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GEOLOGICAL, SOIL AND ROCK MASS EVALUATION FOR RISK ASSESSMENT OF BADR CITY, EGYPT

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Abstract:

The study was conducted to assess the index properties and characterize soils and rocks of badr City, as well as their effects on the construction stability. Geological, engineering geological and geotechnical condition of the rocks and soils was studied on the bases of field description and laboratory analysis. It aims also at providing an alternative solution for the expected concerned problems of these shallow facies. From these facies clay layer which has an obvious dangerous effect on the building construction and on any other establishments. The claystone consists of kaolinite, montmorillonite and illite types. The liquid limit ranges from 49 to 175 %, the plastic limit ranges between 20 and 42 % and the shrinkage limit ranges between 9.88 and 13.3 %. The values of the free swelling of the studied samples are ranging between 98 and 180 %. The swelling pressure ranges from 3 to 6.2 Kg / Cm^2. Claystone of study area can be classified as inorganic clay of high and extremely high plastic soil.

Key words: Engineering geological, Liquid limit, Badr City, Swelling pressure, Rock mass, Soils.

1-Introduction

Badr City is one of the new cities in Egypt. The City is designed to supply work opportunities and services for over one million habitants. The study area is defined by the following co-ordinates. Latitudes 30°06′30′′ and 30°09′30′′ N and longitudes 31°41′ and 31°45′ E .The area is approximately 56. km^2 and located at north of Cairo-Suez road between Km 46 and Km 56 from Cairo along this road, and the south of Cairo-Suez railway, and considered as a part of Cairo-Suez district. (Fig.1). It is about 170 to 250 m. above sea level. The Southern part of the area is a wide plain drainged generally into a north to northwest direction by several water trends that start from the south, southwest and southeast.

The engineering behavior of soil is a function of its moisture content, structure, mineralogical composition and the subsequent stress history. The research work involved a number of fieldworks rock and disturbed soil samples were collected and analyzed for various index and engineering parameters. The laboratory experiments which were carried out on these samples are: Grain seize analysis (20 samples), Atterberg limits (13 samples), X-Ray analysis to Clay minerals (6 samples), Free Swell testing (13 samples) and consolidation tests (7 samples). The soil and rock mass of the City were classified on the basis of their engineering behavior according to Unified Soil Classification Systems (USCS) and classification proposed by International Association of Engineering Geologists (**IAEG, 1981**).

2: Geologic Setting

The geology of the study area has been discussed by many authors such as **Shukri et al, (1971)**. The marine Miocene sedimentary rocks of the area under consideration are covered by younger section of sands gravel's, which are unconformable covered by Pliocene sediments (Fig.2).

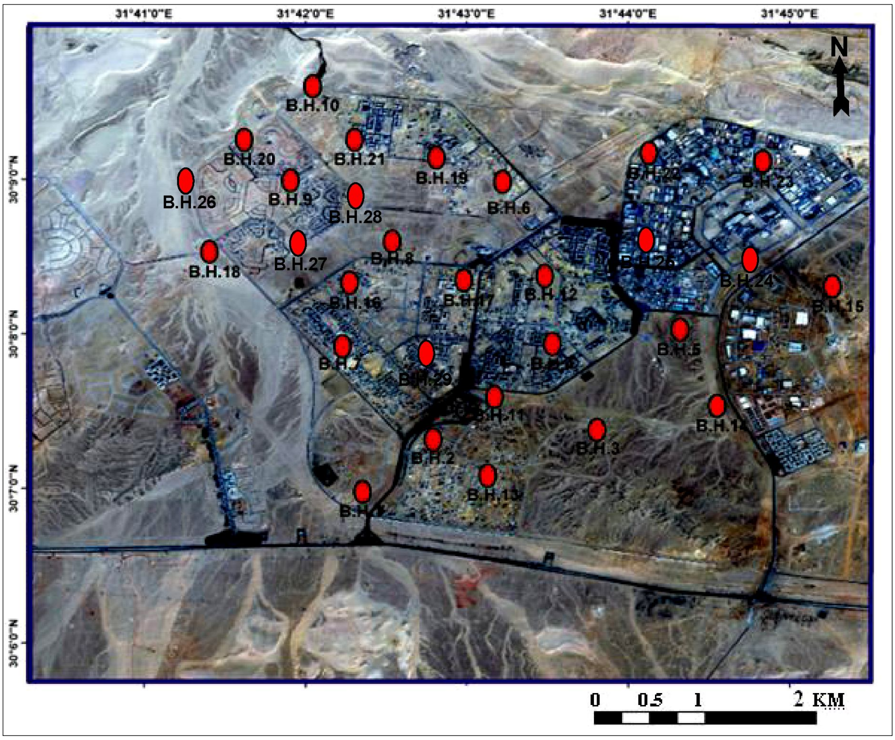

Fig.1: Location Map of the Badr City.

Oligocene Deposits:-

The base of the Oligocene overlies Upper Eocene sediments unconformably. This relation is also known everywhere in the Cairo – Suez district. The Oligocene sediments consist of varicoloured sands and sandstones. The sandstone is medium – hard and even occasionally quartzite. Flint gravels are present, which at the first sight, seem to be concentrated at the upper top of the section. But this concentration is due to removal of the sand matrix by erosion. Evidence of marked solidification is manifested in the presence of solidified wood and quartzite " dykes ".

The thickness of the Oligocene section could not be measured, firstly because the base is not exposed and secondly, the fact at no dip or strike could be determined owing to the lack of bedding. In some localities between Cairo and Suez, basalt lies on top of the Oligocene sediments and is overlain by the marine Miocene deposits.

