Engineering aspects and associated problems of flood plain deposits in Sohag Governorate, Upper Egypt

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Abstract: The flood plain sediments occurred on both sides of the River Nile course which are dominated by alluvial sediments. Signs of deterioration have been seen which characterized by cracking of the superstructures. This due to low bearing capacity, ground settlement and shrinkage and swelling of these soils. The sediments of the floodplain were accumulated during the annual inundation of the Nile causing deposition of fine materials before the construction of the High Dam. Five types of clay minerals were identified throughout the studied sequence, namely smectite and kaolinite were the predominant clay minerals present in all samples, mixed layer (smectite-illite), chlorite and illite. In general, for each unit the SPT "N" values increase downwards with depth. The high C_C values of the studied clayey soil (A-Unit) is ranged between 0.24 and 0.32, that indicated to the loose and very high compressible nature of this type of soil. The geotechnical associated problems of the River Nile flood plain sediments area: the low bearing capacity of the sediments, ground settlement and Shrinkage and swelling.

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Keywords: Geotechnical problems; Standard penetration test (SPT); Undrained shear strength (S_U); Coefficient of compressibility (Co); Nile flood plain sediments; Clay minerals.

1. Introduction

Urban areas in Egypt occupy about 5 % of the territory and they are concentrated along the River Nile between Aswan and the Delta. The flood plain sediments occurred on both sides of the River Nile course which are dominated by muddy sediments in the upper most part. The average thickness of these mud deposits is 10 m between Aswan and Cairo.

Sohag is criss-crossed by a River Nile and most of the Nile Valley of the country is covered by of alluvial sediments. Due to insufficient accommodation for the increasing population. During the last three decades, a large numbers of structures include homes, schools, and offices in Sohag Governorate were built on soft alluvial soil of Nile flood plain sediments. Signs of deterioration have been seen which characterized by cracking of the superstructures. This due to low bearing capacity, ground settlement and shrinkage and swelling of these soils.

The suitability of soils for engineering purposes depends largely on their ability to remain in place and to support whatever loads may be placed upon them either by a permanent structure or transient loads. The civil engineer should be informed among other data of the quantity and type of clay minerals that are present and of their properties in order to evaluate their potential influence on the engineering project. Therefore, it is very important to determine the main geotechnical properties of these soil samples. When civil engineering projects are based on limited site geological conditions, geotechnical problems frequently arise and the work suffers cost increases and delays. To reduce such problems, investigation is recommended to correctly characterize the site and define land units with similar behaviour (Anonymous, 1972, 1976). This information allows the engineering geologist or the geotechnical engineer to develop a conceptual geological model (Fookes, 1997), useful to the site-specific project or to others in the same geological terrain. This model helps to understand site geological conditions, to identify the main geological problems, and to make realistic estimates of material properties.

This paper represents a comprehensive assessment of ground conditions and soil characteristics as well as causes of particular problems

2. Geological setting

From a geologic point of view, Sohag Governorate situated in the Upper Egypt occupying a major section (about 125 km long) from the Nile Valley with an average width varying from 16 to 20 km. Egyptian Nile Valley, where the Nile soil extended along the two banks of the River Nile for about 10 km. Sohag is located 467 km south of Cairo. To the east it is bounded by the Red-Sea Governorate and the Eastern desert and to the west by the New Valley Governorate and the Western desert (Fig. 1). It occupies a region including both the floodplain and the desert fringes between longitudes 31o 15' and 32o 15'E and latitudes 26o 00' and 27o 00'N. It is occupying a major section (about 125 km long) from the Nile Valley with an average width varying from 16 to 20 km, where the Nile flood plain soil extended along the two banks of the River Nile for about 10 km. Contrarily, it constitutes only a very narrow strip along the eastern side and, moreover, it frequently disappears. Geologically the area has been studied by a variety of authors (e.g. Said, 1975, 1981, 1983, 1990; Issawi et al., 1978; Paulissen and Vermeersch, 1987; Issawi and MC Cauley, 1992; Mahran 1992 and 1993; Omer, 1996; Omer and Issawi, 1998 and Hassan, 2005). The sediments of the floodplain were accumulated during the annual inundation of the Nile causing deposition of fine materials before the construction of the High Dam These sediments are mainly muddy in nature and accumulated during the successive stages of the annual Nile floods for thousands of years till the construction of the High Dam.

