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Original Article

Integration of Geophysical and Geotechnical Methods to Detect the Problematic Soil at Beit Al-Watan, New Cairo City, Egypt

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Abstract

Most soil formations in arid areas contain problematic soil that may cause construction failure. This research uses geoelectrical resistivity method and geotechnical investigations for Beit Al-Watan area, New Cairo, Egypt For soil detection. Geoelectric investigation has been carried out to determine sub surface lithology in the studied area and hence tracing the distribution of the clay. Then, the boreholes have been drilled nearest to clay location and soil samples have been taken to determine their engineering properties. The vertical electrical sounding (VES) results indicated that the first surface resistivity layer consists of wadi deposits and has resistivity values ranging from 110 to 474.7 Ω.m and has average thickness of 1.5 m. The second geoelectric layer has resistivity values ranging from 31.9 to 842.7 Ω.m and average thickness of 5 m, while the third layer has resistivity values between 67.4 and 454.1 Ω.m and average thickness of 14.4 m, and the fourth layer has resistivity values between 55.4 and 652 Ω.m and its average thickness is 25.2 m. The engineering investigation results reveal that the soil compressive strength has ranged between 1.85 and >4 kg/cm^2. The average of liquid limit is 76.8%, the average of plastic limit is 26% and the average of plasticity index is 48.5%. The results of free swell are ranged from 30% to 258% with an average 144%. The study indicates that the clay found at shallow depths and small thickness at southern part, whereas it is deeper and thicker at the northwestern part of the area. Since this soil has high swelling, it must be treated by removing 1.5 meters in thickness and is replaced by suitable materials such as layers of clean graded siliceous sand.

1. Introduction

The construction above any problematic soil is one of the main reasons for cracks or collapsing of buildings due to its exposure to the uplifting force resulting in swelling of this soil. It is known that, the neglection of study of soil properties will cause serious problems to the construction. The present paper employs both of the geoelectric resistivity sounding and engineering investigation in the Beit Al-Watan area to achieve the greatest benefit of the study in order to avoid structural failure. The study area is located at the Northeastern Part of New Cairo City, Egypt. It covers an area about 40.8 km^2 and lies between latitudes 30^o 06′ 14.628″ and 30^o 01′ 30.15″ North and longitudes 31^o 32′ 14.935″ and 31^o 36′ 46.319″ East. It is easily reached to the area of study through the Cairo Suez road which bounded it from the north. It is also bounded by Al-Rehab city from the west and both of Madinaty and middle ring road from the east (Figure 1).

The main objective of the present study is using the resistivity measurements and engineering tests of soil to delineate the layers that make construction problems such as clay beds. This research includes both field and laboratory work to achieve effective benefits in construction projects. Field tests aim to detect the distribution of the clay bed within the area and delineate its depth from the surface. Then laboratory tests are

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carried out by doing a set of engineering tests for this clay layer to determine its engineering properties and hence to know its impact on the buildings.

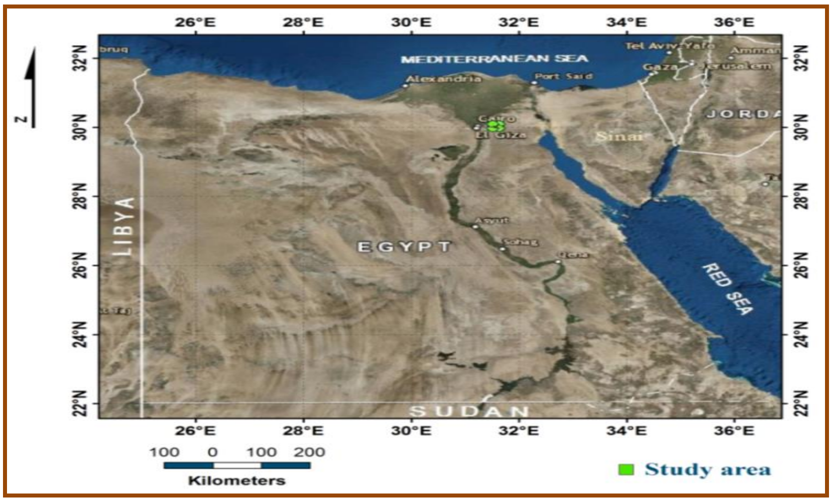

Fig. 1: Location map of the study area

2. Geologic Setting

The study area is covered by sedimentary succession from Eocene to Miocene age as shown in the geologic map (Figure 2). The lithology of the study area is described from bottom to top as follows:

Eocene Rocks which consist of two formations from bottom to top 1): Maadi Formation which is composed of three units from bottom to top; a) sandy limestone and marl. b) sands, shales and marls. c) sandy limestone and 2): Anqabia Formation which is subdivided into El-Nassuri beds 13 m thick of sandstones grading upwards into sandy limestone and Anqabia beds 65 m thick of limestone and shale.

