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Geotechnical Evaluation of Soil for the Suitability of Urban Planning Purposes, Western Bitter Lakes, Suez Canal Region, Egypt

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ABSTRACT

The Bitter Lakes area locates between latitude 30° 00′ N to 30° 30′ N and longitude 31° 45′ E to 32° 25′ E, and covers an area of about 1900km^2. The current study aims at evaluating the geotechnical suitability of lands for urban planning within the study area. Hence, a complete laboratory and in-situ testing programming are carried out. Based on the geological and physiographic nature of the terrane, the study area, is subdivided into three zones; these are the northern plain, the coastal plain of the Bitter Lakes, and the southern plain encompassing Cairo-Suez desert road. The general subsurface soil sequence at the northern plain includes intercalation of poorly graded sand to silty sand and sandy fat clay. The sandy soil and silty sand (types A: 1a, A:1b and A:2) are considered excellent to good as subgrades. The friction angle (ϕ:34.32° - 41.4°) and shear strength (6.93 - 7.6psi) which have higher values, comparable to dense sand. The fat clay (kaolinite) soils have very high swelling potential. For pavement and construction purposes, this clay layer has bad geotechnical behavior, so it must be removed or fixed using Boring piles to depth enough to penetrate this layer. The general subsurface soil sequence at the coastal plain of Bitter Lakes includes intercalation of poorly graded sand and sandy fat clay. The poorly graded sand soil (type A:3) which is excellent to good as subgrade. The clay layer (CH) (Montmorillonite) (type A:7-6) has very high swelling potential; indicating a collapsible soil (ϕ:is 17.35 and q_u is 2.660psi). The general subsurface soil sequence at the southern plain includes intercalation of poorly graded silty sand, sandy silt, sandy fat clay, silty sand, and well graded sand. The sandy silt layer has a slight to medium plasticity, which is non-collapsible soil. High compressive shear strength (6.575psi -8.42psi). The clay layer has low to high plasticity (kaolinite) and very high swelling potential. Based on the admitted California Bearing Ratio (CBR) values (sub-base: 30%, and base: 80%) at the three zones, the top sandy layer is neither suitable for base nor sub-base course. Also, according to soil texture analysis, interpretation of RapidEye satellite images, published soil maps of the study area, and field check, the most suitable and moderately suitable areas for urban purposes are localized at the northern plain. In addition to sporadic areas distributed along the coastal plain of the Bitter Lakes, as well as the central part of the study area.

Keywords: Bitter Lakes; Geotechnical evaluation; Soil suitability; Urban planning.

INTRODUCTION

According to Egypt vision 2030, the Suez Canal corridor development project is the locomotive of development. It includes industrial, infrastructure, urban development projects. The over population in the narrow Nile Valley is becoming so rapid. Therefore, establishing new urban communities to achieve integrated development becomes of vital importance. The area under investigation is considered one of the promising and unexploited areas in the region representing the urban extension of the current and future development. The study area locates between latitude 30° 00′ N to 30° 30′ N and longitude 31° 45′ E to 32° 25′ E and covers an impressive area of about 1900 km^2 (Fig. 1). The current study aims at evaluating the geo-technical suitability of lands for urban planning within the study area. To achieve such aim, a complete laboratory and *in situ* testing programming are carried out.

MATERIALS AND METHODS

When determining whether a soil is suitable for use as urban land, its geotechnical characteristics should be taken into account. An extensive *in situ* and laboratory testing programme was run during the current investigation based on the geotechnical properties.

Study area and soil sampling

Based on the geology of the study area and the type of soil sequence present, various types of maps were used to select the appropriate sample selection. In order to perform the various laboratory tests in accordance with the American Society for Testing Materials (ASTM) and American of State Highway and Transportation Officials (AASHTO) standards, soil profiles (Fig. 2) were accomplished for the study of soil types with depth (Figs. 3 and 4). These profiles were collected, labelled, and packed (Das and Sobhan, 2014).

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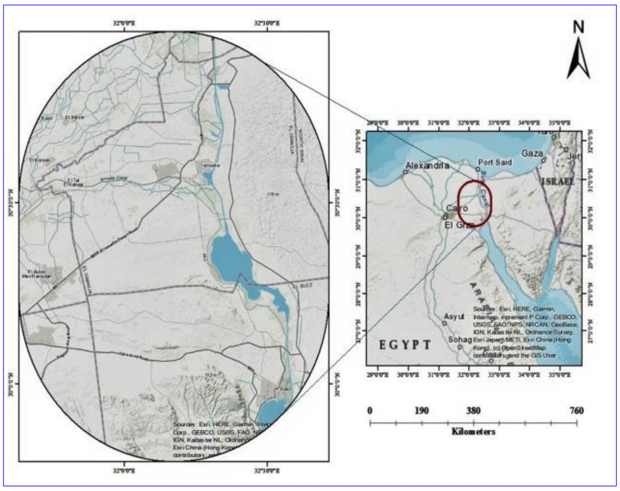

Figure (1): Location map of the study area (Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User).