3. Geotechnical investigation

3.1. Site soil conditions

The first step of site investigation was to collect undisturbed and disturbed samples of recent alluvial deposits from 0- to 30-m depth by drilling three boreholes extending along Sohag Governorate. The investigation sites from north to south are: Tema City (site I), Sohag City (site II) and Gerga City (site III), Theses samples were tested in the field and in laboratory to determine the index engineering properties. A subsurface profile is shown in Fig. (2). It is noted that the proportion of gravels and sands are increase downward at the expense of the proportion of silts and clays.

The alluvial deposits in the studied boreholes can be subdivide lithologically and geotechnically into three distinctive subunits (A, B and C). The soil sequences together with their Unified Soil Classification are given below:

Unit A (floodplain deposits): Inorganic clays of low to medium plasticity, sandy/silty/lean clays (CL): The top soil sequence is predominantly composed of sandy silt varying from one meter to 12 m in thickness especially in site III. This soil sequence is characterized by a low standard penetration test (SPT) resistance indicating a loose condition (Table 1). A floodplain is the low-lying, generally flat area adjacent to a River Nile channel which has been deposited during many thousands of years when river discharge exceeds the capacity of the channel, water rises over the channel banks and floods the surrounding low-lying lands. The average rate of sediment accumulation was about 9cm per century (Ball, 1939). Also, This type of soil are highly porous and permeable (El-Haddad and El-Shater, 1988).

