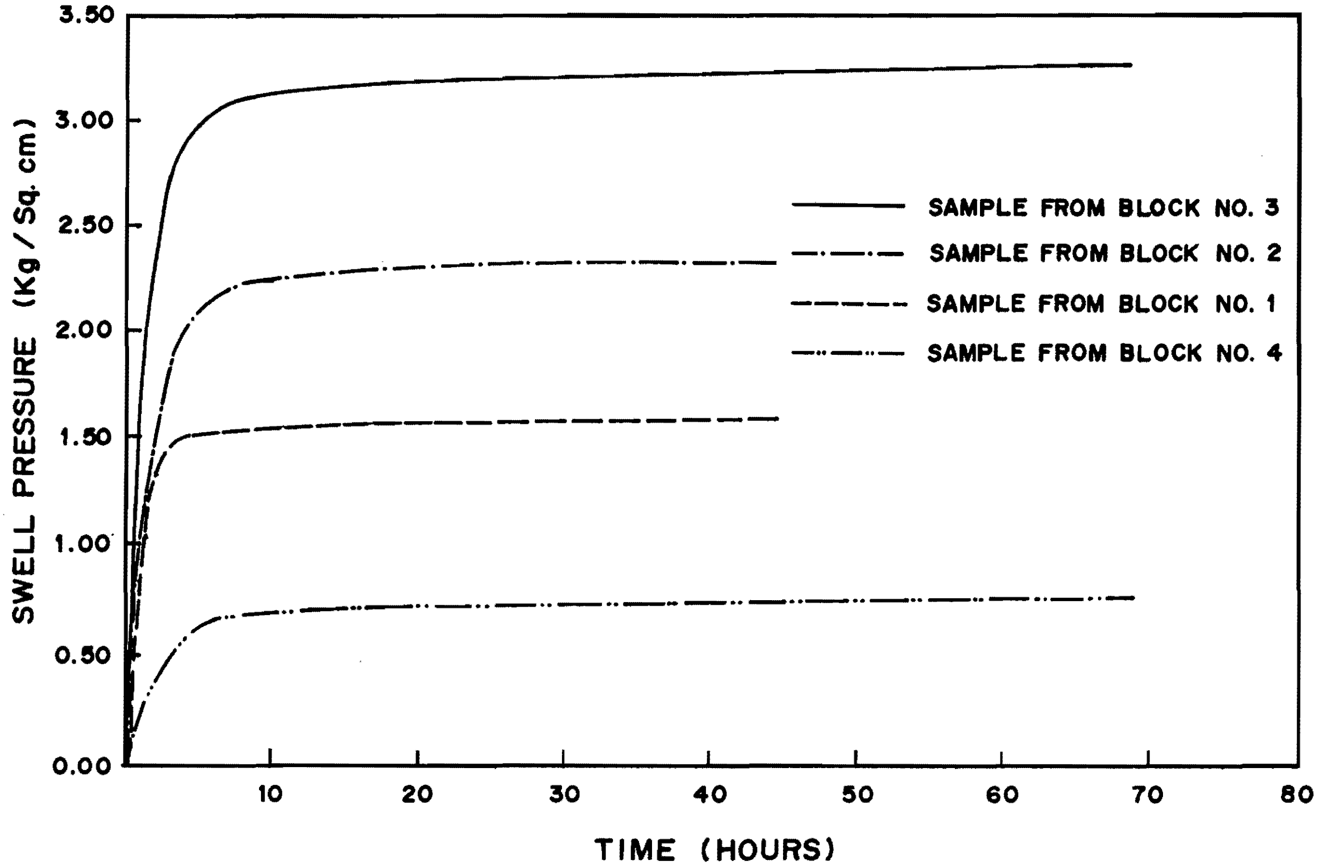

Figure 9. Swell Pressure versus *Time Curve for Samples From Al-Qatif.*

