STABILIZATION OF SOIL SWELLING FOR CONSTRUCTION PURPOSES, USING PHOSPHOGYPSUM AND SODIUM CHLORIDE

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ABSTRACT

This paper deals with the improvement of soil swelling for purposes of constructions by adding industrial waste Phosphogypsum (PG), in addition to the chemical additive sodium chloride (NaCl) to reduce its expansiveness and improve its characteristics for many earth work construction, the test results showed significant decrease in the swelling properties and pronounced reduction in the liquid limit, plastic limit and plasticity index of the clay by increasing the ratios of PG and NaCl. Also the results from x-ray diffraction (XRD) analyses of bentonit only and the mixture (1.2% PG+3% NaCl+95.8% Bent.) showed that, large amounts of Montmoronite clay mineral were approximately transformed to other phases during the reaction. Reaction products are non-swelling clay mineral commonly Kaolinite this is because, the mineralogy of both clay minerals reflects that, Montmoronite is an immature clay mineral while Kaolinite is a mature clay mineral. This maturity state may be attained through the chemical reaction with these additives. So, the PG industrial waste helps to improve the physical characteristics of soil swelling and the results present a very important factor for constructions purposes.

Key Words: Soil swelling, waste PG, NaCl, soil improvement, free swell, liquid limit, plastic limit, plasticity index, x-ray diffraction.

INTRODUCTION

Many arid and semi-arid regions have a problem of soil swelling which is one of the problematic soils, that face many geotechnical engineers in the field (others include collapsible soil, soft clay… etc.). Soil swelling is known to cause severe damage to structures that are founded on it. As a result; some houses and roads were destroyed. The presence of montmorillonite clay in these soils imparts them high swell–shrink potentials (Chen, 1988).

In Egypt, also, there are many soils swelling present in an area in Upper Egypt, south of Aswan City which named as Toshka area, in the new valley and in modern urban areas as the 6 October City.

The climate in Egypt is arid, with high evaporation rates, so that there is always a moisture deficiency in soils and rocks. Problems associated with expansive soils in Egypt are predominantly related to the presence of Montmorillonite clay minerals in the soils. As a result, some structures in New Sohag City were subjected to distress and damage and in worst cases, some building were demolished. On the other hand, the volume of by-product materials generated from industries, such as Phosphogypsum, is a solid waste generated from fertilizer industry. The cost of removal of wastes is continuing to rise day-by-day in our society. Also the disposal of these wastes becomes an environmental danger; Theses wastes pollute the soil, air and water. Now-a-days, the easily available industrial by-products are used for the enrichment of soil properties and become economically sound and environmentally friendly.

This paper aims at the improvement of soil swelling; by the addition of Phosphogypsum and NaCl salt, as chemical additives. Since the soil swelling has the same property of bentonite, we used bentonite as a substitute of the soil swelling. The comprehensive review of literatures shows that, a considerable amount of work related to the improvement of characteristics of soil swelling is done worldwide by using industrial solid wastes as PG.

Yilmaz and Civelekoglu (2009): had studied the effect of gypsum on Atterberg's limit, UCS (Unconfined compressive strength) and cation exchange capacity of bentonite and concluded that, up to 5% addition of PG, the properties of expansive clay improved significantly.

Krishnan *et al.,* (2014): have studied the combined effect of class C fly ash and phosphogypsum on the unconfined compressive strength (UCS) of the expansive soil and had found that UCS increases by the addition of these two stabilizers, which increases further with increasing in curing period.

MATERIALS AND METHODS

(A) MATERIALS USED

Bentonite (B): Bentonite (Na – Montmorillonite) was obtained from Borg El Arab bentonite factory. Montmorillonite, is a highly expansive mineral hase the chemical formula $Si_8Al_4O_{20}\,(OH)_4 \, . \, NH_2O$. The basic structural unit is a layer consisting of two inward pointing tetrahedral sheets with a central alumina octahedral sheet 2:1. The bonding between the successive layers is by van der Waals forces, so it is very weak bonds causing swelling for interlayers in the presence of water (Grim, 1953). Montmorillonite structure is shown in figure (1)

