Geological and Geotechnical Investigations to Detected Foundation Parameters for Some New Urban Areas, Sohag Governorate, Egypt

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Abstract
The study area is located in Upper Egypt as a part of the Sohag Governorate. In this study, the engineering geological properties for soil deposits of three new urban areas in the southwestern part of the Sohag Governorate are discussed and evaluated based on a field survey of soil boring, geotechnical experiment and petrographical examination. The studied area is covered by Quaternary and Pliocene deposits and composed mainly of gravely sand, silty sand, silty clay, clayey silt and rocks. Twenty-three sections, forty-two soil samples and three thin sections were studied. The depth of these samples ranges between land surface and up to 10 meters below underground. The geotechnical tests for the collected soil samples were performed to determine their physical, and mechanical characteristics (grain size distribution, specific gravity, and water content, bearing capacity, free swell and Atterberg limits). From the results, the grain size analysis proved that, the arenaceous sediments (average $MZ=1.75\Phi$) falling in the medium sand grade. Mineralogical studies of X-ray diffraction examination of the collected samples reveal, the argillaceous deposits are composed mainly of montmorillonite, kaolinite and illite. The free swell test is ranging from 20 to 130% indicate that, some of the studied clay samples are high expansive. Thus, these soils are not suitable to direct foundation due to high swelling properties, which have a dangerous effect on the buildings. The liquid limit results range from 13 to 72%, the values of the plastic limit range from 9.8 to 32 % while the values of the shrinkage limit range from 9.3% to 25%. The values of the liquidity index range from 0.06 to -1.60. The liquidity index of studied samples is semi plastic or solid. The values of consistency index of the studied samples range from 0.65 (very stiff) to 2.59 (extremely stiff). The effective friction angle ($\Phi$) ranges from 33.5° to 34.8°. The ultimate bearing capacity for different friction angles of the studied samples are ranging from 1312.2kN/m² to 1533kN/m² So, this type of soil is suitable for direct foundation.

Keywords: Engineering Geology; Geotechnical studies; Sohag and Egypt

1. Introduction
The study area deals of three new urban cities; Sohag New City, Al-Mensha New City, and Bayt Khalaf New Village as part of the Sohag Governorate, Egypt (Fig. 1a). It lies between latitudes 26°20’ and 26°30’N, and longitudes 31°20’ and 31°40’E. In recent years, these areas have been subjected to rapid and increasing changes in land use, particularly with the development of housing, agriculture.

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Many studies used the geotechnical parameters to evaluate the bed foundation condition such as Khalaf & Issa, 2021 and Abu Deif et al., 2017). This study aims to calculate the geotechnical parameters of the foundation materials, as well as study the physical and engineering properties of soils encountered in the study area, and their effects on the construction stability. Thus, twenty-three stratigraphic sections, 42 soil samples and three thin-sections studied from different localities in the study area.

1.1. Geologic Setting

The geologic setting of the study area has discussed as a part of the Nile Valley by many authors since Said, 1990; Omer, et al., 1996, 1998, 2001 and 2003; El-Haddad et al., 2003; Youssef and Omer, 2009 and Abd El Raheem, 2019. It is covered by a thick succession of Tertiary and Quaternary deposits (Fig. 1b). These sediments were treated as the Qena Formation (Proto nile), Kom Ombo Formation (Pre-nile) which composed of gravels and sands with abundant coarse basement fragments, Ghawanim Formation (Eonile) consists of cross bedded fluvialite sands and gravels together with bands and lenses of conglomerates and quartzitic sandstone interbeds. The Dandara Formation (Neonile) is formed mainly of fluvialite fine sand-silt intercalations and accumulated at low-energy environment. The Thebes Platue is the oldest unit in the study area and composed of limestone and flinty limestone of Eocene (Said, 1992; Farrag, 2011 and Abu Seif, 2015).

2. Materials and Methods

2.1. Samples Collection

To carry out the geotechnical & geological studies, 42 soil samples were collected from the study area (20 samples clay; 7 samples silt; 3 rock samples and sands represented by 12 samples). The depth of these samples ranges between land surface and up to 10 meters below ground level. The geotechnical tests for the collected soil and rock samples (42 samples) were performed in engineering geology laboratory of Al-Azhar university. The study area was divided into three sectors represented by new
urban zones as the following; Zone (A): includes new Sohag City; Zone (B): includes Almenshah Algadidah and Zone (C): Biet Khallaf village.