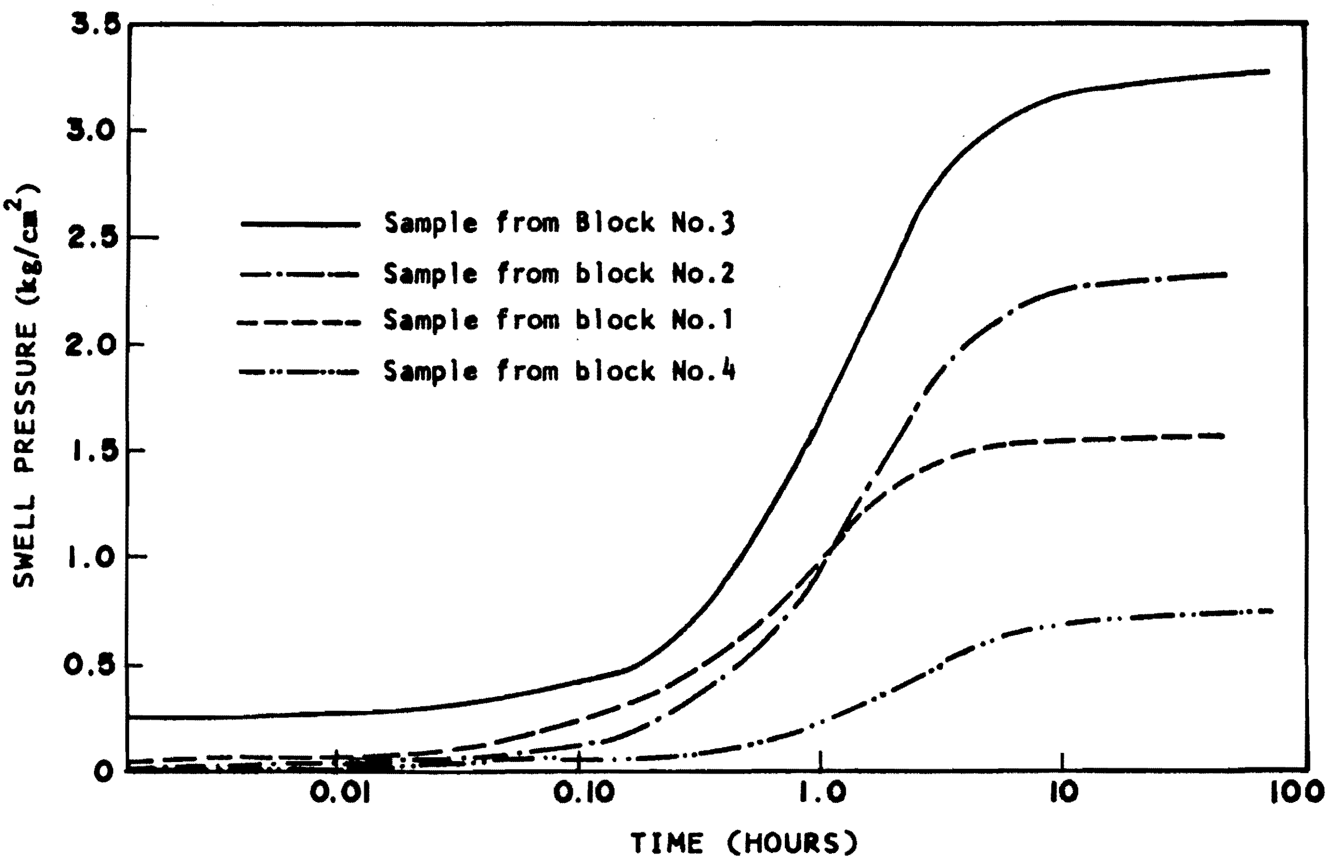

Figure 10. Swell Pressure versus *Time for Al-Qatif Samples. (Semi-Logarithmic Plot)*