Miocene Deposits:-

A: - Marine Miocene:

The marine Miocene sediments are occupying northern part of the mapped area. These are represented by sandy limestone and limestone with few sandstone, which tend to a pound towards the bottom with some conglomerates. The section is generally yellowish and is rich in – macrofossils. Three main lithologic units were recognized in the marine Miocene section. They arranged from base to top as the following:

- Unit "A"

This unit ranges in thickness from about 10 m in western part of mapped area to about 25 m in the east. It is generally composed of yellowish brown and is predominantly sandy facies. This unit lies unconformably over the underlying Oligocene gravels. However, the Oligocene Miocene contact was not easily defined at some localities, where it is masked by gravel wash from the Oligocene.

- Unit '' B '':

It ranges from about 12 m, in the west to about 28 m in the east. It is generally yellowish and consists mainly of intercalation of sandy limestone, marl and shales.

- Unit '' C '':

This Unit ranges from about 15 m in the west to about 18 m in the east. It is mainly composed of limestone riched in "Oysters", with the dominant algae. On the other hand, the uppermost beds are formed of yellowish sandy limestone. The marine Miocene shows a marked thickening east direction towards the Gulf of Suez. This may indicated the deepening of the Miocene sea in that direction. However, the vertical variation in sedimentation, as evidenced by the occurrence of sandstone intercalation.

B: - Non Marine Miocene Deposits:

The non-marine Miocene sediments are recorded in the form of sands, grits and gravels. It overlies unconformably by Oligocene sediments (Fig.2). The non-marine Miocene sands are characterized by dark in color than Oligocene one due to high concentration of heavy minerals.

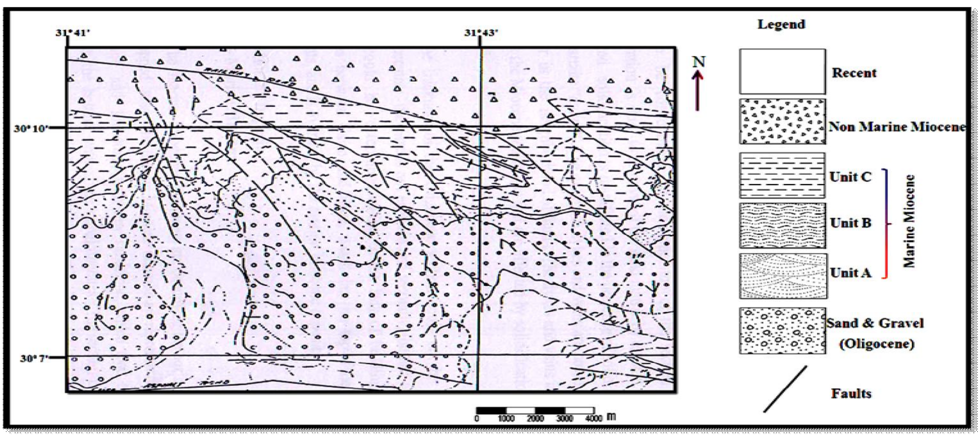

Fig. 2: Geological map of the study area after Shukri and El Ayouty (1971).

The most the different foundations bed of Badr City usually sited on limestone bedrocks that have encountered the problem of fracturing or sited on clay which reported construction damage due to swelling process, (Fig. 3).

Fig.3: Showing some field Outcrop of Claystone beds (3B, 3C&3D), Sandy limestone bed (3A), High way fractures (3E) and water flow under foundation beds (3F).

3. Grain Size Analysis

The quantitative data that an engineer needs depend upon the mechanical properties such as stiffness and strength, and these must be determined from mechanical tests.

Coarse grained soils have good bearing capacities and good drainage qualities, and their strength volume change characteristics are not significantly affected by change in moisture conditions. Fine grained soils have less load bearing capacities compared with coarse grained. The results of the mechanical analysis are tabulated in table (1) and the data are represented in cumulative curves (Fig. 4).

