ENGINEERING AND GEOPHYSICAL APPROACH FOR CONSTRUCTION SITE SELECTION AT AL-AMAL AREA, SOUTHEAST OF CAIRO, EGYPT

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Abstract

Generally, near surface geophysical techniques are widely used for outlining the shallow subsurface features. High resolution microgravity measurements approved its applicability for detecting the near-surface caves and other shallow features. The current paper is aimed at demonstrating the link between geophysical and engineering parameters of the soil and rocks in one package required by engineers. These combined parameters can provide a complete view for near surface features at any site before starting constructions.

Microgravity measurements were carried out in the Al-Amal area southeast of Cairo as a case study in order to detect the near-surface caves and other shallow features. The field measurements were performed using two high resolution gravity meters, Scintrex CG-5 Autograv and LaCoste&Romberg model D, both with resolution of one µGal. The survey showed there are indications of voids/caves in the uppermost subsurface layer formed by the Eocene limestone. Zones of negative Bouguer gravity anomalies were defined in two small subareas under study.

At the same time, rock samples were collected from an exposed section through a small valley in the study area. The collected samples were subjected for soil mechanics tests to study various mechanical and petrophysical properties of the soil and rocks. The grain size analysis revealed coarse grained classification of the soil. The other geomechanical and petrophysical analyses provided detailed rock and soil characterization, such as compressive strength, porosity, bulk density and permeability. In accordance with microgravity, it was found that the first 2 – 3 m represent low strength and low stability formation for big constructions. This layer should be either removed, or the foundations should penetrate to bigger depth.

Inženýrský a geofyzikální přístup k výběru stavebního prostoru v oblasti Al-Amal jihovýchodně od Káhiry, Egypt

Obecně platí, že povrchové geofyzikální přístrojové metody do mělkých hloubek se široce používají pro sledování nehlubokých podpovrchových struktur. Vysoce přesná mikrogravimetrická měření umožňují provádět detekci podpovrchových dutin, které se nalézají blízko povrchu země stejně jako dalších mělce uložených struktur. Tato práce se zaměřuje na spojení, které existuje mezi geofyzikálními a inženýrskými charakteristikami půdy a hornin formou společného výstupu, tak, jak to požadují inženýři. Tyto kombinované charakteristiky umožňují komplexní pohled na nehluboké podpovrchové struktury v libovolném místě ještě před započetím výstavby.

Mikrogravimetrická měření se uskutečnila v oblasti Al – Amal jihovýchodně od Káhiry jako studijní projekt na určování dutin, které leží mělce pod povrchem a dalších nehlubokých struktur. Polní měření se prováděla pomocí dvou vysoce přesných gravimetrů, Scintrex CG-5 Autograv a LaCoste&Romberg model D; oba s přesností 1 µGal. Průzkum indikoval prázdné prostory/dutiny v nejhořejší podpovrchové vrstvě tvořené eocenním vápencem. Na základě měření byly definovány zóny záporných gravitačních Bouguerových anomalií ve dvou malých suboblastech.

Ve stejné době se uskutečnil odběr vzorků hornin z navrženého profilu přes malé údolí ve studované oblasti. Odebrané vzorky byly zkoumány prostřednictvím půdních mechanických testů z hlediska různých mechanických a petrofyzikálních vlastností půdy a hornin. Granulační analýza zjistila, že půda je klasifikována jako hrubě granulární. Další geomechanické a petrofyzikální rozbory poskytly podrobné charakteristiky hornin a půdy, jako je odolnost na tlak, pórovitost, objemová hustota a propustnost. Souhlasně s výsledky mikrogravimetrie se zjistilo, že prvé 2 – 3 m představují formaci s nízkou odolností a stabilitou pro velkou výstavbu. Tato vrstva by buď měla být odstraněna, nebo by se základy měly založit ve větší hloubce.

Key words

microgravity, soil mechanics, petrophysical properties, caves, construction site

1.Introduction

Successful applications of the micro-gravity technique for caves detection can be found, beside others, in Bližkovský (1979), Lakshamanan and Montlucon (1987), Cuss and Styles (1999) and Mrlina (2002). The applicability of microgravity measurements in Egypt for caves detection, especially for archaeological prospection, was proved by Issawy (1997, 2001) and Issawy et al. (2002).