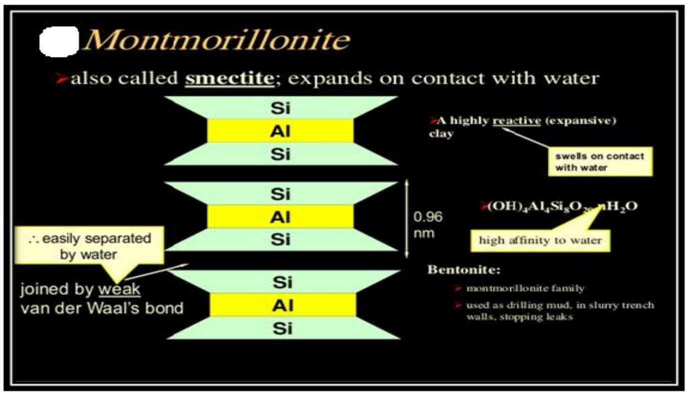

Fig.1: Montmorillonite structure

<u>Phosphogypsum (PG):</u> PG samples were collected from Abu Zaabal Company for Fertilizers and Chemical Industries, Qalubia Governorate, in Egypt.

Sodium Chloride Salt (NaCl).

<u>Mixing Water:</u> Distilled water was used in all tests for mixing operations.

(B) EXPERIMENTAL WORK

The laboratory tests included chemical and geotechnical engineering tests, and analytical techniques (x-ray diffraction). The laboratory studies were carried out on the mixture samples. Samples used in the tests were prepared from bentonite, PG and NaCl.

(a)Chemical Analysis: The chemical tests include chemical analysis to determine some predominant chemical characteristics, e.g. hydrogen ion concentration (pH), total dissolved solids (T.D.S), chlorides and oxides. The chemical analysis of the materials and mixtures were analyzed in the chemical laboratory of the Construction Research Institute (CRI) of the National Water Research Center.

The pH value of a solution is the negative logarithm of the concentration of hydrogen ions moles per liter. The pH value is determined by measuring the electrical potential of a glass hydrogen ion electrode against a reference electrode of known potential. The pH is an important indication of the chemical status of the soil. pH classes are plotted in Table (1), (Joe Scianna, 2002).

Table (1): Soil pH classes

pH Class	pH
Ultra acid	**< 3.5**
Extremely acid	**3.5 - 4.4**
Very strongly acid	**4.5 - 5.0**
Strongly acid	**5.1 - 5.5**
Moderately acid	**5.6 - 6.0**
Slightly acid	**6.1 - 6.5**
Neutral	**6.6 - 7.3**
Slightly alkaline	**7.4 - 7.8**
Moderately alkaline	**7.9 - 8.4**
Strongly alkaline	**8.5 - 9.0**
Very strongly alkaline	**> 9.0**

The pH was determined by means of pH meter, WTW model LF 538.

The Total Dissolved Solids (TDS) is a measure of all dissolved substances in water or soil. TDS is measured in a laboratory and reported as mg/L or ppm. It is determined by means of an electrical conductivity meter (EC meter).

Chloride (Cl^-) was determined volumetrically by titration against silver nitrate using potassium chromate as indicator (Mohr's titration), in which the silver reacts with chloride forming while AgCl precipitate as white ppt.

PH, TDS and Cl analysis are made, according to the generally accepted methods described by (the Standard Methods for the Examination of Water and Wastewater 1985).

(b) Geotechnical Engineering Tests: For geotechnical purposes, a group of different tests can be used to identify the bentonite mixtures formed, that include: free swelling tests, Atterberg Limits (liquid limit, plastic limit and plasticity index)**.** Mixtures were analyzed in the Soil Mechanics and Foundation Laboratory in the (CRI), National Water Research Center.

1- **Free swell index:** This test is performed by pouring slowly 10 grams of dry bentonite, 10 grams of mixture passing through 425 micron sieve, in two different 100 cc glass jars filled with distilled water, the samples are recorded as IS: 2720(Part 40) -1985. The free swell (%) can be calculated through the following equation:

$$\textbf{Free swell (\%)} = \frac{\text{Final volume} - \text{Initial volume}}{\text{Initial volume}} * 100$$

2- **Liquid limit:** The liquid limit test was conducted on mixtures using Casagrande's liquid limit apparatus, as per the procedures laid down in IS 2720 (Part 5) 1985

3- **Plastic limit:** The plastic limit test was conducted on mixtures, as per the specifications laid down in IS 2720 (Part 5) 1985.