Examination programes

Soil characterizations of the study area were performed which includes the following analyses:

Particle size distribution analysis

To assess soil texture, particle-size analysis is used. According to ASTM D 422, the size analysis was performed by a dry sieving test utilising an ELE Sieve Shaker complete with a separate control panel that runs on 220-240 V AC, 60 Hz, and 1 ph (ASTM, 2007). While the hydrometer method based on Stoke's Law was used to assess soils with more than 10% particles (sieve number 200 or 75 m). The percentage of various grain sizes (mm) in the soil are plotted on the particle-size distribution curves, along with their grading to enable soil classification. The fundamental soil characteristics, including effective size, uniformity coefficient (C_u), and coefficient of gradation, were identified. The definitions of the uniformity coefficient (C_u) and the coefficient of gradation (C_c) are as follows:

$$C_u = \frac{D_{60}}{D_{10}}$$

Where; D_{60} is the diameter through which 60% of the total soil mass particles are finer.

$$C_c = \frac{(D_{30})^2}{(D_{60}) x (D_{10})}$$

Where; D_{30} is the diameter through which 30% of the total soil mass particles are finer. If $C_u < 4$ the sample considered to be poorly graded, If C_u is closer to 1 the soil is considered as uniformly graded; for gravel, if $C_u > 4$, it is well graded.

Bulk Density of soil

The bulk density is calculated according to the following equation:

$$Bulk\ density\ (g/cm^3) = \frac{Dry\ soil\ weight\ (g)}{Soil\ volume\ (cm^3)}$$

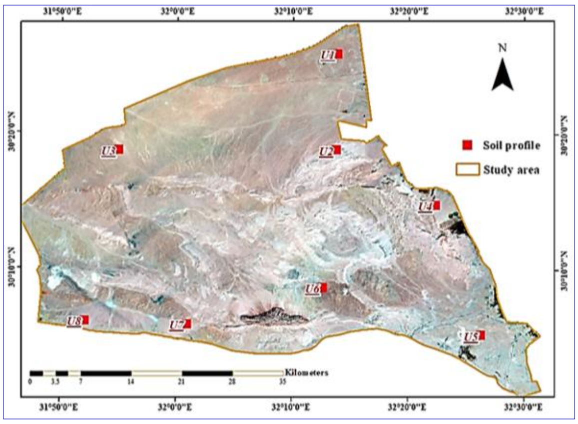

Figure (2): A map displaying various locations where the soil profile was taken.

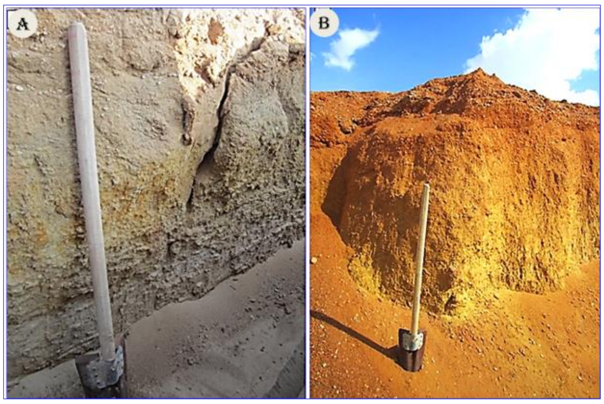

Figure (3): Soil sites at the areas parallel to Cairo – Suez desert road.

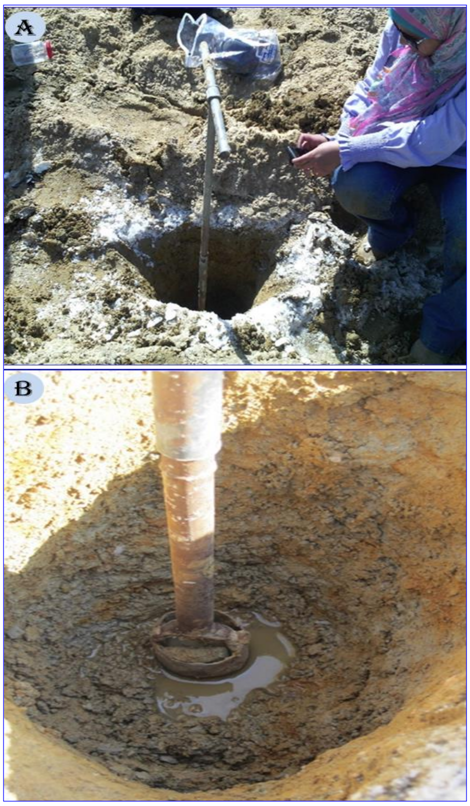

Figure (4): Boreholes using a 10 cm diameter hand-auger at the Abu Sayal Village, (a) boring process, and (b) appearance of water table during boring process.

Moisture content (w)

The moisture content (w) is one of the most characteristic measures of clay behavior. It was performed based on the ASTM Test Designation D22-16 (ASTM, 2016). It defined as the ratio of the weight of water (M_W) present in a given soil mass to the weight of dry soil (M_S) as follows:

$$W_c \% = M_W / M_S \times 100$$

Where W_c % = percentage moisture content.

Direct shear test

This test method covers the determination of the consolidated drained shear strength of a soil material in direct shear and is one of the essential parameters for analyzing and solving stability problems (Karsten *et al.*, 2006). Direct Shear measurement was perf-ormed according to ASTM D3080 (ASTM, 2011). The shear strength parameters of soils are defined as cohesion (c) and the friction angle (ø). The relation-ship between normal stress and shear is given as:

$$\tau_f = C + \delta_n \tan \phi$$

Where τ_f = Shear strength, C = Cohesion (pounds per square inch" psi), δ_n= Normal stress on the failure plane, and ϕ = angle of internal friction.