In the past few years, the constructions of inhabitancies and new cities were extended to the southeast of Cairo, where the cavernous limestone forms near subsurface. The existence of caves and sinkholes represents a hazard for such new urban areas. Therefore, it was important to outline and map the natural voids and cavities common in the limestone formation in this area before building new constructions. In addition, the analysis of the soil and rock properties in the study area can provide complete information in one packet with near subsurface features determined by microgravity surveys.

The area of Al-Amal is located 20 km southeast of Cairo, in the Eastern Desert near Qattamiya region between longitudes 31° 30` and 31° 40` E and latitudes 29°45` and 30° 00` N (Fig. 1). The area of about 2 square kilometres was selected for micro-gravity investigations and studying the rock and soil properties.

Geomorphologic features of the area under study and the surroundings are characterized by the Cairo-Suez district which is bounded from North by an east-west expanding ridge formed of Gebels Genefa, Um Qamar, and Um Raqm. A topographic depression to the south of this ridge is limited to the south by another east-west ridge formed of the hills of Gebels Owibed and Gafra. Further south, there is the third ridge composed of Gebel Al Mokattam and Al Qattamiya.

The geologic setting of the study area and the stratigraphic succession reflect the presence of exposed Cretaceous rocks at the core of Gebel Shabrawet. Two major rocks units are present - the lower unit consists of marl and shale (250 m thick) and the upper unit consists of Turonian to Cenomanian limestone (140 m thick). The middle Eocene rocks cover large areas of the Cairo-Suez district. The Upper Eocene rocks are made up of sandy brownish limestone with sandstone beds. Shukri and Akmal (1953) described a section about 78 m thick. The Oligocene sands and gravels uncomfortably overlie the upper Eocene sediments and underlie the Miocene basal beds. The most