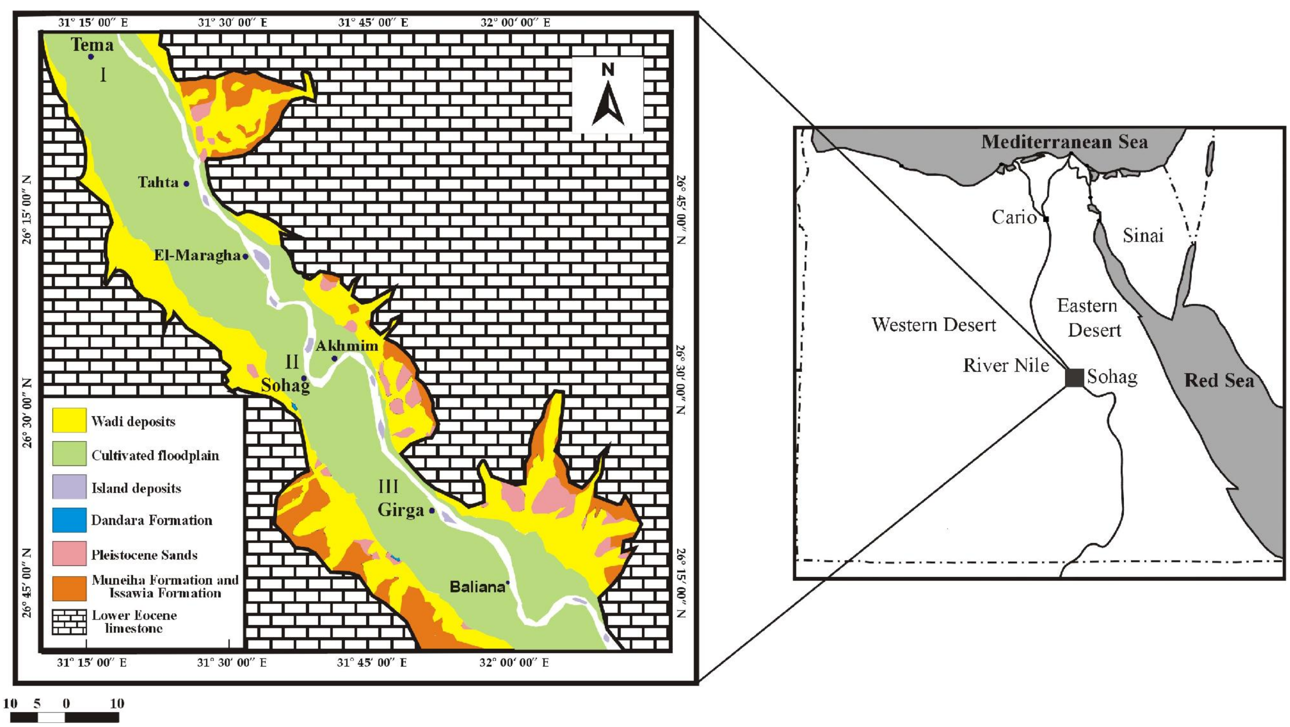

Fig. 1: Geological map of Sohag Governorate, Upper Egypt

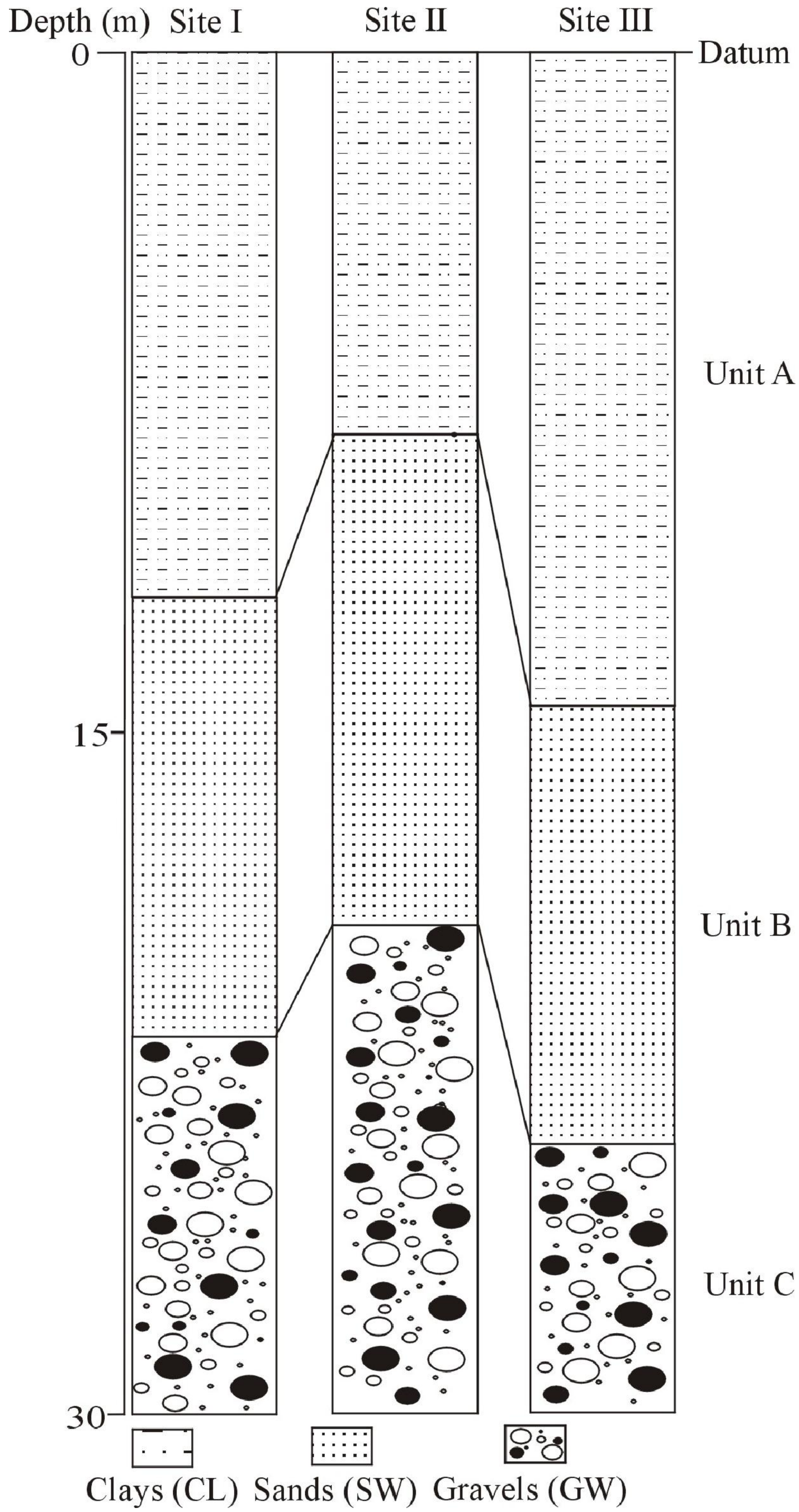

Fig.2: Typical Subsurface profile of the studied sites

Table 1a. Basic geotechnical properties of the Nile Flood Plain sediments.