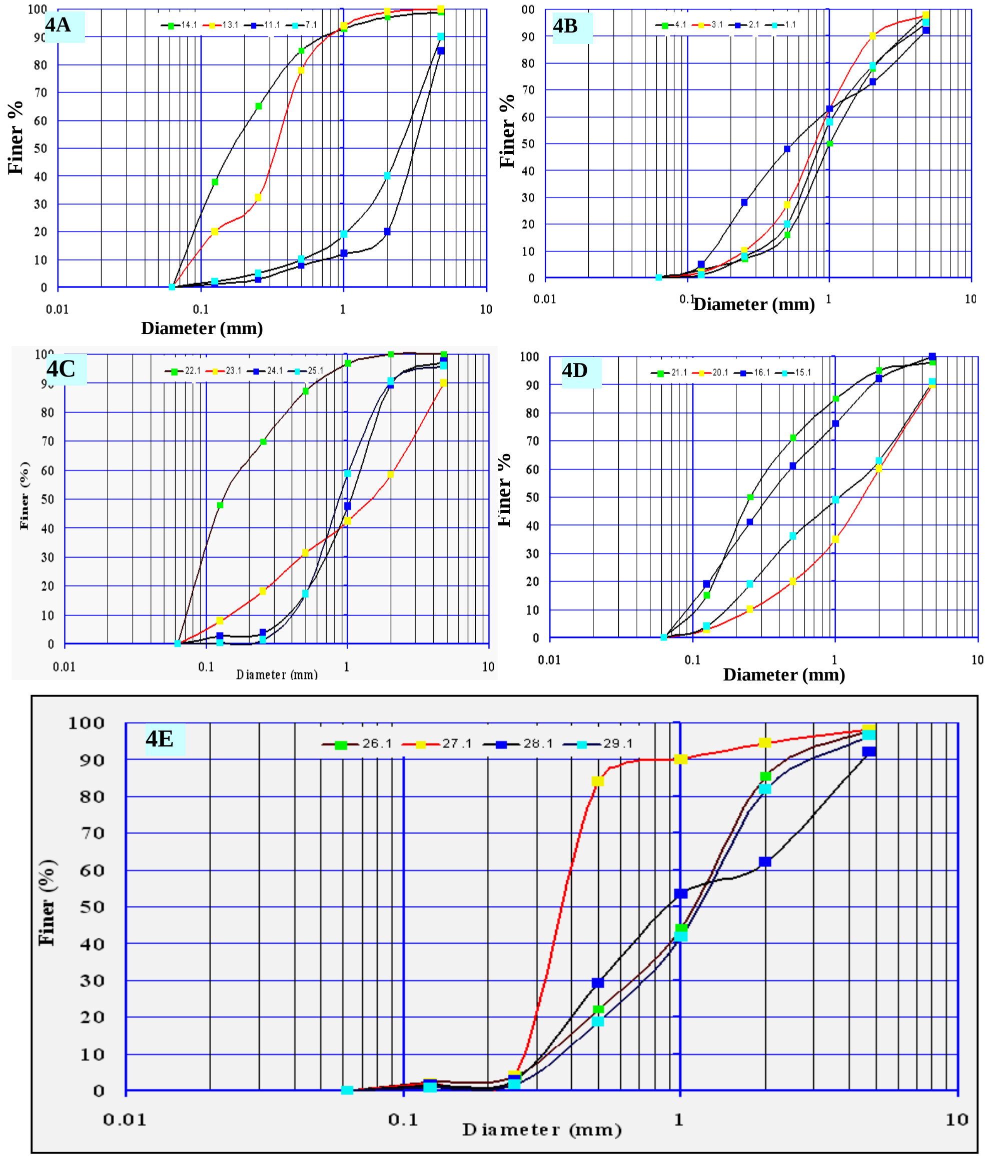

Fig.4: Grain size distribution curves of studied area (4A,4B,4C,4d & 4E)

3.1.Parameters Obtained from Grain Size Distribution Curve:

1- Uniformity Coefficient U.C (measure of the particle size range)
U.C is also called Hazen Coefficient U.C = D60/D10
U.C < 5 --Very Uniform, U.C = 5 -- Medium Uniform, U.C >5 --No uniform
2- Coefficient of Gradation or Coefficient of Curvature C.C (Measure of the shape of the particle size curve)
C.C = (D30)2 / D60 x D10 C.C from 1 to 3 --- well graded
3- Coefficient of Permeability = C.k (D10)2 m/sec

From the table (1) the values of uniformity coefficient indicated that, the studied area is characterized by a range between well – graded and poorly graded soil.

Table (1): Grain Size Data of the Studied Samples at Badr City.

Sample No.	Weight Retained							Mathematical Values Use as Principle for Classification of Soil									
	4 - 2	2 - 1	1 - 0.5	0.5 - 0.25	0.25 -0.125	0.125 -0.063	< 0.063	D10	D25	D30	D50	D60	C.C	U.C	K.C	S.K	S.C
1.1	5.1	15.9	21.6	37.4	11.3	7.3	1.4	0.28	0.55	0.61	0.85	1.2	1.1	4.28	0.19	1.57	1.64
2.1	8.6	18.4	10.3	15.2	19.5	23.2	4.8	0.16	0.25	0.28	0.54	0.83	0.6	5.18	0.27	2.14	3.16
3.1	2.9	7.1	27.4	35.6	17.1	7.6	2.4	0.25	0.45	0.52	0.78	0.92	1.17	3.68	0.27	1.03	1.76
4.1	2.1	19.7	28	33.5	9/2	4.3	3.2	0.32	0.61	0.68	1.0	1.4	1.03	4.37	0.17	1.09	1.71
7.1	10.4	49.5	21.1	9.1	4.7	3.1	2.1	0.5	1.3	1.3	2.4	2.95	1.14	5.9	0.27	0.79	1.64
11.1	14.7	64.3	8.4	4.3	5	2.2	1.1	0.62	2.3	2.55	3.3	3.55	2.95	5.72	0.24	0.90	1.36
13.1	0.2	0.8	4.9	16.1	45.7	12.6	18.7	0.08	0.19	0.24	0.34	0.28	2.42	3.29	0.19	0.73	1.53
14.1	0.8	2.2	4.1	8.4	19.5	27.3	37.7	0.07	0.08	0.11	0.17	0.22	0.73	2.93	0.22	0.96	2.09
15.1	8.9	28.1	13.5	13.2	17.3	15.1	4.0	0.17	0.31	0.39	1.1	1.8	0.49	10.6	0.30	0.74	3.05
16.1	0.3	8.1	17.7	15.0	20.2	22.1	18.7	0.09	0.16	0.18	0.33	0.48	0.75	5.33	0.20	1.26	2.31
20.1	10.1	29.7	25.1	15.3	10.4	7.1	2.5	0.15	0.65	0.82	1.6	1.9	2.35	12.6	0.25	0.76	2.14
21.1	2.1	3.1	9.8	13.9	21.1	35.0	15.8	0.09	0.16	0.18	0.25	0.34	1.05	3.77	0.16	1.53	1.93
22.1	0.0	0.0	3.1	9.4	17,8	21.8	47.9	0.07	0.08	0.09	0.14	0.17	0.75	2.42	0.14	1.30	1.87
23.1	9.9	31.7	15.9	11.2	13.2	10.1	7.9	0.15	0.35	0.48	1.6	2.1	0.73	14	0.33	0.45	3.07
24.1	2.42	8.2	41.5	30.5	13.6	1.2	1.7	0.37	0.6	0.7	1.2	1.4	0.49	3.78	0.29	0.66	1.63
25.1	3.5	6.1	31.9	41.5	15.9	1.1	1.2	0.4	0.56	0.62	0.85	0.95	1.01	2.73	0.28	1.08	1.58
26.1	1.8	12.8	41.2	22.1	18.1	1.6	2.4	0.32	0.55	0.65	1.2	1.4	0.94	4.37	0.26	0.63	1.73
27.1	1.8	3.7	4.2	6.3	80.1	1.7	1.6	0.26	0.3	0.31	0.37	0.4	0.92	1.53	0.1	0.98	1.22
28.1	7.1	11.8	27.6	24.4	26.3	1.3	1.5	0.31	0.45	0.5	0.88	1.9	0.42	6.12	0.26	1.51	2.40
29.1	3.5	14.9	39.7	23.1	17.5	0.7	0.6	0.37	0.62	0.72	1.3	1.5	0.73	5.13	0.2	0.62	1.65