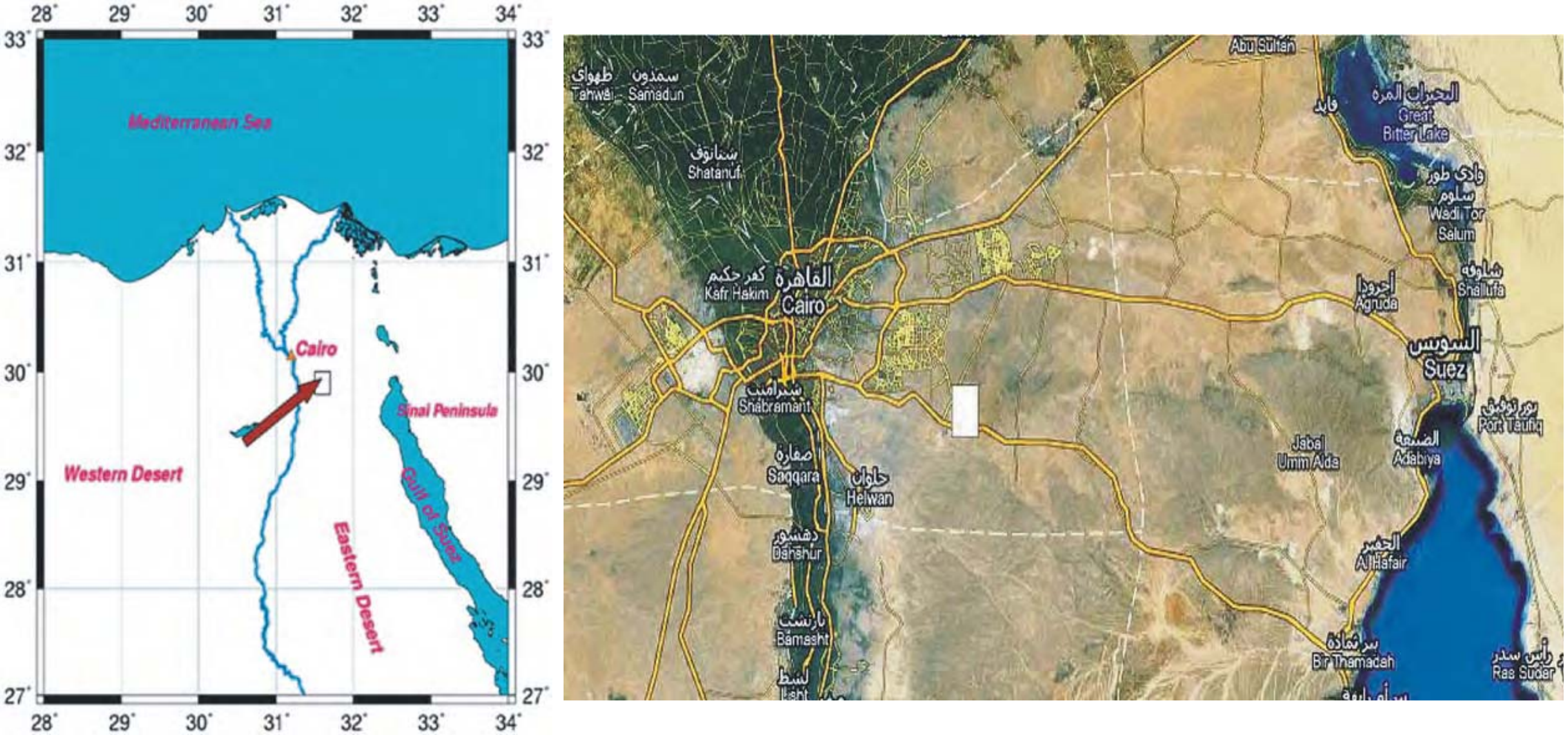

Fig. 1: Location map of the area under study

pronounced faults are the East-West faults which are responsible for the formation of most of the structural and topographic highs of the area. They may have been formed by tangential compressive stress during Pre-Cambrian. According to Said (1962) the stresses which created the structures of the area were rather tensional. The surface formation at the study area is the Upper Eocene.

Some geophysical studies (gravity and magnetic) were carried out in the Cairo-Suez district. According to Nakhla (1982), gravity and magnetic anomalies led Bayoumi and Shenouda (1971) to identify a major syncline occupying the central part of the Cairo-Suez district .This syncline lies within a major graben. The area is also affected by NW oriented faults. The NW and E-W oriented faults extend upward from the Pre-Cambrian to the overlying sedimentary section. They concluded that the total thickness of the sedimentary section ranges from 3000 to 4500 meters. Abdalla et al. (2007) performed a geoelectric resistivity survey in order to outline the shallow subsurface karstic features and cavities. The results of vertical electrical soundings (VES) subdivided the shallow subsurface section in the study area into three main geoelectric zones. The surface zone is composed of sand, gravel and fossiliferous limestone with high resistivity values and small thickness. The second zone is composed of sandy clay and clay with low resistivity values. The third zone is considered to be the bed rock, where it consists of consolidated sand, limestone and marl with relatively high resistivity values.

