Journal of Al-Azhar University Engineering Sector

Vol. 20, No. 74, January 2025, 129-142

EMPHASIING THE IMPACT OF CLAY MINERALOG ON THE SWELLING BEHAVIOR OF EXPANSIVE SOILS

Amr A. NourElDin*

Researcher, Housing and Building National Research Center, Cairo, Egypt (HBRC)

***Correspondence:** amr.gel.hbrc@gmail.com

Citation:

A. A. NourElDin " Emphasizing the Impact of Clay Mineralogy on the Swelling Behavior of Expansive Soils ", Journal of Al-Azhar University Engineering Sector, vol. 20, pp. 129 - 142, 2025.

Received: 03 October 2024

Revised: 16 November 2024

Accepted: 26 November 2024

Doi: 10.21608/auej.2024.313476.1703

ABSTRACT

This study examines the influence of clay mineralogy, particularly clay content, Montmorillonite (MMT) %, on the swelling pressure of expansive soils. Through analyses of various soil samples collected from different sites, the research incorporates combination of physical properties tests, X-ray diffraction (XRD) analysis, microscope scanning (SEM), and swelling pressure evaluations, to establish the relationships. Results indicate that higher percentages of clay content, MMT and liquid limit consistently lead to increased swelling pressures. Clay mineralogy indicates the potential value of the swelling pressure, and although the quantitative values of the pressure are difficult to deduce from the data, it helps to explain the unusual behavior and identify the soil prone to swelling. Notably, the observed variability in swelling pressure among samples, even with similar mineral compositions, highlights the need for site-specific assessments. emphasize the critical importance of managing expansive soils to mitigate potential structural damage and optimize stabilization and construction practices.

KEYWORDS: Expansive Soils, Clay mineralogy, Montmorillonite(MMT), Swelling Mechanism, and Swelling Pressure

التأكيد على تأثير التركيب المعدني للطين على سلوك الانتفاخ في التربة الإنتفاخية

عمرو عبد الرحمن نور الدين

المركز القومي لبحوث الإسكان والبناء

البريد الاليكتروني : amr.gel.hbrc@gmail.com

الملخص

يدرس هذا البحث تأثير التركيب المعدني للطين ، وخاصة محتوى الطين، المونتموريلونيت (MMT) %، على ضغط الانتفاخ للتربة الإنتفاخية. من خلال تحليل عينات التربة المختلفة التي تم جمعها من مواقع مختلفة، يشتمل البحث على مزيج من اختبارات الخصائص الفيزيائية، وتحليل حيود الأشعة السينية (XRD)، والمسح المجهري (SEM)، وتقييمات ضغط الانتفاخ، لتحديد العلاقات. تشير النتائج إلى أن النسب المئوية الأعلى من محتوى الطين، ومحتوى المونتموريلونيت وحد السيولة تؤدي باستمرار إلى زيادة ضغوط الانتفاخ. يشير التركيب المعدني للطين إلى القيمة المحتملة لضغط الانتفاخ، وعلى الرغم من صعوبة استنتاج القيم الكمية للضغط من البيانات، إلا أنها تساعد في تفسير السلوك غير المعتاد وتحديد التربة المعرضة للانتفاخ. والجدير بالذكر أن التباين الملحوظ في ضغط الانتفاخ بين العينات، حتى مع التركيبات المعدنية المتشابهة، يسلط الضوء على الحاجة إلى تقييمات خاصة بالموقع. التأكيد على الأهمية الحاسمة في إدارة التربة الإنتفاخية للتخفيف من أضرار الإنشاءات المحتملة وتحسين ممارسات تثبيت التربة وطرق البناء.

الكلمات المفتاحية : التربة الانتفاخية ، التركيب المعدني للطين ، معدن المونتموريلينيت ، ميكانيكية الإنتفاخ ، ضغط الإنتفاخ.

1. INTRODUCTION

There is a significant role of mineralogical composition in determining the swelling pressure of expansive soils, particularly montmorillonite mineral. It is the key mineral influencing swelling behavior [1]. Increasing montmorillonite content in expansive soils leads to higher swelling potential, liquid limit, and plasticity index, while decreasing shrinkage limit and shrinkage index [2]. Expansive soils are implicitly pointed out associated with large damage to onshore or offshore, over, or underground infrastructures projects in more than 60 countries, on all continents. Despite worldwide efforts to depict, understand, and predict these peculiarities, annual damages related to geomechanical processes produced by variations of water content in expansive soils are reported all over the world. For instance, in UK-£400 million, or in the USA- $15 billion.[3] In the UK, or in China where expansive soil covers more than one hundred thousand square kilometers, expansive soil behavior is stated as one of the most dangerous geological hazards that affect large and diverse engineering projects [4].

Understanding the mineralogy is essential for determining the expected heave, differential heave and swelling pressures and consequently the design requirements for foundations and also the precautions needed for protecting them [5]. Another significant role of determining the clay minerals is selecting suitable materials for ground improvement techniques (like grouting or soil stabilization) [6] . Specific minerals may react differently with additives, affecting the overall strength and stability of the structure.

The extension of urbanization to desert areas revealed the widespread presence of these soils on the map of Egypt, and a lot of scientific research has appeared in this field that shed light on swelling phenomena, and at the same time raised many new questions that need more research. Many civil engineers need to understand this swelling mechanism of the expansive soil and also there is a lack of awareness of the impact of the mineral composition of the expansive soil. Practicing geotechnical engineers generally rely only on measurements of physical properties to define a swelling soil. Agricultural specialists and geologists rely on measurements of mineral composition and chemical properties, which geotechnical engineers should not neglect at all in the case of dry soil.

The main aim of this research is to explain the swelling mechanism of the expansive soil and to study significant role of clay content, Montmorillonite (MMT) content and Exchangeable cations and their effect to the swelling pressure.

2. Characterization of Expansive Soils

2.1. Geotechnical Identification Tests

Method for identifying swelling soils can generally be divided into two levels, the first level includes measuring the physical properties of the soil such as Atterberg limits, free permeation, and susceptibility to volume change. The second level includes determining the mineral composition of the soil such as clay content, Cation exchange capacity, specific surface area, and chemical properties [7].

