Geotechnical and Mineralogical Studies on the Expansive Soil at Qena Region, Egypt

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Abstract— Expansive soils are found in many arid and semi-arid areas in worldwide such as Australia, Canada, China, India, North Africa and the United States. Egypt as a country from north Africa has a lot areas having expansive soil. Qena governorate which is situated at 594 km south Cairo has adequate land area for expansion and being an important industrial, commercial, educational and tourist center in the Upper Egypt region. In Qena, there are several areas where this kind of problematic soil exists in the form of variable-thickness layers in the developed regions, such as new Qena city, Qeft city and El-Salheya area. Therefore, the objective of this study is to investigate some of engineering properties of expansive soil in El-Salheya area which is situated at 2km east Qena governorate where development has a promising future. Representative disturbed samples were taken from two sites in this area. Three samples were taken from each site at depth 1.5m, 3.0 m and 4.5 m. Different laboratory tests were carried out on these samples including, natural water content, natural dry density, grain size distribution, Aterberge limits, unconfined compressive strength, modified proctor, free swelling, swell potential and swelling pressure. These tests were supported by chemical and mineralogical investigations such as X-ray diffraction (XRD) and X-ray fluorescence spectrometer (XRF). The results of these tests showed that the clay in this area has mineral montorillonite predominantly with low to medium expansion. Also, some empirical equations are proposed to determine the expansion indices from soil properties.

Keywords— Expansive soil, Qena, El-Salheya, Free swelling, Swelling pressure, Swell Potential, Atterberge limits.

1 INTRODUCTION

Expansive strata are soil and rocks which contains clayminerals that have the potential for swelling and shrinkage under changing moisture conditions. Clay minerals originate from the weathering of shale, slate, sandstone and limestone. Another source is the diversification of volcanic ash that was deposited under marine conditions during geologic times and settled alone or mixed with shale or limestone [1].

Subtropical climate influences the development of this type of soil and accelerates the desiccation and weathering processes of the source rock. If they contain montmorillonite (smectite group) or a certain type of illite, they will have significant swelling potential where it contacts with water.

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There is no statistical data confirmed about the economic losses due to structures founded on expansive soils in Egypt. Qena governorate which is situated at 594 km south Cairo has adequate land area for expansion and being an important industrial, commercial, educational and tourist center in the Upper Egypt region. In Qena, there are several areas where this kind of problematic soil exists in the form of variable-thickness layers in the developed regions, such as new Qena city, Qeft city and El-Salheya area. Expansive damages to buildings, roads and infrastructures have been widely noticed in these new developed areas.

Study of geotechnical properties of this soil plays an important role in its engineering classification, evaluation of its mechanical behavior, prediction and avoiding of its geotechnical problems. Some geological and geophysical studies had been carried out in Qena governorate and in Upper Egypt,[2], [3], [4], [5], [6], [7], [8].

Construction on this type of problematic expansive soil needs special requirement recommendations due to the hazard effect of this soil with any change of their moisture content. Safe and economic design of different types of construction on expansive soils require information about the expation indices such as swelling pressure, swelling potential and swelling index. For this reasons, we think for this research to identify the characteristics of the soil in the study area to take all precaution when execute any projects in this region. Also, the aim of this study is to investigate the-relationship between the index properties and swelling characteristics of the study soil and to develop empirical equations which help in estimating the swelling behavior of this soil.

2 LOCATIONS AND GEOLOGICAL SETTING OF STUDY AREA

The study area,(El-Salheya), lies between latitudes 26° 09′ 40 to 26° 8′ 48″ N and longitudes 32° 45′ 23″ to 32° 46′ 14″ E, , The study area consists geologically of an alternation fine siliclstic beds,siltstone, clay stone, and fine grained sandstones. They were accumulated on the bank of the River Nile on both east and west sides. Toward the east, in local inland lakes, laminated fine siliclastics (siltstone and clay stone) and stromatolitic limestone and lime mud were laid down [9]. The studied soil belongs to the Neo-Nile stage of the Nile evolution (Dandara formation). The distribution of the sediments is mapped in some details in a geological map as shown in Fig. 1.

