Effect of Soil Chemical Components on Their Mechanical Properties under Different Loads, Marsa Alam City, Red Sea Coast, Egypt

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Abstract: In recent years, there has been worldwide interest for problematic soils which may cause engineering problems when these soils are located under foundations. These soils are found in abundance in the semi-arid regions of tropical and temperate climate zones as in Marsa Alam city, where annual evaporation exceeds precipitation. This work is a trail to discuss the geotechnical characteristics of some different types of sedimentary rocks in Marsa Alam city which lie on the south of red sea coast at Egypt. To achieve this study, five samples of different soils and sedimentary rocks were chosen to evaluate their mechanical properties under different loads by using Oedometer apparatus. These soils are Evaporite, Claystone, Dolomitic Limestone, Marl and Conglomerate. Using X- Ray Diffraction (XRD) analysis, mineralogical data of samples were investigated. Using X- Ray Fluorescence (XRF), chemical data indicated that the collected samples possess different types of major elements according to the kind of sample where the cations of elements play an important role in the reaction of water with soils. When water molecules, being dipoles, they are adsorbed both to the surface of the crystals lattice and to the cations. Petrographic properties were carried out in order to define the mineralogical composition, texture and hence rock type by using Polarizing Microscope. The Atterberg limits (liquid limit, plastic limit and plasticity index) were carried out only for samples that contain appreciable amounts of clay such as Claystone and Marl. According to the results of the study, the designers can expect the geotechnical behavior of different types of soil under different loads to avoid hazards of problematic soils in foundations of different constructions or these found as sub-grad under pavement layers of roads.

[Kenawi M. A. and Mohamed M. Badry. **Effect of Soil Chemical Components on Their Mechanical Properties under Different Loads, Marsa Alam City, Red Sea Coast, Egypt.** *Life Sci J* 2017;14(3):6-14]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 2. doi:10.7537/marslsj140317.02.

Key words: Problematic soil, Claystone, Marl, Evaporite, Dolomitic Limestone, Conglomerate

1. Introduction

Marsa Alam is a promising city in Egypt which lies on the south of red sea coast (Fig.1). This city is famous for many activities such as tourist and mining works specially production of gold. So many constructions such as buildings, roads, etc. will be established in this city in the future. It is necessary to do geotechnical and geological study on the soils and sedimentary rocks in Marsa Alam city to expect their geotechnical behavior under different loads and avoid hazards of problematic soils.

1.1. Problematic soils.

The soils of various genesis, age and composition, formed in different climatic and geological conditions are referred to as problematic ones in engineering geology. They are characterized by specific properties that give rise to many difficulties in designing and construction.

1.2. The used sample.

Five different types of sedimentary rocks were collected from different places of Marsa Allam city.

Fig. (1): Location map of studied samples area.

The description of these samples is illustrated in the following:

1- Claystone samples, composed mainly of clay minerals. Formation with late Miocene age.

2- Evaporite, composed mainly of anhydrite and contain some carbonate between the small anhydrite crystals. Formation with late Miocene age.

3- Marl composed of clay minerals and carbonate minerals in equal ratio. Formation with late Pliocene age.

4- Dolomitic Limestone, composed of calcareous materials as calcite and also non-carbonate minerals. Formation with late Miocene age.

5- Conglomerate composed of rock fragment as fellent, granite, felsit and diabas. Formation with late Pliocene age.

1.3. Scope of the present study

The main purpose of this present study is:

1. Investigation of the mineral and chemical composition of these samples by (XRD) and (XRF) methods, also do some investigations as petrographic study, grain size analysis and consistency limits.
2. Using Oedometer apparatus to study the mechanical properties of these samples under different loads.
3. Determination of the relationship between the components of these rocks and their mechanical properties.

2. Literature review.

Many investigations were carried out on problematic soils like Terzaghi & Peck, 1967, El-Tahlawi *et al*., 1973, Pettijohn, 1975, Fookes, 1978, Sowers, 1979, Akili, 1980, Erol, 1989, Boogs, 1992, Bell, 2000, Ahmed & Abu El anwar, 2002, Portar, 2005, Azam 2006, Mahrous *et al*., 2010, Moaydi *et al.,* 2011 and Ismaiel & Badry 2013.

3. Experimental work.

3.1. Oedometer tests.

Blocks of these sedimentary rocks were cut into slabs of similar thickness (19.0mm). These slabs were shaped into cylindrical form by core machine. The sample were trimmed and inserted into cylinder of 19.0mm height and 50.0 mm diameter, (Fig.2).

To determine the behaviour of tested samples by using Oedometer apparatus, there were four different stresses were used (25, 50, 100, 200 kpa).

3.2. Measurements of consistency limits.

Consistency limits (liquid limit, plastic limit) tests were carried out on Claystone and Marl, which a fine grained soil can exist.