<u>Abbreviations</u>
C.C = Coefficient of Curvature U.C = Uniformity of Coefficient K.C = Kurtosis of Coefficient S.C = Sorting Coefficient SK.C = Skweness of Coefficient

4. Clay Mineral Composition:

Clay particles have a large specific area. Between various clay minerals, montmorillonite is the most expansive type and have the large specific surface area. Because of their high specific surface area, these minerals are always hydrated in nature with absorbed water. It is known that all clay soils swell and shrink as their moisture content changes but the smectite group had the biggest magnitude of swelling and shrinking.

Three oriented particle mounts were prepared from the pure clay fraction (< 2 μm) and X-rayed for the semi quantitative identification of clay minerals. They were prepared by pipetting of the clay suspension on glass slides. One of these mounts was suggested to X-ray in its original state (untreated). The second were X-rayed after saturation with ethylene glycol (glycolated) and the third after heating at 550˚C for two hours (heated). The X-ray diffractograms of oriented particle amounts of selected samples are presented in (Fig.5).

4.1. Kaolinite:

Kaolinite, $Al_4\ Si_4O_{10}\ (OH)_8$ is composed of a single tetrahedral and a single alumina octahedral sheet combined in units. The kaolinite mineral is formed staking the layer of 7A° thick one above the other with base of the silica sheet bonding to hydroxyls of the gibbsite sheet by hydrogen bond, the kaolinite sheets are difficult to dislodge. Kaolinite is generally formed in warm moist regions as a residual weathering product or sometimes by hydrothermal alteration of other aluminosilicates. Kaolinite is the most predominant mineral of abundance in the studied clay samples (63.92%).

4.2. Montmorillonite:

It is the most common mineral of the montmorillonite group, which has important Base Exchange properties, is built up of 3 layer units comprising two silicon layer separated by an aluminum layer. Some aluminum is usually replaced by magnesium or iron, and small amounts of sodium or calcium are then attached, as ions lying between the 3 layer units or around the edges of the minute crystals. The layers are held together by weak van der waals forces and exchangeable ions. Water can easily enter the bond and separate the layers in montmorillonite, causing swelling. The montmorillonite is the second Mineral in the studied samples (29.38 %).

4.3. Illite :

Illite is characterized by a series of weak broad peaks of lines 9.9A°, 4.44A° and 3.35A° that are not appreciable affected by glycolation or heat treatment. It is similar in many respects to white mica, but has less potassium and more water in its composition. It has a much lower base exchange capacity than smectite.