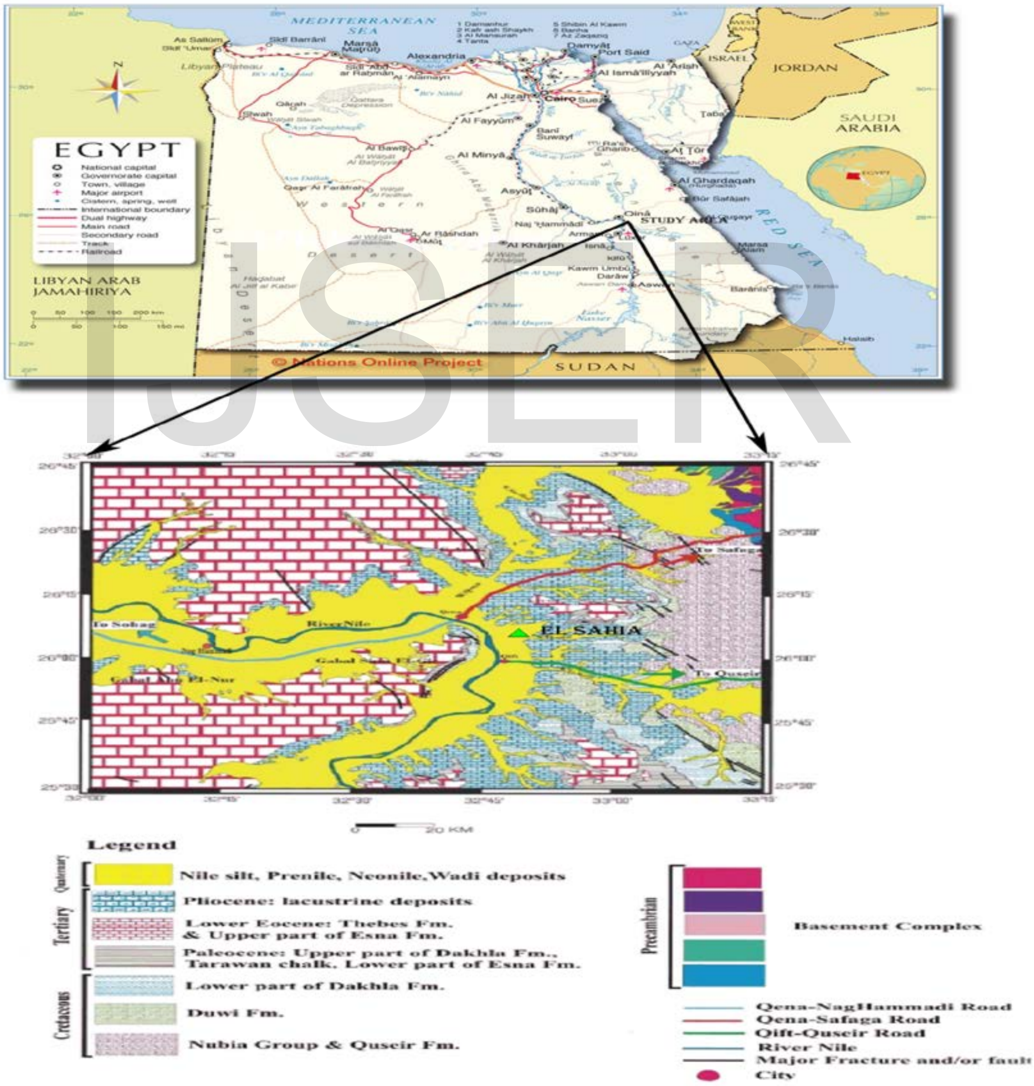

Fig. 1. Location and geological map of El-Salheya area

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3 EXPERIMENTAL WORKS

The soil samples used in this investigation were collected from El-Salheya area, Qena, Egypt. Field visit was carried out to collect the soil samples and to make visual observations. The visual observations of the site indicated several structural damages in this area which is a typical indication of swelling soils, as shown in Fig. 2.