2.2. Role of Micro Scale Aspects of Expansive Soil Behavior

The behavior of swelling soils at the microscopic level takes into account the mineral composition of clay grains and how they interact with the chemistry of water in the soil. It also shows the cation attracted to soil grains.

2.3. 2.2.1. Mineral composition

Some research papers discussed the significant role of clay mineralogical composition. Elkhateeb et al. [8] emphasizes the importance of the integration of geophysical investigation and mineralogical analysis of the foundation soil for optimal characterization of a site.

Most clay minerals are formed in the form of sheets or layers. The clay grain of the swelling soil consists of microscopic plates with negative charges on the surfaces of the plates. There are three groups of minerals whose degree of expansivity is described as follows:

1-kaolinite group: non-inflatable.

2-a group similar to Mica: it includes Illites, and Vermiculite, which may cause susceptibility to swelling, but the resulting swell does not cause problems.

3- Smectite group: it includes Montmorillonite (MMT): it is highly prone to swelling and the most problematic clay minerals.

In nature, these groups may appear singly or clustered. The structure of all these groups consists of wafer crystals and what distinguishes the mineral composition of clay is the physical arrangement of the different layers that make up the crystals and how they are interconnected [7].

2.4. 2.2.2. Bonding between plates or layers

The bonding between silica sheets in the MMT mineral is due to Van der Waal forces. In the Illite Mineral, the bonding between silica sheets is by potassium ion. The volume of the potassium ion fills the space between the silica sheets. The presence of a potassium ion in this space between the silica sheets creates a strong bond between them [9]. Therefore, the Illite minerals have much less swelling than what happens in the minerals of the MMT form.

2.5. Swelling mechanism

2.6. 2.3.1. Initial swell

When the soil is exposed to water and absorbs moisture, the water fills the voids, causing the first swelling, which depends on the dry density. The higher the ratio of voids relative to the total volume , the lower the density and, consequently, the first swelling is higher, and the absorption process continues until the saturation point (similar to the shrinkage limit), at which time the swelling becomes the result of the mineral composition of the clay.

2.7. 2.3.1.1. Swelling due to mineral composition

Clay (by microscopic examination) consists of crystals , and these crystals are groups of plates in the form of layers , similar to the pages of a book and clay minerals are distinguished from each other according to how these plates are installed and interconnected with each other.

When the absorbed water is limited to the outer surfaces of clay minerals and the spaces between the crystals, it is called an inter-Crystal swelling. As shown in **Fig. 1**, when water permeates between the crystal-forming layers, the swelling volumetric change in this case is called intra-Crystal swelling (intra-Crystalline swelling). Gillot, 1968 [10] reported that when the swell is inside the crystal-forming plates (intra-Crystalline swelling), this occurs as a result of the fact that the attractive force that binds the plates together is less than the attractive forces responsible for absorbing water.

The swelling of clay minerals does not occur as a result of a difference in the nature of the forces acting, but it is caused by a difference in the amount of these forces that occur as a result of a set of factors, the most important of which is related to the chemistry of mineral crystals. For example, the surface composition of MMT is similar to non-inflatable Illite. But in Illite there are higher charges per unit area on the surfaces than in MMT, so the strong internal interconnection between the layers makes the water unable to penetrate between those layers (plates).

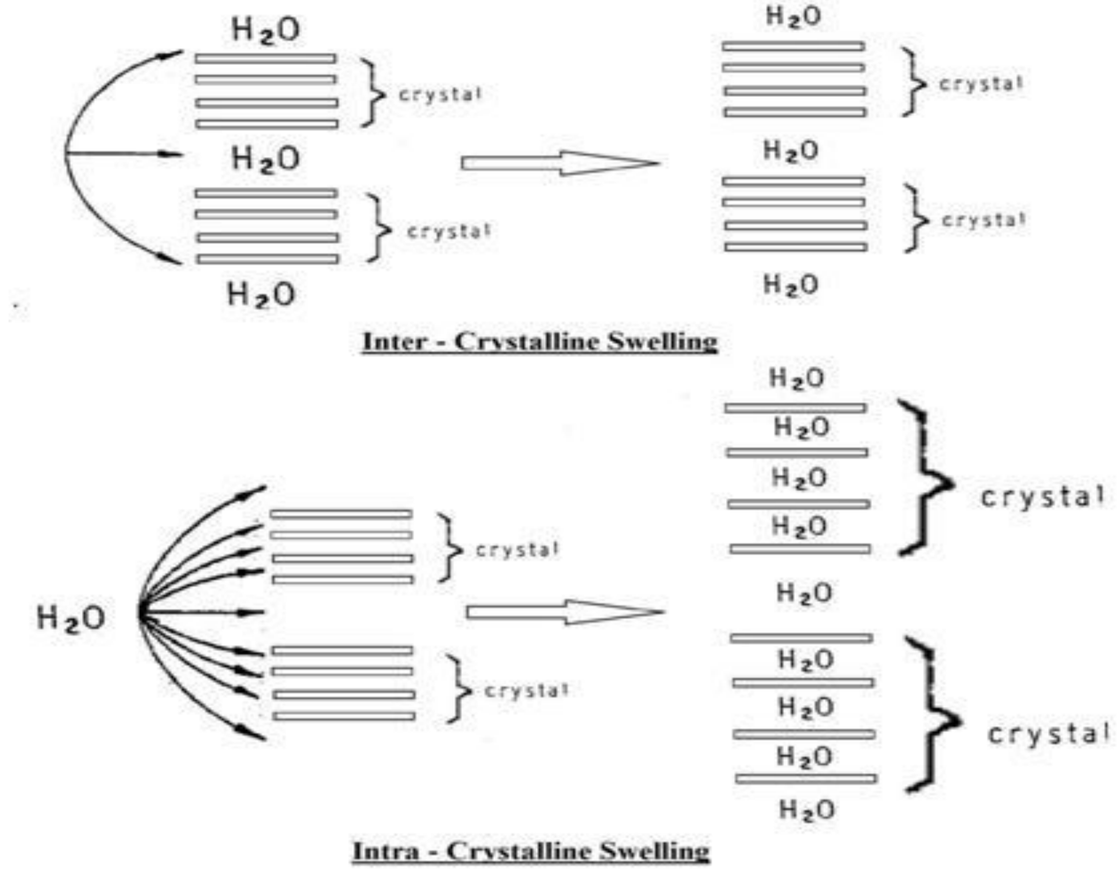


Fig. 1: water absorption by clay mineral [10]

The mineral MMT saturated with sodium exchange ion is considered to be of the greatest ability to swell over all other clay minerals, as the crystals of these minerals in water separate into plates after the exchange sodium ion and water molecules occupy the space between these plates.