(c) Analytical Techniques (X- Ray Diffraction): the bulk x-ray diffraction (XRD) is one of the most widely used techniques in the identification of clay minerals using Bragg's instruments; it determined the crystalline phases in the reaction products. X- ray diffraction of the bulk samples were analyzed in x- ray diffraction laboratory in the National Research Center (NRC).

RESULTS AND DISCUSSION

After mixing bentonite with the additives, the chemical composition of bentonie is changed according to the types of additives.

(a)Chemical Analysis: the chemical composition of bentonite was determined as shown in table (2).

Table (2): Chemical composition of the used bentonite.

T.D.S %	**2.892**
Cl^- ppm	142
PH %	8.2
SiO_2 %	68
R_2O_3 %	5
CaO %	2
MgO %	0.5
Loss in ignition %	19.8

1- Variation of Total Dissolved Solids (TDS), Chlorides and pH of bentonite: The total dissolved solids in percent are obtained by summation of the cations and anions values. TDS increased by increasing the additives, as shown in Tables (3, 4 and 5). Salinity can affect the soil physical properties by causing fine particles to bind together into aggregates have a positive effect on the soil aggregation and stabilization. The acidic or alkaline characteristics of a soil sample can be quantitatively expressed by the hydrogen ion-activity commonly designated as pH. Increase with the various percentages of PG and NaCl has successively increased the pH of Bentonite. Increase or decrease in the pH for samples due to the Physical properties and chemical analysis of the individual mixture.Table (3) illustrated that, when the PG was mixed with bentonite, the pH of the bentonite was reduced from 8.2 to 6.2 for sample 1 and 8.06 for sample 2. The pH of PG, which was used in the test, was 4.4. The reduction in the soil pH was an indication that, the soil had changed from being alkaline to being slightly acidic. **(Hoddinott and Lamb, 1990)** explained that, a decrease in the pH of soil was due to the cation exchange at the surface of clay particles, high cation valence and the acidic environment decreases the double layer thickness around the clay particles. Increase in the PH is noticeably in the samples of Tables (3,4 and 5).

Table (3): Effect of Phosphogypsum on the TDS, Cl^- and pH of bentonite.

	Materials used percentage		**Chemical analysis**		
Samples	**PG%**	**Bent.%**	**T.D.S%**	**pH**	**Cl^-ppm**
1	0.6	99.4	3.187	6.20	2290
2	1.2	98.8	3.500	8.06	2361
3	1.8	98.2	5.683	9.17	2485
4	2.4	97.6	6.490	9.20	2490
5	3	97	6.298	9.90	1775

Solubility of salts in water decreases the ability of bentonite particals to absorb the water. The main sources of chloride are NaCl salt. Chloride increases by increasing the concentration of NaCl, as shown in Tables (4 and 5).The observed changes in free swell may be attributed to NaCl, that contains Cl^{-} enabling to form covalent bonds with bentonite. Reaction compounds are decrease the repulsive forces between the clay particles imparting flocculated structure with some cementation or binding, that should have been responsible for decreasing the free swell. Furthermore, the decrease in swelling is attributed to the decrease in the thickness of Diffuse Double Layer (DDL), resulting in a flocculation of the clay particles. In other words, reducing the thickness of the DDL causes the soil skeleton to shrink and causing a decrease in the repulsive forces, thus helping flocculation of the clay particles, which subsequently became gritty or granular ((Akbulut and Arasan, 2010) forming hydrogen bonds. The bonding is sufficiently stronger than Van der Waals forces, so there is no interlayer swelling in the presence of water (Mitchell and Soga, 2005).