Soil samples were obtained by open excavation from two sites A and B. The disturbed sampleswere taken from depths 1.5m, 3.0m and 4.5m below ground surface for each site.

Fig. 2. Examples of structure damage caused by expansive soil in the study area

3.1 Chemical Analysis

Chemical analysis is carried out by X-ray fluorescence spectrometer (XRF) technique using the instrument JEOL, JSX 3222, Japan. Chemical analysis of studied samples indicated that they have high content of ferric oxide (Fe_2O_3) and aluminum oxide (Al_2O_3), which are the main elements of clay minerals and where the increasing of swelling strain of these samples related to the increasing of ferric oxide (Fe_2O_3) and aluminum oxide (Al_2O_3), the percentage of chemical composition of (Fe_2O_3) and (Al_2O_3) are 19.20 % and 12.85 % respectively as shown in Table 1.

TABLE 1
RESULTS OF CHEMICAL ANALYSIS

Site	Sample No.	Chemical composition %									
		MgO	Al2O3	SiO2	K2O	CaO	TiO2	MnO	Fe2O3	SO3	LOI
A	1	2.21	12.85	44.47	1.61	5.79	2.98	0.77	19.20	5.29	5.00
	2	2.88	12.67	47.41	1.60	5.10	2.50	0.72	18.11	5.11	4.38
	3	2.11	12.82	46.20	1.49	5.20	2.34	0.79	18.70	5.19	5.16
B	4	1.97	10.30	46.20	1.32	5.97	2.22	0.73	19.00	5.33	6.96
	5	1.70	10.00	47.51	1.80	6.01	2.00	0.72	18.22	5.19	6.85
	6	2.05	11.50	47.40	1.46	5.80	2.00	0.69	18.00	4.50	6.30

LOI= Loss of ignition at 1000 °C.

3.2 Mineralogical Composition

X-ray diffraction method was utilized for identification of the different types of clay minerals present in the tested soils. The mineralogical analysis of six representative samples was carried out using PW1710 BASED diffractometer with a generator operating at 40 kV, 30 mA. The mineralogy of studied soils provides the basis for understanding their geotechnical behavior. It also helps to identify types of clay minerals such as high activity smectite minerals, calcite, quartz and other minerals. It was found that The clay minerals present in El-Salheya clay fraction were montmorillonite as major constituent, as well as kaolinite and discrete illite as minor constituents. The clays as montmorolonite in the soil is a good indication of the swell potential. These problems of excessive expansive characteristics lead to much damage to the structures built in and on these soils. The test results are shown in Table 2.

TABLE 2
RESULTS OF MINERALOGICAL ANALYSIS.

Test No	Sample No.	Major Cont.	Minor Cont.	Trace Cont.
A	1	Quartz , Montmorillonite	Kaolinite, Illite.	Calcite.
	2	Quartz, Montmorillonite, Allite.	Kaolinite.	--------
	3	Quartz, Montmorillonite.	Illite, Calcite, Kaolinite.	--------
B	4	Quartz, Montmorillonite.	Calcite.	Kaolinite.
	5	Quartz, Montmorillonite.	Calcite.	Kaolinite, Allite.
	6	Quartz, Montmorillonite.	Calcite, Kaolinite.	Illite.

3.3 Basic Soil Tests

The following tests were conducted on soil according to the ASTM. Liquid limit and plastic limit tests were conducting according to ASTM 4318. Particle size distribution was conducted according to ASTM D421. Modified compaction tests were conducted according to ASTM D1557. Swell tests were carried out according to ASTM D4546. The results of these tests are shown in Table 3.