In addition to smectite, there are some minerals with swelling plates that are able to absorb water into the crystals between the inner plates. Examples of such minerals are vermiculite, chlorite, hallowsite and some minerals formed by alternating layers, but the resulting swelling in these minerals is much less than in the case of sodium MMT (Na-montmorillonite). In general, when water is able to penetrate to the internal surfaces, the saturated volume of the clay mass unit becomes much larger than it occurs only on the external surfaces and the volumetric change is greater.

3. Experimental Works

3.1. Materials

Twenty-two expansive clay soils samples were collected from different places in Egypt. Sampling was done in areas representative of those zones of expansive soils to ensure that findings are applicable. Selecting varied locations helps capture a wide range of conditions. Samples are blocks of soil that can swell in their natural state. And they were divided into three groups. The first group from the al-Ayyat site consists of 7 samples at different depths, and the second group includes 6 samples from various sites in Giza and at a depth of about 3.00 meters from the Earth's surface. As for the third Group, 9 more samples were brought from various places from Al-Qusayr, New Valley, Kom Osheim, Badr, Shorouk and Katameya at depths from 3.00 to 6.00 meters below the surface of the Earth. The material locations and depths of soil samples used in this study is summarized in **Table 1.**

Table 1: Locations, depths, Atterberg limits, classification, dry density and water content of samples

No	Location	Depth	LL %	PL %	P.I	Sh.L %	Class.	γ_{dry} gm/cm^3	W/C %
1	al-Ayyat	4	68	26	42	9.6	CH	1.71	12.9
2	al-Ayyat	20	64	24	40	6	CH	1.81	6.6
3	al-Ayyat	35	39	16	23	21.1	CL	1.84	5.5
4	al-Ayyat	15	79	30	49	7	CH	1.74	10.6
5	al-Ayyat	27	33	16	17	17.5	CL	1.78	8.1
6	al-Ayyat	30	72	28	44	8	CH	1.75	10
7	al-Ayyat	40	66	26	40	6.7	CH	1.72	12.1
A	AbuHummus	3	84	33	51	8	CH	1.46	17.4
B	Kafr Hamid	3	90	35	55	11.5	CH	1.63	24.5
C	Tahma	3	55	23	32	5.5	CH	1.72	21.8
D	Abu Subaih	3	78	30	48	14	CH	1.56	23.3
E	Al-Saff	3	80	31	49	7.5	CH	1.6	24.4
F	Abu Khams	3	82	31	51	8	CH	1.66	21.4
G1	Al-Qusayr		67	27	40	15	CH	1.88	4.74
G2	Al-Qusayr		81	32	49	16	CH	1.93	4.45
H	Kom osheim	3	125	46	79	12	CH	1.82	4.56
I	Shorouk W	3	42	19	23	14	CL	1.74	5.38
J	Badr 1	3	89	33	56	16	CH	1.87	6.65 %
K	Katameya 1	4	74	26	48	14	CH	1.8	8.79
L1	New Valley (L1)	2	40	17	23	13	CL	----	----
L2	New Valley (L2)	4	35	15	20	19.5	CL	----	----
L3	New Valley (L3)	5	41	17	24	10	CL	1.86	3.44

3.2. Experimental Procedure

One of the most important indicators of identifying a swelling soil is the presence of the MMT mineral. The mineral composition of clay can be identified from or by chemical analysis, but the most widespread methods are X-ray diffraction (XRD) and scanning electron microscope (SEM) available at HBRC. The predominant clay mineral in the soil reflects on the plasticity of the soil. It also affects the swelling of the soil. Therefore, it is expected that there is a correlation between soil plasticity and its susceptibility to swelling. The X-ray diffraction (XRD) technique [11] was always used in researchs deal with clay minerlogy [12,13,14]. XRD pattern is based on the presence of diffraction peaks characteristic for each of crystalline species present in a sample. The intensity of the sharpness of these peaks are dependent not only on the number and the corresponding diffraction planes present in the examined sample but also on the particle size, chemical composition and pre-treatments during clay separation. The approximate proportions of clay minerals for different samples were determined according to the method recommended by the US Geological Survey and using some of its coefficients.

To assess the physical and hydro-mechanical properties of soils, laid down standards found in the literature were utilized: Sieve analysis [15]; Hydrometer analysis [16]; Atterberg limits [17]; Shrinkage limit [18]; water content [19] and dry density [20]. **Table 1** summarized the results of all previous tests.

The tests of measuring the swelling pressure in the odometer were carried out according to the ASTM standard [20] in two ways, the preload method (PS1), in which the sample is immersed in the device at a small load of about 7 KPA (0.07 kg/cm^2) and left to swell until the volumetric change is confirmed, then the loads are gradually placed to return the sample to its initial size and set the swelling pressure. And the second method (PS3), the test is performed in the same way using 3 samples under 3 different loads and the swelling pressure is set at each load, from which the swelling pressure can be set for the sample.

4. Results of Tests

4.1. Classification of tested samples

The classification of 5 samples from the first group (al-Ayyat) were classified hard dry silty clay and the color varied from gray to brown and two samples were gray-yellow sandy silty clay. The samples of the second group (Giza) were further classified as gray or brown hard silty clay. As for the samples of the third group (scattered places), although they were taken from scattered places, most of them were classified as dark gray or gray hard silty clay tending to brown or yellow and interspersed with flakes of yellow sand, as in the sample of Kom Osheim (H) and the New Valley (L3). In general, it turned out that the soil samples studied differ at the same site, at different sites and at different depths, however, all samples have a high to very high susceptibility to swelling.

4.2. Atterberg Limits tests

For the first group: **Table 1** shows the values of the liquid limit and the plastic limit as well as the plasticity index. The classification in terms of plasticity on the A-line chart are: 5 samples were classified as high plasticity clay (CH) and two samples (3), (5) as low plasticity clay (CL), where the ratios of the liquid limit of the five samples range from 64% to 79%, while the plasticity index ranges from 24% to 30%. For samples (3) and (5), the liquid limit values are 39% and 33%, respectively, and the plasticity index is 16%.