Age	Depth (m)	Gravel %	Sand %	Silt %	Clay %	LL	PL	PI	Soil Type	SPT (N)	Consistency	Su, (kPa)	CC	Free Swelling	Swell Percent%	Swell Pressure	Smectite	Kaolinite	Mixed laver	Chlorite	Illite
Recent	1	0	25	4	26	4	2	1	CL	3	Soft	15-	0.								
	2	0	26	5	21	4	2	1	""	4	""		0.	6	9.	1.	4	3	1	5.	1.
	3	0	27	5	19	4	2	1	""	5	Mediu	30-	0.								
	4	0.	29	4	22	4	2	1	""	7	""	""	0.								
	5	0.	33	4	21	4	2	1	""	8	Stiff	""	0.	7	10	1.	5	2	1	5.	2.
	6	1.	40	4	17	4	2	1	""	10	""	60-	0.								
	7	1.	41	4	17	4	2	2	""	11	""	""	0.								
	8	1.	42	4	14	4	2	2	""	11	""	""	0.	7	12	2.	5	2	1	5.	2.
	9	2.	42	4	15	4	2	2	""	12	""	""	0.								
	10	3.	45	3	17	4	2	2	""	12	""	""	0.	7	11	1.	5	2	1	5	2
Late Pleistocene	11	1	58	2	6				S	14	""										
	12	1	56	2	9				""	14	""										
	13	1	55	2	6				""	15	""										
	14	1	56	2	6				""	15	""										
	15	1	57	1	7				""	15	""										
	16	1	55	2	8				""	16	Very										
	17	1	58	1	6				""	17	""										
	18	2	61	1	5				""	18	""										
	19	5	42	7	0				G	19	""										
	20	5	39	6	0				""	20	""										
	21	5	39	5	0				""	21	""										
	22	5	40	3	0				""	22	""										
	23	5	39	3	0				""	23	""										
	24	5	40	2	0				""	23	""										
	25	5	39	3	0				""	26	""										
	26	5	40	3	0				""	27	""										
	27	5	38	4	0				""	30	""										
	28	5	40	3	0				""	30	""										
	29	5	38	3	0				""	32	Hard										
	30	6	37	3	0				""	33	""										

Table 1b. Basic geotechnical properties of the Nile Flood Plain sediments.

Age	Depth (m)	Gravel %	Sand %	Silt %	Clay %	LL	PL	PI	Soil Type	SPT (N)	Consistency	Su, (kPa)	CC	Free Swelling	Swell Percent%	Swell Pressure	Smectite	Kaolinite	Mixed laver	Chlorite	Illite
Recent	1	0	1	6	20	3	2	1	CL	3	Soft	15-	0.								
	2	0	1	6	18	3	`	1	""	3	""	""	0.	7	10	1.	5	2	1	7.	1.
	3	0	2	5	17	3	2	1	""	4	""	""	0.								
	4	0	2	5	15	3	2	1	""	5	Mediu	30-	0.								
	5	0.	3	5	15	3	2	1	""	6	""	""	0.	7	13	2.	5	2	1	6.	1.
	6	0.	3	3	23	3	1	1	""	7	""	""	0.								
	7	1.	4	3	21	3	2	1	""	9	Stiff	60-	0.	7	10	1.	5	3	1	7	3
Lat	8	4.	5	2	14				S	10	""										
	9	6	5	2	17				""	11	""										

	10	5.	5	2	16				""	12	""
	11	7	5	2	16				""	13	""
	12	8	5	1	15				""	14	""
	13	9	6	1	13				""	14	""
	14	10	6	1	11				""	14	""
	15	11	6	1	10				""	15	""
	16	12	6	1	5.				""	15	""
	17	51	4	5	0				G	18	Very
	18	54	4	5	0				""	18	""
	19	55	4	4	0				""	22	""
	20	61	3	5	0				""	22	""
	21	62	3	6	0				""	22	""
	22	59	3	4	0				""	25	""
	23	60	3	4	0				""	26	""
	24	61	3	3	0				""	26	""
	25	62	3	3	0				""	27	""
	26	60	3	3	0				""	27	""
	27	61	3	4	0				""	29	""
	28	59	3	4	0				""	30	""
	29	57	3	5	0				""	32	Hard
	30	56	4	3	0				""	33	""

Table 1c. Basic geotechnical properties of the Nile Flood Plain sediments.