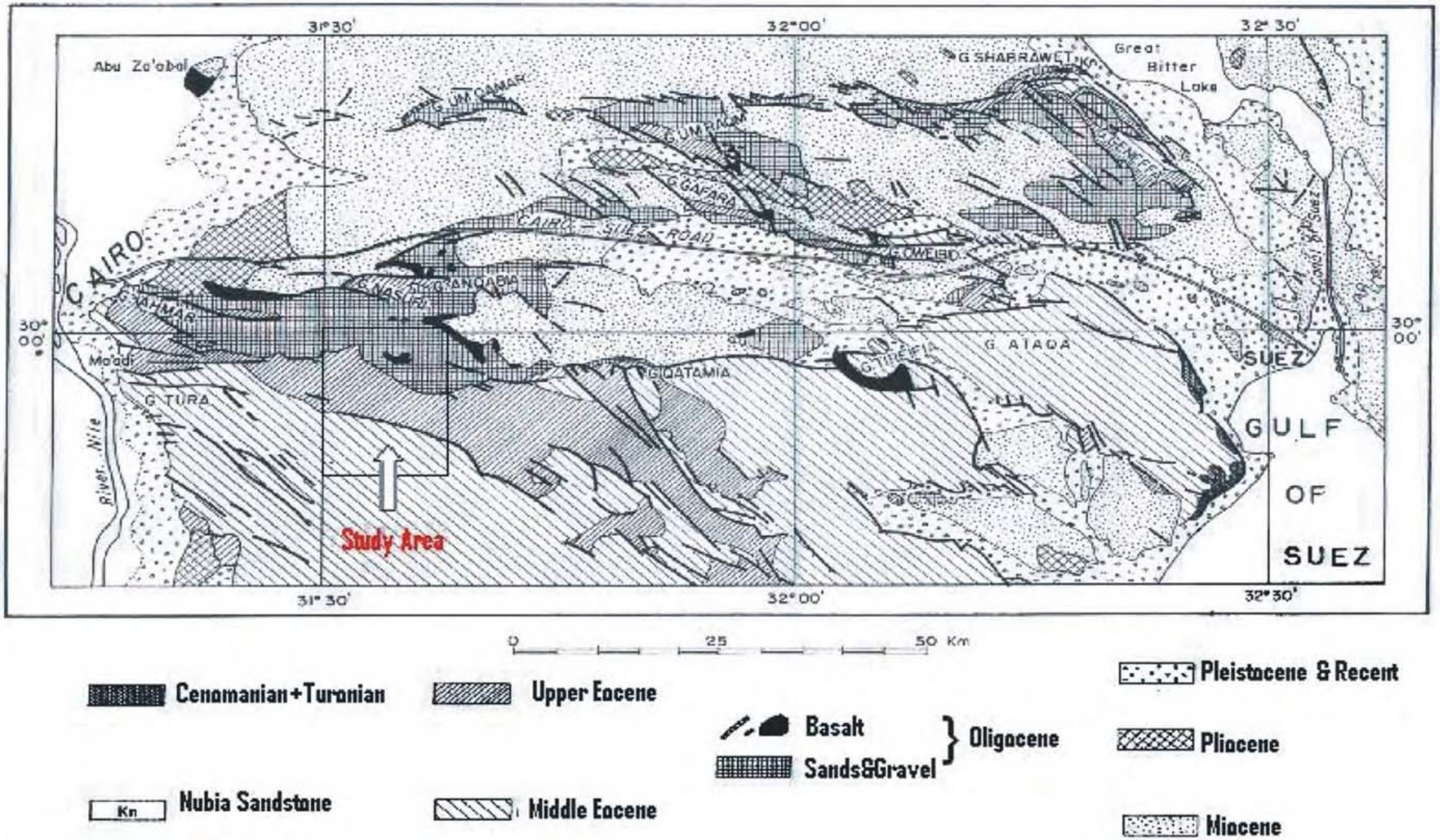

Fig. 2: Geological map of the larger area (Said, 1962)

2. Microgravity measurements

The microgravity technique consists of measuring minute variations of the gravitational pull of the Earth. Gravity anomalies arising from voids and cavities are superimposed upon much larger variations due to height, latitude and regional geological variations, and are virtually undetectable by conventional gravity investigations. Although the method is simple in principle, measurement of the minute variations in the gravity field of the Earth requires the use of highly sensitive instruments, strict data acquisition procedures and quality controls, careful data reduction and sophisticated digital data analysis techniques to evaluate and interpret the data.