3.3. Grain size:

Only Claystone sample (fine grain sample) was analyzed to determine the grain size analysis using pipette method.

3.4. Mineralogical analysis.

Aphillips X-ray diffractmeter with Cu Kα radiation generated at 40KV and 30 MA was used to obtain the diffractograms of minerals for random powder bulk samples as well as oriented sample.

3.5. Geochemical analysis.

Geochemical analyses were carried out using Philips X-ray fluorescence Spectrometer Model PW16 overnight.

3.6. Petrographic tests.

The mineralogical composition of a rock is not enough to explain its geotechnical behaviour because texture is also very important. By using polarizing microscope, microstructure variations of rocks with similar mineralogical composition were studied and petrographic properties were carried out in order to define the mineralogical compositions and hence the rock types.

Fig. (2): Sample after trimmed in Oedometer cylinder

4. Results and Analysis.

4.1. Mineralogical analysis

The bulk mineralogical analysis of samples exhibited the ratio of different minerals in every samples (Table.1). In this table clay minerals are found in two samples which recorded different expansion when contact with water in geotechnical study using Oedometer apparatus. Mineralogical analysis (XRD) of bulk Claystone sample exhibited that it contains a clay minerals which represented in smectite (montmorrillonite) clay minerals which characterized by swelling when contact with water (Fig. 3).

Also analysis of Evaporite sample showed the dominance of anhydrite and halite minerals. Dolomitic limestone sample characterized by the dominance of dolomite (65.62%) as shown in X-ray diffraction pattern of bulk sample of dolomite (Fig.4), where the peak of dolomite is main peak.

4.2. Chemical analysis

The results of the analyzed four samples listed in (Table.2). From this table the collected samples posses different types of major elements according to their kind. The results indicated that the ratio of chlorides CL^- and sulfates (SO_3^{--}) is more than standard specification in all represented samples because they near from Red Sea coast, where chlorides not more than 400 ppm (AASHTO, T291) but sulfates not more than 600 ppm (AASHTO, T290). Also, the lost of ignition (L.O.I) were high ratio in carbonate samples (Dolomitic limestone and Marl) more than another samples.

4.3. Consistency limits.

Consistency limits for two samples (Claystone and Marl) are given in (Table.3).

Table (1): The mineralogical composition of studied bulk samples.

Sample	Qz%	K-Feld. %	Plag. %	Calc %	Dol. %	Anhy.%	Hem. %	Halit. %	Clay. %	Sum
Claystone	32.03	18.8	7.21	0	7.06	6.17	0	7.06	21.67	100
Evaporite	0.58	0	0	0	2.01	66.58	1.1	29.73	0	100
Marl	4.14	4.84	0	46.84	0	0	0	7.44	36.74	100
Dolo. Ls.	0	0	0	33.38	65.62	0	1	0	0	100
Conglom.	9.24	7.99	3.7	28.17	0	2.76	12.27	3.8	32.07	100

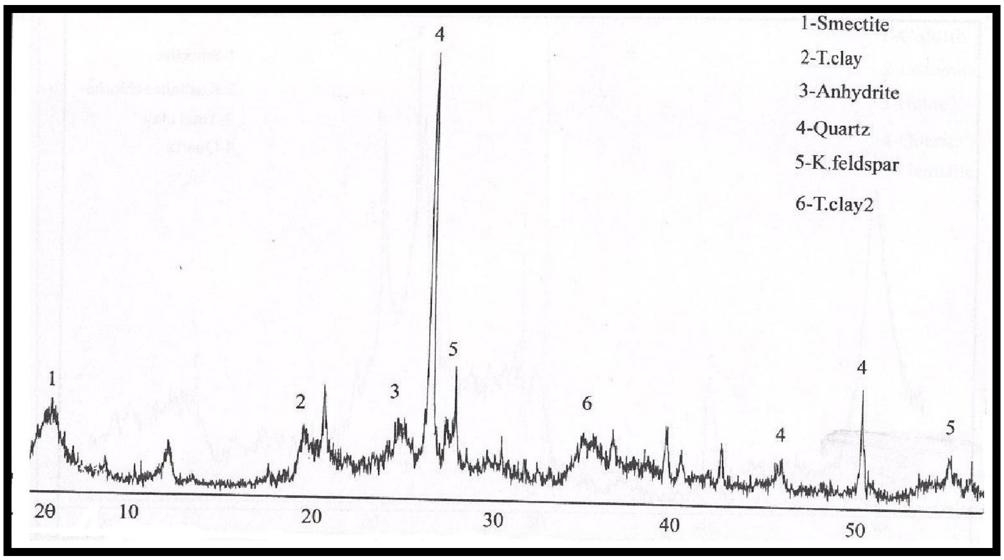

Fig. (3): X-ray diffraction pattern of bulk sample of Claystone.