For the second group: **Table 1** shows the values 9of the liquid limit and the plastic limit as well as the plasticity index. Their classification on the A-Line of all samples was high plasticity clay (CH), where the liquid limit values ranged from 55% to 90%, and the plasticity limit from 23% to 35%.

It is clear from **Table 1** that the liquid limit for most samples (K), (J), (G2), (G1) ranged from 67% to 89% while sample (H) the liquid limit was 125% and the plasticity index for these samples ranged from 27% to 46% and the liquid limit values for samples Shorouk W (I) and New Valley (L3) were 41, 42% and the plasticity index was 19, 17% respectively. The first five samples were classified according to A-Line as high plasticity clay (CH) and the other samples low plasticity clay (CL).

For the first group, the shrinkage limit (Sh.L.) for the five samples ranges between 6% and 10%, while for the two samples (3) and (5) they are 21% and 18%. the smaller Sh.L., the more susceptible the soil is to swelling. For the second group: Sh.L. for samples (A), (C), (E), (F) ranges from 6% to 8% and sample (B), (D) Sh.L. for them was slightly higher than the rest of the samples 11,5%, 14%, respectively. For the third group: the Sh.L.values for the five samples ranged from 12% to 16% and the lowest value was for the New Valley sample (L3) 10%.

4.3. Gradation and Hydrometer test (Clay Content)

For the first group: it is clear from **Table 2** that in the samples the percentage of clay content smaller than 2 microns ranges from 72% to 81%, except for sample No. (3) and No. (5), the percentage of Clay was 5%, 33%, respectively. For the second group, the percentage of clay content in 5 samples (B), (C), (D), (E), (F) ranges from 58% to 92% and sample (A) the percentage of clay content was 22%. For the third group. **Table 2** shows that the percentage of clay content in 5 samples of this group ranged from 54% to 94% and the lowest percentage of clay content for samples is Shorouk W (I) which recorded 32%, it followed by the New Valley sample (L3) was 38%.

4.4. Mineral composition of clay tests

The results turned out that the clay minerals of the samples are MMT, kaolinite and with different degrees of crystallization and proportions, while non-clay minerals often consist of gypsum, calcite, quartz, feldspar and dolomite. **Fig.2** & **Fig. 3** show a sample of site Abu Subaih (No. D) with 68.5% MMT, 12.6% kaolinite and 1.9% illite. In addition, the exchangeable cations Ca^{2+}/Na^{+}. the other results of the rest of samples are listed in **Table 2**.

For Al-Ayyat group, which consists of 7 samples, the proportion of MMT for samples (3)&(5) ranged from 32% to 5,45% for the other five samples (1)،(2)،(4)،(6)،(7) the clay content ranged from 72% to 81%. This is largely evidence of the high weathering of the soils on this site. And the positive exchange ion varied from Ca^{2+} / Mg^{2+} to Ca^{2+} (calcium-magnesium to calcium only).

The second group consists of 6 samples taken from different sites in Giza. It is noted that sample A contains the lowest percentage of MMT 17% and the lowest percentage of clay content of 22%, which indicates that the swelling is low. The rest of the samples of this group from (B) to (F), the proportion of MMT in them ranged from 7.35% to 7.69%, while the percentage of clay content ranged from 58% to 93%. The proportion of MMT and the high clay content is evidence of the high wettability of the soil. The exchange positive ion was one Ca^{2+}/ Na^{+} calcium sodium for all samples.

For the third group consists of 9 samples, The approximate percentage of MMT in most samples of this group ranged from 27.5% in the short sample (G2) to 58.3% in the catamaran sample (K), and the percentage of clay content in this group ranged from 54% to 94%, and 38% was a sample.(L3) and the proportion of MMT for the sunrise sample (I) is 8.6%, and for the New Valley sample (L3)is 26%, while the clay content of the two samples respectively is 32%, 38%.There is a similarity between the two samples (3), (5) in terms of a lower percentage of clay content of 5%, 33% than the percentage of clay in other samples and the lowest percentages of MMT have 5,3%, 19%, and swell pressure tests were not performed for the presence of cracks, breaks, layers of sand and gypsum crystals in the stone blocks taken from the site and it is not possible to extract undisturbed samples from them and test them in the odometer.

Table 2: Results of Clay Content, XRD, Exchangeable cations determination tests

No	Location	Clay content %	Non Clay %	Clay minerals			
				MMT %	Kaolinite %	Illite %	Exchangeable cations
1	al-Ayyat	72.00	28	35.00%	35.50%	1.50%	Ca^{2+}/Mg^{2+}
2	al-Ayyat	77.00	23	45.50%	21.00%	10.50%	Ca^{2+}/Mg^{2+}
3	al-Ayyat	5.00	95	3.50%	1.00%	0.50%	Ca^{2+}
4	al-Ayyat	72.00	28	37.00%	27.50%	7.00%	Ca^{2+}
5	al-Ayyat	33.00	67	19.00%	11.00%	3.00%	Ca^{2+}/Mg^{2+}
6	al-Ayyat	80.00	20	33.00%	46.00%	1.00%	Ca^{2+}
7	al-Ayyat	81.00	19	32.00%	43.00%	6.00%	Ca^{2+}/Mg^{2+}
A	AbuHummus	22.00	78	17.00%	4.30%	0.60%	Ca^{2+} / Na^{+}
B	Kafr Hamid	92.00	8	69.70%	22.30%	1.20%	Ca^{2+} / Na^{+}
C	Tahma	58.00	42	35.70%	20.80%	1.50%	Ca^{2+} / Na^{+}
D	Abu Subaih	83.00	17	68.50%	12.60%	1.90%	Ca^{2+} / Na^{+}
E	Al-Saff	89.00	11	57.30%	27.60%	4.10%	Ca^{2+} / Na^{+}
F	Abu Khams	63.00	37	52.90%	8.10%	2.00%	Ca^{2+} / Na^{+}
G1	Al-Qusayr	54.00	46	31.60%	18.70%	3.70%	$Ca^{2+}/Mg^{2+}/Na^{+}$
G2	Al-Qusayr	66.0	34	27.50%	13.60%	24.80%	Ca^{2+}/Mg^{2+}
H	Kom osheim	63.00	37	30.80%	29.60%	2.60%	Ca^{2+}/Mg^{2+}
I	Shorouk W	32.00	68	6.80%	20.70%	4.50%	Na^{+}
J	Badr 1	83.00	17	35.30%	44.50%	3.20%	$Ca^{2+}/Mg^{2+}/Na^{+}$
K	Katameya 1	94.00	6	58.30%	20.10%	15.60%	Ca^{2+}/Mg^{2+}
L1	New Valley (L1)	38.00	60	26.00%	10.50%	1.50%	Na^{+}
L2	New Valley (L2)	38.00	66	26.00%	10.50%	1.50%	Na^{+}
L3	New Valley (L3)	38.00	62	26.00%	10.50%	1.50%	Na^{+}

