Characterization of rock formation at Toshka fourth depression – Egypt

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\textbf{ABSTRACT}

Recently, the Egyptian south valley has been considered as one of the most promising developments for the mega projects such as power stations, roads and bridges. Fresh water channels were extended through to transfer water from Nasser Lake to the irrigated land in the western desert in order to save the groundwater storage for the later usage. Rock formations generally represent a great challenge in civil engineering due to their wide spatial variability, whether vertically or horizontally. This paper presents the results of a geotechnical study that was carried out across the Toshka fourth depression, Egypt. The study comprises a comprehensive investigation programme in the field and complemented with laboratory testing programme to evaluate the physical and mechanical rock properties. The geotechnical investigation included executing boreholes with a depth up to 100 m; core and bulk samples were extracted and recovered. Moreover, an extensive laboratory testing programme was conducted on the samples. Additionally, Rock Mass Rating System was used to identify the rock mass properties, considering the effect of discontinuities planes, layers joint roughness conditions, slaking rate and in addition to the effect of wetting and drying on Rock Mass strength parameters. The results indicated that the geological formation generally composed of limestone intercalated with layers of silty claystone or clayey siltstone. The results of this study cover, among others, rock mass strength properties that should be considered as a design parameters or regarded as guidelines for the design of any future development in the region.

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\textbf{Introduction}

The south valley in the Egyptian Western Desert is attracting interest from the Egyptian government. The government seeks to increase both private and foreign investments for industrial and agricultural fields especially in this area. Huge development of transportation, communications and energy
networks are growing in complexity. The South Valley in the western desert located west of the Nasser Lake has become one of the most promising and important attractions for reservation of fresh water from Lake Nasser and to be one of the biggest cultivated areas in Egypt. Toshka Depressions (TDs) are located in the Western Desert of Egypt at the west of Lake Nasser. They naturally consist of four deep-cut basins and located at 250 km south of Aswan [1]. Toshka area is considered to be an ideal region for dunes and can be used as a model for other regions in the Western Desert of Egypt and North Africa [2] [3]. El-Aziz [4] and Hassan [5] stated that Alluvial soils of Toshka Depression are classified as “slightly saline soils, according to soil salinity class. Also, soil reaction tends to be moderate. Labib and Nashed [6] developed empirical relationships between swelling pressure, swelling potential, plasticity index and clay content for clay from Toshka region in Upper Egypt. They reported that the values of the swelling pressure ranged from 4.0 to 24 kg/cm².

The government strategy is to encourage agricultural and industrial development in south valley for both Egyptian and foreign investors. This area has necessitated rapid and comprehensive establishment of design guidelines across this new area to be used in the design of the proposed mega projects and structures such dams, bridges, power station and others. Several geological and geotechnical characterization studies have been conducted to be guidelines for future development. Accordingly, geotechnical designer is confronted with rock material as an assemblage of blocks separated by discontinuous, joints, fault and other factors. Such characterization specifically targeted the rock formation in the region. Therefore, rock mass properties in addition to intact rock properties should be investigated. The objective of the current study is to acquire better understanding of the nature and origin of the rock formation at the Toshka Fourth Depression. The investigation programme comprised several drilling boreholes with depth up to 100 m, in addition to field and laboratory testing programme. Results of the carried out investigation were used for site characterization and evaluation of rock mass strength parameters that might be used in any geotechnical design across the area and the factors that may affect these parameters.

**Studied area**

The investigated site is located at the end of the Toshka Fourth Depression (Figure 1), in the direction of the New Valley, along Darb El Arbein road to Paris oasis. The latitude and longitude coordinates of the site are (23° 38’ 18”) North and (30° 31’ 48”) East. The adopted site for this study was chosen to be a vital area for constructing one of the planned dams across the studied area.
Geomorphology of south valley area

The Toshka Fourth Depression is dominated by a relatively thick sedimentary succession of Mesozoic age with few scattered exposures of Pan African Basement Rocks and Phanerozoic within-plate volcanic sedimentary successions. The Fourth Depression starts with upper Cretaceous sediments, represented by limestone beds. Limestone covers great parts of the Fourth Depression and has different colors and shades including yellow, yellowish gray, yellowish brown and reddish brown. Interbeds of light gray to dark gray claystone and siltstone are common, especially in the upper layers of the succession.