Proctor Compaction characteristics

The test determines the maximum unit weight that a soil can be compacted by using a controlled com-pactive force at optimum water content. The compactive effort is the amount of mechanical energy that is applied to the soil mass ASTM: D1557 (ASTM, 2012) specifications using EL25-9095/01 automatic soil compactor.

California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test is a measure of resistance of soil material to penetration of standard plunger under controlled density and moisture conditions. The test was conducted, according to ASTM D1883 (ASTM, 2016) designations on compacted soil samples using CBR test accessory set ELE 24-9150/01 and CBR penetration piston assembly 24-9179. The plot of the load and penetration was drowning. The correct load reading corresponding to each penetration was recorded the percent slope. In meantime, the slope suitability classes were determined based on the work of Ranatunga (2001), and Gizachew and Ndao (2008) as follow:

$$CBR = (PT/PS) \times 100$$

Where PT = Corrected test load corresponding to the chosen penetration from the load penetration curve.

PS = Standard load for the same penetration taken from the table below (Table 1).

Table (1): Standard Load values at Plunger penetration.

Penetration of Plunger (mm)	Standard Load (kg)
2.5	1370
5	2055

Atterberg limits and Consistency indices

Atterberg (1911) defined three consistency limits: shrinkage limit (SL), plastic limit (PL) and liquid limit (LL) for fine grained soil. Atterberg's original liquid and plastic limits were determined using Casagrande cup method according to ASTM D 4318 (ASTM, 2000). The plasticity index (PI) is the range of water content over which the soil exhibits a plastic behavior. It was calculated as liquid limit minus plastic limit (Grieve, 1980).

Swelling potential

The test was conducted, according to IS: 2720 (Part 40) - 1977 designations on a disturbed soil samples (i.e., ground and sieved finer than 0.425mm). Swelling behavior of compacted clays is assessed by free-swell index, swelling potential and swelling pressure in laboratory. Generally, the larger the fraction of clay size particles and the soil plasticity index the larger swelling potential. Among the clay minerals, montmor-illonite has the highest tendency to expand since it can develop enough specific surface with unsatisfied water absorption forces.

RESULTS AND DISCUSSION

Based on the geological and physiographic nature of the terrane, the study area is subdivided into three zones; these are the northern plain, the coastal plain of the Bitter Lakes, and the southern plain (Cairo-Suez Road). The geotechnical results attained from the carried testing program are discussed as follows:

The Northern Plain

Site no.1

The subsurface soil sequence, at site no.1, includes intercalation of sand and sandy fat clay. The particle-size parameters of the sand layers such as uniformity coefficient (C_u) and gradation coefficient (C_c) are determined from the particle-size distribution curve (Fig. 5). Based on the calculated uniformity coefficient (C_u, 2.22 - 2.63), and gradation coefficient (C_c, 1 to 1.15), the sand soil samples are considered poorly graded sand (SP) and A-1-b type, which is excellent to good subgrades for pavement. The CBR ratio of the surface sand layer is 26.2 %.

Figure (6) illustrates the penetration curve of surface sandy soil. Based on the admitted CBR values for sub-base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course. Although the soil according to ASSHTO classification is considered excellent to good subgrades, the soil, based on CBR values, is not suitable as base or subbase, hence, these soils must be replaced by suitable type such as SW (Well-graded sand) and SM (Silty Sand) (CBR 20 – 50%). The results of proctor test reveal that optimum moisture content (OWC) of the surface sand layer is 10.6 %, and the maximum dry density (MDD) value is 1.77 g/cm^3 and the compaction curve is shown in Figure (7), which is typical curve for poorly graded sand (ASTM D-698).

The normal stress- horizontal displacement curve of surface soil is illustrated in Figure (8). The friction angle (ϕ: 41.4) and shear strength (6.93 psi) which are of higher value, comparable to dense sand. On the other hand, the fat clays subsurface soil and according to USCS system are high plasticity clays (CH), where liquid limit reaches 96%. While, according to AAS-HTO system, it is classified as A-7-6, which is moderate to poor subgrades. The moisture content W% = 40.3% which is high value, liquid limit LL = 96%), and PL: 23% which is comparable to that of kaolinite clay mineral (Das, 2010).

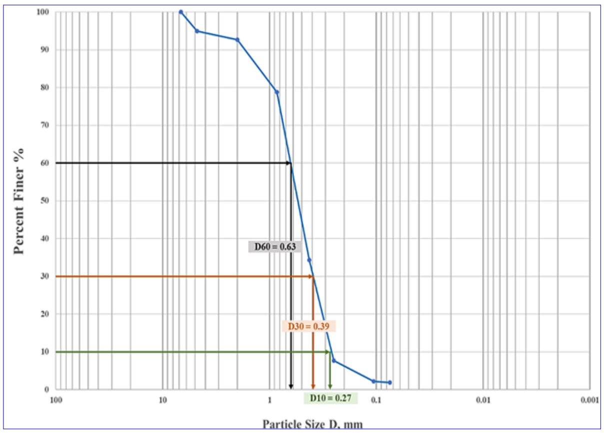

Figure (5): The particle-size distribution curve of the surface sand layer, site no.1.