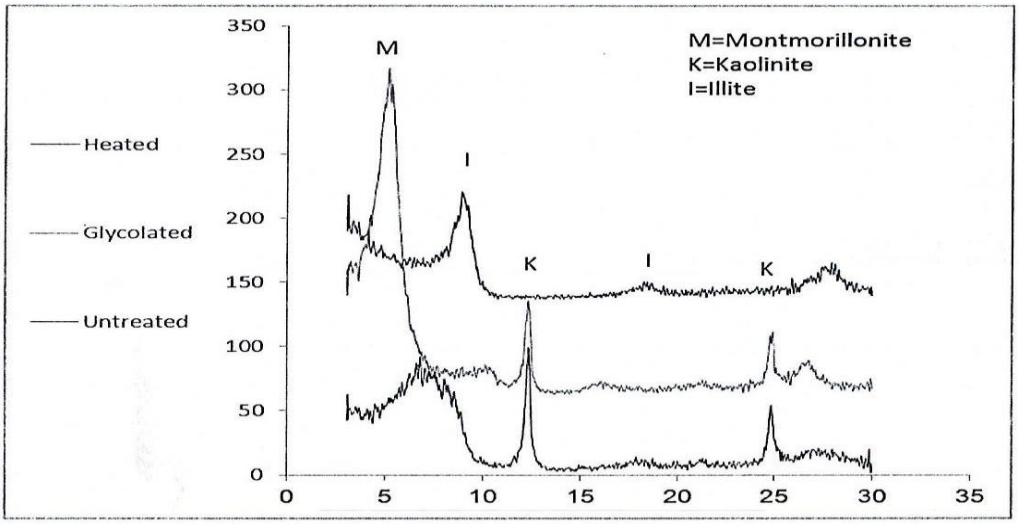
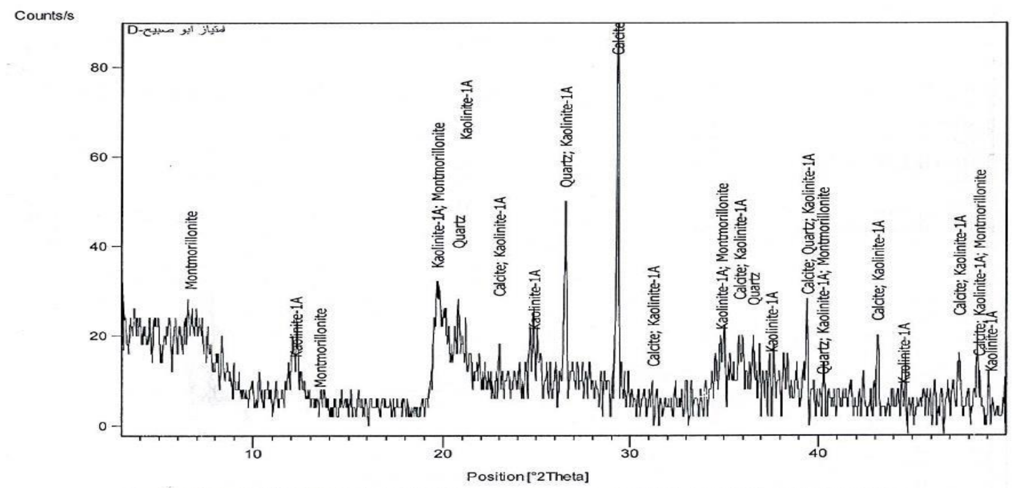


Fig.2 : Untreated, Glycolated, and Heated XRD Patterns of site Abu Subaih (No. D)



Compound Name	Chemical Formula
Calcite	$Ca\ C\ O_3$
Quartz	$Si\ O_2$
Kaolinite- 1A	$Al_2\ Si_2\ O_5\ (O\ H)_4$
Montmorillonite	$Na_x\ (Al\ ,\ Mg)_2\ Si_4\ O_{10}\ (O\ H)_2 \cdot z\ H_2O$

Fig. 3 Completed signal quantification with labeled peaks of site Abu Subaih (No. D)

4.5. Swelling Pressure tests results

The results of swelling pressure in the odometer by the both methods (PS3) & (PS1) are listed in **Table 3** and shown in **Fig. 4.** The tests were conducted on the sample (L3) only for the similarity of its mineral composition with samples (L1), (L2).

The figure shows that maximum swelling pressure value measured by the first method (one sample PS1) is sample (K) which recorded 6000 KPa. On the other hand, sample (I) recorded 160 KPa. While, sample (J) gives the highest value 4000 KPa for the second method (3 samples PS3) and the lowest value 220KPa was measured for sample(A). It is also noticed that for all samples except the Al-Ayyat samples gives higher values with (PS1) method than (PS3). This is agree with the conclusion of the paper by Mazen [21].

Table 3: Results of the swelling pressure of the samples of the three groups.