Limestone is formed after natural compaction of lime particles, and then cementation was developed. Generally, cementation occurs through two ways; first through the enlargement of existing particles by the growth of jackets of additional quartz derived from lime bearing solutions. The second method is by the deposition of cementing matters from water percolating such as silica and kaolinite clays, iron oxides, e.g. hematite, and carbonates, e.g. calcite. Limestone generally forms in nearly flat horizontal beds, but some locations with more resistant limestone beds make some relatively higher hillocks which may weather into conical or flat-topped hills.

Site investigation and subsurface formation

The subsurface investigation programme comprises of 39 boreholes, with depths ranging between 30 and 100 m. Borehole drilling was carried out using compressed air (dry drilling) to protect any uncemented formation that may be encountered and to keep rock samples at their intact conditions,
especially initial moisture content. Continuous sampling had been made using double core type sampler. The drill holes and samples were 102 and 82 mm diameters, respectively. The core length was 2000 mm, and extracted samples have more than 90% recovery. According to ASTM D5079-90 [7], all extracted samples were kept and transported in wooden boxes for laboratory testing. Groundwater was not encountered down to the end of the drilling depth.

Visual inspection of the recovered core samples revealed that the main subsurface formations comprise sedimentary rocks of limestone, intercalated with layers of silty claystone and clayey siltstone. Based on the boreholes profiles and visual inspection, a lithological section has been developed and shown in Figure 2, which represents a typical lithological section at the Fourth Depression. Accordingly, the following lithology could be typically anticipated across the investigation area, however, with different layers’ thicknesses:

1) Loose Sand (I): Surface wind-transported with varied thickness between few centimeters and to up to 6.00 m. It contains some silt, limestone fragments of pebble size. This layer is highly permeable and not suitable as a bearing stratum. Chemical analyses carried out on this layer indicated aggressive potential.
(2) Intercalated limestone and clastic sedimentations of clay-stone, silt-stone and sandy-siltstone:
(a) Limestone (II), which is fossiliferous limestone, argillaceous with cracks that are filled with calcareous silt. The layer has irregular shapes, different thickness and dip angles. Parting of silt or silt-stone existed in few locations. It has moderately hard strength and poor-to-excellent rock quality. It was recovered with different thickness between 8 and 72 m depth. However, it was interbedded with different layers of siltstone and/or claystone. The stone has close to widely spaced cracks in some locations.
(b) Siltstone (III), which is composed of silt mixed with fine sand, calcareous pebbles, broken sea shells and pockets of iron oxides and gypsum crystals veinlets. It has different thicknesses and dip angles and was separated by limestone or claystone layers.
(c) Claystone (IV), thinly laminated with very fine grained and has different colors. It was recovered as weak stone with very closely spaced, gypsum crystals veinlets and frequent parting of iron oxides and silt.

X-Ray diffraction analyses for seven clay samples from different boreholes were carried out at the central laboratory sector of the Egyptian Geological survey and Mining Authority to identify the clay minerals. The samples were scanned using Philips X-Ray Diffraction equipment model PW/1710 with Fe-filter, Co-radiation (\(\lambda = 1.971\text{Å}\)) at 40 KV, 30 MA and scanning speed of 0.02°/sec. The reflection peaks between \(2\theta = 2^\circ\) and \(60^\circ\), corresponding spacing \((d, \text{Å})\) and relative intensities \((I/I_0)\) were obtained. The X-Ray diffraction analyses revealed that the samples were composed of Montmorillonite and Kaolinite as major constituents and traces (which is less than 5%) of Quartz, Gypsum, Hematite and Illite (Table 1). However, Figures 3 and 4 show the microscanning of one clay sample and the X-Ray diffraction results.

| Borehole No. | Major Const. | Minor Const. | Trace Const. |
|--------------|--------------|--------------|--------------|
| G3           | Montmorillonite and Kaolinite | -            | Quartz       |
| G6 (25.60)   | Montmorillonite and Kaolinite | -            | Gypsum and Quartz |
| G6 (42.40)   | Montmorillonite and Kaolinite | -            | Gypsum and Illite |
| G8           | Montmorillonite and Kaolinite | Quartz      | Quartz       |
| G10          | Montmorillonite and Kaolinite | -            | Quartz       |
| G22          | Illite       | -            | Quartz       |
| S2           | Montmorillonite and Kaolinite | -            | Quartz and Gypsum |

*Trace<5%
A comprehensive testing programme was carried out on the recovered sample. All laboratory tests were conducted according to ASTM [8] and E.E.P [9]. The laboratory tests comprised particle size distribution, Atterberg Limits, bulk density, absorption, free swell, specific gravity, unconfined compressive strength (for natural and soaked samples), consolidation, direct shear, permeability, rate and amount of slaking, and finally mineral analysis. The following section will illustrate results of some of the carried out tests for each layer.
**Loose sand (II)**

This layer was highly permeable and not suitable as a bearing stratum. Additionally, chemical analyses indicated a high aggressiveness against construction materials.