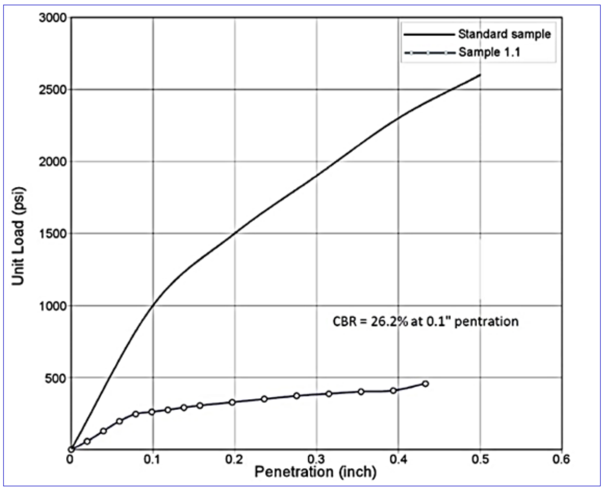

Figure (6): Load penetration curves of surface soil, site 1.

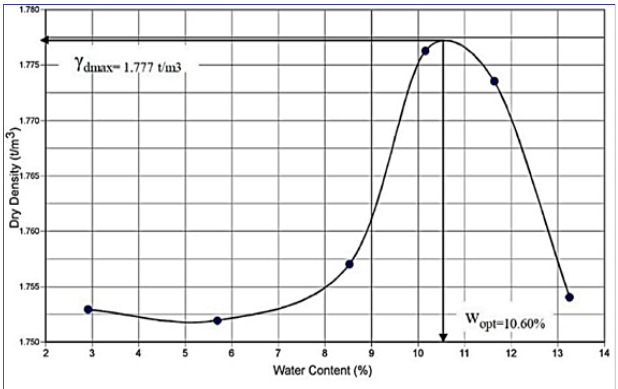

Figure (7): The compaction curve of the surface sand layer, site 1.

The plasticity index (PI= 73%) so the soil is considered to have very high plasticity (Burmister, 1949), and to have very high swelling potential (Millogo *et al.,* 2008). The bulk density is very low (<1.1g/cm^3), where it reaches 1.07 g/cm^3. For construction purposes, this clay layer has bad geotechnical behavior, so it must be removed or fixed using Boring piles to depth enough to penetrate this layer. The layer has an organic content equals 0.8%, which is very low (<1.0%).

The normal stress- horizontal displacement curve of subsurface clayey soil is illustrated in Figure (8). The friction angle (ϕ: 16.32°) and shear strength (2.492 psi) which is considered low value and has the risk of collapsing.

Site no.2

The subsurface soil sequence, at site no.2, includes intercalation of poorly graded silty sand and sandy fat clay. Based on the calculated uniformity coefficient (Cu, 2.1) and gradation Coefficient (Cc, 0.7), the surface sand layer is poorly graded silty sand (SP), A-1-b type which is considered excellent to good subgrades. The bulk density is moderate (1.4-1.6 g/cm^3), where it reaches 1.5g/cm^3.

The CBR ratio is 9.3%, and based on the admitted CBR values for sub-base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course. Based on the general relationship between CBR values and the suitability of soil as subgrade (Das, 2010), but for use as base and sub-base, this surface sand layer should be removed and replace by adequate soil type for pavement purposes.

The results of proctor test reveal that optimum moisture content (OWC) of surface sand layer is 8.4%, and the maximum dry density (MDD) value is 2.06g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved in-situ using sand cone method or other suitable method such as core cutter method, sand replacement method, rubber ballon method and radiation method before the establishment of highways. The friction angle (ϕ: 34.32°) and shear strength (7.038 psi) which is considered high value and is comparable to medium dense sand.

According to USCS system the fat clay subsurface soil considered high plasticity clay (CH), where liquid limit reaches 80%. While, according to AASHTO system, it is classified as A-7-6, which is moderate to poor subgrades. The moisture content (W%) = 36.3% which is high value, LL= 80%, and PL= 20% which is comparable to that of kaolinite clay mineral (Das, 2010). The plasticity index PI= 60%, so the soil is considered to have very high plasticity (Burmister, 1949), and to have very high swelling potential (Millogo *et al.*, 2008). The bulk density is low (1.1-1.4 g/cm^3), where it reaches 1.18g/cm^3. For construction purposes, this clay layer has bad geotechnical behavior, hence, it must be removed or fixed using Boring Piles to a depth enough to penetrate this layer.

The friction angle (ϕ: 19.36°) and shear strength (2.998 psi) which is considered low value and is collapsible soil, and this must be taken into consideration during the establishment of both shallow and deep foundations. The layer has an organic content equals 0.2%, which is very low (<1.0%).