Age	Depth (m)	Gravel %	Sand %	Silt %	Clay %	LL	PL	PI	Soil Type	SPT (N)	Consistency	Su, (kPa)	CC	Free Swelling	Swell Percent%	Swell Pressure	Smectite	Kaolinite	Mixed layer	Chlorite	Illite
Recent	1	0	2	5	23	4	2	1	CL	3	Soft	15-	0.								
	2	0	2	5	20	3	2	1	""	4	""	""	0.								
	3	0	2	5	15	3	2	1	""	4	""	""	0.	6	10	1.	4	2	1	9	2
	4	0	2	5	14	4	2	2	""	5	Mediu	30-	0.								
	5	0	2	5	15	3	2	1	""	6	""	""	0.								
	6	0	2	5	16	3	2	1	""	6	""	""	0.								
	7	0.	2	5	19	4	2	2	""	6	Stiff	60-	0.	7	11	1.	5	2	1	7.	2.
	8	0.	3	5	14	4	2	2	""	7	""	""	0.								
	9	0.	3	5	14	3	2	1	""	7	""	""	0.								
	10	1.	3	5	13	4	2	1	""	8	""	""	0.								
	11	1.	3	5	11	4	2	2	""	8	""	""	0.	7	13	2.	5	2	1	6.	2
	12	1.	3	4	16	3	2	1	""	9	""	""	0.								
Late Pleistocene	13	1	5	2	5				S	12	""										
	14	1	5	2	8				""	14	""										
	15	1	5	1	9				""	15	""										
	16	1	5	1	8				""	16	""										
	17	1	5	1	8				""	15	""										
	18	1	5	2	7				""	17	Very										
	19	1	5	2	6				""	17	""										
	20	2	4	2	7				""	17	""										
	21	5	3	1	0				G	19	""										
	22	5	3	1	0				""	21	""										

	23	6	2	9	0	""	22	""
	24	6	2	7	0	""	26	""
	25	6	3	6	0	""	26	""
	26	6	3	5	0	""	28	""
	27	5	3	6	0	""	29	""
	28	5	3	5	0	""	30	""
	29	5	4	3	0	""	32	Hard
	30	5	4	4	0	""	33	""

Unit B (channel sands); Well-graded sand (SW): This zone is predominantly well-graded sands of channel sediments. The SPT 'N' values range from 10 to over 18 showing a general increasing downwards (Table 1). The shape of the grain size distribution curve of this type is considered "smooth.", C_U value > 6, C_C value from 1 to 3 is required (Fig. 3).

Similarly, unit C (channel gravels): Well-graded gravel (GW): This zone is predominantly well-graded gravels. The SPT 'N' values range from 18 to over 33 showing a general increasing downward (Table 1). The shape of the grain size distribution curve of this type is considered "smooth.", C_U value > 6, C_C value from 1 to 3 is required (Fig. 3).

The channel sands and gravels of Pleistocene age generally friable and highly porous and permeable. They represent the main aquifer which yields large quantities of groundwater in the Nile Valley. It has an average thickness of 150 m in Sohag area (Abdel-Moneim, 1992).