**Limestone (II)**

Permeability coefficient was one of the parameters determined during the testing programme. The conventional tri-axial cell was used to determine permeability coefficient. Rock sample was immersed in water for 48 hours, then insulated by rubber membrane and placed in the tri-axial cell. The samples were subjected to all around pressure equal to the overburden pressure and then subjected to axial flow at a certain pressure. Knowing the dimensions of the tested sample, the amount of flow at certain time, and the excess pressure head, the coefficient of permeability was calculated by applying the common Darcy's law. The permeability of the formations ranged between 3.50E-09 cm/sec and 9.7E-6 cm/sec, Figure 5. However, few in situ permeability tests were carried out and the obtained permeability coefficients ranged between 1 x 10^{-7} cm/sec and 1 x 10^{-4} cm/sec.

Bulk density was considered as a basic physical property as it could be used in conjunction with the specific gravity and water content to evaluate porosity and other design parameters. The bulk density of the tested rock samples was determined at the natural water content. Results are shown in Figure 6, presenting wide range from 1.74 t/m^3 to 2.58 t/m^3 in the bulk density. Specific gravity was also determined and ranged between 2.38 and 2.96.

One of the important rock properties is the absorption percentage. The absorption percentage was determined for non-active rock sample, i.e. limestone. Rock samples that get affected by water, for example volume change or disintegration when subjected to water such as claystone, were excluded from that test. The absorption percentage could be used in conjunction with
bulk density and specific gravity to determine void characteristics. The determination of absorption percentage was carried out by soaking the rock sample in water and was boiled for 4 hours. The results of this test are shown in Figure 7. The sample was oven dried, and the absorption percentage was calculated by the following equation:

\[
\frac{(\text{wet sample weight} - \text{dry weight})}{\text{dry weight}} \times 100
\]

Uniaxial compressive strength of the rock samples was thoroughly investigated, aiming to reach or establish an appropriate approach to get representative strength parameters that could be used or recommended for the design stage. Moreover, it was necessary to identify the factors that could affect the rock layers’ strength parameters and that could be accounted for during design stage. Sedimentary rocks are generally vulnerable to wetting and drying cyclic. Materials like well-cemented limestone and dolomitic limestone are durable because they can sustain several wetting and drying cycles without considerable disintegration. Nevertheless, they have less strength at wetting conditions due to water effect in the micro-cracks. Accordingly, it was decided to investigate soaking effect on the uniaxial compressive strength. A number of rock samples were tested for uniaxial compressive strength at their natural water content. Some samples from the same depth of those

Figure 6. Bulk density variation of rock samples with depth at natural water content.

Figure 7. Absorption percentage of the tested limestone samples.
tested for uniaxial compressive strength were fully soaked for 48 hours, then tested for uniaxial compressive strength. The uniaxial compressive strength of rock samples tested at their natural water content gave values that ranged from 4.20 kg/cm$^2$ to 973.3 kg/cm$^2$. However, the soaked samples gave uniaxial compressive strength that ranged from 109.1 kg/cm$^2$ to 492.8 kg/cm$^2$ as shown in Figure 8. The results shown in Figure 8 indicated that soaked uniaxial compressive strength are less than those for natural samples by an approximate range from 15% to 45%.

Slaking test which is the measure for rock sample resistance to weakening and disintegration resulting from a standard cycle of drying and wetting named slaking was carried out in accordance with ASTM D4644 [10]. The main purpose of this test is to evaluate qualitatively the durability of rock samples in a server environment using the following equation:

$$I_d = \left[\frac{(W_f - C)}{(B - C)}\right] \times 100$$

Where: $I_d$: slake durability index, 2$^{nd}$ cycle

$W_f$: mass of the drum plus oven-dried sample retained after second cycle (gm)

$B$: mass of drum plus oven-dried sample before the first cycle (gm)

$C$: mass of the drum (gm)

The rate of slaking is classified in terms of change in the liquidity index $\Delta L_L$ following the soaking in water for 2 hours.

$$\Delta L_L = \frac{\Delta W}{(LL - PL)}$$

Where: $\Delta L_L$: Change in the liquidity index

$\Delta W$: Change of water content after soaking for two hours on filter paper in a funnel.