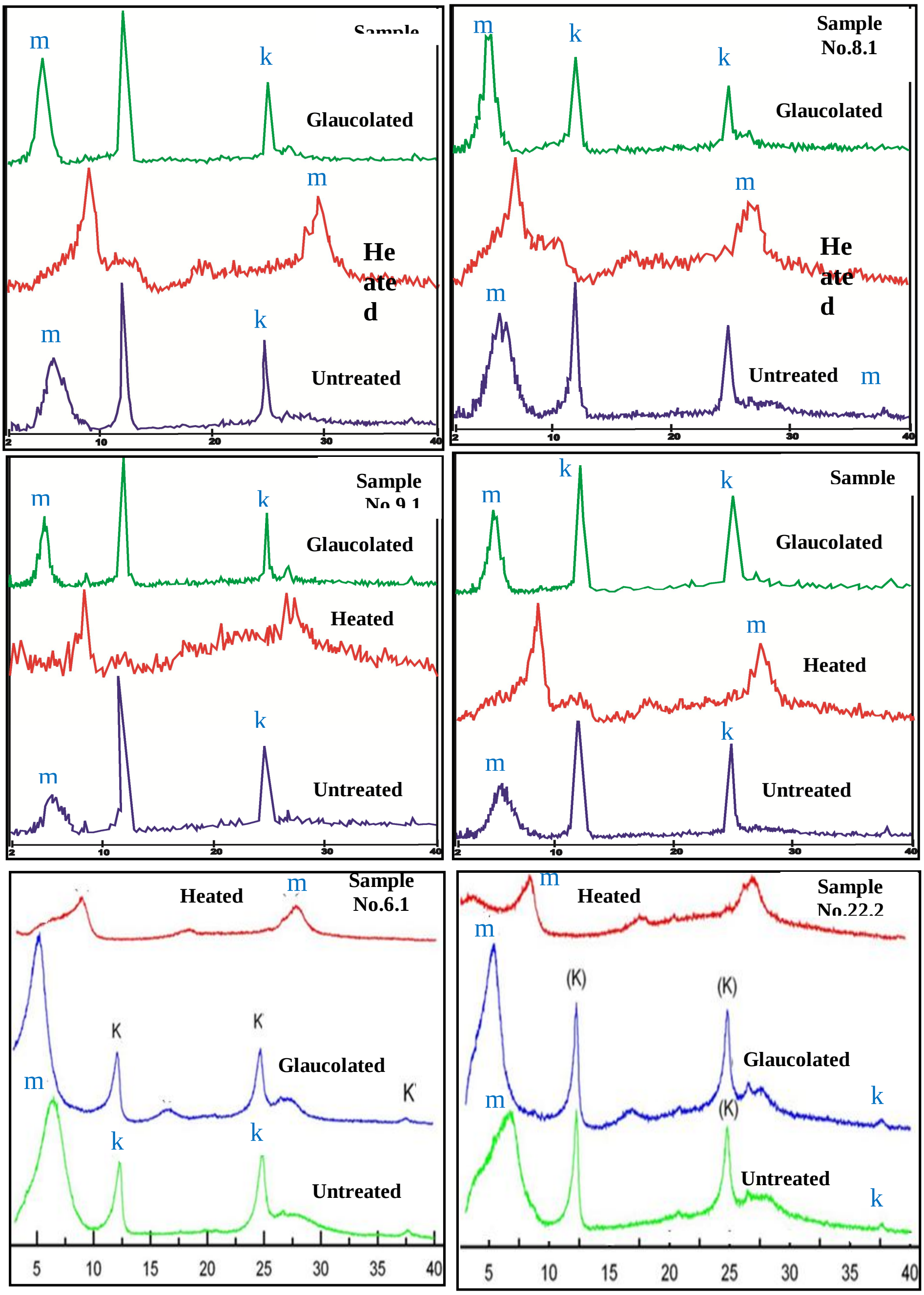

Fig. 5: X-Ray diffraction of the studied clay minerals, samples (5.1, 6.1, 8.1, 9.1, 12.1 and 20,1) at Badr City.

Illite consists of repeated layers of one alumina sheet sandwiched by two silicate sheets. The illite is the third mineral in the studied samples (6.7 %).

5. Petrography and Rock Strength

The international society for rock mechanics has published suggested methods for petrographically examining these rock features that have a bearing on mechanical behavior that can only be observed with a microscope **(ISRM, 1978).**The thin section petrography is one of the most practical methods to express specific characteristics of the diagenetic processes affecting the consolidated rocks. To accomplish this study more than 10 thin section were prepared representing the encountered lithologies. The uniaxial compressive strength (U.C.S) of the different facies were determined and the samples were prepared according to (**ISRM, 1981)**. The petrographical analysis of Badr City indicated the presence of five carbonates microfacies association. These are as follows:

5.1-Sandy Algal Dolo Biomicrosparite (Packstone):

This microfacies consists of fine to coarse, sub-angular to subrounded detrital quartz grains (30 – 40%), Algae shell fragments (15%) commonly scattered throughout a mosaic, dolomitic matrix. The amount of the dolomite crystals varies from place to place ranging in size from microcrystalline to mesocrystalline dolomite. The dolomite crystals of both sizes are euhedral to subhedral and rhombic (Fig.7A&7B). The material strength was estimated in the field (R.Q.D) and laboratory (U.C.S). The rock quality values of these facies ranging between 10 -15 % and the unconfined compressive strength ranging between
20 – 27 Kg /Cm^2.

5.2- Sandy Dolomitized Biomicrite (Packstone):

Sandy dolomitized biomicrite microfacies consist of detrital quartz (30%) with shell fragments embedded in microcrystalline calcareous matrix. The quartz grains are coarse to medium grained, most grains are monocrystalline partially polycrystalline with normal and wave extinction, few grains are elongated shape, moderately sorted to illsorted and some quartz grains are fractured due to pressure (Fig.7C&7D).

The rock quality values of these facies ranging between 15-25 % and the unconfined compressive strength ranging between 40 – 95 Kg / Cm^2.

5.3- Sandy Micrite (Packstone):

This microfacies association consists of quartz embedded in micritic matrix. The quartz grains are fine to medium grained, with normal extinction, (45%) most grains are monocrystalline with few polycrystalline grains, overgrowths recorded (Fig.8E&8F). The rock quality values of these facies ranging between 12-18 % and the unconfined compressive strength ranging between 28 – 39 Kg / Cm^2.

5.4- Calcareous Quartz Arenite:

The quartz grains are fine to coarse grained, subrounded to rounded, some of them are subrounded to subangular and few grains are elongated shape, moderately sorted (Fig.8G&8H). The rock quality values of these facies ranging between 14-20 % and the unconfined compressive strength ranging between 30 – 45 Kg / Cm^2.

5.5- Algae Biomicrite (Packstone):

This microfacies consist of a fragment a coralline algae, with its characteristics reticulate appearance caused by thin micrite walls separating small, more or less rectangular cells. The spar-filled holes within the skeleton, called conceptacles, are also characteristic (Fig.8K&8L). The rock quality values of these facies ranging between 17-22 % and the unconfined compressive strength ranging between 28 – 42 Kg / Cm^2.

7. Geotechnical Properties of Clay

The majority of laboratory tests on clays are: initial water content, specific gravity, atterberg limits, consistency indices, chemical analysis and swelling pressure.