2.2. Laboratory Tests

The following geotechnical tests carried out for the collected samples based on the soil type: Sieve analysis, Specific gravity, Atterberg limit, free swell, X-ray diffraction and petrography. All samples recovered during the field investigation were transported to the laboratory for visual reclassification and testing. The program of laboratory testing included classification, determination of physical and mechanical properties. The examined soil samples are classified according to the Unified Soil Classification System (USCS) ASTM D-2488. The performed tests on the studied soil samples, including particle size distribution, Atterberg limits, direct shear test and X-ray diffraction. The grain size analysis tests performed on soil samples were conducted according to ASTM D-422. Atterberg limits tests (liquid limit and plastic limit) were performed on fine-grained soil samples, which pass through the standard sieve No. 40 based on ASTM-D 4318. The sediment was analyzed using Gradistat software version 8.0 Blott, (2001). The grain size classified according to Wentworth, 1992. Petrography has done by microscopic examination for three thin sections to identify the textures and diagenetic characteristics for each rock type.

3. Results and Discussion

3.1. Geological Characteristics

The geological investigations include grain size analysis of soil, thin-section of the rock samples, lithological description, depositional environment of sediments and mineralogical identification.

3.1.1. Sedimentological parameters

The main purpose of the grain size analysis is for identify the description and textural parameters of the soil. Another purpose is to define the depositional environment of clastic sediments and to estimate the subsurface sediments. The results of the grain size analysis are tabulated in Table 1. According to Folk and Ward, (1957), the graphic mean size values classified as coarse to fine sand grade with range from 0.52 f to 2.99 f the majority of the examined samples are medium sands (5 samples) and fine sands (5 samples), while a few of them are coarse sands (2 samples). The value of sorting coefficient (σI) ranges from moderately well sorted (0.62 f) to poorly sorted (1.89 f).

The majority of the studied samples are poorly sorted (6 samples) and some of them are moderately sorted (4 samples) while 2 samples are moderately well sorted. The skewness ranges from 0.39f to 0.42f and classified as strongly coarse skewed to strongly fine skewed. It reflects strongly fine skewed due to enrichment of coarse grain sand. The kurtosis (KG) value of the studied samples ranges from 0.459 f to 1.70 f and classified as very platykurtic to very leptokurtic. It is had good load bearing capacities and good drainage qualities, and their strength and volume change characteristics are not significantly affected by change in moisture conditions (according to Folk and Ward, 1957). So, this type of soil is suitable for direct foundation, that from the stand point of applied sedimentology. The results of soil classification explained in Table 2. The data are represented by cumulative curve (Fig. 2).
Fig. 2. Cumulative curves of arenaceous sediments for studied samples (5.1, 5.2, 7.1, 8.2, 9.1, 10.1, 11.1, 12.1, 14.1, 15.1, 15.2, 17.1, 18.1, 20.1)

Table 1. The results of the mechanical analysis

| Sample | Weight % of fraction | Median textures parameters |
|--------|----------------------|---------------------------|
|        | 4-2  | 2-1  | 1-0.5 | 0.5-0.25 | 0.25-0.125 | 0.125-0.074 | <0.074 | MZ  | 6I  | SK  | KG  |
| 5.1    | 0    | 0.22 | 8.2   | 21.6    | 57.68      | 5.26        | 6.58   | 2.206| 0.950| -0.111| 1.482|   |
| 5.2    | 0.2  | 0.34 | 12.26 | 31.64   | 50.4       | 2.76        | 2.22   | 1.997| 0.820| -0.262| 0.886|   |
| 7.1    | 0.02 | 0.1  | 1.25  | 4.5     | 60.56      | 15.86       | 17.44  | 2.990| 0.919| 0.390 | 0.990|   |
| 8.2    | 2.76 | 3.34 | 14.28 | 31.6    | 44.82      | 1.72        | 1.44   | 1.781| 1.004| -0.305| 0.986|   |
| 9.1    | 8.58 | 9.5  | 23.94 | 13.36   | 16.4       | 8.94        | 18.78  | 1.832| 1.899| 0.181 | 0.719|   |
| 10.1   | 0    | 0    | 4.3   | 33.86   | 56.89      | 3           | 1.95   | 2.120| 0.665| -0.191| 0.782|   |
| 11.1   | 8.86 | 1.52 | 6.16  | 12.3    | 60.54      | 6.92        | 3.7    | 2.058| 1.161| -0.386| 1.665|   |
| 14.1   | 34.24| 4.56 | 20.5  | 15      | 21.9       | 2           | 1.8    | 0.841| 1.196| 0.428 | 0.459|   |
| 15.1   | 1.78 | 0.22 | 2.22  | 7.3     | 77.5       | 7.3         | 3.4    | 2.495| 0.623| -0.021| 1.700|   |
| 15.2   | 44.48| 4.26 | 22.78 | 14.06   | 13.1       | 0.74        | 0.38   | 0.523| 0.985| 0.759 | 0.642|   |
| 17.1   | 8.36 | 4.2  | 7.4   | 9.46    | 60.9       | 3.8         | 5.88   | 1.900| 1.326| -0.390| 1.598|   |
| 18.1   | 14.5 | 2.48 | 14.48 | 22.26   | 41.36      | 2.2         | 2.72   | 1.390| 1.288| -0.364| 0.699|   |
| 20.1   | 66.88| 1.54 | 5.12  | 6.78    | 14.88      | 2.18        | 2.26   | 0.420| 1.085| 0.424 | 0.790|   |
Table 2. The results of classification of soil samples according to Folk and Ward, (1957).