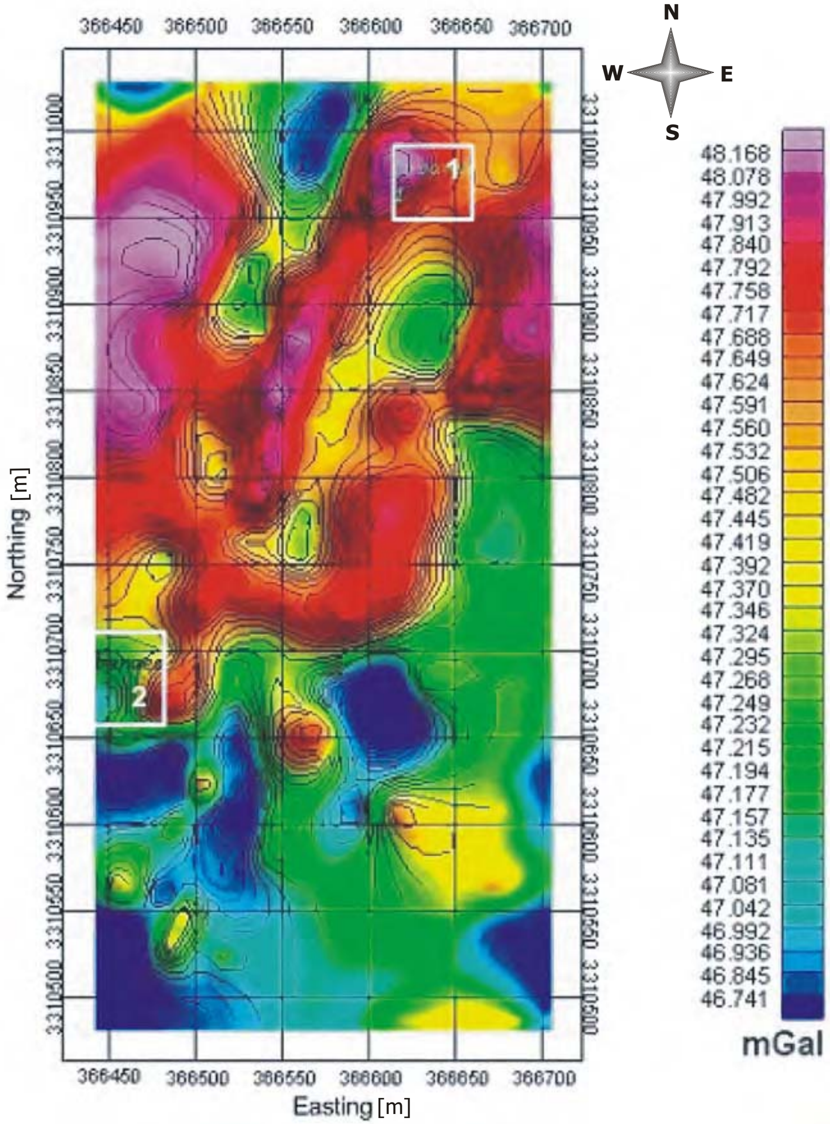

Fig. 3: Bouguer anomaly map of Al-Amal area for 5-25m irregular random grid spacing; two subareas 1 and 2 are marked by rectangles at W and NE part of the area. Coordinates are in WGS84/UTM system.