![Figure 8. Uniaxial compressive strength for rock samples.](image)
Figure 9 shows the slaking rate results which indicate that the tested rock samples have slow to very fast slaking rate and hence durability, then they have an impact in design parameter.

**Siltstone (III)**

Siltstone is characterized by very low permeability, high to sever slaking potential and very low to medium durability. The uniaxial compressive strength of this stone is highly degraded after soaking. The saturated shearing strength parameter of this stone is 4.8 kg/cm² for cohesion as a maximum value 20° as internal friction. Chemical tests indicated moderate aggressive effect on construction materials. In addition, uniaxial compressive strength of the natural samples ranged from 4.2 kg/cm² to 824 kg/cm². Meanwhile, all samples used for soaking tests were disintegrated upon soaking, and hence there was no sample to test.

**Claystone (IV)**

It has a relatively large change in characteristics upon wetting. Swelling characteristics were investigated using odometer test, and the method of constant pressure equals to overburden pressure of the tested sample. The amount of free swell obtained ranged from 2.0% and 12%. However, swelling pressure was determined using constant volume odometer tests and the obtained swelling pressure ranged from 0.3 to 7 kg/cm². Direct shear test was carried on soaked samples and gave shearing strength parameters upon wetting of 21 kg/cm² for cohesions and 23° for internal friction.

Regarding permeability, laboratory test results indicated that clay samples have low coefficient of permeability ranging from $1 \times 10^{-8}$ to $1 \times 10^{-6}$ cm/sec. Field permeability tests indicated an average value of $1 \times 10^{-4}$ cm/sec. Chemical test results indicated moderately aggressive behavior to construction materials. Plasticity indices were determined

![Figure 9](image-url)
for fine grained materials. The plasticity indices express the activity of the soil during the presence of water and will assist to evaluate swelling or consolidation potential for the soil. Since samples were recovered in dry condition, then all tested samples were submerged in water for 48 hours. After that, samples were washed on sieve No. 40 as per the relevant specifications ASTM D4318-00 [11]. The results are shown in Figures 10 and 11 and summarized as follows:

Generally, it is obvious that the Atterberg limits and natural water content of the tested clay samples increased by increasing the depth, the tested clay samples. Complete mineral analyses were carried out on three different rock samples from two different boreholes as described in Table 2. The testes were carried out to identify the mineralogical compositions for each rock samples. The results of the mineralogical composition are tabulated in Table 3.

**Figure 10.** Natural water content of the tested clay samples. Liquid limit ranged from 20.3% to 109.9%. Plastic limit ranged from 12.8% to 36.0%. Plasticity index ranged from 8.2% and 79.1%. Shrinkage limit ranged from 9.3% to 25.8%. Water content ranged from 1.0% to 79.0%.

**Figure 11.** Atterberg limits for clay samples.
The strength of a jointed rock mass depends on several parameters and factors, most of which is the properties of the intact blocks. Displacements are normally controlled by the geometrical shape of the blocks and condition of the planes separating those blocks. Normally, the rock mass strength parameter could be determined by the following procedure:

- The Rock Mass Rating (RMR) system is used to evaluate the RMR values for the investigated/studying rock mass layer. It is a function of uniaxial compressive strength, rock quality designation (RQD), joint spacing, condition of joints and ground water condition. The RMR system was developed by Bieniawski [12,13] and Romana [14].
- The geological strength index (GSI) is determined and applied to the rock mass strength parameters derived from the RMR system in the previous step. The GSI is a system that has been introduced by Hoek [15] and Hoek et al [16] to provide reduction factors that has to be applied to rock mass strength considering the different geological conditions of the site.

### Table 2. Description of analyzed rock samples.

| Sample No. | Depth (m)   | Description                                                                 |
|------------|-------------|-----------------------------------------------------------------------------|
| 1          | 5.00–6.00   | Yellowish white, fine grained, slightly discolored, fossiliferous limstone,  |
|            |             | moderately hard, widely spaced                                              |
| 2          | 31.15–34.00 | Gray to dark gray, thinly laminated claystone, weak, closely spaced, parting |
|            |             | of silt and iron oxides                                                     |
| 3          | 36.50–37.50 | Grayish white to yellowish white, fine grained fossiliferous, porous,       |
|            |             | Limstone, moderately hard, wide spaced with occasional seams of calcareous  |
|            |             | silt, iron oxides staining, longitudinal cracks filled with calcareous silt. |