| Sorting Coefficient | Classification       | Studied samples |
|----------------------|----------------------|-----------------|
| Under 0.35           | Very well sorted     | -               |
| 0.35 - 0.50          | well sorted          | -               |
| 0.5 - 0.71           | Moderately well sorted | 10.1, 15.1     |
| 0.71-1.00            | Moderately sorted    | 5.1, 5.2, 7.1, 15.2 |
| 1.00-2.00            | poorly sorted        | 8.2, 9.1, 11.1, 14.1, 17.1, 18.1 |
| 2.00-400             | Very poorly sorted   | -               |
| Over 4.00            | Extremely poorly sorted | -            |

| Grade Limits | Classification | Studied samples |
|--------------|----------------|-----------------|
| -1.00 to 0.00 | Very coarse sand | -               |
| 0.00 to 1.00  | Coarse sand     | 14.1, 15.2      |
| 1.00 to 2.00  | Medium sand     | 5.2, 8.2, 9.1, 17.1, 18.1 |
| 2.00 to 3.00  | Fine sand       | 5.1, 7.1, 10.1, 11.1, 15.1 |
| 3.00 to 4.00  | Very fine sand  | -               |
| 4.00 to 5.00  | Coarse silt     | -               |

| Skewness value | φ-units           | Studied samples |
|----------------|-------------------|-----------------|
| 1.00 to 0.30   | Strongly fine-skewed | -               |
| 0.30 to 0.10   | Fine-skewed       | 7.1, 15.2, 9.1, 14.1 |
| 0.10 to -0.10  | Near-symmetrical  | 15.1            |
| -0.10 to -0.30 | Coarse-skewed     | 5.1, 5.2, 10.1, 11.1, 15.1 |
| -0.30 to -1.00 | Strongly coarse-skewed | 18.1, 17.1, 11.1, 8.2 |

| Kurtosis value | Classification | Studied samples |
|----------------|----------------|-----------------|
| <0.67          | Very platykurtic | 14.1, 15.2      |
| 0.67-0.90      | Platykurtic     | 5.2, 9.1, 10.1, 18.1 |
| 0.90-1.11      | Mesokurtic      | 7.1, 8.2        |
| 1.11-1.50      | Leptokurtic     | 5.1             |
| 1.50-3.00      | Very leptokurtic | 11.1,15.1,17.1 |
| >3.00          | Extremely leptokurtic | -        |

3.1.2. Depositional environment

The relationships between the various grain-size parameters are used to determine the depositional environment of sands (Friedman, 1967; Moiola and Weiser, 1968). Friedman, 1967 concluded that a plot between skewness and standard deviation is most effective in differentiating river and beach sands. By applying this relationship for the investigated sediments, the examined samples lie in the river field (Fig. 3a). Moiola and Weiser, 1968 used the textural parameters in various combinations as environmental indications. The plotting of the studied sand samples on their diagram, they deposited in the river environment (Fig.3b). These results are consistent with previous studies that these sediments were deposited in a riverine environment as one of the early stages of the river Nile. Fig. 4 shows the selected stratigraphic section.