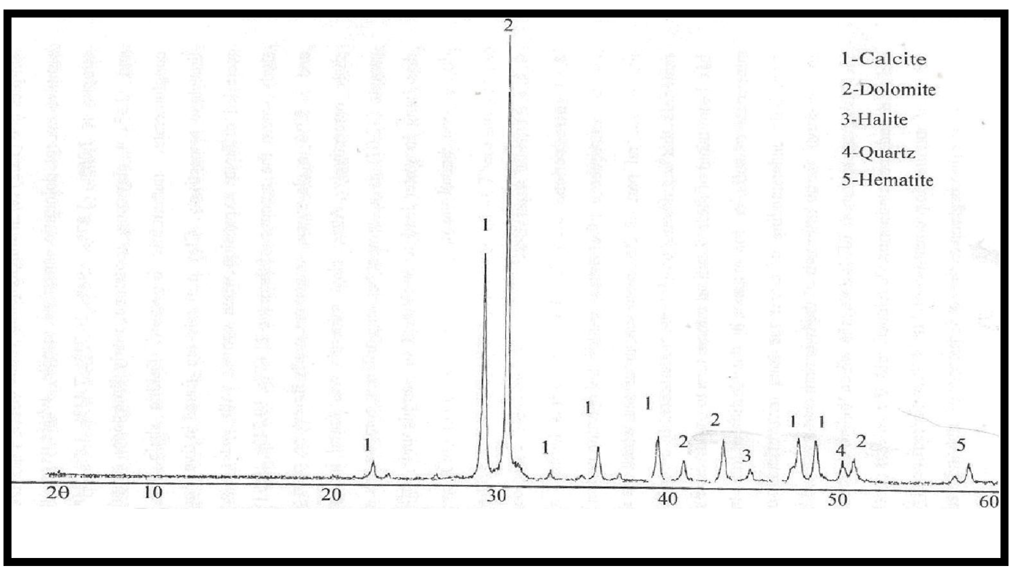

Fig. (4): X-ray diffraction pattern of bulk sample of Dolomite.

Table (2): The chemical composition of studied bulk samples.

Sample	Claystone	Evaporite	Marl	Dolomitic limestone
SiO_2	72.48	42.5	22.0	11.3
TiO_2	1.3	1.29	0.85	0.25
Al_2O_3	5.9	0.8	4.1	0.51
Fe_2O_3	7.17	1.69	7.21	1.32
MnO	0.01	0.01	0.01	0.02
MgO	5.0	5.0	2.7	11.0
CaO	0.7	21.0	28.0	33.6
Na_2O	1.3	1.29	2.85	0.25
K_2O	0.6	0.2	0.27	0.42
P_2O_5	0.3	0.02	0.01	0.02
CL	0.32	0.41	0.9	0.16
SO_3	0.2	0.28	0.26	0.19
L.O.I.	5.0	24.9	31.0	40.8
Total	100.28	99.4	100.16	99.84

Table. (3): Consistency limits

Sample	Marl	Claystone
Liquid limit	37	32
Plastic limit	28.5	18
Plasticity index	8.5	14

4.4. Petrographic study.

Petrographic properties were carried out in order to define the mineralogical composition, texture and hence rock type. Three types of samples (Evaprite, Conglomerate and Dolomitic limestone) only described under polarizing microscope as thin sections. These samples can be investigated as following.

4.4.1. Evaporite sample.

The sample occurs as regular six-side shape crystals similar to gypsum crystals which occur in porphyro- plastic texture. They are interpreted as gypsum crystals which have been replaced by anhydrite. These crystals are cemented by calcareous material (Fig.5).

4.4.2. Conglomerate.

The rock is composed of rock fragments of sedimentary and igneous rocks such as chert, granite, felsite and diabase, as the main components. Quartz, feldspar and iron oxides grains occur as accessories. It is poorly sorted and the grains are rounded to sub rounded. The rock fragments are cemented by calcareous matrix. The calcareous matrix is partially replaced by silica to form a siliceous cement due to the diagenetic processes (Fig.6).

4.4.3. Dolomitic limestone.

The rock is composed mainly of calcite and dolomite crystals. The detrital quartz, feldspar and iron oxides found as accessories. These components are embedded in microspary calcite cement. The rock is characterized by wack stone texture. (Fig.7).