Table (4): Effect of NaCl on the TDS, Cl^{-} and pH of bentonite

	Materials used percentage		Chemical analysis		
Samples	**NaCl%**	**Bent.%**	**T.D.S%**	**pH**	**Clppm**
6	0.6	99.4	10.690	8.30	1420
7	1.2	98.8	11.840	9.21	2130
8	1.8	98.2	12.020	9.60	2148
9	2.4	97.6	11.430	9.70	3408
10	3	97	12.050	10.08	4260

Table (5): Effect of phosphogypsum and NaCl on TDS, Cl^- and pH of bentonite.

	Materials used percentage			Chemical analysis		
samples	**PG%**	**NaCl%**	**Bent.**	**T.D.S%**	**pH**	**Clppm**
11	1.2	0.6	98.2	6.835	9.50	2556
12	1.2	1.2	97.6	10.200	9.54	2414
13	1.2	1.8	97	10.150	9.74	2840
14	1.2	2.4	96.4	10.500	9.75	3373
15	1.2	3	95.8	12.570	9.83	1420

(b) Geotechnical Engineering Tests:

1- Free Swell Test Results: Free swell is affected by several chemical factors, the most interesting factor is the PH. By increasing the PH value, the free swell decreases as shown in figures (2, 3 and 4).

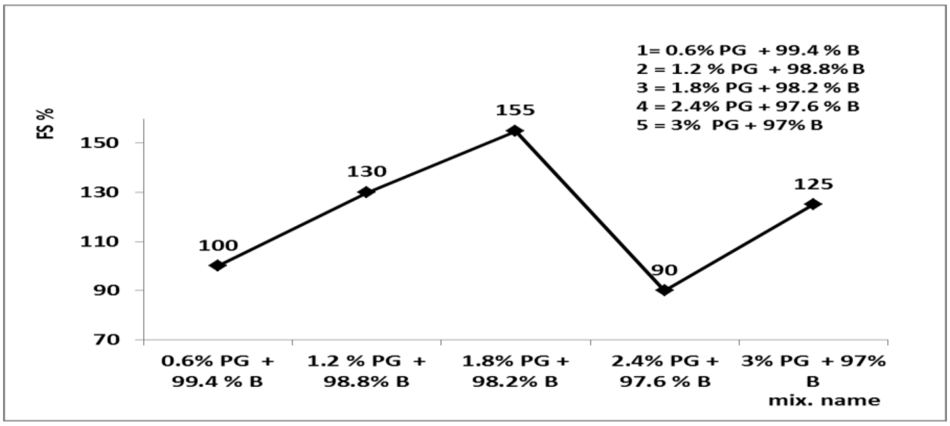

Fig.2: Effect of addition of PG on the free swelling of bentonite.

This figure illustrates that, when bentonite was mixed with 0.6% PG, the free swelling of the bentonite was reduced from 320% to 100% in mixture 1, but when it mixed with 1.2 % PG and 1.8% free swelling decreased to 130% for mixture 2 and 155% for mixture 3 respectively. After that, free swelling decreased again to 90 % at ratio 2.4% PG for mixture 4, and this is the very effective mixture and the best one in this figure. For addition of 3% PG, the free swelling decreased to 125% for mixture 5.

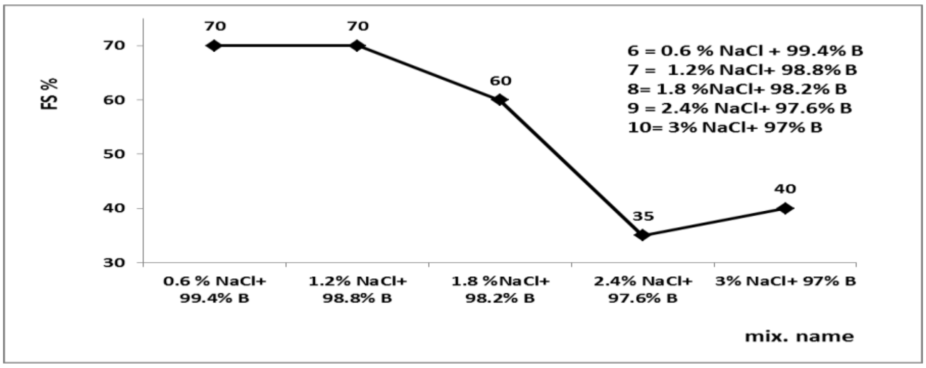

Fig .3: Effect of different percentages of NaCl on the free swelling of bentonite.