3.2. X-ray diffraction (XRD)

The XRD test was done on ten representative samples were chosen for mineralogical investigation from the three selected sites. Each sample was examined in three forms: as an oriented clay sample (untreated); as an oriented clay sample treated with ethylene glycol; and as an oriented clay sample heated to 550°C for 2h. The clay particle sizes in the samples were <2µm. The identification of the clay minerals was based on the basal reflections (001), according to the X-ray powder diffraction results of Weaver (1958 and 1967), Carrol (1970), Millot (1970), Chen (1977) and the ASTM cards. Five types of clay minerals were identified throughout the studied sequence, namely smectite and kaolinite were the predominant clay minerals present in all samples, mixed layer (smectite-illite), chlorite and illite (Table 1, Fig. 4). These results were agreed with a number of studies have previously been made on clay fractions in the alluvial soils of Egypt (Hamdi et. al., 1968; Abdel-Kader and Abdel-Hamid, 1974 and Hanna and Beckmann, 1975). According to these investigations, the dominant minerals in the clay fraction as a whole are smectite, kaolinite, and illite. They (op. cit.) found the mineralogical composition of the clay fractions is nearly the same.

3.3. Standard penetration test (SPT-N) and undrained shear strength (SU)

Engineering properties can be determined by means of tests carried out in the field and laboratory. In order to avoid certain difficulties during sampling processes in coarse-grained soils and the disturbance of the sampling in fine-grained soils, in situ tests are frequently used. The standard penetration test (SPT) is used for soil exploration in geotechnical applications and foundation design (Sivrikaya and Toǧrol, 2006). The SPT has the advantages with the easiness of the test procedure and the simplicity of the equipment employed. This test is the most commonly used penetration test in Egypt. In geotechnical engineering, the engineering properties of soil layers must be known down to the required depths. The SPT is widely used around the world. The SPT test is carried out in various types of soils ranging from soft clay and loose sand to very stiff clay and dense sand. It is possible to estimate the undrained shear strength of fine-grained soils from SPT data.

SPT "N" values, are used to calculate important engineering properties of soils such as the internal friction angle (ϕ′), relative density (Dr), and bearing capacity and settlement of coarse grained soils (Schmertmann and Palacios, 1979; Kovacs *et al*., 1981; Farrar *et al.*, 1998). The undrained compressive strength (qu) is an important characteristic for fine-grained soils and it gives an idea about their consistency. In addition, it is used to estimate both the undrained shear strength (Su) and the sensitivity of clays (Sivrikaya and Toǧrol, 2006).

The SU-values based on the SPT "N" values and the consistency of the studied samples were calculated according to Tschebotarioff (1973) as shown in Table (1). The SPT "N" values range between 3 and 12 in the case of clayey soil (Unit A) that indicating a loose condition. SPT "N" values vary from 10 to 18 in the case of well graded sand soil (Unit B) and ranged from 18 to 33 in case of well graded gravels (Unit C).

In general, for each unit the SPT "N" values increase downwards with depth.

3.4. Compressibility characteristics of clayey soil

The compressibility of a soil is conditioned by the capacity of the soil voids to decrease in volume under a pressure. It is also assumed that the pore volume decrease due to a large degree of packing of soil grains. Settlement is the most common reason for failure of foundation and it is therefore of great importance to understand the mechanics of settlement. Compressibility of clayey soils is due to mechanical (deformation, reorientation and sliding of particles or domains with respect to one another, expulsion of pore fluid etc.) and physicochemical factors. Physicochemical factors may play dominant role in the compressibility of clayey soils depending on the clay mineral composition and the type of exchangeable cations present in the exchange complex (Blot 1956; Olson and Mesri 1970; Mitchell 1993).

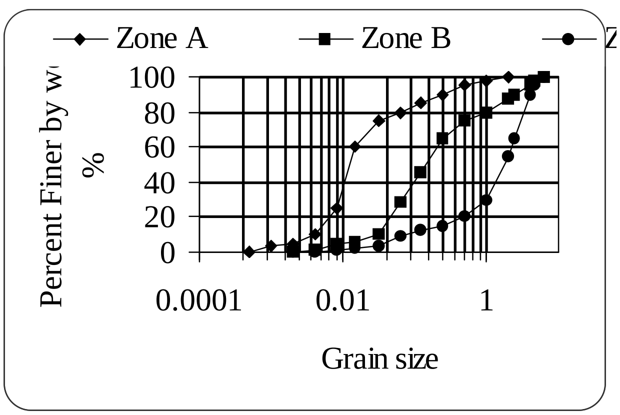

Fig. 3: Grain-size distribution curves for studied sediments.