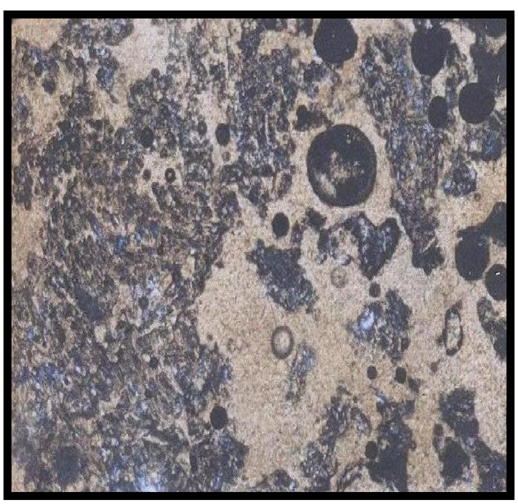

Fig. (5): Photomicrograph of Evaporite sample.

Fig. (6): Photomicrograph of Conglomerate sample.

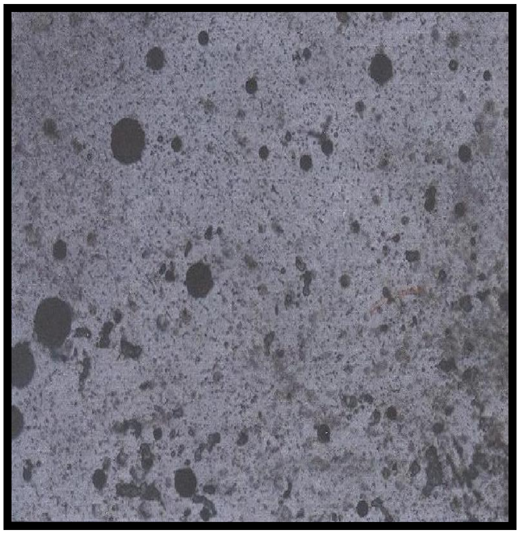

Fig. (7): Photomicrograph of Dolomitic limestone sample.

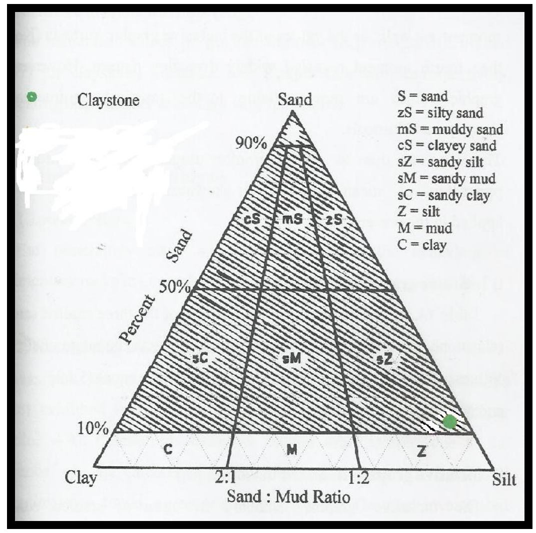

Fig. (8): nomenclature of analyzed sample (Folk, *et al.* 1970).

4.5. Grain size analysis.

Grain size distribution was carried out on Claystone sample. The results of the grain size analysis were grouped into sand, silt and clay (Table.4). The calculated percentage of this sample was plotted on a ternary diagram constructed according to Folk *et al.* (1970). The sample was plotted in sandy silt zone (Fig.8). The suitable nomenclature of this sample is sandy siltstone.

Table.(4): Nomenclature of studied sample.

Sample	% of sediment types		
	Sand	Silt	Clay
Claystone	12.64%	81.71%	5.54%

4.6. Mechanical properties.

4.6.1. Effects of stress level on the vertical soil deformation.

For each soil type, the vertical deformation was recorded along certain period of time under stress level of 25, 50, 100 and 200 kpa. Test results for each soil type could be discussed as follows:

4.6.1.1. The relation between the vertical displacements versus time.

Figures from (9) to (13) show the relation between the vertical displacements versus time for the soil samples. It could be noticed that the zero time started from the moment of adding water to the loaded soil specimen.

Figure (9), shows the vertical deformation versus time under different applied of stress levels of Claystone sample, where the sample was swelling under stress level of 25Kpa. It began to compress with increase of stresses value of 50Kpa, 100Kpa and 200Kpa. The rate of increase of settlement values with respect to time generally increase as both time and stress level increases. The difference of settlement values and their rate of increase under effect of three stresses (50, 100 and 200Kpa) moderately small.

The Evaporite sample, Figure (10), shows that the sample recorded settlement as the time proceeds for all applied stress levels. The rate of increase of settlement values with respect to time generally increases. as both time and stress level increases. For a relatively high stress level of 200Kpa, both the settlement values and its rate of increase are relatively very high compared with the lower stresses levels of 100, 50 and 25Kpa.

The Marl sample was heaved under effect of stress level (25Kpa), but it began to compress with increasing stress levels. For a relatively high stress level of 200Kpa both the settlement values and its rate of increase was relatively very high as compared with the lower stress levels (Fig.11).