From figure (3) we notice that, after the improvement with salt NaCl, this causes change in the properties of bentonite related to the ratio of salts, translates into a decrease of the free swelling of bentonite from 320 % to 70% for mixtures 6 and 7, to 60% free swelling for mixture 8. Then free swelling decreased to 35% for mixture 9, which is partly due to the ionic reactions of salt (NaCl) with clay minerals and this is the best mixture. After that, the free swelling slightly decreased for the mixture 10 to 40%, in which this mixture is also a good mixture.

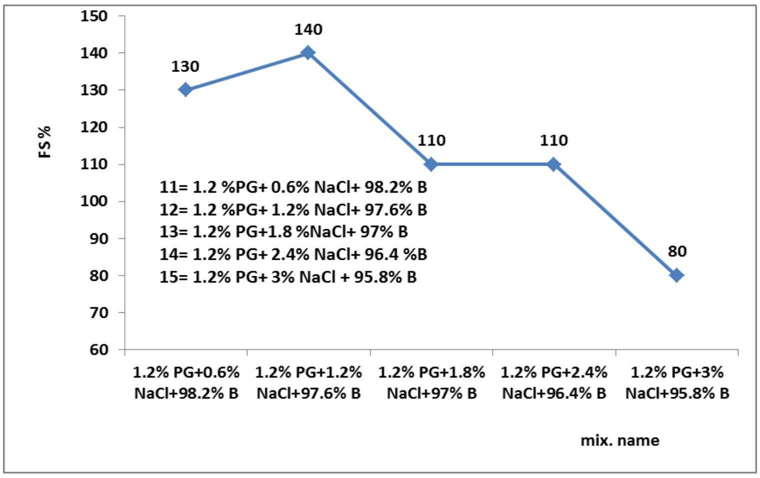

Fig.4: Effect of different ratios of NaCl + 1.2% PG on the free swelling of bentonite.

In this figure, the free swelling of the mixtures decreased with an increasing of the NaCl ratio at constant ratio of (PG) = 1.2%. The free swelling decreased to 130% for mixture 11 and decreased to 140% for mixture 12. Increasing the NaCl ratio leads to decrease the free swelling to 110% for mixtures 13&14 respectively, reaching to free swelling = 80% for the best mixture from this group samples (15) by increasing the NaCl ratio to 3% .

2- Atterberg's Limits Results: The addition of PG and NaCl affects many of the engineering properties of bentonite. These include the liquid limit (LL), plastic limit (PL) and plasticity index (PI). The physical properties of the used bentonite are shown in Table (6)

Table (6): Physical properties of the used bentonite.

L.L (%)	P.L (%)	S.L (%)	P.I (%)	Clay content (%)	Activity AB	Free swelling(%)
442.8	42.5	30	400.3	82	4.88	320

The following table illustrated that with the increase of percentages of additives there is usually a general decrease in the liquid limit of bentonite from 442.8% to smaller percent. The plasticity index and the plastic limit of bentonite are decreased from 400.3% and 42.5% respectively to lower values as shown in the following table.

Table (7): Atterberg's Limits of the mixture samples

	Materials used percentage			Atterberg's Limits		
Samples no.	PG%	NaCl%	Bent.%	LL %	PL %	PI %
1	0.6	0	99.4	224.2	35.9	188.4
2	1.2	0	98.8	192.6	43.0	149.6
3	1.8	0	98.2	183.5	41.7	141.8
4	2.4	0	97.6	182.5	37.7	144.8
5	3	0	97	200.1	39.7	160.4
6	0	0.6	99.4	246	23.30	222.7
7	0	1.2	98.8	227	28.90	198.1
8	0	1.8	98.2	178.5	31.00	147.5
9	0	2.4	97.6	145.4	28.80	116.6
10	0	3	97	131.8	26.60	105.2
11	1.2	0.6	98.2	286.5	32.2	254.2
12	1.2	1.2	97.6	185.4	39.6	145.8
13	1.2	1.8	97	158.3	38.7	119.6
14	1.2	2.4	96.4	134.6	27.6	106.9
15	1.2	3	95.8	128.6	31.6	97.1