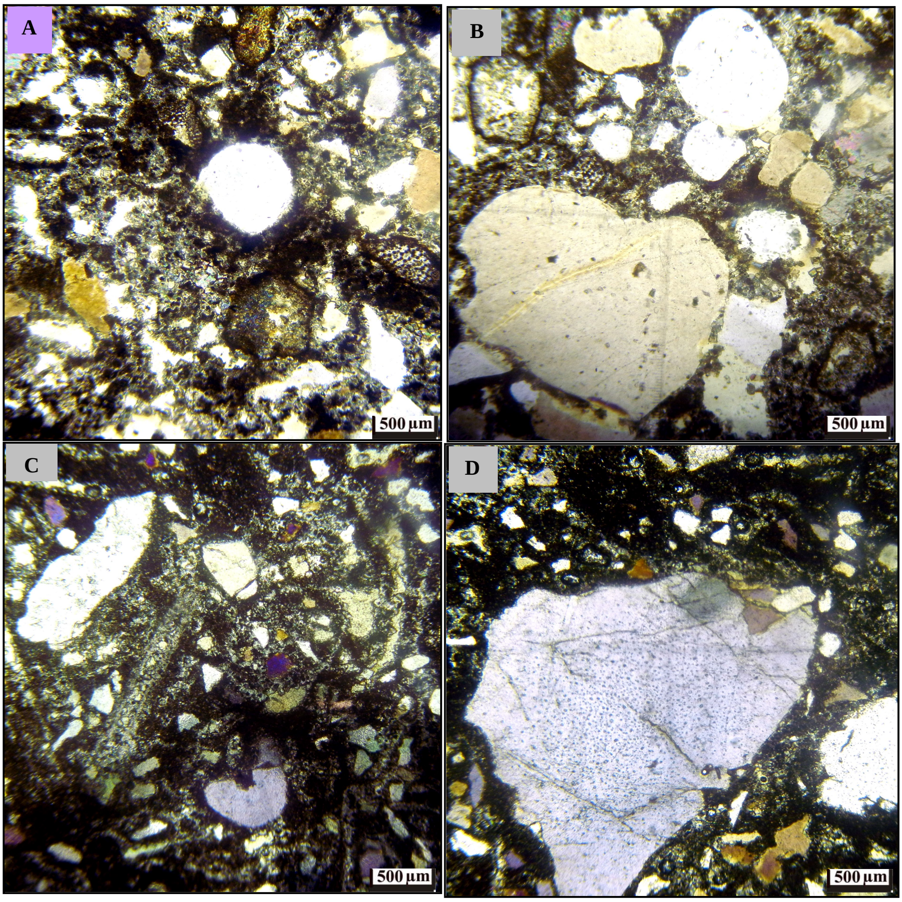

Fig.7: Photomicrograph showing Sandy Algal Dolo Biomicrosparite 7A&7B, Sandy Dolomitized Biomicrite 7C&7D.

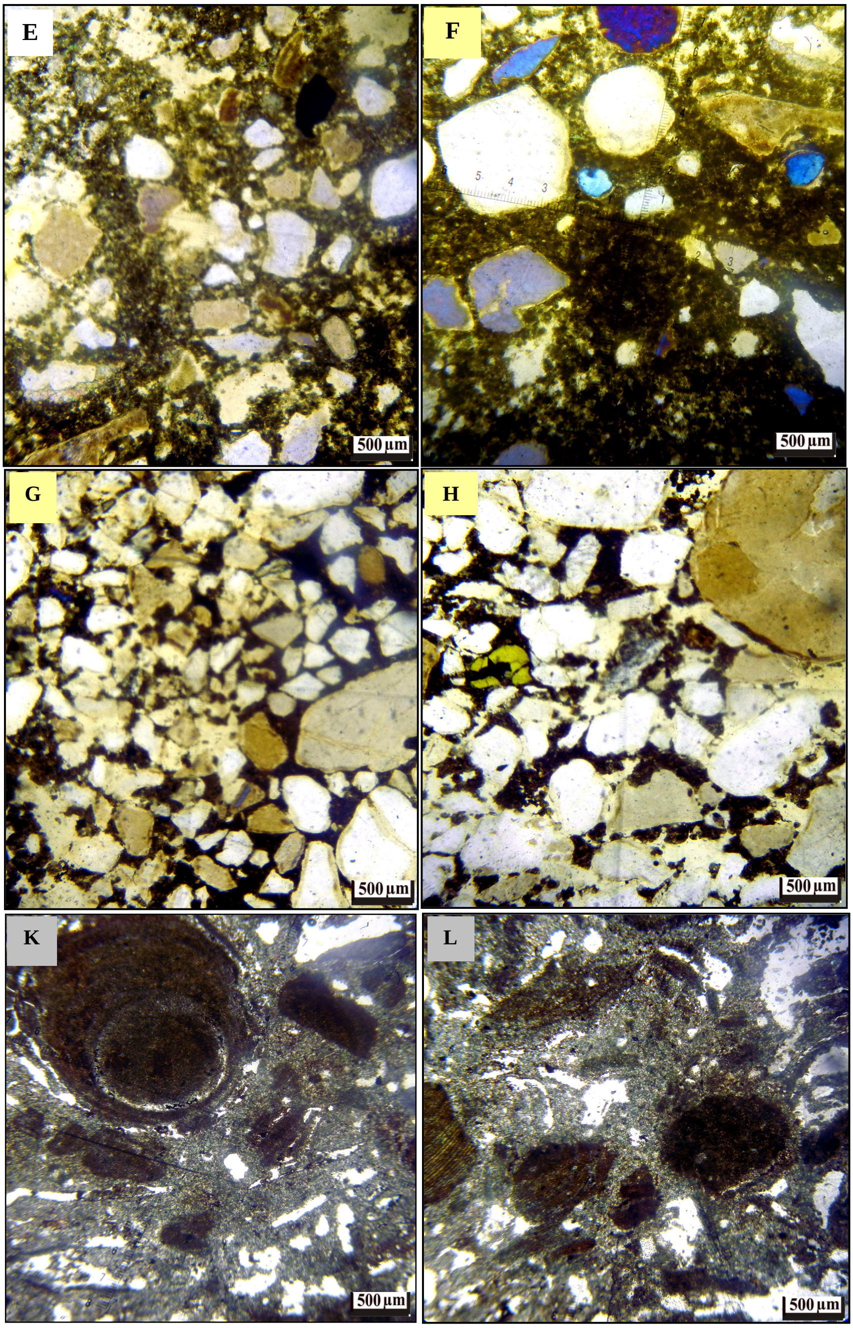

Fig.8: Photomicrograph showing Sandy Micrite 8E&8F, Calcareous Quartz Arenite 8G&8H and Algae Biomicrite 8K & 8L.

7.1. Atterberg Limits of Fine Soil

Atterberg limits are empirically developed but widely used procedures for establishing and describing the consistency of soil. The engineering properties (uses) of fine grained soils are, generally, related to these index properties. The more plastic a soil means the more compressible, higher shrinkage-swell potential and the lower is its permeability will be (**Abramson et al, 1996**). Plastic index is important in classifying fine-grained soils and is fundamental to the Casagrande plasticity chart.

7.1.1. Liquid Limit (L.L)

The results of the liquid limit of studied samples are given in Table (2). Results of the liquid limit range between 49 to 175 %.

7.1.2. Plastic Limit (P.L.)

The results of the plastic limit of studied samples are given in Table (2).The values of the plastic limit range between 20 to 42%.