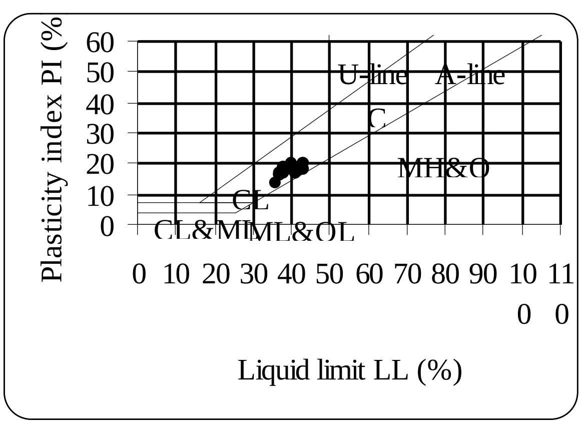

Fig. 4: XRD chart of clay minerals of unit A sediments.

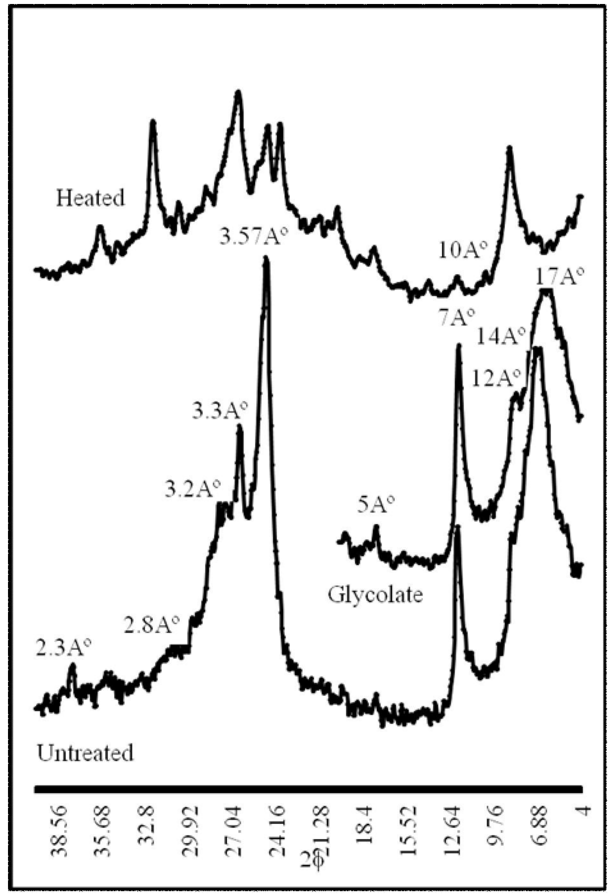

Fig. 5: Swelling potential classification of unit A sediments.

Plasticity and compressibility are typical properties of clays. Atterberg's limits of a clayey soil reflect the clay content and clay type of a soil. Compression index is also a clay dependent parameter. Among different correlations between the engineering and index properties of soils, which are often used to lessen the work load of a soil investigation program, Skempton's relationship (1944) between compression index (CC) and liquid limit (wL) given as Cc=0.009 (wL-10). The CC values were calculated using the Skempton (1944) formula: Co=0.009 (LL-10). The high CC values of the studied clayey soil (A-Unit) is ranged between 0.24 and 0.32 (Table 1, Fig. 5), that indicated to the loose and very high compressible nature of this type of soil (Maslov, 1987)

4. Geotechnical associated problems

Many parts of the world suffer from constructing problems that associated with flood plain clay soils. These problems include, ground settlement, low bearing capacity and swelling. These problems which greatly affect the safe and economic land utilization of the plains.

Alluvial deposits are generally granular and present favorable conditions, however, development activities in Egypt on these deposits are encountered with numerous geotechnical problems which greatly affect the safe and economic land utilization of the plains. These geotechnical problems: the low bearing capacity of the sediments, ground settlement and Shrinkage and swelling

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4.1. Bearing capacity of soils

The low bearing capacity of the studied soils is the principal foundation problems in Sohag Governorate which related to the low resistance of the underlying soil to shearing resistance. Low bearing capacity is a problem that mainly affects the clay soil (CL) A-Unit of the flood plain sediments. Building foundations on these soils in this area must take into account the low shear strength of sediments and accordingly there are two frequently-used solutions. For low rise buildings, the most commonly used is a raft foundation, 1 or 1.5m deep and 60 to 80 cm thick. This type of foundation has the advantage of better support for differential ground settlement. Because the flood plain sediments are heterogeneous, geotechnical properties vary greatly over a short distance. In practice, various types of shallow foundations such as pad, strip and compensating types are used for light structures with pressures ranging from 25 to 40 kPa at depths between 1.5 and 3.0 m (Delgado, *et. al*., 2003).