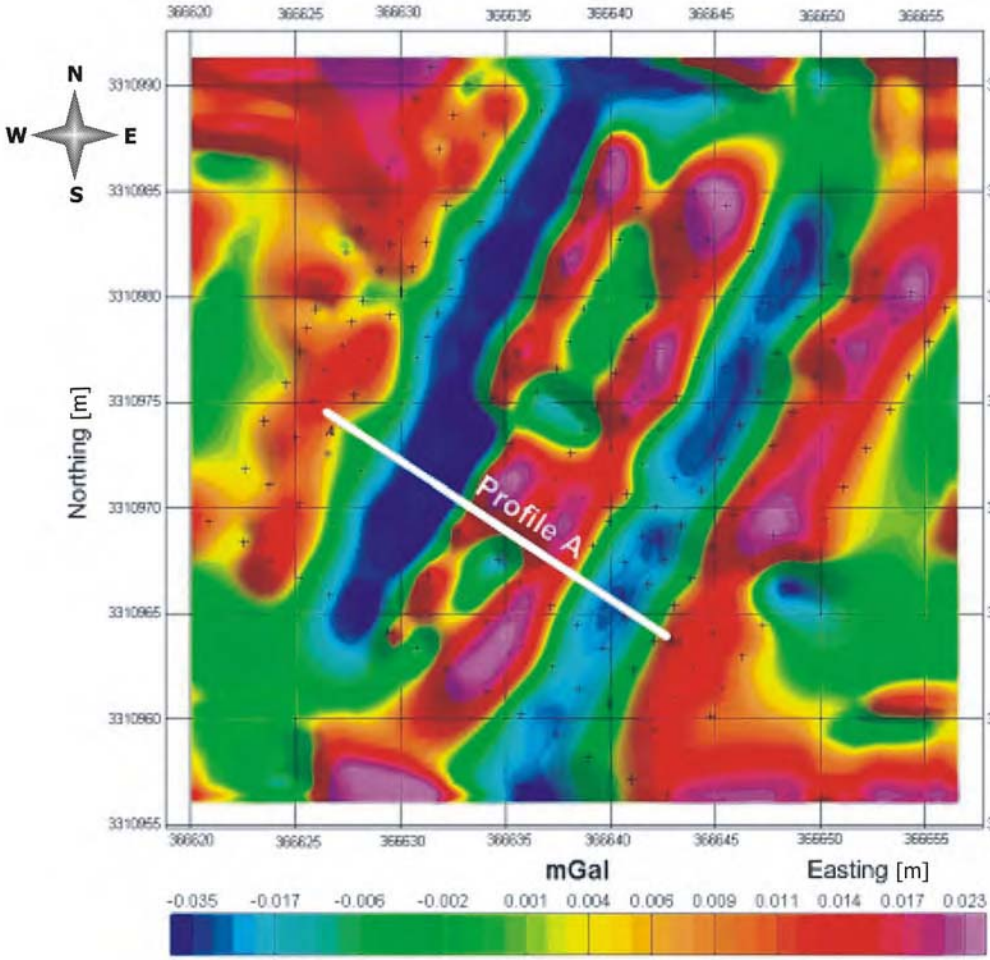

Fig. 4: Bouguer anomaly map of Subarea 1, Profile A location.

2.1 Gravity data acquisition and processing

Closely spaced gravity stations in regular or semi-regular grid may enable to increase survey resolution, so that cave/void gravity disturbance can be recognized at the background of geological and topographical effects. Therefore, we started our micro-gravity survey using an irregular grid spacing of 5 - 25 meters as a reconnaissance phase in order to get a general view about the maximum and minimum gravity signals distribution in the study area. At this stage, gravity data were acquired using Scintrex CG-5 Autograv with resolution of 1 microGal (1 μGal = 10^{-8} ms^{-2}); this gravity meter system is based on a quartz spring which introduces a very small temperature changes and hence, the drift correction also can be automatically corrected with high precision in most cases. The precision of the micro-gravity survey was kept as high as possible considering very small gravity signal of voids. We achieved the standard deviation of 5.5 micro-Gals. The position and elevation of 137 stations were determined using Trimble differential Global Positioning System (GPS) with accuracy better than 2 cm. Geosoft Oasis Montaj software version 7.2 of Geosoft Inc. was used for gravity data adjusting and presentation. The assumed average surface rocks density of 2.20 g cm^{-3} (2200 kg m^{-3}) was selected for the calculation of Bouguer gravity anomalies, which the Bouguer anomaly map of the study area was produced of (Fig.3). This density corresponds to the values determined from the rock samples in Tab.4. Terrain corrections were substituted by 2.5D forward gravity modelling of shallow valleys, otherwise the terrain was flat.

The Bouguer anomaly map of the area (Fig. 3) can be divided into two parts depending on the distribution and trends of Bouguer gravity values. The main trend in the northern part of the study area is NE to SW, with relatively low amplitudes of gravity signals. The southern part of the area is characterized by relatively flat gravity field with number of more or less isometric anomalies with relatively high amplitudes. Since this Bouguer anomaly map in Fig.3 was aimed mainly at gravity reconnaissance of the whole study area, the second phase of detailed microgravity survey was started by dividing the area to few subareas according to the qualitative evaluation of the map. In this second gravity campaign, separated grids with line interval of 2 meters were designed. Gravity readings were taken at