Fig. 3. Studied samples on (a) Friedman, (1967); (b) Moiola and Weiser, (1968) diagrams
3.1.2. Petrographical description

The classifications of Dunham (1962), and Embry and Klovan (1971) were used to identify the microfacies types of the studied carbonate rocks. It assists to interprets the depositional environment for understand the diageneric processes affecting the consolidated rocks. the petrographical examination of the studied samples revealed different microfacies types, carbonate and weathered basalt. The following detailed description of these thin sections.

- **Lime-Mudstone (sparry micrite)**
  
  The determined carbonate microfacies include lime-mudstone (sparry micrite) and grainstone (sparite). The thin-section photomicrograph shows that the studied sample (S.22.1) is composed mainly of fine to coarse, anhedral to subhedral dense calcite mineral. In addition, fine micritic calcite was observed in the fabric, filling interspaces in groundmass of thin section. Also, coarse to fine subrounded and angular quartz crystals were detected. Moreover, peloids are recognized which can be produced by the pelletizing action of organisms. (Fig. 5a).

- **Grainstone (sparite)**
  
  The thin-section photomicrograph shows that the studied sample (S.22.2) is composed mainly of medium to coarse, anhedral to subhedral calcite mineral. In addition, fine micritic calcite was observed in the fabric, filling interspaces in groundmass of thin section. Moreover, peloids are recognized which can be produced by the pelletizing action of organisms. (Fig. 5b).

- **Weathered basalt**
  
  The thin-section photomicrograph shows that the studied sample (S.4.1) is composed mainly of fine to medium grains of elongated albite grains. Also, augite, olivine minerals were detected (Fig. 5c).

![Fig. 4. Detailed description for selected sections](image-url)
3.1.3. Mineralogical identification

The X-ray diffraction examination of 7 samples (3 bulk and 4 clay fraction samples) selected from different localities, were carried out fractions in order to identify the non-clay and clay minerals. The X-ray examination revealed that, sample No. S.22.1 composed mainly of calcite mineral with subsidiary of quartz mineral (Fig. 6a), sample No. S.22.2 composed entirely of calcite mineral (Fig. 6b). X-ray diffraction examination of weathered basalt has undergone high alteration to clay minerals especially to montmorillonite mineral as identified (Fig. 6c). Accessory minerals include quartz and montmorillonite minerals. Plagioclase, augite and olivine form abundant porphyritic crystals. Plagioclase occurs either as phenocrysts or as a major constituent of the groundmass.

3.1.4. Clay mineral composition

The X-ray diffractograms of oriented particle amounts of selected samples are presented in Fig.7. The clay minerals in the studied samples are represented by montmorillonite, kaolinite and Illite. The montmorillonite is the most predominant in the studied samples.
3.2. Geotechnical Characteristics

The type of bed foundation at the study area is mainly soils that derived from the weathering of surrounding rocks. So, determination of engineering parameters for subsurface material is very important before foundation design. These parameters are Effective Diameter (D10), Uniformity Coefficient (Cu), Curvature Coefficient (Cc) and Insoluble Residue. these parameters summarized in Table 3. The laboratory tests on sands and gravels include sieve analysis and carbonate percent. The shape of the particle size distribution curves can be expressed approximately by a uniformity coefficient, defined as the ratio D60/D10, where D60 and D10 are the particle sizes corresponding to the cumulative percentages 60 and 10 respectively. According to uniformity coefficient (Cu), samples no. (S.5.1, S.5.2, S.7.1, S.8.2, S.10.1, S.11.1, S.15.1, S.17.1 and S.18.1) classified as very uniform soil while samples No. (S.9.1, S.14.1 and S.15.2) classified as non-uniform soil (well graded soil).

According to Unified Soil Classification System, all of the studied samples are poorly graded except samples no. (S.9.1, S.14.1 and S.15.2) which are well graded. It’s a good soil for buildings. Fig. 8 shows grain size distribution curves of studied fine soil samples (Uniform curves).
3.2.1. Initial water content (Moisture content)

Changes in moisture content, either by wetting or drying can be avoided by sealing the sample with an impermeable material such as paraffin wax or polythene (Stimpson, 1970). The samples collected and putted in polythene and take it to the laboratory. The results of water content summarized in Table 3.

3.2.2. Free swell test

Soils having free swell value as high as 100% can cause considerable damage to lightly loaded structures while soils having free swell value below 50% seldom exhibit appreciable volume change even under very light loads (Holtz and Gibbs, 1956). The percentage of free swell is determined by:

\[ F.S = \left( \frac{V_f - V_i}{V_f} \right) \times 100 \]  \hspace{1cm} (1)

Where:
- F.S = Free swell
- \( V_f \) = Final volume.
- \( V_i \) = Initial volume.