(c) X-Ray Diffraction (XRD) Results: The minerals of the raw materials of the reaction products can usually be identified from the diffraction lines, although it is not possible to determine the exact proportion of each mineral of reaction product in a mixture. Understanding and interpretation of the diffraction patterns are based on the fact that, each crystalline material has its own characteristic atomic structure, which diffracts the x-ray in a characteristic pattern (Barr *et al.*, 1995). The samples were analyzed using the XRD; the control sample of pure clay soil (Bentonite) and the other samples, which produced larger changes in the free swelling. x- ray diffraction diagrams for bentonite and sample no. 15: (1.2%PG + 3% NaCl + 95.8% Bent.) are shown in the following figures.

X-Ray Diffraction of Bentonite

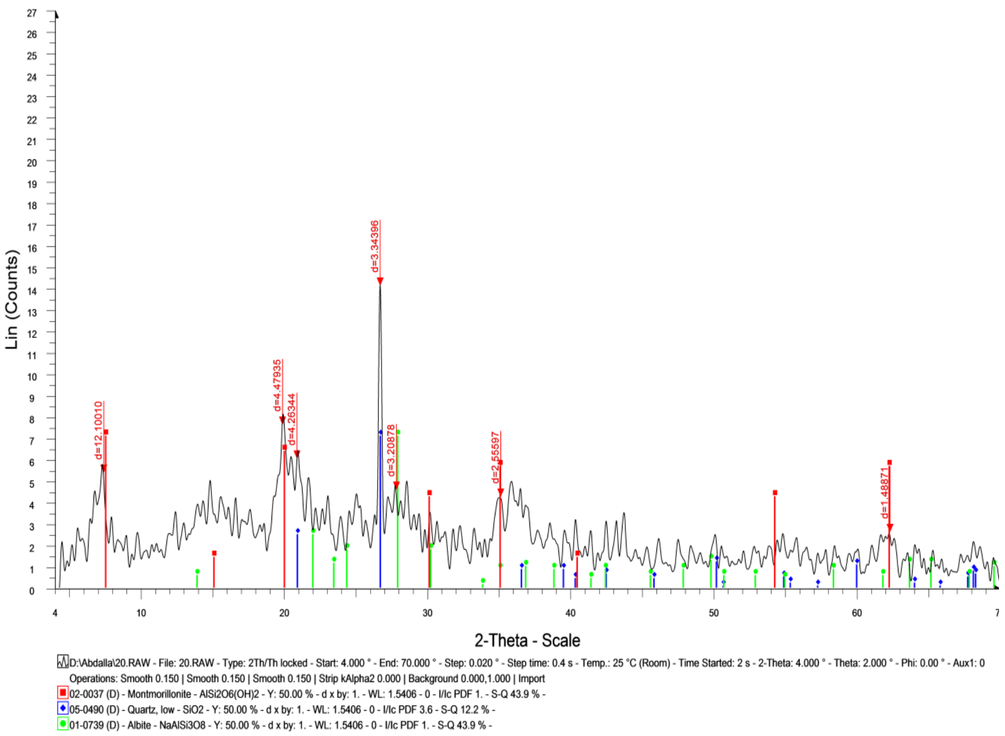

Fig.5: Spectrum x - ray diffraction of bentonite alone**.**

The XRD of bentonite soil alone is shown in figure (5). This figure illustrates the general appearance of the control sample of the pure clay Bentonite. The XRD pattern of the untreated bentonite indicates the presence of montmorillonite, quartz… etc. XRD traces of the montmorillonite showed eight main broad peaks. Note that, the montmorillionite has sharp peaks than the other mineral components, since it has a much more complex crystalline structure.