TABLE 3
RESULTS OF GEOTECHNICAL TESTS

Site	Sample No	Passing sieve No 10 (%)	Passing sieve No 40 (%)	Passing sieve No 200 (%)	Atterberg Limits		
					L.L	P.L	P.I
A	1	98.56	95.66	91.86	44.30	26.50	17.80
	2	98.00	95.20	91.40	44.80	27.00	19.20
	3	99.58	98.42	97.04	45.00	28.00	20.00
B	4	98.60	95.80	91.04	41.00	26.00	15.00
	5	97.30	95.00	90.80	41.00	26.00	15.00
	6	95.94	93.06	90.06	43.50	26.50	17.00

L.L = Liquid limit, P.L= Plastic limit, P.I= Plasticity index

TABLE 3
CONT.

Site	Sample No.	Soil content %			Activity	R.C	L.S %
		Clay	Silt	Sand			
A	1	15	83.84	1.16	1.19	2.03	10.0
	2	15.4	84.03	0.57	1.25	2.05	10.7
	3	16	83.5	0.5	1.25	2.15	10.79
B	4	14.3	84.5	1.2	1.05	2.46	8.99
	5	15.58	84.02	0.4	0.96	2.46	9.44
	6	15.6	84.1	0.3	1.09	2.17	9.18

Where:-

Activity is defined as the ratio of plastic index to percent of clay fraction finer than 0.002 mm

R.C= Relative consistency=((L.L-W_c)/P.I)

L.S= Linear shrinkage

TABLE 3
CONT.

Site	Sample No	Natural water content%	γ_b g/cm^3	γ_d g/cm^3	qu (kg/cm^2)	$\gamma_{d\,max}$ g/cm^3	OMC%
A	1	9.00	1.88	1.72	4.34	1.75	16.40
	2	9.80	1.85	1.68	4.65	1.74	15.00
	3	10.55	1.81	1.64	5.27	1.72	16.30
B	4	8.00	1.89	1.75	4.32	1.82	13.12
	5	8.00	1.816	1.68	4.34	1.81	13.50
	6	9.25	1.84	1.68	4.18	1.82	15.00

Where:-

γb= Bulk density, γd= Natural dry density, qu= Unconfined compressive strength based on $\gamma_{d\,max}$ and OMC, $\gamma_{d\,max}$ =Maximum dry density according to modified Proctor test, OMC=Optimum moisture content according to modified Proctor test

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3.5 Free Swelling test

The free swelling test is one of the most commonly used simple tests for estimating soil swelling potential. This test is performed by pouring 10 cm3 of dry soil, passing through sieve no 40 (0.425mm diameter), into a 100 cm3 graduated cylinder. The cylinder is then filled with distilled water and the swelled volume of the soil is measured after the material settles [10].

Free swelling is then given by:-

$Fs = (V-Vo) / V_O \times 100$

Where:-

Fs = Free swelling

V = Final volume after swell

V_O= Volume of dry soil, 10 cm^3

Results of the free swelling tests are given in Table 4

TABLE 4

RESULTS OF FREE SWELLING TESTS

Site	Sample No	Free Swelling %
A	1	92.8
	2	93.3
	3	95.0
B	4	91.4
	5	91.9
	6	93.0

The results illustrated that the free swelling ratio of the studied soil is ranging from 91.4 to 95%, this means that these soils have ability to swelling and there are an expected problems due to these soils.

3.6 Specimen Preparation for Oedometer Tests

To study the magnitude of possible swelling in clay, simple laboratory oedometer tests are conducted on remolded specimens. Swell potential tests and swelling pressure tests are considered the common two testes used for studying the swelling behavior of expansive soil. Remolded specimens were made at maximum dry density and optimum moisture content according to modified proctor test. A circular mould (17mm high and 50mm in diameter) was used to produce soil specimens for swell potential and swelling pressure tests. To obtain a soil specimen at a maximum dry density and optimum moisture content, a dry weight of the prepared soil to fit the volume of the mould at the required density was weighed and thoroughly mixed with the right amount of distilled water to achieve the prescribed moisture content. The moist soil was then placed in the mould and pressed by a hydraulic jack to exactly fit the mould. The mould was then disassembled to extract the soil specimen. The soil specimen was, then, gently placed over a porous stone in the testing ring. The ring was fixed with the clamp and the clamp was fixed to the testing cell by means of three screws. Another porous stone was placed the on the top of the specimen. The assembled cell was placed in the oedometer swelling device and a small surcharge (6.9kPa) wasplaced on the soil specimen, and the dial gauge was set to zero [11].