Oligocene Rocks which are represented by the Cairo Facies (Gebel Ahmar Formation) of sand and gravels sediments and volcanic basaltic sheets.

Miocene Rocks which consist of Marine Miocene (Hommath Formation) made up of fossiliferous calcareous sandstone and arenaceous limestone and Non-Marine Miocene (Hagul Formation) of coarse grained sands intercalated by gravels beds and fossil wood **(**Swedan, 1991**).**

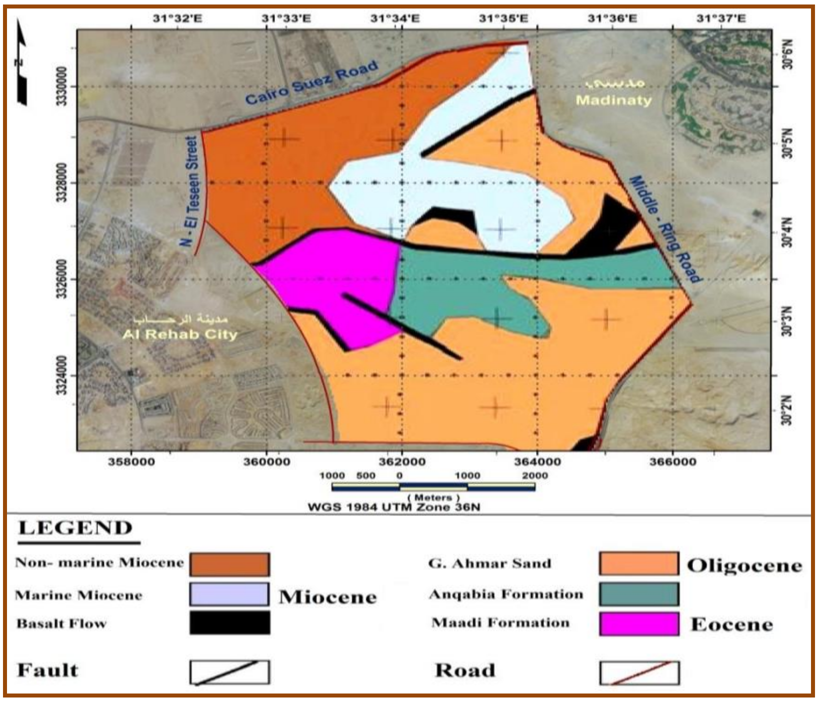

Fig. 2: Geological map of the study area modified after **(**Swedan, 1991**).**

3. Results and Discussion

3.1 Geophysical investigation:

The major problem facing the construction in desert areas is the subsurface conditions of layers. Geophysical surveys are playing an important role in civil engineering projects in defining the subsurface conditions. Electrical resistivity survey is extensively used in construction in order to detect underground conditions prior to the drilling of engineering boreholes within the site. In the current research, the vertical distribution of the resistivity layers within the study area were examined by the procedure of vertical electrical resistivity soundings (VES) using Schlumberger array. The current electrode spacing (AB/2) ranges between 1m as minimum to 200 m as maximum. The distance between the current electrodes is sufficient to detect the required depths from an engineering point of view. Twenty electric resistivity soundings stations were carried out in the study area (figure 3).

The field data of the geoelctric soundings were interpreted to identify the subsurface succession for the geoelectric layers in the study area. The results of the electrical VES's in term of resistivity, thickness and depth are summarized in table 1. They indicated that; the first surface resistivity layer consisting of wadi deposits has resistivity values ranging from 110 to 474.7 Ω.m with average thickness 1.5 m. The resistivity of the second geoelectric layer ranges from 31.9 to 842.7 Ω.m with average thickness of 5 m, while the third layer has resistivity values between 67.4 and 454.1 Ω.m and average thickness of 14.4 m, and finally the fourth layer has resistivity values ranging from 55.4 to 652 Ω.m and average thickness 25.2 m.