Dolomitic limestone sample recorded the settlement values at low stress of 25Kpa equal the settlement values under stress of 200Kpa, (Fig.12).

The Conglomerate sample have the same values of settlement under stress levels of 25Kpa and 50Kpa while another high stress levels of 100Kpa and 200Kpa, both settlement values and their rate of increase are also equal but they relatively high as compared with the two lower stress levels of 25Kpa and 50Kpa (Fig. 13).

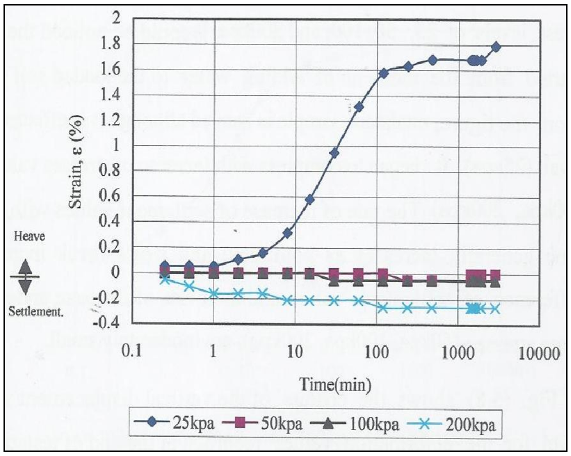

Fig. (9): vertical deformation versus time under different applied stresses for Claystone sample.

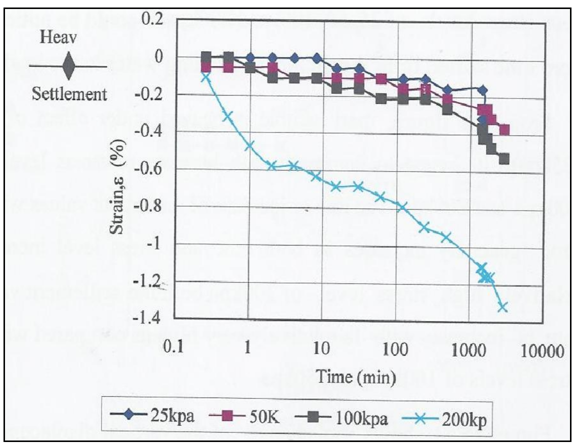

Fig. (10): vertical deformation versus time under different applied stresses for Evaporite sample.

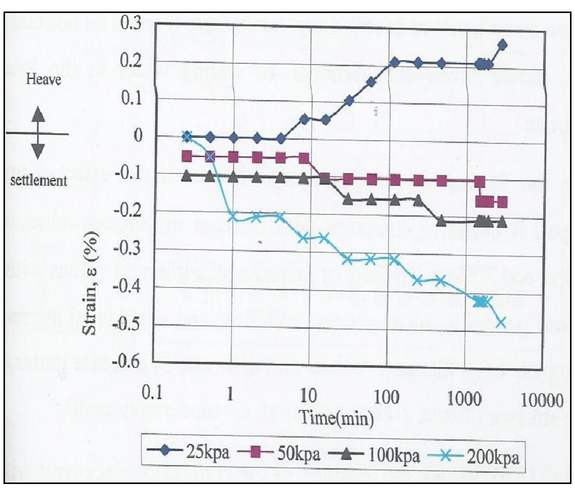

Fig. (11): vertical deformation versus time under different applied stresses for Marl sample.

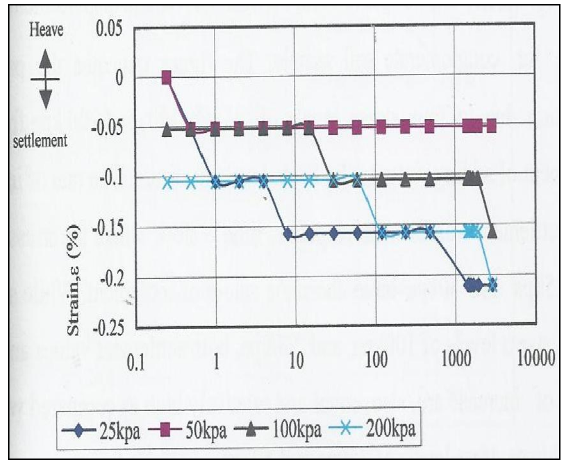

Fig. (12): vertical deformation versus time under different applied stresses for Dolomitic limestone sample.