7.1.3. Shrinkage Limit (S.L.)

The results of this test are given in Table (2).The values of this limit range between 9.88 to 13.3%.

Table (2): Atterberg limits of the studied claystone samples.

Sample No.	Specific Gravity(G_S)	Liquid Limit (L.L.)	Plastic limit (P.L.)	Plasticity Index	Free Swell	Shrinkage Limit(S.L.)
5.1	2.08	104	33	71	160	12.7
6.1	2.66	120	42	78	170	13.11
7.2	2.31	84	32	52	100	13.3
8.1	2.66	49	20	29	110	12.08
9.1	2.13	75	27	48	180	11.13
12.1	1.79	175	37	138	120	10.75
13.2	2.14	96	29	67	95	11.7
14.2	2.17	102	28	74	130	12.3
15.2	2.11	104	30	74	135	10.45
18.1	2.15	109	30	79	140	11.17
20.2	2.29	71	28	43	107	9.88
22.2	2.02	84	28	56	98	10.7
23.2	2.12	88	29	59	110	11.11

7.2. Swelling Potential of Clays

Expansive soil can be identified either indirectly or directly in the laboratory.

7.2.1. Indirect Identification of Expansive Soil

The indirect methods include mineralogical analysis free swell, colloid content, plasticity index and activity. Clay mineralogy is also the dominant factor in controlling the plasticity of clay soil. Based on the X-ray diffraction examination the clay mineralogy are as follows: kaolinite, montmorillonite and illite.

Free swell tests consists of placing a known volume of dry soil in water and noting the swelled volume after the material settles, without any surcharge, to the bottom of a graduated cylinder. The difference between the final and initial volume, expressed as a percentage of initial volume, is the free swell value (**Chen, 1975**). Results of free swell tests of the soils of the study area are presented in Table 3. According to **Bell (1983)**, soils having free swell value as high as 100% can cause considerable damage to lightly loaded structures, and soils having free swell value below 50% seldom exhibit appreciable volume change even under very light loadings.

The values of the free swelling of the studied samples are given in Table 3 and range between 98 to 180 %. The all samples with free swell of greater 50%. Hence, considerable attention should be given in foundation design even for light structures on such soils because their value shows expansiveness property.

7.2.2. Direct Identification of Expansive Soil

The direct methods for the identification of expansive soils are more reliable and depend on the use of several types of swelling apparatus (**Ohri, M (2003).** The swelling pressure values of the selected examined samples determined from this test are given in Table 3. The final swelling percentage is drawn versus the vertical applied pressure, as shown in (Figs 9 and 10).

Table (3): Swelling pressure Values of some Claystone Samples Obtained by Oedometer Test.

Sample No.	Mineralogical Composition	Swelling pressure kg/cm^2
5.1	Kaolinite and Montmorilonite	4.4
6.1	Kaolinite and Montmorilonite	4.9
8.1	Kaolinite and Montmorilonite	6.2
9.1	Kaolinite, Montmorilonite and illite	3.1
12.1	Kaolinite and Montmorilonite	5.5
22.2	Kaolinite and illite	3
23.2	Kaolinite and illite	3.4

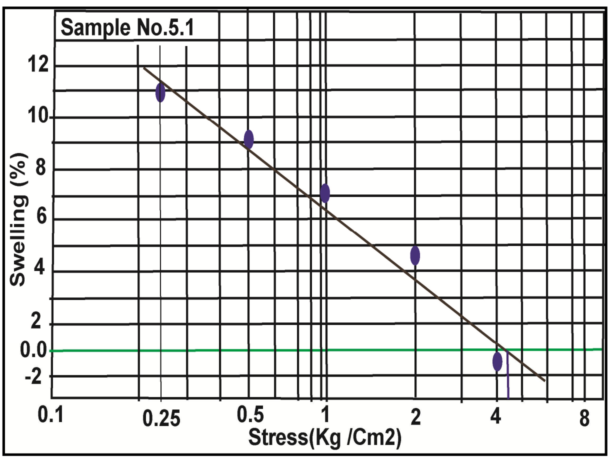

Fig.9: Relationship between swelling percent and applied pressure (sample No. 5.1).