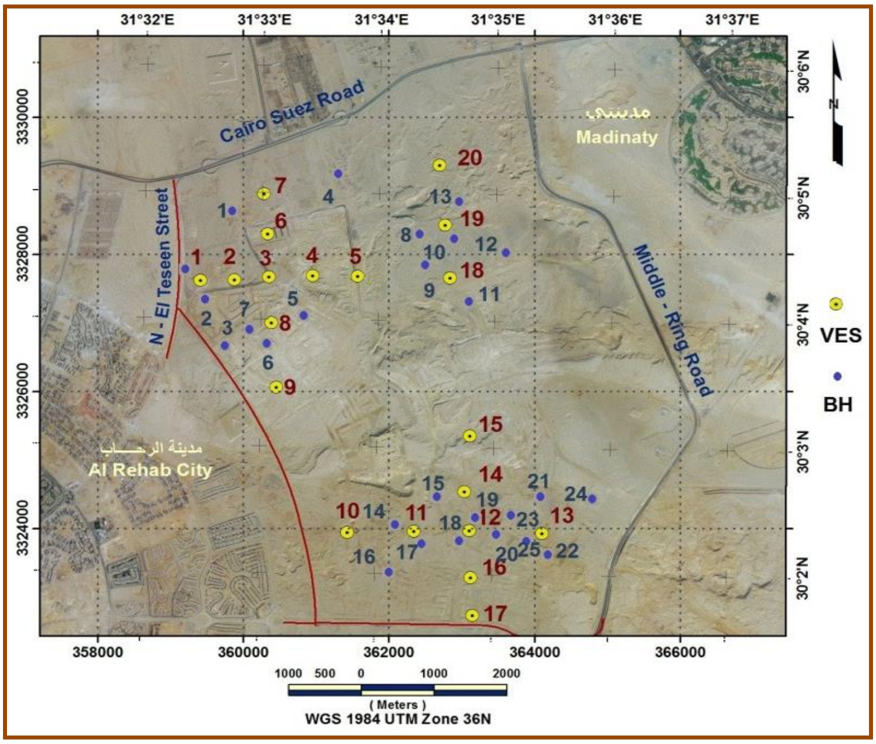

Fig. 3: Location map of VES and Bore holes (BH).

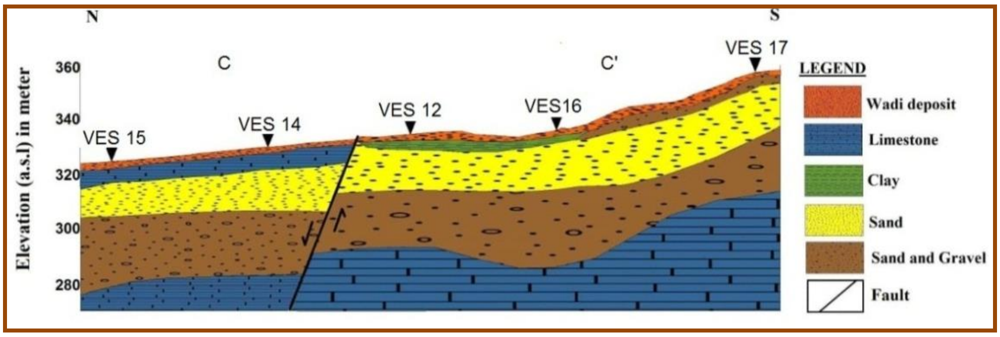

Fig. 4: Illustrate Geoelectric Cross Section C-C'.

Four geoelectric cross-sections have been carried out to illustrate the vertical and horizontal variations of the different geoelectric layers in the study area. Selective example is given in figure 4 representing cross section C-C'. This geoelectric cross section extends through VES's 15, 14, 12, 16 and 17 trending north south direction. It reflects the presence of five layers as follow; wadi deposit, limestone, clay, sand and sand and gravel. Structurally, normal fault might be found at the central part of this section.

Table 1: Interpreted Results of the Geoelectric Soundings (Resistivity (ρ), Depth and Corresponding Thickness (h) of Different Geoelectric Layers).