Sample no. (15) X-Ray Diffraction

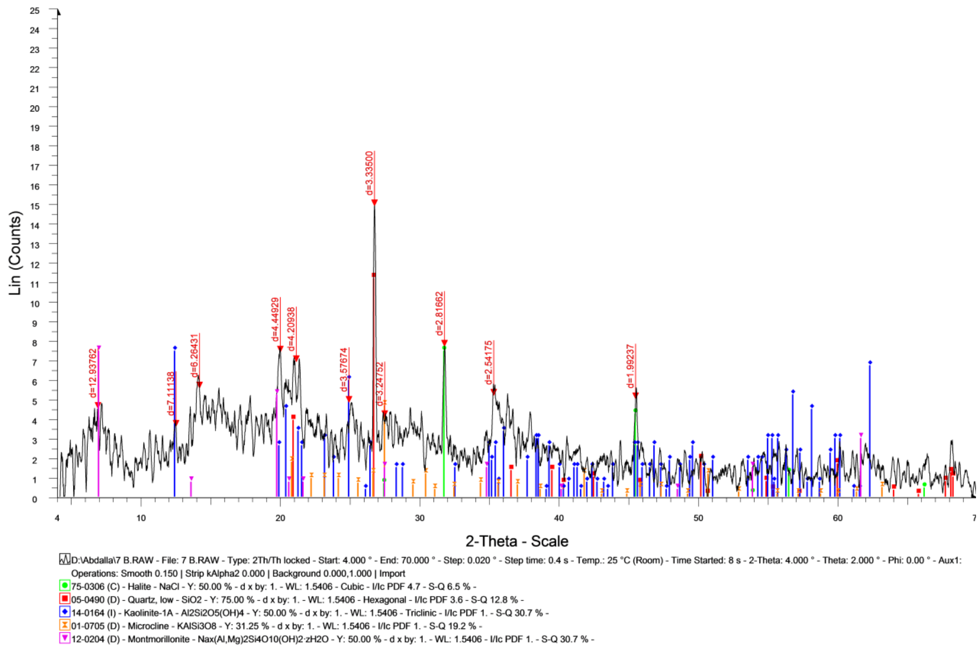

Fig.6: spectrum x- ray diffraction of sample no. 15 (1.2% PG+ 3% Nacl + 95.8% bentonite).

The bentonite soil mixed with (1.2% PG+ 3% NaCl), as shown in figure (5), the XRD results showed the marked departure in peaks, when compared to the XRD of bentonite soil alone. The mineral that is most composed was kaolinite, but quartz and halite (NaCl) minerals were also found in minor amounts as non-clay components, added to the non-swelling microcline (silty clay) and small amount of montmorillonite mineral. Minerals were presented as following in decreasing order as: Kaolinite> microcline> quartz> montmorillonite> halite. So, if we increase the percentages of additives more than these percentages, we expecte that all the montmorillonite mineral will converted totally to kaolinite.

Kaolinite has chemical formula $Si_4Al_4O_{10}(OH)_8$. Kaolinite basic structural unit is a layer consisting of tetrahedron and octahedron sheets 1:1. The bonding between the successive layers is by Van der Waals forces and hydrogen bonds. The bonding is sufficiently strong that. There is no interlayer swelling in the presence of water (Mitchell and Soga, 2005). Thus, kaolinite is a non-expansive mineral. Also the plasticity of kaolinite is very low compared to other types of silicate clays. Kaolinite structure is shown in figure (7).

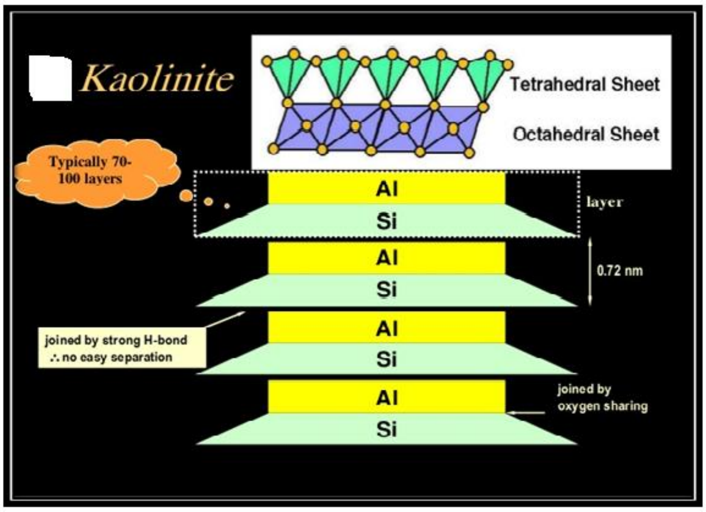

Fig.7: Kaolinite structure

CONCLUSIONS

The following points can be concluded from the results of this work:

1. The rate of swelling of bentonite decreases with increasing the additives percentage; as the percentage of NaCl increases, there is apparent reduction in the free swelling.
2. The higher of hydrogen ion concentration "pH" of samples, therefore the lower the free swell of soil. Salinity can affect the soil physical properties by causing fine particles to bind together into aggregates have a positive effect on the soil aggregation and stabilization, due to the formation of Kaolinite mineral, that have strong hydrogen bonds, that are stronger than Van der Waals bonds in montmorillonite.

3. The liquid limit, plastic limit and plasticity index of swelling soil decreases with increasing the ratio of additives.
4. Through analytical technique (x- ray diffraction) was used to identify the reaction products of PG and NaCl with bentonite showed that, the montmorillonite was approximately transformed to a non-swelling clay mineral commonly Kaolinite; Kaolinite> montmorillonite.

From the results of the present study, it can be concluded that, by adding additives of PG and NaCl with the expansive soil is an effective way to tackle the problem of swelling and they are good stabilizer of expansive clay soil.

From the study, it is recommended that the soil stabilization is based on additives. As additives increased in the mixture specially NaCl, the mixture will be more stabilized. Also, we can use other chemicals such as, potasium chloride (KCl) salt expecting that, it will give good results

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تحسين خصائص التربة الإنتفاخية للأغرض الإنشائية باستخدام الجبس الفوسفورى وكلوريد الصوديوم

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المستخلص

الهدف من هذا البحث هو دراسة تثبيت وتحسين الخصائص الهندسية للتربة الطينية الانتفاخية لأنها غير صالحة للاستعمال كطبقة أساس أو تحت الأساس فى المنشآت بسبب ضعف قوة تحملها ولدونتها العالية. لذا كان من الضروري التفكير فى طرق ووسائل تساهم فى تحسين خصائصها بالإستفادة من المخلفات الكيميائية الصلبة، مثل مخلف الجبس الفوسفورى (الفوسفوجبسم $CaSO_4$) الناتج من صناعة الأسمده والذى يشكل فى الوقت الحاضر إحدى المشكلات التى تواجه العالم ، إذ يحتوى على آثار للعديد من الشوائب المعدنية التى تتخلف بالأطنان والتى لها تأثير سلبى على البيئة مسببة تلوثا وضررا بيئيا وصحيا لكافة الكائنات الحية. فى هذا العمل تمت معاملة هذه التربة بنسب مختلفه من مخلفات مادة الجبس الفوسفورى، بالإضافه إلى ملح كلوريد الصوديوم. ولقد اظهرت النتائج أن المخلفات الصناعية و كلوريد الصوديوم بتركيزاتها المختلفة تعمل على تقليل نسبة الانتفاخ الحر فى التربة، بحيث أصبحت التربة غير انتفاخية. كما لوحظ بأن هذه المخلفات الصناعية ومع زيادة تركيزها فى التربة تقلل من حد السيوله (LL) وحد الدونه (Pl) ودليل اللدونة (PI) بشكل كبير، فى حين لوحظ بان هذه المخلفات تعمل على رفع قاعدية التربة إلى الدرجة المطلوبة للتثبيت. ولقد أفادت نتائج تحليل حيود الأشعة السينيه أيضا أن معدن المونتموريليونيت، المسبب للإنتفاخ، قد تحول إلى معدن الكاولينيت وهذا المعدن غير قابل للإنتفاخ، لأنه يحتوى على روابط هيدروجينيه قويه بالإضافه إلى روابط فاندر فال. وهكذا بصورة عامه، يمكن اعتبار المخلفات الصناعية (الجبس الفوسفورى) مع إضافة كلوريد الصوديوم ذات تأثيرات إيجابية على الخواص الهندسية للتربة وبالإمكان استخدام تلك المخلفات في الأغراض الإنشائيه.