### Table 3. Mineralogical analyses of rock samples.

| Sample No. | Value | Value | Value | Item | Value | Value | Value |
|------------|-------|-------|-------|------|-------|-------|-------|
| Sample depth | 5.00  | 34.00 | 36.50 | Sample depth | 5.00  | 34.00 | 36.50 |
| L.O.I | 36.86 | 22.71 | 32.24 | SO₃ | 0.36 | 0.46 | 0.17 |
| SiO₂ | 8.91 | 27.86 | 13.59 | K₂O | 0.4 | 1.91 | 0.05 |
| Al₂O₃ | 1.85 | 7.46 | 1.76 | Cl | 0.04 | 0.04 | 0 |
| Fe₂O₃ | 7.25 | 23.73 | 10.85 | Total | 99.83 | 99.92 | 99.89 |
| CaO | 40.96 | 10.64 | 36.8 | S.R | 0.98 | 0.89 | 1.08 |
| MgO | 2.29 | 4.2 | 1.33 | A.R | 0.26 | 0.31 | 0.16 |

**Rock mass strength parameters**

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- The geological strength index (GSI) is determined and applied to the rock mass strength parameters derived from the RMR system in the previous step. The GSI is a system that has been introduced by Hoek [15] and Hoek et al [16] to provide reduction factors that has to be applied to rock mass strength considering the different geological conditions of the site.
As an illustrated example, a chosen rock layer through one of the deepest borehole (100 m) drilled in the site was used to apply the previously mentioned procedure to estimate rock strength parameters that could be used in the design. Applying the presented procedure for the borehole shown in Tables 4 and 5, two conditions were obtained as follow:

1. GSI = RMR76, where ground water rating is set to 10 (dry), and the adjustment of orientation rating is set to 0 (very favorable).
2. GSI = RMR89 – 5, where ground water rating is set to 15 (dry), and the adjustment of orientation rating is set to 0 (very favorable).

The strength of rock mass can be expressed according to Hoek and Brown failure criterion [17] in terms of principal stresses:

\[ \sigma_1 = \sigma_3 + q_u \cdot \sqrt{m_b \left( \frac{\sigma_3}{q_u} + S \right)} \]  

(1)

Where: 
- \( q_u \) = the unconfined compressive strength 
- \( m_b \) = the value of constant \( m \) for the rock mass, which is independent on rock type  
- \( S \) = is independent on rock type

\[ m_b = m_i \cdot e^{(GSI-100)/28} \]  

(2)

Where: \( m_i = 10 \) for limestone, 9 for siltstone, 4 for claystone, where

\[ S = e^{(GSI-100)/9} \]  

(3)

The values of \( (m_b) \) and \( (S) \) parameters for the different types of rock were calculated using Equations 2 and 3; results are shown in Table 4.

The strength of rock mass of each layer was estimated according to Bieniawski [13]. Once the value of RMR is determined, the class rating of rock mass can be estimated and consequently the shear strength parameters according to Mohr-Coulomb failure criterion.

**Limestone**

RMR values of the limestone ranged between 22 and 75. These values indicated that these formations have class II and IV, which classified as fair to poor rock mass.

Hence, for the limestone, the shear strength parameter \( (c) \) varied from 1 to 4 kg/cm², while the angle of internal friction ranged between 15 and 45°. Also the GSI ranged from 17 to 70 and the rock mass modulus ranged from 71,000 to 500,000 kg/cm².
Table 4. Rock Mass Rating (RMR) system parameter’s rate (G6).

| Layer Depth | Layer Description | Rock Intact Strength | R.Q. D. | Spacing Of Discontinuity | Discontinuity Condition | Ground Water Condition | Un-Adjusted RMR | Rock Mass Strength Parameters |
|-------------|-------------------|----------------------|---------|--------------------------|-------------------------|------------------------|----------------|-------------------------------|
| 0.00–4.00   | I                 |                      |         |                          |                         |                        | 59             | 1.618702 0.010509             |
| 4.00–5.00   | III               | 1                    | 8       | 10                       | 25                      | 15                     | 70             | 3.08267 0.035674              |
| 5.00–8.25   | III               | 7                    | 13      | 10                       | 25                      | 15                     | 59             | 2.081188 0.010509             |
| 8.25–11.30  | II                | 1                    | 8       | 10                       | 25                      | 15                     | 49             | 0.647178 0.003459             |
| 11.30–27.40 | IV                | 1                    | 3       | 5                        | 25                      | 15                     | 70             | 4.732092 0.135335             |
| 27.40–32.50 | II                | 4                    | 18      | 20                       | 25                      | 15                     | 82             | 4.732092 0.135335             |
| 32.50–37.80 | IV                | 1                    | 3       | 5                        | 25                      | 15                     | 49             | 0.647178 0.003459             |
| 37.80–40.00 | II                | 4                    | 18      | 20                       | 25                      | 15                     | 82             | 4.732092 0.135335             |
| 40.00–42.00 | IV                | 1                    | 3       | 5                        | 25                      | 10                     | 44             | 0.541341 0.001985             |
| 42.00–47.15 | IV                | 1                    | 3       | 5                        | 25                      | 10                     | 44             | 0.541341 0.001985             |
| 47.15–50.00 | II                | 7                    | 17      | 20                       | 20                      | 7                      | 71             | 3.194755 0.039866             |
| 50.00–93.65 | IV                | 4                    | 3       | 5                        | 10                      | 7                      | 29             | 0.712846 0.000375             |
| 93.65–100   |                   |                      |         |                          |                         |                        | 59             | 1.618702 0.010509             |