VES No.	Parameters	Geoelectric Layers				
		1	2	3	4	5
VES 1	ρ (Ohm. m)	286.7	226.7	67.8	613.5	366.6
	h (m)	1	3.8	21.1	22.7	
	d (m)		1	4.8	25.8	48.5
VES 2	ρ (Ohm. m)	456.4	288.9	161.3	55.8	801.0
	h (m)	1.9	8.2	14.1	25.8	
	d (m)		1.9	10.2	24.3	50
VES 3	ρ (Ohm. m)	435.9	387.4	136.6	55.4	818.1
	h (m)	3.9	8.6	12.6	24.1	
	d (m)		3.9	12.5	25.1	49.3
VES 4	ρ (Ohm. m)	110.3	203.6	454.1	77.6	723.6
	h (m)	2.3	7.1	14.4	23.9	
	d (m)		2.3	9.4	23.7	47.6
VES 5	ρ (Ohm. m)	186.3	106.4	429.6	66.7	635.8
	h (m)	2	3.7	15.9	29.8	
	d (m)		2	5.7	20.7	50.5
VES 6	ρ (Ohm. m)	246.2	347.6	178.8	85.5	803.9
	h (m)	1.6	10.2	12.2	26.9	
	d (m)		1.6	11.9	24.1	51
VES 7	ρ (Ohm. m)	474.7	340.4	172.3	60.2	823.1
	h (m)	1.5	10	11.6	24.7	
	d (m)		1.5	11.5	23.1	47.8
VES 8	ρ (Ohm. m)	264.7	203.6	91.1	618.9	415.2
	h (m)	1	4.3	21	25.8	
	d (m)		1	5.3	26.3	52.1
VES 9	ρ (Ohm. m)	385.8	155.3	67.4	652	417.6
	h (m)	0.7	4.3	18.9	27.1	
	d (m)		0.7	5	23.9	51
VES 10	ρ (Ohm. m)	452.5	154.8	441.6	347.3	502.4
	h (m)	2.3	4.5	12.2	29	
	d (m)		2.3	6.8	19	48
VES 11	ρ (Ohm. m)	249.5	44	183.9	333.4	412.7
	h (m)	1.3	2.8	10.6	28	
	d (m)		1.3	4.2	14.8	42.8
VES 12	ρ (Ohm. m)	248.3	47.1	146.2	314	410
	h (m)	1.2	2.9	16.5	21	
	d (m)		1.2	4.1	20.6	41.6
VES 13	ρ (Ohm. m)	426.6	387.8	180.7	271.5	503
	h (m)	1.4	3.3	20.1	24.8	
	d (m)		1.4	4.8	24.9	49.7
VES 14	ρ (Ohm. m)	244.4	406.9	173.2	376.4	522.3
	h (m)	1.6	5.2	15.6	23.7	
	d (m)		1.6	6.8	22.5	46.2
VES 15	ρ (Ohm. m)	256	575.3	196	306.6	580.6
	h (m)	1.6	4.8	14.1	26.1	
	d (m)		1.6	6.4	20.5	46.6
VES 16	ρ (Ohm. m)	364.9	31.9	132.9	362.4	541.2
	h (m)	0.7	2.1	17.5	30	
	d (m)		0.7	2.9	20.3	50.4
VES 17	ρ (Ohm. m)	426.8	293.6	120.9	316	545.4
	h (m)	1	3.9	18.1	23	
	d (m)		1	4.9	23.1	46
VES 18	ρ (Ohm. m)	394.2	791.7	77.9	121.1	371.8
	h (m)	1.1	2.5	11.5	32.8	
	d (m)		1.1	3.5	15.1	47.8
VES 19	ρ (Ohm. m)	252.1	842.7	84.2	149.9	297.3
	h (m)	1.6	4.7	9.5	27.1	
	d (m)		1.6	6.3	15.8	42.9
VES 20	ρ (Ohm. m)	215.5	612.5	86.5	143.4	325.7
	h (m)	1.6	6.8	10.9	29.6	
	d (m)		1.6	8.3	19.3	48.9

Fig. 5: Outcrop of clay bed in the study area.

3.2 Clay layer distribution

The clay layer is considered one of the problematic soils in engineering sense, and therefore it must be considered when dealing with construction purposes, especially if it is located at shallow depths. Figure 5 shows the outcrop of clay bed in the study area. From the VES's results, the clay has resistivity less than or equal to 91.1 Ω.m and its depths have been deduced and represented in figure 6 in the form of contour map. This map illustrates that the clay found at shallow depth with small thickness at the south part of the study area, whereas it is deeper and thicker at the northwestern part of the area.