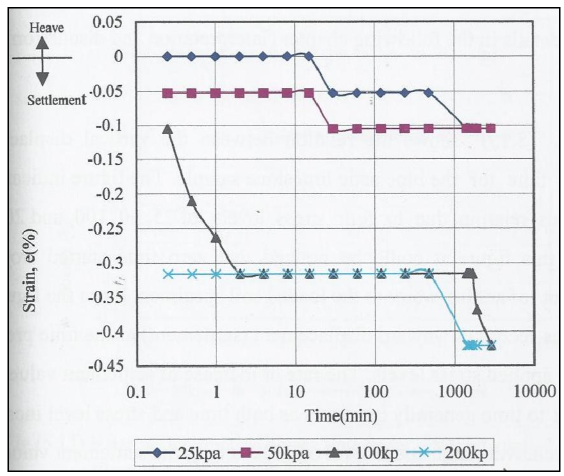

Fig. (13): vertical deformation versus time under different applied stresses for Conglomerate

4.6.1.2. The change of the vertical displacement with stress level.

Figures from (14) to (18) shows the change of the vertical displacement with stress level for the deformation values recorded at the end of tested period of 24 hours. Fig. (14) shows the vertical deformation versus stress level for Claystone sample, it could be noticed from this figure that the heave of sample happened under effect of (25Kpa). Under effect of the other stresses, the settlement values and its rate of increase with respect to stress increases. Fig. (15) shows that both the settlement values and its rate of increase with respect to stress increases. Fig. (16) shows the vertical deformation versus stress level for Marl sample, it could be noticed from this figure that the heave of sample happened under effect of (25Kpa). Under effect of the other stresses, the settlement values and its rate of increase with respect to stress increases. It could be noticed from Figure

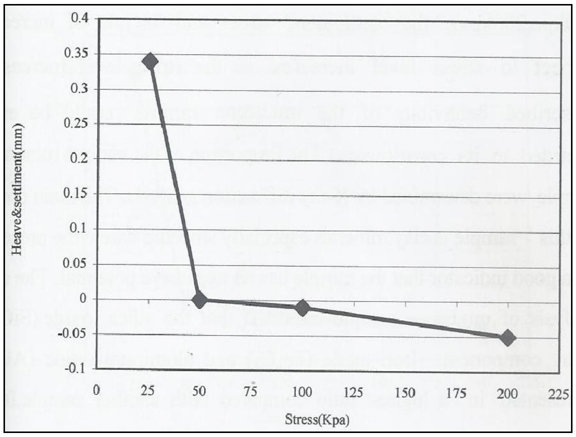

Fig. (14): vertical deformation versus stressfor Calystone sample.

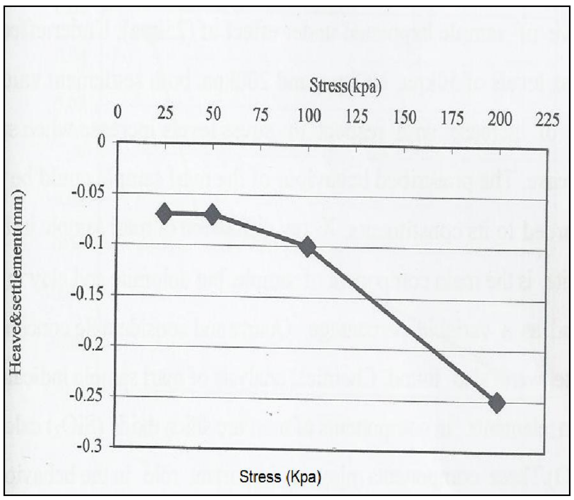

Fig. (15): vertical deformation versus stress for Evaporite sample.

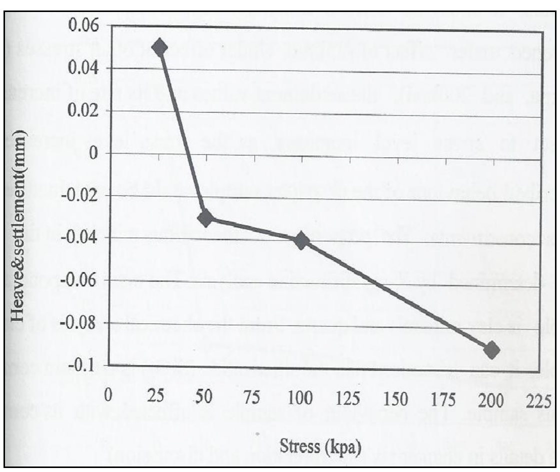

Fig. (16): vertical deformation versus stress for Marl sample.