The soil top layer (A) is unsuitable soil for carrying spread foundations safely. Soil improvement techniques are suggested. If these methods prove to be more economic than using deep foundations, they will be adopted:

1-It is economic to remove this layer and replace it with compacted sand or gravel.

2-Soil improvement techniques include compaction, deep compaction, preloading accompanied by sand drains, use of stone columns, injections, and concrete piles. Selection of the suitable methods depends on economy and nature of project.

4.2. Ground settlement

Ground settlement constitutes the principal geotechnical difficulty of the fine grained flood plain sediments. This problem is associated with fine sediments because the compressibility of sands and gravels is generally low (Smith and Smith, 1998). Settlement is particularly important in the flood plain sediments. Settlement is another major foundation problem in Sohag Governorate related to the loose and compressible nature of the surficial soil. The compression index, extracted from the record, ranged between 0.24 and 0.32 (Table 1). That means the surficial clay soil is of loose and very high compressible type (Maslov, 1987).

Structural settlement in the Sohag Governorate varies from a few centimeters to more than 50cm. Where, loading is high, deep foundations are usually used to reduce settlement. Another solution is ground improvement by vibro-replacement (gravel columns) of the ground to a depth of up to 10–15 m (Delgado, *et. al.*, 2003).

4.3. Shrinkage and swelling

Shrinkage and swelling are well-known phenomena causing damage to building foundations, roads, aircraft runways, underground service lines, etc. It is caused by a deficiency or excess of water (Youssef *et al*., 1957; Popesco, 1980). Shrinkage and swelling soils are often characterized by high LL and PI caused by a variable content of more active clay minerals. Plasticity values of the studied soils are given in Table 1. The data are not strictly comparable because they are collected at different sites.

Undisturbed representative samples were chosen (Table 1), to determine swelling pressure as well as swelling percent using oedometer test. The Swelling pressure of the studied fine-grained soil of flood plain sediments varies from 1.8 to 2.4 kg/cm^2 (medium expansion, Chen, 1975). The free swell test was carried out typically as described by Holtz and Gibbs (1956), the free swell values of the studied samples ranged between 65 and 70% (Table 1). Ranganatham and Satyanarayana (1965) (quoted by Derriche *et. al.*, 1998) used plasticity index (PI) as classification indicator, PI-values of the studied clayey soil ranged from 14 to 20 (low swelling potential). Swelling measurements values are indicative of the low-medium swelling potential. For light structures, this can cause excessive uplift pressure inflicting damage. The problem of swelling can be handled, among others, by designing structures sufficiently rigid or flexible to accommodate the anticipated movement. Therefore, footings, piers, foundations, etc. should be placed at sufficient depths. It is common to place compacted sand (or sand and gravel or pit run gravel) cushion as buffer flexible layer between the foundation and the swelling clay.

9. Summary and Recommendations

This work can be considered as a simple geotechnical model of the Nile flood plain sediments in Upper Egypt. Thus, the following four points are of special interest and should be connected with the future projects.

(1) The geological features of the Nile flood plain soil in Sohag Governorate, Upper Egypt, had a great influence on the evolution of ground conditions and soil properties.

(2) Soil test data from the development projects cover almost the entire Nile flood plain soil in Sohag

Governorate indicate that the subsoil is dominated by sandy clay and sandy materials. A typical subsurface profile shows that the cover has a variable thickness comprising soft fine-grained cohesive soils graded down ward into well-graded sandy soil. There are broad similarities with respect to the textural composition over large distances..

(3) Sohag Governorate especially in flood plain region has encountered numerous specific construction problems because of its unique sedimentation history. The top most soils are too weak to support heavy foundations.

(4) A sufficient safety factor must be done in the design of any construction founded on this soil type.

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