3.6.1 Swelling Pressure Tests

Swelling pressure (Sp) of a soil is the external pressure that needs to be placed over a swelling soil to prevent volume increase. The most reliable means of measuring swelling pressure is laboratory determination using one-dimensional consolidometer. This method is called direct measurement and the test is conducted on the soil of the study area.

Figs 3 and 4 show the change of the vertical displacement (Heave or Settlement) of the studied samples with different stress levels recorded at the end of tested period of 24 hours for each stage of loading. It could be noticed from these figures that the heave of the studied sample decreases with increasing the stress levels. The swelling pressure values of the studied soil samples are ranging from 141 to 159 kPa.

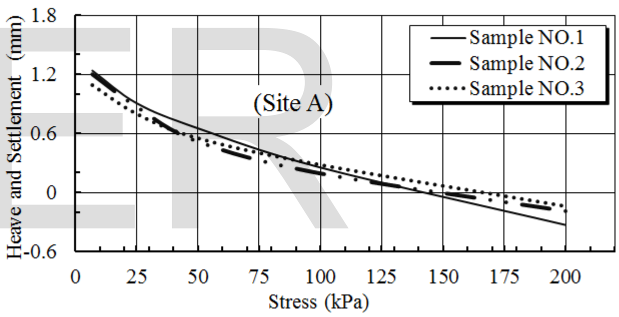

Fig.3. Vertical displacement versus stress levels for study soils in site A

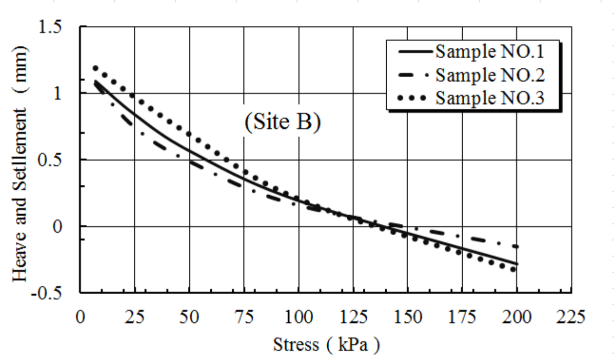

Fig.4. Vertical displacement versus stress levels for study soils in site B

3.6.1.1 Swelling Pressure Vs Plasticity index

The relationship between swelling pressure and plasticity index (PI) is shown in Fig. 5. From this figure it can be seen that there are a tendency of increment of the swelling pressure as the plasticity index increases and manifested in a linear

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relationship. A suggested equation was developed as:-

Sp (kPa) =41.938 $e^{0.2649PI}$ (1)

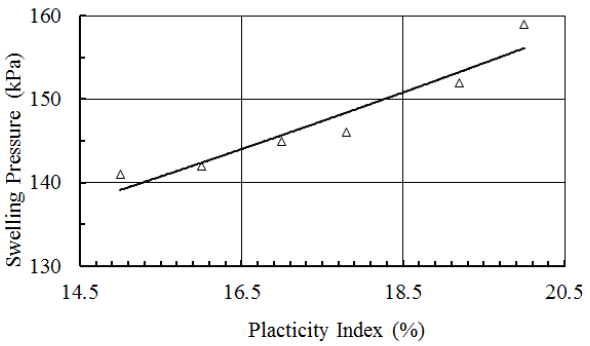

Fig.5. Swelling pressure Vs plasticity index

3.6.2 Swell Potential Testes

Swell potential (S %) is defined as the percentage increase in the original height of the specimen. In the swell potential test, the specimen is placed in the oedometer under a small surcharge of about 6.9 kN/m^2,water is then added to the specimen and the expansion of the volume of the specimen is measured until an equilibrium is reached. The swell potential is calculated as follows:-

$$S(\%) = \frac{\Delta H}{H} \times 100\% \quad (2)$$

Where:-

ΔH = Height of swell due to thesaturation,

H = Original height of the specimen.