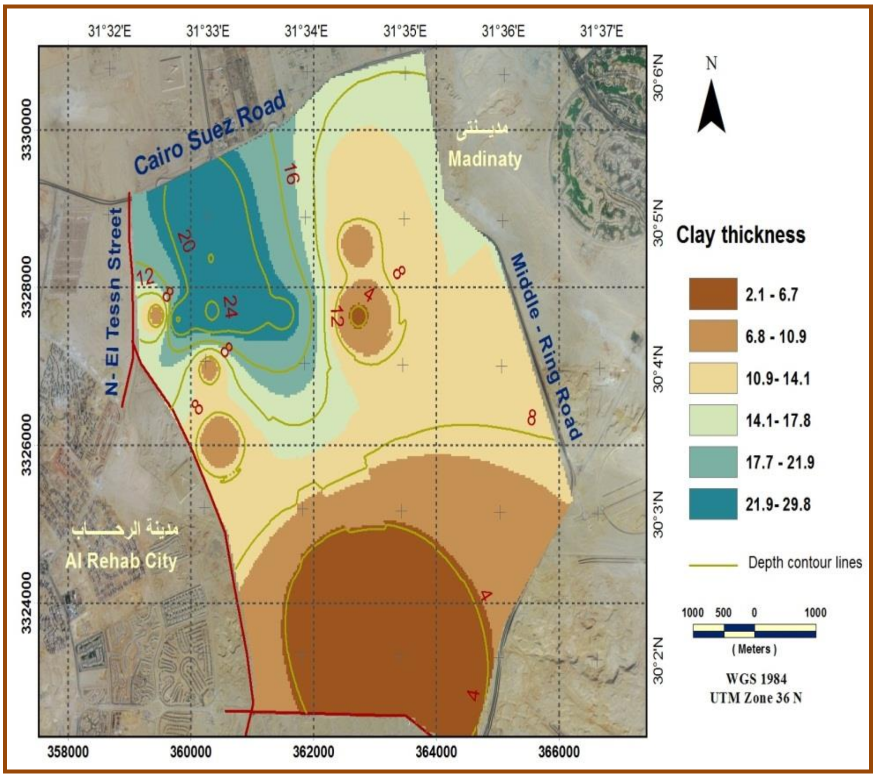

Fig. 6: Clay isopach contours map

3.3 Geotechnical investigation:

The clay layer has been examined by a set of engineering tests such as unconfined compressive strength and the samples have been tested in the laboratory measuring initial moisture content, atterberge limits, and free swell test (Table-2).

1 - Unconfined compressive strength

The unconfined compressive strength is one of routinely test that applied on the saturated clay soil to describe its consistency whether it is soft, medium or stiff. The results of unconfined compressive strength ranged between 1.85 and >4. Based on the Egyptian code for soil mechanic (2001), the consistency of the cohesive soil in the studied area could be described as very stiff or hard except for sample 21 which might be described as stiff.

2- Water content determination:

Natural soils may have different quantities of water. Most laboratory tests in soil mechanics require the determination of water content (Das, 2002). Water content (WC) is the ratio of weight of water in a soil to the weight of soil particles after drying. It has been found that the clay layer has original water content ranged from 17% to 28 %, with an average of 21.4% of water content.

3 -Atterberge limits:

The procedure and the description of this test was discussed by (ASTM, 2005) standard. Atterberg limits are important for giving information about soil classification and also for construction designing. Atterberg limits are categorized as liquid limit and plastic limit. These limits are to ensure that the soil will not change too much in its volume with different moisture contents.

Liquid limit (LL):

It is defined as the smallest moisture content at which the soils are convert from the plastic state to the liquid state. The testing results of clay layer in the study area illustrated liquid limit ranged from 55% to 95 %, with an average of 76.8%.

Plastic limit (PL):

It is the smallest water content at which the soil changes from semi solid state to plastic state. The test of clay shown plastic limit value which varies between 19% and 33 %, the average is 26%.

4- Plasticity index (P.I):

The procedure of this test method has been described by (ASTM, 2005**).** Plasticity index represents the moisture content at which the soil behaves as if in a plastic state. If the plasticity index of a soil was greater it will be the engineering problems associated with using this soil as an engineering material (Bowles, 1984**)**. The results of studied sample indicated that the plasticity index of finegrained soil ranged from 35 to 62 %. Based on **(**Sowers, 1979) specifications limits: the fine soil in the study area is considered as high plastic cohesive clay soil.