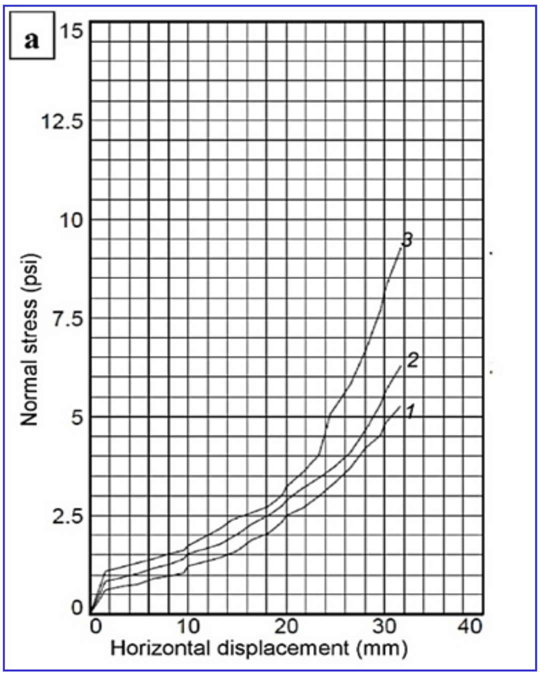

Figure (8): The plot of direct shear test of surface soil, site no.1.

Site no. 3

The subsurface soil, at site no.3, includes intercalation of poorly graded sand (SP), silty sand (SM), and well-graded sand (SW). Based on the calculated uniformity coefficient (C_u, 4.06) and gradation Coefficient (C_c, 0.84), the soils are poorly graded sand (SP), and A-1-a type which is considered excellent to good subgrades. The bulk density is high (1.6-2 g/cm^3) in the topmost poorly graded sand layer (SP), where it reaches 1.71g/cm^3, which is high.

The CBR ratio is 31.4% and based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the site is suitable for base but is not suitable for sub-base course. Based on the general relationship between CBR values and the suitability of soil as subgrade (Bowles, 1992), the surface sand layer is considered good sub-grade and suitable as base, but not as sub-base.

The results of proctor test reveal that optimum moisture content (OWC) of surface sand layer is 9%, and the maximum dry density (MDD) value is 2.02 g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved *in situ* using sand cone methods or other suitable method before the establishment of highways. Meanwhile, the silty sand (SM) (depth: 1.5-2.5m), according to AASHTO system is classified as A-2 (moisture content: 12.79%), which is considered excellent to good subgrades. The bulk density is high (1.6-2g/cm^3), reaching 1.64g/cm^3. The frictional angle (ϕ) is 39.89°, and the compressive shear strength value is 7.614 psi which is a high value which is comparable to dense sand. The moisture content W% = 12.79%% which is low value, LL= 32%, and PL= 11% which is comparable to that of kaolinite clay mineral (Das, 2010). The plasticity index (PI= 21%), so the soil is considered to have high plasticity (Burmister, 1949), and to have high swelling potential (Millogo *et al.*, 2008), once again, this has bad geotechnical properties must be taken into consideration.

The Coastal Plain of Bitter Lakes

Site no.4:

The subsurface soil sequence, at site no.4, includes intercalation of poorly graded sand (SP) and sandy fat clay. Based on the calculated uniformity coefficient (Cu) (2.27) and gradation Coefficient (Cc) (1.33), the soils are poorly graded sand (SP), and A-3 type which is considered excellent to good subgrades.

The CBR ratio of sample (4.1) is 12.9% and based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the site is neither suitable for base nor for sub-base course.

The results of proctor test reveal that optimum moisture content (OWC) of surface sand layer is 11.9%, and the maximum dry density (MDD) value is 1.17g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved *in situ* using sand cone methods or other suitable method before the establishment of highways. The frictional angle (ϕ) is 44.31°, and the compressive shear strength value is 8.364 psi which is very high value and is comparable to very dense sand. On the other hand, the subsurface clay layer (CH), according to AASHTO system is classified as A-7-6 (moisture content: 32%), which is considered mod-erate to poor subgrades. The liquid limit LL= 141%, and PL= 27% which is comparable to that of Montmorillonite clay mineral (Das, 2010), that containing very low organic matter (0.3%). The plasticity index (PI= 114%), so the soil is considered to have very high plasticity (Burmister, 1949), and to have very high swelling potential (Millogo *et al.*, 2008), and must be taken into consideration, especially during the establishment of foundations. The bulk density is 1.13g/cm^3, which is low value. The frictional angle (ϕ) is 17.35, and the compressive shear strength value is 2.660psi which is low value indicating a collapsible soil, which is considered to be bad from the geotechnical point of view (Seleem *et al.*, 2022).

The lower sand layer, based on USCS is considered poorly graded sand, and according to the AASHTO is of A-3 type which is considered excellent to good subgrades. The frictional angle (ϕ) is 42.53°, and the compressive shear strength value is 7.649psi which is high value and is comparable to very dense sand. Based on the admitted CBR values for sub-base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course (Seleem *et al.*,2022). Based on the general relationship between CBR values and the suitability of soil as subgrade, this sand layer is considered moderate subgrade. The results of proctor test reveal that optimum moisture content (OWC) of the lower sand layer is 5.8 %, and the maximum dry density (MDD) value is 1.94 g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved in situ using suitable method before the establishment of highways.