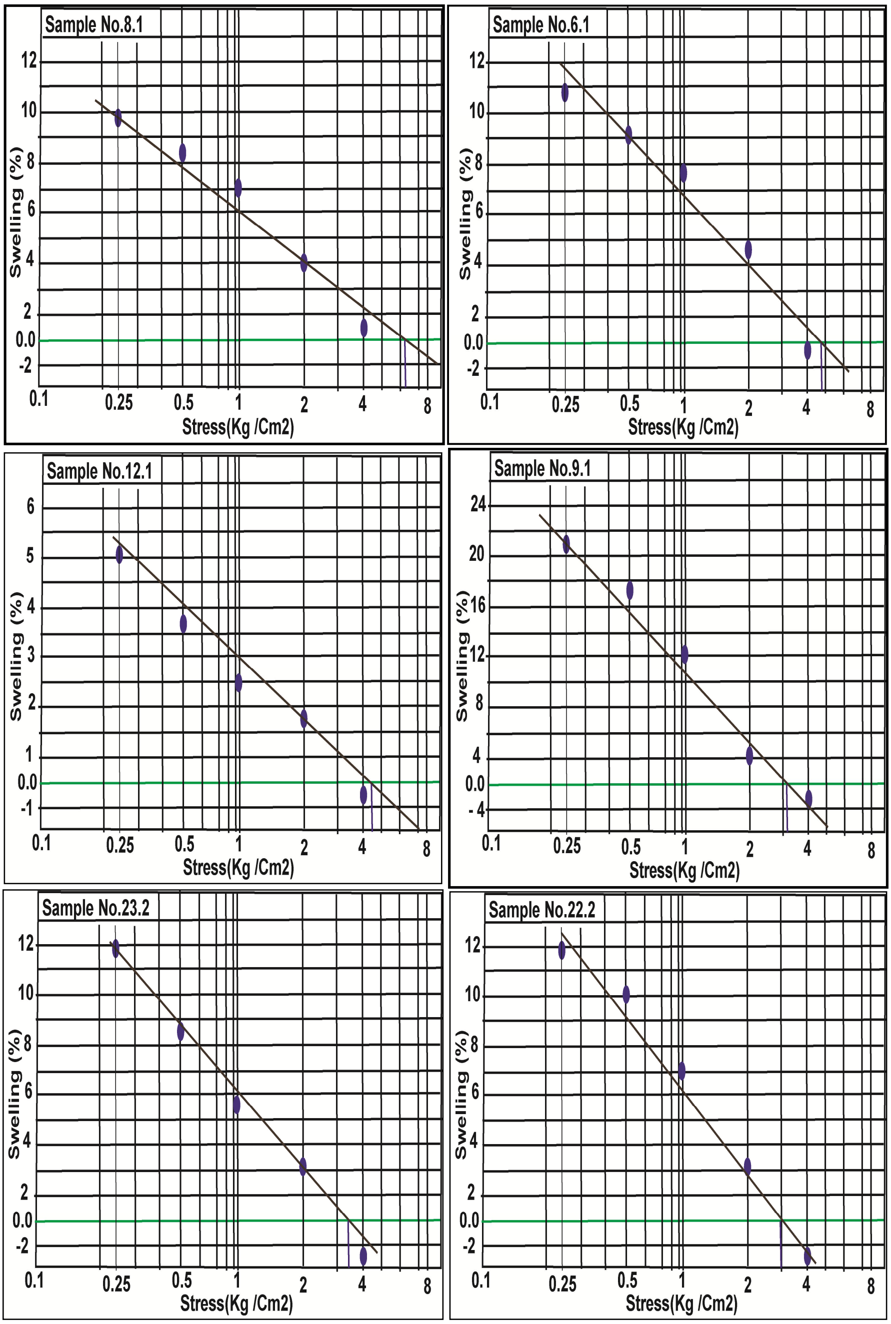

Fig.10: Relationship between swelling percent and applied pressure (samples No. 6.1, 8.1, 9.1, 12.1, 22.1 and 23.2)

The results of swelling pressure differentiated because of clay type, for example sample no. (8.1) by using X-ray analysis the percentage of montomorollonite increase. So the swelling pressure is 6.2 Kg/cm^2. While sample no. (22.2) consists of kaolinite and illite with low montomorollonite .So the swelling pressure is 3 Kg/cm^2.

8. Classification of Engineering Properties of Soil

Approximate assessment of the engineering properties of soils can be obtained from the index properties after appropriate classification is made. From geotechnical or engineering geological point of view, the classification of soil may be done with the objective of finding the suitability of the soil for construction or foundations.

By using plasticity chart according to **Casagrand´s (1948*)*** (Fig.11) shows the claystone of study area can be classified as inorganic clay of high and extremely high plastic soil.

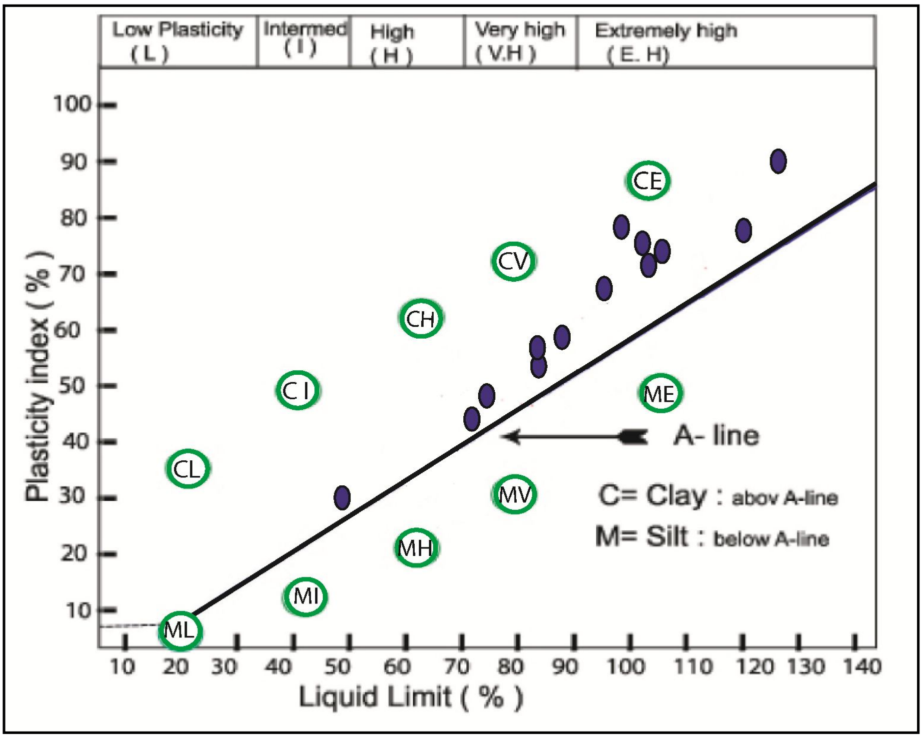

Fig.11. Shows that, the claystones of study area can be classified as inorganic clay of very high to extremely high plastic soil

Recommendations

Potentially expansive soils were identified in the studied area in many places. Hence, care should be taken in constructing civil engineering structures on such type of soils. Moreover, expansive soils in the City were found to cause failure of roads and buildings. Expansive soils are difficult to use in the construction of highway, lightweight structures, construction of subsurface drainage by concrete pipes, etc due to their swelling nature. Hence, removing part of the expansive soil or lowering the foundation deeper than normally used for stable soils is recommended. Further, detailed study on expansive soils and engineering properties, like swelling potential, consolidation characteristics, rock mass properties, are also recommended.

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