No	PS3 kPa	PS1 kPa	No	PS3 kPa	PS1 kPa	No	PS3 kPa	PS1 kPa
1	1906	1500	A	220	290	G1	600	3000
2	1600	1000	B	790	3900	G2	1250	5000
4	900	550	C	390	1000	H	820	2100
6	1700	1400	D	800	3800	I	300	160
7	1700	1100	E	880	4100	J	4000	4000
			F	540	3200	K	2000	6000
						L3	1100	264

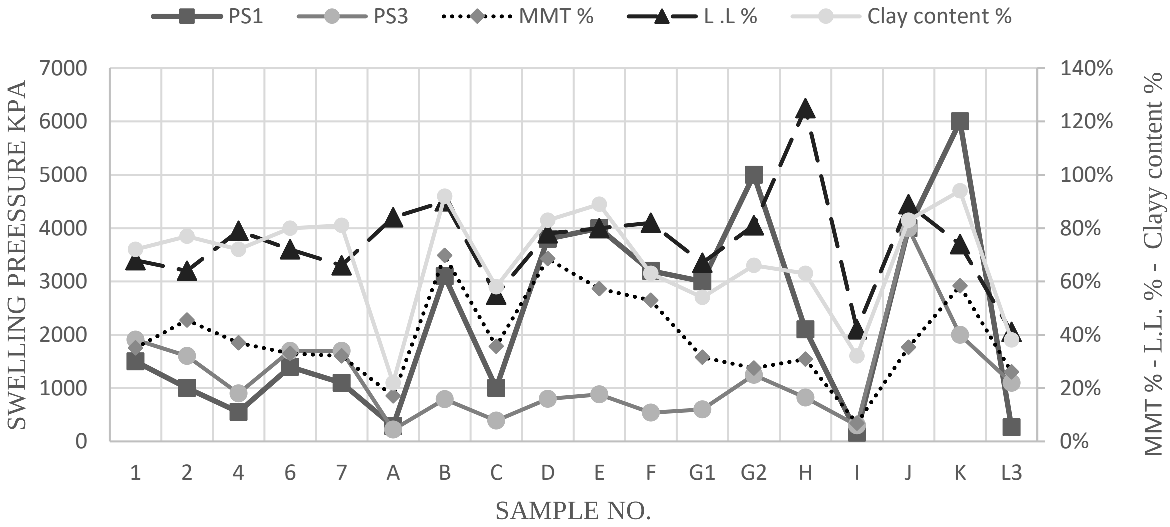


Fig. 4 Results of the Swelling pressure (PS1, PS3) of all samples with MMT%,L.L% and ClayContent %

5. Disscusion

The plotted ressults of **Fig. 4** suggest that thee higher percentages of MMT and clay content typically interlate with higher swelling pressures. This is a logic trend as they together express the spread of materials that cause soil swelling. Likewise liquid limit significantly affect the swelling pressur values of these samples as L.L. give us an indication of soil plasticity and consequently the expansive behavior. However, we note that sample B, despite the highest percentage of clay (92%), MMT(69.7%),and LL(90%) we did not obtain a maximum value for swelling pressure. We conclude from this that all other variables such as (dry density(1.63 kg/cm^3), cations type (Ca^{2+} / Na^+) must be taken into account along with the mineral composition together at the same time. Therefore, we cannot link the swelling pressure values to the percentage of clay only or MMT only or both together only, as these relations are qualitative not quantitative. This graph is similar to results of Abu Seif et al. [22]

In summary, the chart illustrates complex interactions between swelling pressure, clay content, and liquid limit, but engineers must understanding these relationships. It is crucial for applications such as construction, and soil management, where soil swelling behavior has significant implications.

5.1. Impact of Atterberg limits on Swelling Pressure

The graph of **Fig. 5** shows that L.L. and PI exhibits a somewhat consistent trend alongside swelling pressures. This suggests that higher liquid limits may be tends a higher swelling pressure. Sh.L values are nearly constant, so insignificant role is concluded.

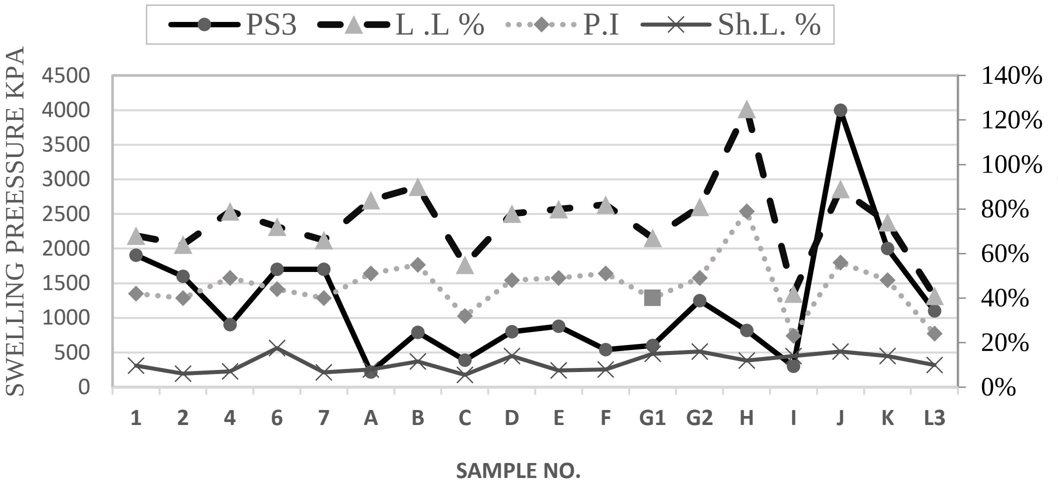


Fig. 5 Results of the Swelling pressure (PS3) of all samples with L.L%, P.I.. and Sh.L. %

5.2. Impact of Clay Content Ratio on Swelling Pressure

To study the effect of a specific independent variable on a non-independent variable, the change in the values of the other independent variables must be fixed or be so close. So, when studying the effect of the clay content ratio on the swelling pressure, it must be ensured that the values of other variables are close, such as the MMT ratio, moisture, density, and type of exchangeable cations. Comparing the results of all samples, sample (G1) & (J) were chosen to study that effect as shown in **Table 4**. These two samples have (MMT%, Exchangeable cations, dry density and water content) values are so close, The increase of clay content ratio from 54% to 83%, produce a huge increase of swelling pressure from 600 KPa to 4000 KPa.