The Southern Plain (Cairo-Suez Road)

Site no.5

The subsurface soil sequence, at site no.5, includes intercalation of poorly graded silty sand and sandy fat clay. Based on the calculated uniformity coefficient (C_u) (3.3), and gradation coefficient (C_c) (0.98), the sand soil samples are considered poorly graded sand (SP) and A-3 type which is considered excellent to good subgrades. The CBR ratio of the surface silty sand layer is 11.4 %. Based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course. The results of proctor test reveal that optimum moisture content (OWC) of the surface silty sand layer is 10.7 %, and the maximum dry density (MDD) value is 1.89 g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved in situ using sand cone methods before the establishment of highways.

The friction angle (ϕ: 44.31°) and shear strength (8.418 psi) which are very high value, comparable to very dense sand. On the other hand, the clay layer (CH) (depth: 3-5.5m), according to USCS system, is high plasticity clays, and to AASHTO system is classified as A-7-6 (moisture content: 39.5%), which is considered moderate to poor subgrades. The liquid limit, LL= 86%, and PL: 24% which is comparable to that of kaolinite clay mineral (Das, 2010), were containing low organic matter (1.3%). The plasticity index (PI= 62%), so the soil is considered to have very high plasticity (Burmister, 1949), and to have very high swelling potential (Millogo *et al.,* 2008), and must be fixed before the establishment of any engineering structure. The bulk density is 1.29g/cm^3, which is low value (1.1-1.4 g/cm^3). The frictional angle (ϕ) is 17.19, and the compressive shear strength value is 3.27psi which is moderate value indicating a slightly collapsible soil.

Site no.6

The subsurface soil sequence, at site no.6, includes intercalation of poorly graded sand, sandy silt, and sandy fat clay. Based on the calculated uniformity coefficient (C_u) (1.92), and gradation coefficient (C_c) (0.82), the sand soil samples are considered poorly graded sand (SP) and A-3 type which is considered excellent to good subgrades.

The CBR ratio of the surface silty sand layer is 17.3 %, based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course, so it must be replaced. The results of proctor test reveal that optimum moisture content (OWC) of the surface silty sand layer is 10.9 %, and the maximum dry density (MDD) value is 1.81 g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved in situ using sand cone methods before the establishment of highways. The friction angle (ϕ: 40.44°) and shear strength (6.65 psi) which are high value, comparable to dense sand. On the other hand, the sandy silt subsurface layer (ML) (depth: 2.5-5m), according to USCS system, is high plasticity clays, and to AASHTO system is classified as A-4 (moisture content: 23.8%), which is considered moderate to poor subgrades. The liquid limit, LL= 11%, and PL= 10% which is comparable to that of kaolinite clay mineral (Das, 2010), that containing very high organic matter (6%). The plasticity index (PI= 1%), so the soil is considered to have slight plasticity (Burmister, 1949), and to have very low swelling potential (Millogo *et al.,* 2008). The bulk density is 1.22g/cm^3, which is low value (1.1-1.4 g/cm^3). The frictional angle (ϕ) is 24.43° is low, and the compressive shear strength value is 8.42psi which is very high value.

On the other hand, the lower clay layer (CH) (depth: 5-8 m), according to USCS system, is high plasticity clays, and to AASHTO system is classified as A-7-6 (moisture content: 14.47%), which is considered moderate to poor subgrades. The bulk density is 1.68g/cm^3, which is high value (1.6-2 g/cm^3). The frictional angle (f) is 37.97º, and the compressive shear strength value is 7.629psi which is high value indicating a non-collapsible soil. The CBR ratio of the surface silty sand layer is 43.1 %, based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the layer is suitable for base but is not suitable as sub-base course. The results of proctor test reveal that optimum moisture content (OWC) of the surface silty sand layer is 8.3%, and the maximum dry density (MDD) value is 2.098g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved in situ using sand cone methods before the establishment of highways.

Site no.7

The subsurface soil sequence, at site no.7, includes intercalation of poorly graded sand, sandy lean clay (CL), sandy fat clay (CH), silty sand (SM), and well-graded sand (SW). Based on the calculated uniformity coefficient (Cu) (2.41), and gradation coefficient (Cc) (1.21), the sand soil samples are considered poorly graded sand (SP) and A-3 type which is considered excellent to good subgrades. The CBR ratio of the surface silty sand layer is 27.7 %, based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course.

The results of proctor test reveal that optimum moisture content (OWC) of the surface silty sand layer is 12.2 %, and the maximum dry density (MDD) value is 1.762g/cm3. The attained maximum dry density, for pavement purposes, must be achieved in situ using sand cone methods before the establishment of highways. The friction angle (ϕ: 44.28°) and shear strength (6.948

psi) which are high value, comparable to dense sand. On the other hand, the sandy lean clay (CL) layer (depth: 3-4.8m), according to USCS system, is high plasticity clays, and to AASHTO system is classified as A-6 (moisture content: 17.5%), which is considered moderate to poor subgrades. The bulk density is 1.32g/cm3, which is low value (1.6-2 g/cm3). The frictional angle (ϕ) is 23.03o which is very low value, and the compressive shear strength value is 6.575psi which is high value indicating a non-collapsible soil.