Fig. 6 shows the relation between the vertical displacements versus time for the collected samples.When the soil reaches its maximum heave, the final heave was measured and swell potential was calculated according to (2). It was found that the value of swell potential ranges from 4.55 to 5.00 % and the time required for equilibrium is about 1000 minute for all tested samples.

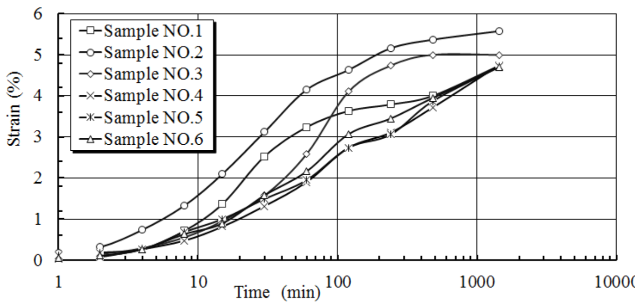

Fig.6. Vertical deformation versus time at stress levels 6.9 kPa for study soil

3.6.2.1 Swell Potential Vs Plasticity Index

The relationship between swell potential and plasticity index is shown in Fig.7. From this figure it can be seen that there is a tendency of increment of the swell potential as the plasticity index increases and manifested in a linear relation. A suggested equation was developed as:-

S (%) =3.4269 $e^{0.0186PI}$ (3)

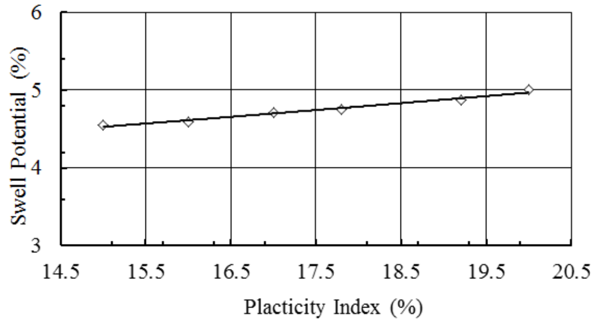

Fig.7. Swell potential Vs plasticity index

3.7 Swelling Pressure Vs Swell Potential

The relationship between swelling pressure and swell potential is shown in Fig.8. From this figure it can be seen that there is a tendency of increment of swelling pressure as the swell potential increases and manifested in a linear relation. A suggested equation was developed as:-

Sp = 39 (S-1) (4)

Where:-

Sp = Swelling pressure (kPa)

S = Swell potential (%)

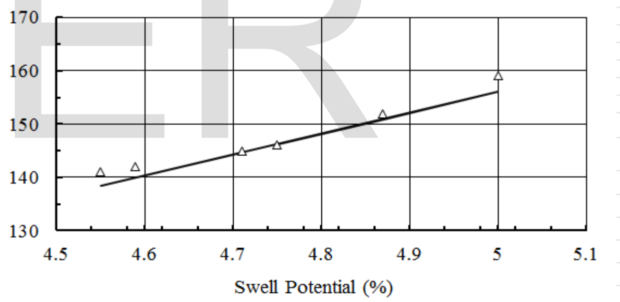

Fig. 8. Swelling pressure Vs swell potential for study soil

4 RESULTS AND DISCUSSION

4.1 Soil Classification

Soil classification is an important aspect of laboratory tests, which tells the characteristic of the soil under interest. There are different methods of classification based on the identification tests performed on the soil. These methods are discussed in details as follows:-

4.1.1 Classification According to Unified Soil Classification System (USCS)

The basis for USCS is the liquid limit and plasticity index of a soil [12]. According to this classification scheme most of the soils of the study area are considered intermediate expansive soil (CI), which shows that the soil is clay of medium plasticity.