The value of the free swelling of the studied samples are summarized in Table 3. It ranges from 20% to 130%. indicate that, some of the studied clay samples are high expansive. So, this type of soil is not suitable to direct foundation because of its high swelling property.
3.2.3. Atterberg Limits

The liquid limit ranges from 13 to 72 %. The plastic limit depends on the type and amount of clay fraction in soil. The value of the plastic limit for the studied samples range between 9.8 to 32 %. The moisture content, in percent at which volume of the soil mass ceases to change, is defined as shrinkage limit. The values of the shrinkage limit range from 9.3% to 25%. Atterberg limits summarized in table 3.

3.2.4. Plasticity Index (P.I.)

The plasticity index is the numerical difference between the liquid limit and the plastic limit. The term plasticity describes the ability of a soil to undergo an unrecoverable deformation at constant volume without crumbling, and this property is assigned to the presence of the clay minerals (Craig, 1982). So, plasticity index is given by:

\[ P.I = \text{Liquid Limit} - \text{Plastic Limit} \] (2)

The plasticity index values of the studied samples range from 3.2 to 48, All values id given in table 3, the clay samples of study area classified as inorganic silt, clayey silt, silty clay and clay, where the most of studied samples are high plastic soil. According to Chen, (1988) classification, the swelling potential of the collected samples classified as low to very high based on plasticity index were, plasticity index ranges from 3.2 to 48.

3.2.5. Liquidity Index (L.I.)

It is the ratio of the difference between natural water content and plastic limit to the plasticity index. The liquidity index used to predict the physical state of the soil at its natural moisture content. The numerical data for this prediction proposed by Whitlow (1983) is as follows:

\[ \text{L.I} = \frac{\text{Water Content} - \text{Plastic Limit}}{\text{Plasticity Index}} \]

L.I < 0: Soil is in semi-plastic solid or solid state.
0 < L.I < 1: Soil is in plastic state.
L.I > 1: Soil is in liquid state.

The liquidity index values of studied samples ranged from (-0.06 to -1.60), according to Whitlow (1995), it classified as semi-plastic to solid.

3.2.5. Consistency Index (C.I.)

It is the ratio of the difference between the liquid limit and natural water content to the plasticity index. It is calculated according to the following:

\[ \text{Consistency index} = \frac{\text{Liquid limit-water content}}{\text{Plasticity index}} \] (3)

The values of consistency index of the studied samples range from 0.65 to 2.59. according to Ranjan and Rao (2007), it classified as stiff to hard soil.
The sedimentological studies deal with a grain size of sand sample analysis, and X-ray diffraction. The results of grain size analysis proved that the arenaceous sediments (average MZ=1.75 f) in the medium sand grade. The distribution curves are generally of poorly sorted, strongly fine skewed and mesokurtic. The constructed histogram indicates that, the grain sizes of New Sohag city are generally of unimodal with the exception of only 3 samples which shows bimodal and 2 samples are trimodal characteristics. Mineralogical studies of X-ray diffraction analysis of collected samples reveal that, the argillaceous sediments are composed essentially of montmorillonite, kaolinite and illite. Geotechnical studies deal with the physical and mechanical properties of soil samples encountered New Sohag city, as well as their effects on the construction stability. The geotechnical studies include grain size analysis, specific gravity, free swell and Atterberg limits. Grain size parameters are effective diameter, it ranges from 0.086mm to 0.53mm. Uniformity coefficient Cu ranges from 1.52 to 12.79 and Cc range from 0.59 to 1.79. The studied samples are poorly-graded soil according to Unified Soil Classification System. Free swell test is ranging from 20 to 130 %, that indicates some of the studied clay samples are high expansive. So, this type of soil is not allowed to direct foundation because of its high swelling property, which has dangerous effect on the buildings. Atterberg limits include the liquid and plastic limits, the results of the liquid limit range from 13 to 72%. The values of the plastic limit range from 9.8 to 32 %. While the values of the shrinkage limit range from 9.3% to 25%. The plasticity index ranges from 3.2 (low plastic) to 48 (high plastic). The values of the liquidity index range from -0.06 to -1.60. The liquidity index of studied samples is semi-plastic or solid. The values of consistency index of the studied samples range from 0.65 (very stiff) to 2.59 (extremely stiff).

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