The liquid limit, LL= 25%, and PL: 9% which is comparable to that of kaolinite clay mineral (Das, 2010), that containing low organic matter (1.2%). The plasticity index (PI= 16%), so the soil is considered to have medium plasticity (Burmister, 1949), and to have low swelling potential (Millogo *et al.,* 2008). On the other hand, the lower clay layer (CH) (depth: 4.8-8.8m), according to USCS system, is high plasticity clays, and to AASHTO system is classified as A-6 (moisture content: 21.72%), which is considered to have bad geotechnical characters, and must be removed or fixed. The bulk density is 1.43g/cm^3, which is moderate value (1.4-1.6 g/cm^3).

Generally, the bulk density soil sequence of site no.7 is increasing with depth, where it is 1.32 in the sandy lean clay layer (CL), 1.43g/cm^3 in the sandy fat clay (CH) layer, and finally it reaches 1.6 in the lower well-graded sand layer. Also, the moisture content increases with depth, where it is 17.5% in the sandy lean clay layer (CL), 21.72 in the sandy fat clay (CH) layer, and finally it reaches 30.45% in the lower silty sand layer (SM).

Site no.8

The subsurface soil sequence, at site no.8, includes intercalation of poorly graded sand (SP), sandy fat clay (CH), sandy lean clay (CL), and well-graded sand (SW). Based on the calculated uniformity coefficient (C_u) (2.86), and gradation coefficient (C_c) (0.86), the sand soil samples are considered poorly graded sand (SP) and A-1-a type which is considered excellent to good subgrades. The CBR ratio of the surface silty sand layer is 14.4 %, based on the admitted CBR values for sub- base (30%) and base (80%) materials supporting intensive track, the site neither suitable for base nor sub-base course. The bulk density is 1.63g/cm^3, which is high value (1.6-2 g/cm^3). The results of proctor test reveal that optimum moisture content (OWC) of the surface silty sand layer is 10.3 %, and the maximum dry density (MDD) value is 1.92g/cm^3. The attained maximum dry density, for pavement purposes, must be achieved in situ using sand cone methods before the establishment of highways. The friction angle (ϕ: 36.55°) and shear strength (7.151psi) which are high value, comparable to dense sand.

On the other hand, the sandy fat clay layer (CH) (depth: 4.8-6.5m), according to USCS system, is high plasticity clays, and to AASHTO system is classified as A-7-6 (moisture content: 21.85%), which is considered moderate to poor subgrades that containing very low organic matter (0.6%). The bulk density is 1.64g/cm^3, which is high value (1.6-2 g/cm^3). The friction angle is low (ϕ: 21.68°) and shear strength (5.642psi) which are moderate value.

The sandy lean clay (CL) (depth: 6.5-7.7m) is A-6 type which is considered moderate to poor subgrades and has very high-water content (48.2%). The bulk: is 1.43g/cm^3, which is moderate value (1.4-1.6 g/cm^3). The liquid limit, LL= 32%, and PL= 11% which is comparable to that of kaolinite clay mineral (Das, 2010). The plasticity index (PI= 21%), so the soil is considered to have medium plasticity (Burmister, 1949), and to have moderate swelling potential (Millogo *et al.*, 2008).

Soil Suitability for Urban planning and pavement purposes

The soil suitability map of the current study area, modified after Monsef *et al*. (2022), was produced based on the following aspects: a, The geotechnical properties of soil; b, The soil texture analysis; c, The interpretation of RapidEye Satellite Images; d, The published soil maps of the study area, and e, The field checks.

Careful investigation of the soil suitability map for urban planning and pavement purposes (Fig. 9) discloses that the most suitable and moderately suitable areas for urban purposes are localized mainly at the Northern Plain. In addition to sporadic areas distributed along the coastal plain of the Bitter Lakes, as well as the central part of the study area.

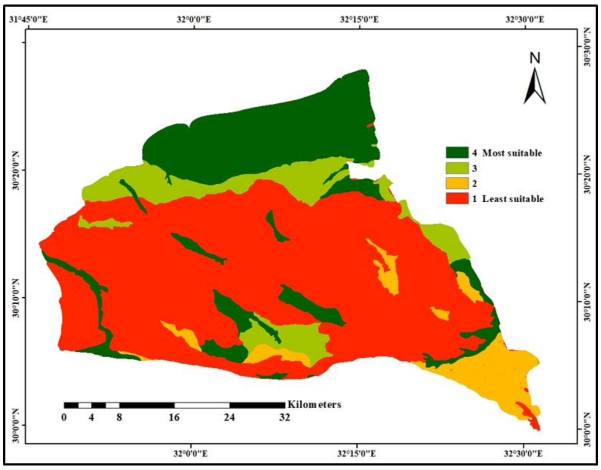

Figure (9): Soil suitability for urban planning and pavement purposes (see Monsef *et al.,* 2022).

CONCLUSIONS

Based on the geological and physiographic nature of the terrane, the study area, is subdivided into three zones; these are the northern plain, the coastal plain of the Bitter Lakes, and the southern plain (Cairo-Suez Road). The general subsurface soil sequence at the northern plain includes intercalation of poorly graded sand to silty sand (SP) and sandy fat clay (CH). The sandy soil (SP) and silty sand (SM) are considered excellent to good subgrades. The fat clay (CH) (kaolinite) soils have very high swelling potential. For pavement and construction purposes, this clay layer has bad geotechnical behavior, so it must be removed or fixed using Boring piles to depth enough to penetrate this layer. The general subsurface soil sequence at the coastal plain of Bitter Lakes includes intercalation of poorly graded sand (SP) and sandy fat clay (CH). The poorly graded sand soil (SP) is excellent to good subgrades.