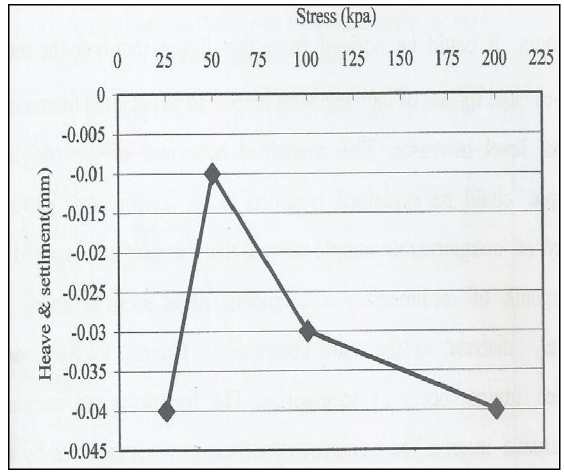

Fig. (17): vertical deformation versus stress for Dolomitic limestone sample.

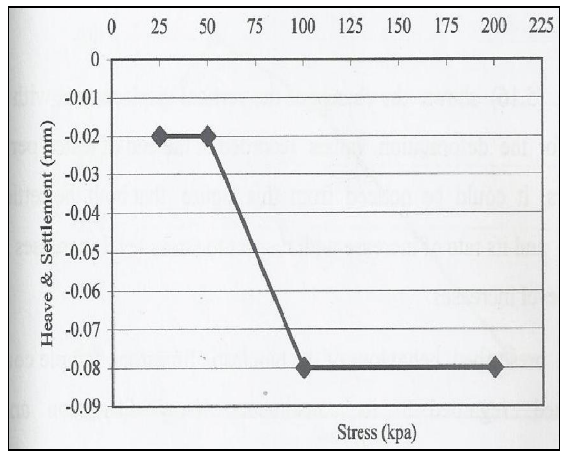

Fig. (18): vertical deformation versus stress for Conglomerate sample.

(17) that the vertical deformation versus stress level for Dolomitic limestone sample didn't increase with respect to stress increasing. Fig. (18) shows the vertical deformation versus stress for Conglomerate sample, it could be noticed that both the settlement value and its rate of increase with respect to stress level increases where the settlement under effect of 25Kpa and 50Kpa have same values but under 100Kpa and 200Kpa have same values.

5. Conclusion and discussion.

These samples collected from different places and different formations in Marsa Allam city near coast of Res Sea around the main roads of this important city. The samples were choosed carefully as uncommon in foundations such as sand, gravel or pure clay where these mentioned types were studied by many scientists. Different five samples were studied which are Claystone, Marl, Evaporite, Dolomitic limestone and Conglomerate represents the variation uncommon soils in foundations for all places of Marsa Alam city. These variation samples have different compositions, so the results showed different behaviors of these investigated samples under different loads, where some of these samples (Claystone and Marl) heaved when contact with water under low stress (25kpa) but they compressed with increasing these stresses (50Kpa, 100Kpa and 200Kpa). One sample (Evaporite) was settlement under all stresses and it must be noticed that the settlement increased with increasing of loads. Other samples (Dolomitic limestone and Conglomerate) recorded slight settlement may be related to effect of loads because they have hard component which do not dissolve in water or swelling by contact with it.

The interpretation of this different behavior can be explained as Claystone sample gave swelling strain of 1.79% under 25Kpa, while it compressed under high loads to reach minus 0.26% under 200Kpa. This swelling related to several factors such as mineralogical composition where claystone bulk sample has ratio of clay fraction of 21.67% (Table. 1), and have smectite (montmorrillonite) clay mineral as shown in (XRD) analysis (Fig.3).

Sample recorded a value of plasticity index of 14%. From chemical analysis of claystone sample (Table 2), it can be found that the ratio of Al_2O_3 and Fe_2O_3 is 5.9% and 7.17% respectively, where the presence of cations of Al^{+++} and Fe^{+++} increase the water content in the crystals according to Gerogory (1956) who indicated that univalent ions Na^{+} are loosely bond to soil crystals. The bivalent ions Ca^{++} and Mg^{++} are adsorbed to it somewhat more firmly. The trivalent ions Al^{+++} and Fe^{+++} can be bond very strongly. At the sometime water molecules, being dipoles, are adsorbed both to the surface of the crystals lattice and to the cations. Some water molecules may even penetrate into the interior of the crystal lattice. Also, Mitchell (1986) indicated that in dry smectite clay, the negative charge is balanced electrostatically by exchangeable cations surrounding the particles. Cations in excess of those needed to neutralized the electronegativity of such clay particles and their associated anions present as salt precipitates. When a clay comes in contact with water, the clay particles are surrounded by a hydrous double layer. Also, granulometric analysis of claystone sample revealed that it contains high percentage of fine grains that is 81.71% as silt grains and 5.54% as clay grains (Table 4). This high ratio of fine grains of claystone sample cause increasing its compressibility.

Marl sample, this term (marl) mean these sedimentary rocks which contain approximately calcareous material equal clay materials, this sample has expansive properties but it lower than claystone sample where it is 0.26% versus stress level of 25Kpa. Interpretation of Marl behavior depending on its mineral composition where it contains calcite ratio of 46.84% and clay of 36.74% while chemical analysis indicated that it has ratio of CaO 28%. Also, its plasticity index was small (8.5%).