Table 4 : Comparison Results of the swelling pressure to study clay content effect

No.	site	Clay content	MMT %	Exchangeable cations	γ_{dry}	W/C %	PS3 (KPa)
G1	Al-Qusayr	54.00%	31.60%	Ca2+/Mg2+ /Na+	1.88	4.74	600
J	Badr 1	83.00%	35.30%	Ca2+/Mg2+ /Na+	1.87	6.65	4000

5.3. Role of MMT Content on Swelling Pressure

Comparing the two samples (C) and (F), , as shown in **Table 5**, the percentage of clay content in them is approximately equal 58%, 63% respectively and with the same cations, while the MMT in (C) is 35.7 % lower than its percentage in the sample (F) 52.9 % and the swelling pressure by (3 samples) for sample (C) was 390 KPA less than the swelling pressure measured in the same way for sample (F) 540 KPA with close value of the dry density of the two samples.

Table 5 : Comparison Results of the swelling pressure to study MMT effect

No.	site	Clay content	MMT %	Exchangeable cations	γ_{dry}	W/C %	PS3 (KPa)
C	Tahma - Al-Ayyat	58.00%	35.7%	Ca2+ / Na+	1.72	21.8	390
F	Abu Khams	63.00%	52.9%	Ca2+ / Na+	1.66	21.4	540

5.4. Role of Exchangeable Cations on Swelling Pressure

The results of minerlogical tests revealed 5 types of cations Ca^{2+}/Mg^{2+}, ca^{2+}/Na^{+}, Ca^{2+}, $Na^{+}/Ca^{2+}/Mg^{2+}$, and Na^{+} as shown in **Fig.6**. The highest swelling pressure was recorded (4000KPa) with $Na^{+}/Ca^{2+}/Mg^{2+}$ groups. while the groups ca^{2+}/Na^{+} achieved the lowest value (880 KPa). Sufficiently safety factor must be put in geotechnical engineer considerations when constructions that were built on or in like this type of swell-able clay.

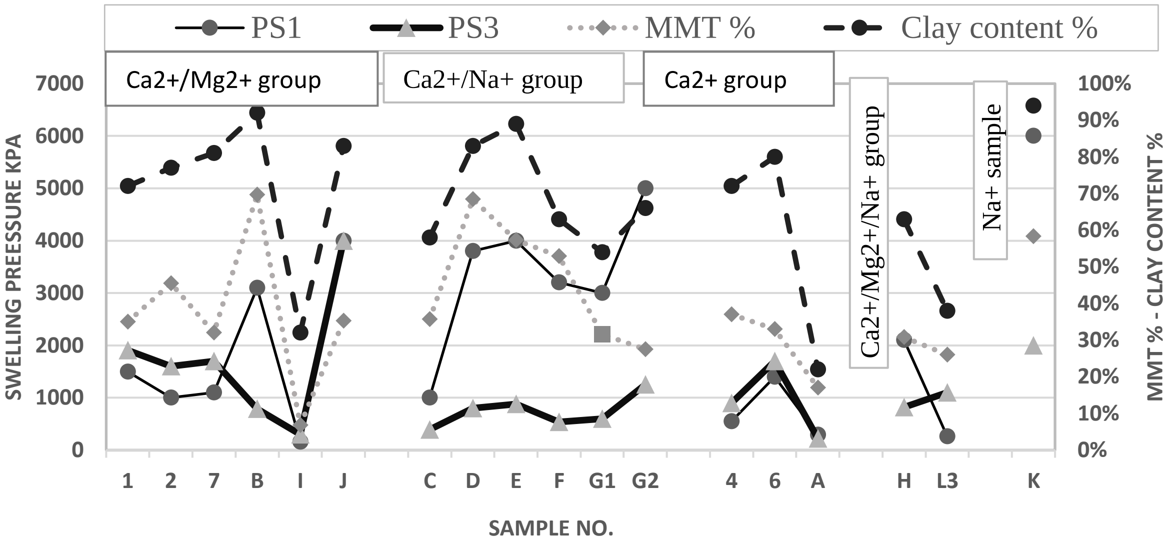


Fig. 6 Results of the swelling pressure of all samples (PS1, PS3)grouped according to their cations type

Comparing the two samples No. (1) and No. (4), , as shown in **Table 6**, you notice that the percentage of clay content is the same, which is 72%, and they contain close proportions of MMT 35%, 37%, respectively, as for the cation, in sample No. (1) it is Ca^{2+}/Mg^{2+} and in sample (4) Ca only, which led to the difference in swelling pressure by (3 samples) (1906) KPA sample No. (4) it is (900) KPA that is with the convergence of the values of moisture content and dry density between the two samples.

Table 6 : Comparison Results of the swelling pressure to study Exchangeable Cations effect

No.	site	Clay content	MMT %	Exchangeable cations	□ dry	W/C %	Ps3 (KPa)
1	al-Ayyat	72.00%	35.0%	Ca2+/Mg2+	1.71	12.9	1906
4	al-Ayyat	72.00%	37.0%	Ca2+	1.74	10.6	900

6. SUMMARY AND CONCLUSIONS

The research investigates the behavior of expansive soils, focusing on the effects of clay content, Montmorillonite (MMT) content, and exchangeable cations on swelling pressure. It analyzes various soil samples from different sites, providing detailed comparisons of their mineral compositions and physical properties. The tests conducted include Atterberg limits, hydrometer tests for clay content, and assessments of swelling pressure under different conditions. Key findings indicate that the swelling capacity of the soils is influenced significantly by their mineralogical components- particularly the presence of MMT. The mineral composition reveals a predominance of MMT among other clay minerals, which correlates with varying swelling pressures. Additionally, the role of different exchangeable cations (such as Ca^{2+}, Na^{+}, and Mg^{2+}) is highlighted, indicating that the type of cation affects the plasticity and swelling behavior of the soils.

1) **Influence of MMT**: The study confirms that Montmorillonite content is a crucial factor in determining the swelling potential of expansive soils. Higher MMT content generally leads to increased swelling pressures, indicating that soils rich in MMT require careful consideration in engineering applications.

2) **Clay Content and Swelling Pressure**: There is a strong correlation between clay content and swelling pressure. Higher clay content tends to elevate swelling pressure, emphasizing the importance of thorough characterization of soil in construction.

3) **Role of Exchangeable Cations**: The type of exchangeable cations present in the soil has a notable impact on swelling behavior. Different cation combinations affect both the swelling pressures and plasticity indices, indicating the need for geotechnical engineers to account for these factors during site assessments.