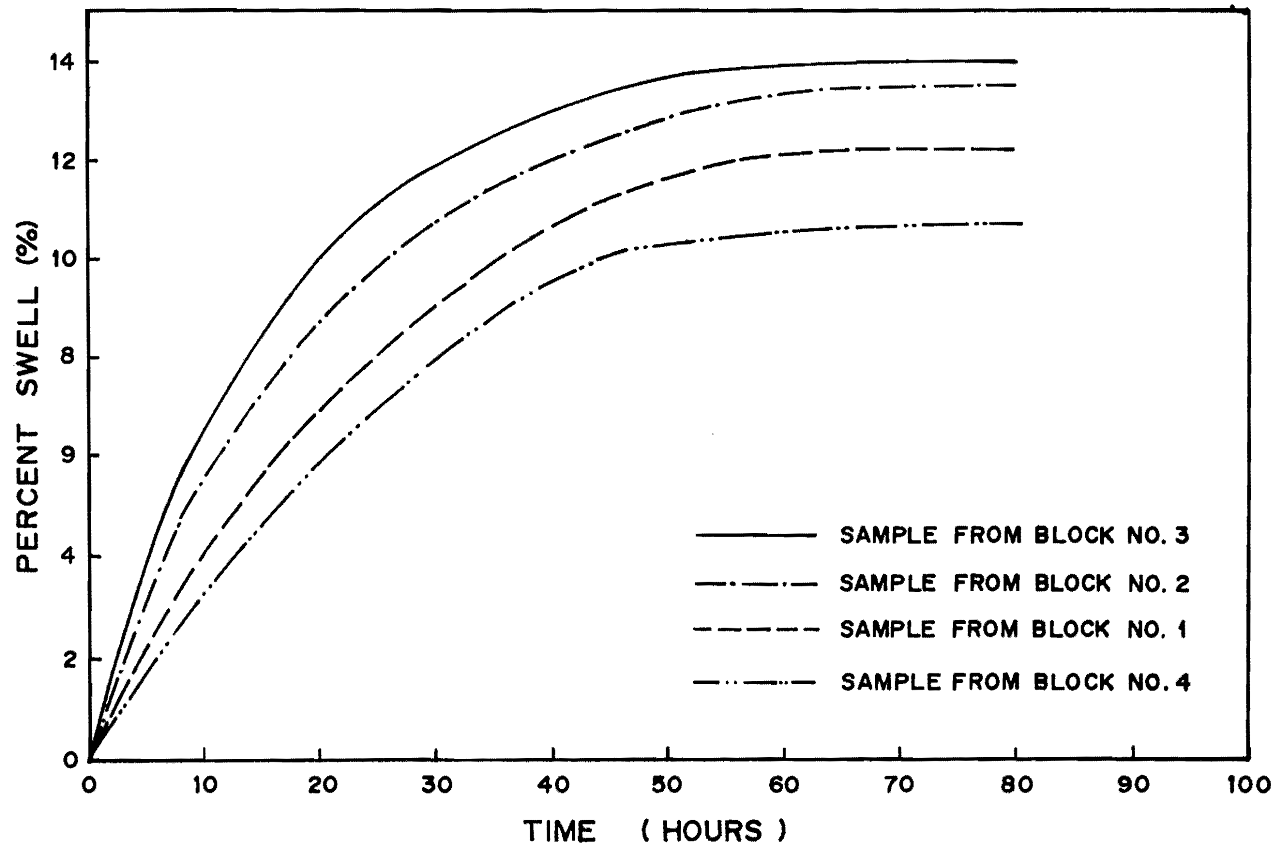

Figure 11. Percentage of Swell versus *Time Curves for Al-Qatif Soil.*

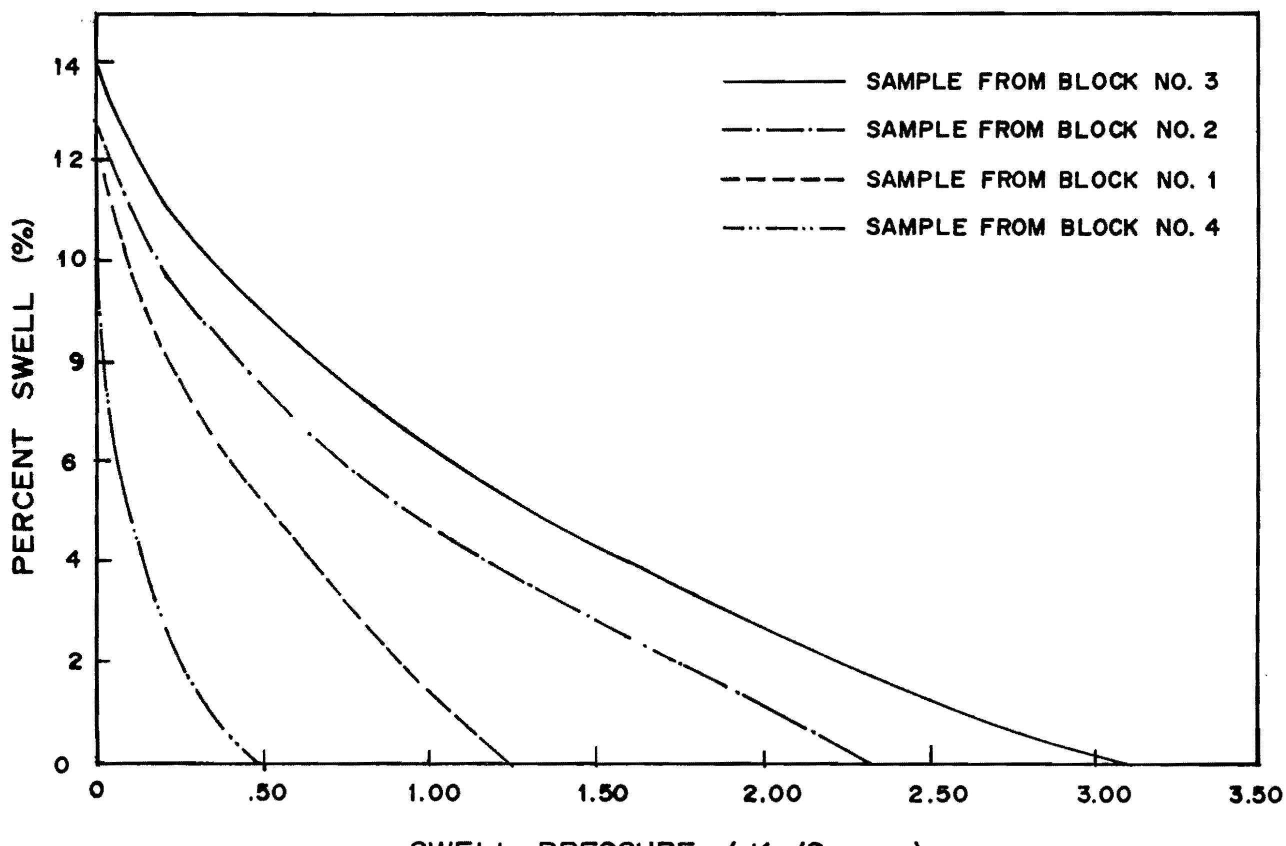

Figure 12. Relationship Between Percentage of Swell and Swell Pressure.

expansive clay with other expansive soil formation found in the Kingdom indicates that Al-Qatif clay can be categorized as highly expansive; a maximum percentage of swell of 12% was obtained by Dhowian [4] in the five different investigated areas around the Kingdom which is less than the 14%, recorded for Al-Qatif clay.

Gerald Gromko [6] has found that the laboratory test results are correlated fairly well with field measurements of heave. However, it should be noted that in the laboratory swelling tests the samples are confined in a metal ring with no soil movement or water flow in the lateral directions, while in the field some radial water flow may occur with slight lateral soil movement. Also, in the laboratory a small portion of the soil mass is used to simulate the field conditions. Hence, a large number of samples should be collected and tested, so the highest swelling measurement will not be missed. However, if the soil possesses marginal or high swelling pressure, precautions need to be taken. Several treatment procedures have been successfully used to counteract the adverse effects of expansive soils [1].

CONCLUSIONS

Based on the geotechnical investigation and mineralogical indentification of Al-Qatif clay, the following conclusions are drawn:

1. Geotechnical properties, chemical analysis, and mineralogical composition indicate that Al-Qatif clays have high swelling potential.
2. X-ray diffraction and SEM analysis of soil samples indicate the existence of montmorillonite, the highly expansive clay mineral.
3. The high values of pH and cation exchange capacity of Al-Qatif clay confirms the presence of a high content of montmorillonite.
4. Direct measurements of swelling pressure and the percentage of swell show that Al-Qatif clay can be characterized as highly expansive.
5. The properties of Al-Qatif clays vary from one location to another even though the locations are very close (heterogeneous), so special precautions against differential swelling should be taken to safeguard structures which are going to be constructed in the area.

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