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4.1.2 Classification According to American Association of Highways and Transportation Officials (AASHTO)

The AASHTO system uses similar techniques of USCS, but the dividing line has an equation of PI= LL-30. It generally classifies a soil broadly into granular material and silt-clay material. The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7 [12]. According to this system the soil of the study area falls in the region of A-7-6.

4.1.3 Classifications Based on Activity

Activity which is defined as the ratio of the plastic index to percent of clay fraction finer than 0.002mm is one means of classifying expansive soils based on their index property. According to [13] clays are classified with respect to their activity, as shown in Table 5. According to this classification, the study soils are considered as normal active clay where the values of activity range between 0.96 to1.25.

TABLE 5

CLASSIFICATION OF EXPANSIVE SOIL ACCORDING TO ACTIVITY

Degree of activity	Activity
Inactive	Clay less than 0.75
Normal	Clay 0.75 -- 1.25
Active	Clay greater than 1.25

Another way of identifying the expansive soil is to use the activity method quoted by [14].The proposed classification chart is shown in Fig. 9. Based on this classification the degree of soil expansion in study area is low.

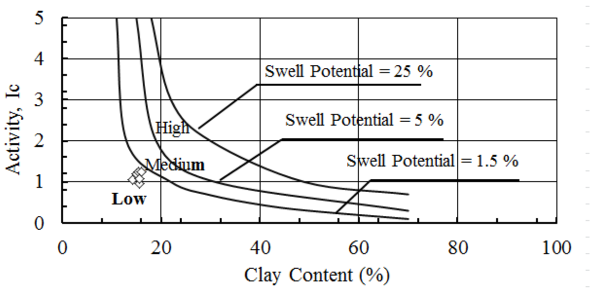

Fig.9. Classification chart based on clay content and activity

4.1.4 Classifications Based on Plasticity Index

Plasticity index is a parameter which can be used as a preliminary indicator of the swelling characteristics of a soil. The following values were proposed by [15] to relate soil expansivity and plasticity index.

TABLE 6

SOIL CLASSIFICATION BASED ON PLASTICITY INDEX [15]

Soil Expansivity	Plasticity index (P.I)
Low	≤ 15
Medium	10-35
High	20-50
Very High	>50

Relating the plasticity index of the study soil with the above given range reveals that the soil falls in the range of medium swell potential.

Dakshanamanthy and Raman [16] proposed another classification system based on liquid limit and plasticity index as shown in Fig.10.

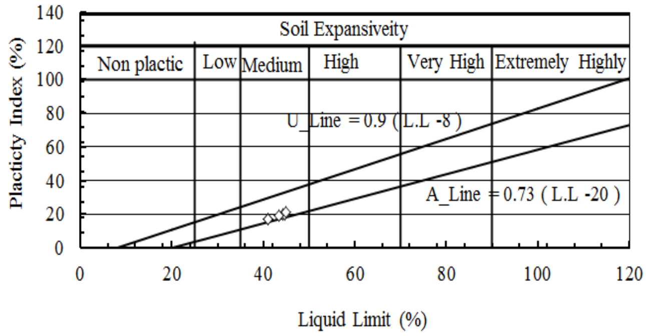

Fig.10. Classification chart based on liquid limit and plastic index

According to this system the soil of the study area falls in the range of medium swell potential.

4.1.5 Classifications Based on Swell Potential

Seed et al [14] proposed classification system for expansive soils according to the values of swell potential as shown in Table 7.

TABLE 7

SOIL CLASSIFICATION ACCORDING TO SWELL POTENTIAL [14]

Degree of Expansion	Swell potential
Low	0-1.5
Medium	1.5-5
High	5-25
Very High	>25

According to this classification, the study soils are considered as medium expansion where the values of swell potential range between 4.55 to 5.00%.

4.1.6 Classifications Based on Swelling Pressure

Geraid [17] proposed classification system for expansive soils according to the values of swelling pressure as shown in Table 8.