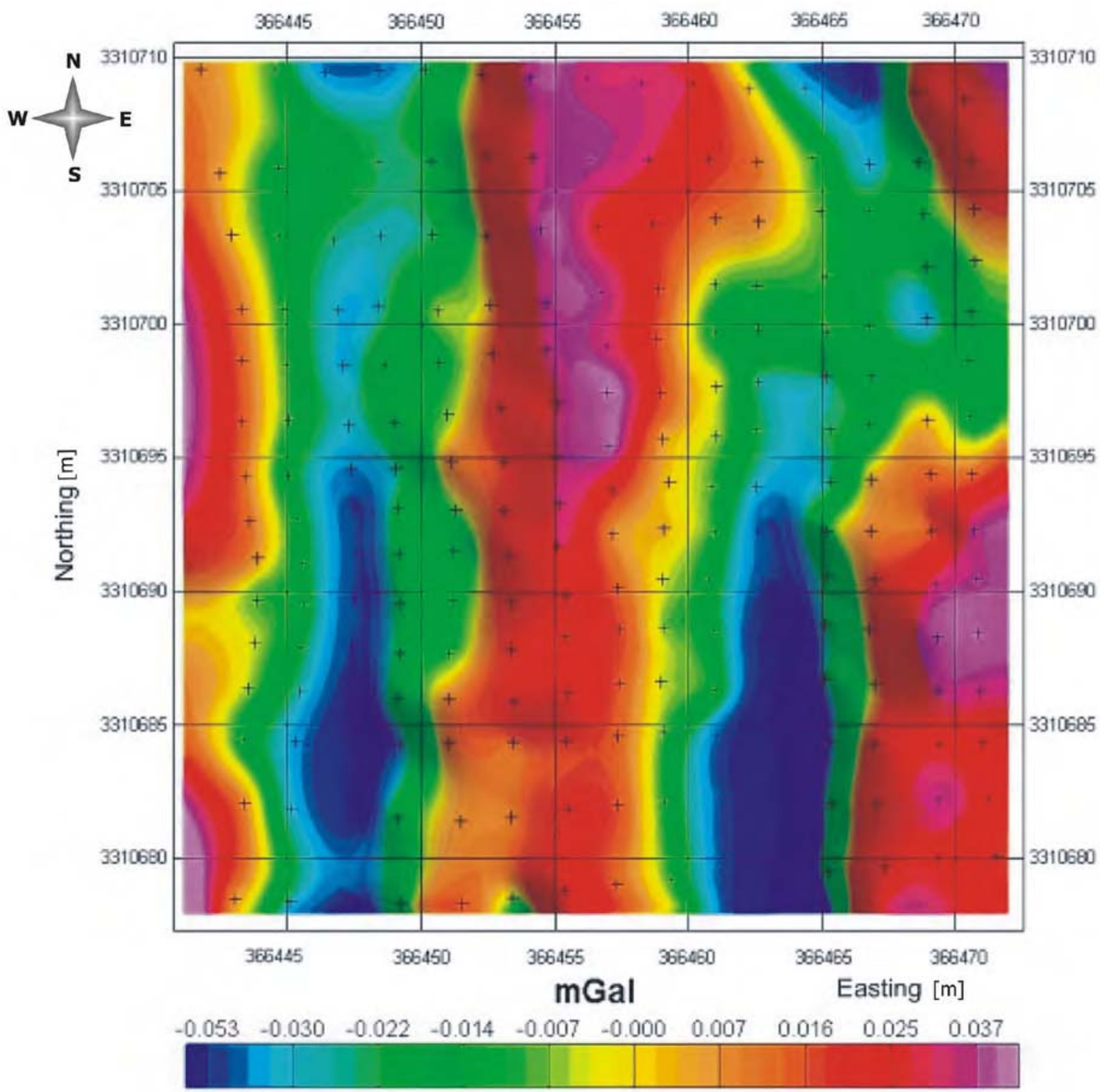

Fig. 5: Bouguer anomaly map of the Subarea 2

320 stations spaced at an interval of 1m. Gravity data were acquired using a LaCoste&Romberg gravity meter model D with resolution of 1 microGal in parallel to the Scintrex CG-5 Autograv. The standard deviation of the gravity measurements using LCR model D was 6 microGals, similar to Scintrex CG-5. The data of both gravity meters were precisely adjusted and processed daily to repeat and confirm any considerable gravity signal. The Bouguer anomaly maps of the two selected subareas were established. We present these two subareas as an example of a detailed microgravity survey, with the respective Bouguer anomaly maps in Figs. 4 and 5.