From petrographic study and mineralogical analysis, it can be noticed that both Dolomitic limestone sample and Conglomerate sample composed of hard and insoluble materials, so the small settlement that occur according to results of Oedometer test related to effect stress levels only.

Evaporite sample recorded maximum value of settlement strain (ε%) is 1.3% of initial volume under stress level of 200Kpa, where the vertical deformation of Evaporite sample versus stress level of 200Kpa was 0.25mm from total thickness of sample (19mm). Also, by drying the Evaporite sample for period (24hours) in the air temperature., it loosed (0.4%) from initial weight. From mineralogical composition and petrographic study, it can be found that this sample composed of anhydrite, halite and calcareous materials, where all these components are dissolved in water causing Interval settlement.

Recommendations

Many of geotechnical tests and studying of the sample components must be involved before establishment any construction to avoid the hazard of uplift which occurs as result of expansive soils or subsidence phenomenon associated with the dissolution of Evaporite rocks.

References

1. AASHTO, T 290 (2013): Standard Method of Test for Determining Water-Soluble Sulfate Ion Content in Soil, Single User Digital Publication. American Association of State Highway and Transportation Officials, Washington, DC.
2. AASHTO, T 291 (2013): Standard Method of Test for Determining Water-Soluble Chloride Ion Content in Soil, Single User Digital Publication. *American Association of State Highway and Transportation Officials*, Washington, DC.
3. Ahmed, M. I. S. and Abu el-Anwar, E. A. (2002): Petrophysical properties of some carbonate rocks at Abu Raosh area, Egypt. J. Geol. (27): 27-42.
4. Akili, W. (1980): Some properties of remolded carbonate soils, Eastern Saudi Arabia, proc. 10th int. conf. SMFE, Stokholm, 537.
5. Azam S. (2006): Larg-scale Odometer for assessing swelling and construction behaviour of Al-Qatif clay. In Al-Rawas AA, Goosen

MFA (eds) Expansive soils: recent advances in characterization and treatment. Balkema puplishers-Taylor and Francis, The Netherlands, pp: 85-99.
6. Bell, F. G. (2000): Engineering properties of soils and rocks. Black well science Ltd, United Kingdome. 482pp.
7. Boogs, J. S. (1992): Petrology of sedimentary rocks. Macmillan Puplishing company, New York. 707pp.
8. Casagrande, (1932): Research on the Atterberg limits of soils. Puplic Roads, (13): 121-136.
9. El Tahlawi, M. R., Soliman, A. and Gomma, W. (1973): Geological and Geotechnical evaluation of the Eocene limestone of the Nile valley, Egypt. The Bulletin of the faculty of engineering, Assiut university, (1): 151-161.
10. Erol, A. O. (1989): Engineering geological considerations in a salt dome region surrounded by sabkha sediments, Saudia Arabia. Eng. Geol., (26): 215-232.
11. Folk, R. L., Andrews, P. B. and Lewis, D. W. (1970): Detrital sedimentary rocks classification and nomenclature for use in New Zealand. New Zealand journal of geol. And geophiscs. (13): 937-968.
12. Fookes, P. G. (1978): Middle east-Inherent ground problems. Q. J. Eng. Geol, (11): 33-49.
13. Gerogory, P. T. (1956): Soil mechanics, foundations and earth structures. McGRAW-Hill Book company, New York, Tronto, London: 655pp.
14. Ismaiel, H. A. and Badry, M. M. (2013): Lime chemical stabilization of expansive deposits exposed at El-Kawther quarter, Sohage Region, Egypt. Geosciences, 2013, 3 (3): 89-98.
15. Mahrous A.M., Tantawi M., El-Sageer H. (2010): Evaluation of the engineering properties of some Egyptian limestones as construction materials for highway pavements. Construction and Building Materials journal, Vol. (24) pp:2598-2603.
16. Mitchell, J. K. (1986): Partical problems from surprising soil behaviour. ASCE. J. of Geotech. Eng., (112): 2859-2893.
17. Moaydi H., Bujang B.K., Fatemeh M., Afshin A. and Alinza, P. (2011): Effect of sodium silicate on unconfined compressive strength of soft clay. Electronic Journal of Geotechnical Engineering (EJGE), Vol. (16) pp:289-295.
18. Pettijohn, F. J. (1975): Sedimentary rocks, Harper and Row pub. New York.
19. Portar, L. A. (2005): Geotechnical Engineering I, GCE-4011, Florida International Universty.
20. Sowers, G., F. (1979): Introductory soil mechanics foundations (4^{th} edn). Macmilan, New York, 621pp.

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