According to this classification, the study soils are considered as low expansion where the values of swelling pressure range between 141 to 159 kPa.

TABLE 8

SOIL CLASSIFICATION ACCORDING TO SWELLING PRESSURE, [17]

Degree of Expansion	Swell pressure (kPa)
Low	<196
Medium	196-392
High	392-687
Very High	>687

5 VALIDATION OF DEVELOPED RELATIONSHIP

5.1 Swell Potential

There are different equations suggested by different researches to determine indirectly the swell potential, some of these equations are listed below

1. Seed [14]

$S (\%) = 60KPI^{2.44}$ (5)

Where:-

S = Swell potential (%)

PI= plasticity index (%)

$K = 3.6 \times 10^{-5}$

2. Chen [15]

$S (\%) = 0.2558e^{0.0838PI}$ (6)

3. Saleem [18]

$S (\%) = 2.7993e^{0.0341PI}$ (7)

4. Abdallah [19]

$S (\%) = 2.2+0.1(PI)$ (8)

Fig.11shows the relationship between swell potential and plasticity index for study soil in comparison with those predicted from the equations proposed by different authors, [14], [15], [18] and [19], from this figure, it can be seen that the swell potential value obtained from suggest equation in this study is in a good agreement with that obtained from equation proposed by both [18] and [19].

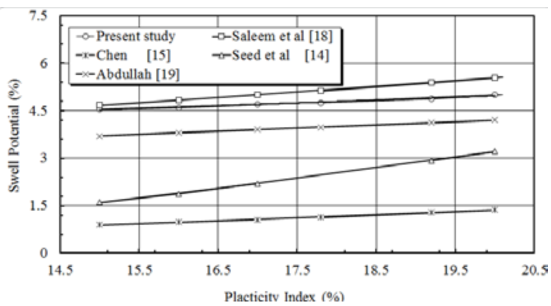

Fig. 11. Swell potential Vs plasticity index for different models

5.2 Swelling Pressure

The swelling pressure is calculated according to the empirical equation that is presented below by [20].

$Ps = 32.47 S$ (9)

Where: -

Ps=swelling pressure (kPa)

S = swell potential (%)

Fig.12 shows the relationship between swelling pressure and swell potential, for study soil in comparison with this predicted from (9). From this figure, it can be seen that the swelling pressure value obtained from suggest equation in this study is nearly in an agreement with that obtained from (9).

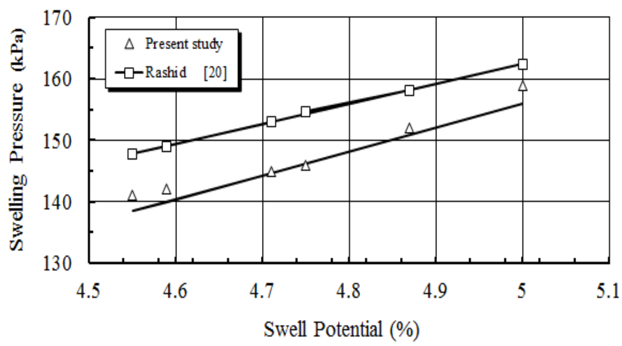

Fig. 12. Swell potential Vs Swelling pressure

6 CONCLUSIONS

Analysis and interpretation of the laboratory results and the field observations led to the following findings:-

1. The soil in El-Salheya area contains the clay mineral montmorillonite predominantly.
2. The index properties show that the clay soil in El-Salheya area are medium expansive.
3. The studied soil was geotechnically classified as intermediate expansive soil (CI) according to USCS and as A-7-5 according to AASHTO.
4. The regression analysis showed that there is a relationship between index propertiesand swelling characteristics of studied expansive soil.
5. Evaluation of the previously developed equations with the present study showed that the necessity of formulation of specific equations for specific areas.
6. The newly developed equations can be used for estimation of swelling characteristic of the studied soil.
7. Swelling pressure value of the samples is ranging from 141 to 159kPa at optimum moisture content and maximum dry density.

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