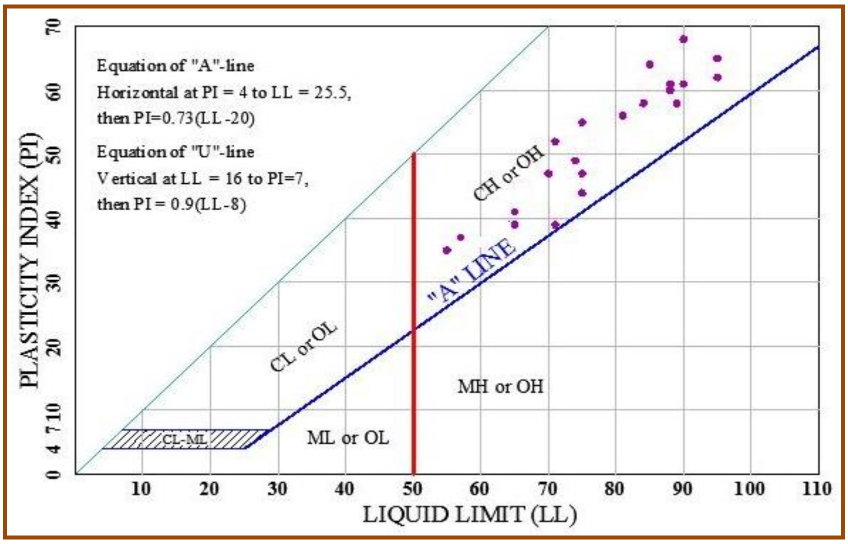

Fig. 7: Classification of fine-grained soil after (Casagrande, 1984)

5- Free swell test:

The swell soil is known as expansive soil, problematic soil or reactive soil. It is composed of high percentages of clay particles. This soil has a low value for shearing in its wet state. The volume of this type of soil increases if it is exposed to an amount of water. According to (Burland, 1990), the volume changes in clay occur as a result of loading and unloading. When a load is applied to a clay soil, its volume is reduced due to a reduction in the void ratio. The results range between 30 to 259 %. The vast majority of these results were more than 50%. Based on the Egyptian code for soil mechanic, great attention must be given when dealing with this soil.

6- Unified soil classification system of fine soil for engineering purpose

Based on the previously mentioned Atterberg limits, the liquid limits versus plasticity indexes are plotted on the plasticity chart (Figure 5). In this chart, the A-line chart separates between inorganic silt and clay soil. Hence, the plasticity charts according to (Casagrande, 1984) show that, the clay in the studied area could be classified as inorganic clay with high and very high plasticity.

Table -2: Engineering properties of clay layer within study area

BH. No.	Depth (m)	W.C %	Atterberge limits		(P.I) %	qu (Kg/cm^2)	Free Swell %
			(L.L) %	(P.L)%			
1	7	23	90	29	61	>4	…..
2	3	20	95	33	62	>4	241
3	7	22	88	27	61	>4	….
4	6	25	75	31	44	>4	…
5	7	22	75	20	55	3.1	94
6	4	18	71	19	52	>4	….
7	9	23	81	25	56	>4	…..
8	5	21	65	26	39	3.4	…..
9	2	21	70	23	47	>4	151
10	5	18	89	31	58	>4	219
11	7	25	88	28	60	>4	…..
12	6	20	95	33	62	>4	259
13	7	27	72	25	47	>4	….
14	8	22	95	30	65	>4	100
15	8	24	71	32	39	2.5	110
16	4	19	85	21	64	>4	80
17	3	20	90	22	68	>4	110
18	7	28	74	25	49	3	70
19	3	17	55	20	35	2.5	30
20	5	22	84	26	58	>4	130
21	10	21	65	24	41	1.85	30
22	3	18	71	30	41	2.75	60
23	20	22	75	28	47	>4	120
24	17	21	57	20	37	3.2	50
25	18	22	66	21	45	>4	100

Conclusion

The combination of geophysical and geotechnical measurements in construction projects becomes indispensable, they complement each other in the detection of problems. The geophysical exploration helped the determination and the distribution of clay layers within the study area, while the geotechnical investigation important to know its engineering properties. The results have shown that the clay is found at shallow depths and small thickness at southern part of the study area, whereas it is deeper and thicker at the northwestern part of the area. The fine soil in the studied area is considered high plastic cohesive clay soil its consistency in most of the study area can be described as very stiff or hard. Since this soil has high swelling, attention must be given during construction above this soils type.

Recommendations

The fine grained soil in the studied area has a high swelling percent and is classified as inorganic clay with high and very high plasticity. In soil mechanics sense, this type of soil is considered one of the problematic soils and represents a risk zone that may cause construction failure. At shallow depths, this soil must be treated by removing 1.5 meters in thickness and is replaced by suitable materials such as layers of clean graded siliceous sand with fines content not more than 10% and plasticity index of less than 4. The new suitable soil, that has been used to refill layers, must be compacted to achieve standard requirements. The thickness of each layer after compaction shouldn't exceed 0.25 m.

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