4) **Variation among Samples**: The study highlights significant variability in swelling pressures among different samples, even with comparable clay and MMT percentages. This variability necessitates a site-specific approach when assessing soil stability and suitability for construction projects. This is vital for safe construction practices, as swelling soils can damage structures if not properly managed.

ACKNOWLEDGMENTS

The author wish to acknowledge the support of the soil mechanics and geotechnical engineering institute, National Housing and Building Research Center (HBRC) especially prof.Dr. Mazen O.& Prof. Dr. Amira AbdelRahman.

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

[1] Reddy, P.S., (2022). Montmorillonite Content of Expansive Soils and Its Relationship with Swelling and Consistency Properties. 13-21. https://doi.org /10.1007/978-981-19-3371-4_2
[2] Reddy, P. S.,Mohanty, B. and Rao, B.H.,(2020). Influence of clay content and montmorillonite content on swelling behavior of expansive soils, International Journal of Geosynthetics and Ground Engineering, 6(1), 7–12.https://doi.org/10.1007/s40891-020-0186-6
[3] Dang, L.C., Khabbaz, H.(2019). Experimental Investigation on the Compaction and Compressible Properties of Expansive Soil Reinforced with Bagasse Fibre and Lime., In: McCartney, J., Hoyos, L. (eds), Recent Advancements on Expansive Soils. GeoMEast 2018. Sustainable Civil Infrastructures. Springer Nature Switzerland, pp. 64–78. https://doi.org/10.1007/978-3-030-01914-3_6
[4] Stãnciucu M., Dogaru I., (2024). Geotechnical Hazards Induced by Montmorillonite Presence., Book Chapter, Available from: https://doi.org/10.5772/intechopen.1004762
[5] Nelson, J.D. , Chao C., Overton D.D. and Nelson,E.J.,(2015). Foundation Engineering For

Expansive Soils, Published by John Wiley & Sons. Inc,. Hoboken. New Jersey, Published simultaneously in Canada Copyright.

[6] Gonawala, R.J., Kumar, R., and Chauhan, K.A.(2019). Stabilization of Expansive Soil with Corex Slag and Lime for Road Subgrade., In: McCartney, J., Hoyos, L. (eds), Recent Advancements on Expansive Soils. GeoMEast 2018. Sustainable Civil Infrastructures. Springer Nature Switzerland, pp. 1–14. https://doi.org/10.1007/978-3-030-01914-3_1

[7] Elshater, A., et al. (2019). Geological and Engineering Characteristics of Expansive Soils in Western Desert, Egypt, Civil Eng Res J., 7(2). http://dx.doi.org/10.19080/CERJ.2019.07.555707

[8] Elkhateeb, S. O., Dosoky, W., Mohamed, A., & Abbas, M. A. (2022). Geoelectric and mineralogical studies for foundation soil characterization in new Luxor city, Upper Egypt. Arabian Journal of Geosciences, 15(1220). https://doi.org/10.1007/s12517-022-10450-6

[9] Attah, L. E., Oden, M.I., (2010). Physico-Chemical Properties And Industrial Potential Of Some Clay Deposite InCalabar Area, South Eastern Nigeria, Global Journal of Environmental Sciences, Vol 9, No. 1&2, 39-49. https://www.ajol.info/index.php/gjes/article/download/79207/69522.

[10] Gillot, J.E., (1968). Clay in engineering geology, Elsevier Pub. Comp. London. N.Y.

[11] Brindley, G.W., and G Brown. (1984). Crystal Structures of Clay Minerals and their X-ray Diffraction Identification. London: Mineralogical Society.

[12] Lasheen, E.S., Rashwan, M.A., & Azer, M.K. (2023). Effect of mineralogical variations on physico-mechanical and thermal properties of granitic rocks. Scientific Reports, 13.

[13] Mohamed, M. S., Amer, S. A. M., & Abdel-Kader, G. A. (2021). Clay mineralogy in relation to geomorphic aspects in Wadi El-Natroun depression soils, Western deserts, Egypt. Menoufia Journal of Soil Science, 6, 363-375. https://miss.journals.ekb.eg

[14] Souileh, A., Mabrouk, A., Ouadif, L., & El Hachmi, D. (2024). Analysis of the geotechnical and mineralogical characteristics of the Settatt-Khouribga shale clay for potential civil engineering applications. Research on Engineering Structures & Materials. https://doi.org/10.21608/sjsci.2022.249078

[15] ASTM (2009). Standard test method for particle-size distribution of soils using sieve analysis, D 6913; 04.09 (PA USA: American Society for Testing and Materials) https://doi.org/10.1520/d6913-04r09.

[16] ASTM (2016). Standard test method for particle-size distribution (gradation) of fine-grained soils using the sedimentation sedimentation hydrometer) analysis, D 7928; 04. 09 (PA USA: American Society for Testing and Materials) https://doi.org 10.1520/d7928-16e01.

[17] ASTM (2017). Standard test method for liquid limit, plastic limit, and plasticity index of soils D 4318; 04.008 (PA USA: American Society for Testing and Materials) Doi:10.1520/d4318-17e01.

[18] ASTM (2024). Standard Test Method for Shrinkage Factors of Cohesive Soils by the Water Submersion Method D4943; 18 (PA USA: American Society for Testing and Materials) DOI: 10.1520/D4943-18R24

[19] ASTM (2016). Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass; D2216; 04.08 (PA USA: American Society for Testing and Materials) Doi: 10.1520/D2216-98

[20] ASTM (2014). Standard Test Methods for One-Dimensional Swell or Collapse of Soils; D4546; 04.08 (PA USA:American Society for Testing and Materials) DOI:10.1520/D4546-14

[21] El-Sohby and Mazen (1980). On Measuring Swelling Pressure by two Methods ,Seventh Regional Conf. for Africa for S.M.F.E., Accra (Ghana), PP. 775-783.

[22] Abu Seif, E.-S. S., El-Shater, A. A., & Amin, A. (2022). Geological evolution and swelling potentiality of Paleonile clays in Nile Valley, east Sohag, Upper Egypt. Sohag Journal of Science, *7*(3), 11-28. https://doi.org/10.21608/sjsci.2022.249078