*I – Sand, II – Limestone, III – Siltstone, IV – Claystone
Silty claystone to claystone

RMR values of the siltstone ranged between 37 and 52. These values indicated formations with class III and IV, which classified as fair to poor rock mass. Hence, for this formation, the shear strength parameter (c) varied from 1 to 3 kg/cm$^2$, while the angle of internal friction varied from 15 to 35°. Also the GSI ranged from 32 to 47 and the rock mass modulus ranges from 71,000 to 94,000 kg/cm$^2$.

It is noticed that the estimated shear strength parameters from (RMR) system after Bieniawski [13] did not include the effect of rock slaking in case subjected to soaking into water. Hoek [15] considered the effect of lithology of rock mass through the value of (mi), which equaled to 4 for claystone and 9 for limestone. The results of the carried out calculations are listed in Tables 4 and 5.

Table 5. Shear strength parameters and rock mass modules (G6).

| Un-Adjustment RMR | Adjustment RMR | Geological Strength Index (GSI) | Rock Mass Class | Cohesion of the Rock Mass (Kg/cm$^2$) | Internal Angle of friction for Rock Mass (deg) | Rock Mass Modules (Kg/cm$^2$) |
|-------------------|----------------|---------------------------------|----------------|--------------------------------------|-----------------------------------------------|-------------------------------|
| 59                | 52             | 47                              | III            | 2–3                                  | 25–35                                        | 40,000                        |
| 70                | 63             | 58                              | II             | 3–4                                  | 35–45                                        | 260,000                       |
| 59                | 52             | 47                              | III            | 2–3                                  | 25–35                                        | 40,000                        |
| 49                | 42             | 37                              | III            | 2–3                                  | 25–35                                        | 94,000                        |
| 82                | 75             | 70                              | II             | 3–4                                  | 35–45                                        | 500,000                       |
| 49                | 42             | 37                              | IV             | 1–2                                  | 35–45                                        | 94,000                        |
| 82                | 75             | 70                              | II             | 3–4                                  | 35–45                                        | 500,000                       |
| 44                | 37             | 32                              | IV             | 1–2                                  | 35–45                                        | 71,000                        |
| 71                | 64             | 59                              | IV             | 1–2                                  | 35–45                                        | 280,000                       |
| 29                | 22             | 17                              | IV             | 1–2                                  | 15–25                                        | 71,000                        |

**Silty claystone to claystone**

Conclusion

(1) The geological formations of the Toshka Fourth Depression generally comprise top layer of wind-transported loose sand, mixed with some silt and some limestone fragments of pebble size. This layer is considered unsuitable as a bearing stratum.

(2) The top layer is followed by a main layer of limestone which is intercalated (or as a successive layers) of argillaceous rocks of siltstone and claystone.

(3) All argillaceous rocks loose up to 80% of its strength when soaked in water.

(4) A combination of limestone with clay stone or siltstone gives properties worse than one type of rock alone.

(5) All the encountered rock formations are impervious. If circumstances allow for water flow, then it produces internal erosion which might be a problem for hydraulic structures.
(6) According to the results of the RMR procedure that applied on each layer of one of the deepest borehole, it is found that rock layers are generally fair to poor rock.

(7) According to the sample calculation carried out on one of the borehole, it can be concluded that shear strength parameters depending on RMR alone is not accurate and would result in some overestimated capacities, especially in the case of side slope stability, dam’s foundation and tunnels

Disclosure statement

No potential conflict of interest was reported by the author(s).

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