Whereas, the clay layer (CH) (Montmorillonite clay mineral) has very high swelling potential; and collapsible nature (ϕ: is 17.35 and q_u is 2.660psi). The general subsurface soil sequence at the southern plain includes intercalation of poorly graded silty sand (SM), sandy silt, sandy fat clay (CH), silty sand (SM), and well graded sand (SW). The sandy silt layer (SM) has a slight to medium plasticity, which is non-collapsible soil. high compressive shear strength (6.575psi - 8.42psi). The clay layer (CL & CH) (kaolinite) has very high swelling potential, and must be fixed for construction purposes.

Based on the admitted CBR values (sub- base: 30%, and base: 80%) at the three zones, the top sandy layer is neither suitable for base nor sub-base course. Also, according to geotechnical properties, soil texture analysis, interpretation of RapidEye satellite images, published soil maps of the study area, and field check, the most suitable and moderately suitable areas for urban purposes are localized at the northern plain. In addition to sporadic areas distributed along the coastal plain of the Bitter Lakes, as well as the central part of the study area.

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التقييم الجيوتقني للتربة و ملائمتها لأغراض التخطيط الحضري، غرب البحيرات المرة، منطقة قناة السويس، مصر

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الملخص العربـــي

تقع منطقة البحيرات المرة بين خطي عرض 00' 30° و 30' 30° شمالاً وخطي طول 45' 31° إلى 25' 32°شرقاً، وتغطي مساحة تبلغ حوالي 1900 كم^2. تهدف الدراسة الحالية إلى تقييم ملائمة الأراضي الجيوتقنية للتخطيط العمراني داخل منطقة الدراسة. ومن ثم، تم إجراء بعض الأختبارات المعملية والحقلية. و بناءًا على الطبيعة الجيولوجية والفسيولوجية للتضاريس، تنقسم منطقة الدراسة إلى ثلاث مناطق؛ هي السهل الشمالي والسهل الساحلي للبحيرات المرة والسهل الجنوبي الذي يشمل طريق القاهرة السويس الصحراوي. و يتضمن التتابع العام التحت سطحي للتربة في السهل الشمالي خليط من الرمل سيئ التدرج في الحجم الحبيبي إلى الرمل الغني بالطمي والطين الرملي. و تعتبر التربة الرملية (SP) والرمل الطميي) (SM) الأنواع A-1-a, A-1-b & A-2) ممتازة إلى جيدة كطبقات بناء تحت سطحية. حيث أن زاوية الاحتكاك لهذه الطبقات هي (41.4° - 34.32° =ϕ) وقوة القص (6.93 – 7.6 رطل) والتي لها قيم أعلى مقارنة بالرمال الكثيفة. تتميز التربة الطينية الدهنية (الكاولين) بإمكانية انتفاخ عالية جدًا. وتعتبر هذه الطبقة الطينية ذات سلوك جيوتقني سيئ لأغراض الرصف والبناء. لذلك يجب إزالتها أو تثبيتها باستخدام دعامات تصل إلى العمق الكافي لإختراق هذه الطبقة. و يتضمن التسلسل العام للتربة تحت السطحية في السهل الساحلي للبحيرات المرة الرمل سيئ التدرج (SP) والطين الرملي الدهني .(CH) و تعد التربة الرملية سيئة التدرج في الحجم الحبيبي (SP) النوع (A-3) ممتازة إلى جيدة لأغراض البناء. اما طبقة الطين (Montmorillonite) (CH) النوع (A-7-6) لها قدرة عالية جدًا على الأنتفاخ. وهذا مؤشر إلى قابلية التربة للانهيار 17.35 =ϕ) و قوة قص= 2.660 رطل). اما التتابع العام للتربة تحت السطحية في السهل الجنوبي عبارة عن الرمل الغريني سيئ التدرج (SM) والطمي الرملي والطين الرملي الدهني والرمل الطميي والرمل ذو التدرج الحبيبي الجيد. و تتميز طبقة الطمي الرملية بمرونة خفيفة إلى متوسطة، وهي عبارة عن تربة غير قابلة للإنهيار ذات قوة قص عالية الانضغاط (6.575 – 8.42 رطل). كما تتميز طبقة الطين) (CL & CH)الكاولين) بإمكانية انتفاخ عالية جدًا.و بناءً على قيم CBR المقبولة (القاعدة الفرعية: 30٪ ، والقاعدة: 80٪) في المناطق الثلاث، فإن الطبقة الرملية العلوية ليست مناسبة كمواد بناء أساسية أو فرعية. و وفقًا لتحليل نسيج التربة، وتفسير صور القمر الصناعي RapidEye، وخرائط التربة المنشورة لمنطقة الدراسة، والفحص الميداني، تم تحديد المناطق الأكثر ملائمة للأغراض الحضرية في السهل الشمالي. بالإضافة إلى مناطق متفرقة موزعة على طول السهل الساحلي للبحيرات المرة وكذلك الجزء المركزي من منطقة الدراسة.