2.2 Gravity data evaluation

The Bouguer anomaly map in Fig. 4 (Subarea 1, total 236 gravity points) shows relatively low gravity signals (maximum difference about 100 µGal). The gravity field is characterized by two parallel gravity anomalies oriented NNE-SSW. In case the negative strips are related to subsurface geological features, they may indicate zones of weakness with possible presence of voids (caverns, caves), either empty, or filled by fractured rock debris and/or sand. As the strike of anomalies is in good accordance with the occurrence of surface voids and caverns, we may deduce that the anomalies reflect such buried features. This would be important information for construction engineers as for designing proper construction foundation plans.

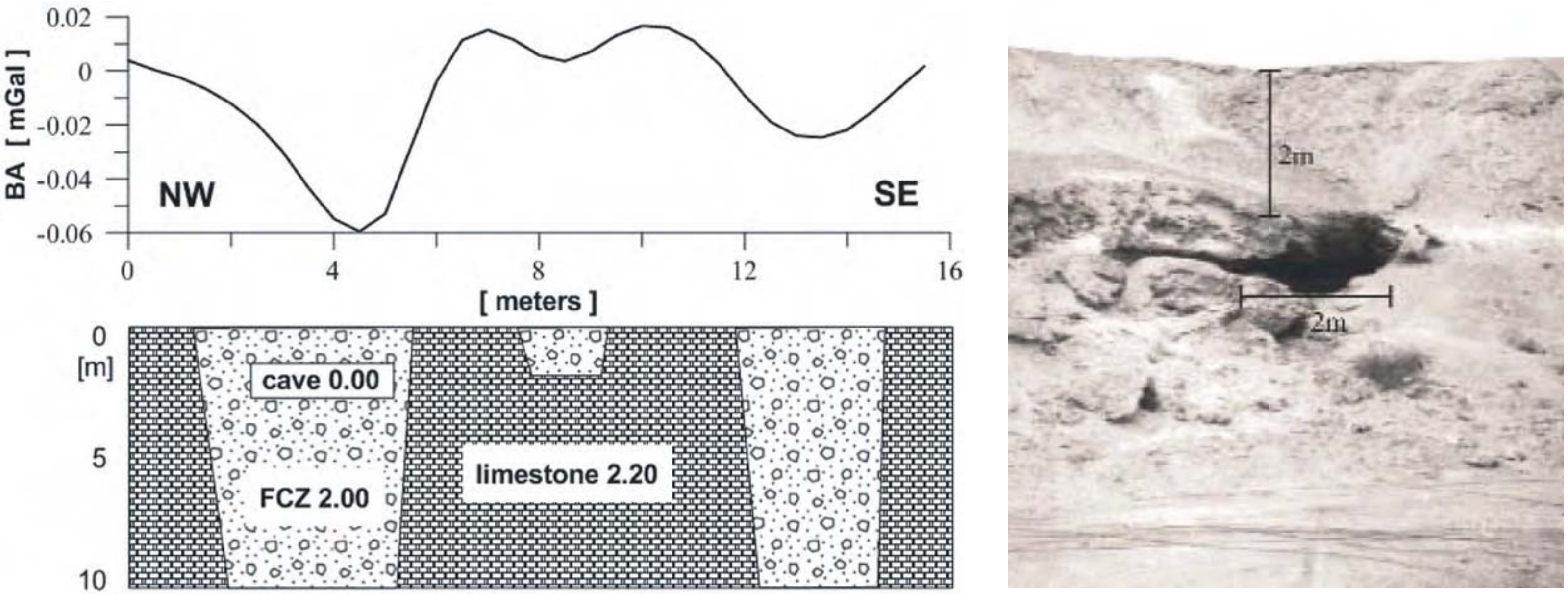

Fig. 6: Gravity 2.5D tentative model of observed Bouguer gravity anomaly Profile A in Subarea 1 (Fig. 4); FCZ fractured cavernous zone; photo (right) showing type of caves common in the surrounding area.

The other detailed Bouguer anomaly map in Fig. 5 (Subarea 2, total 256 gravity points) is characterized by presence of S-N gravity gradient with gravity values increasing towards north. This gradient is significantly disturbed by two S-N heading zones of lower gravity (maximum difference about 280 μGal). There may be the same source of these negative gravity zones as suggested in Subarea 1.

One gravity profile NW-SE was chosen crossing the centre of the gravity anomalies in the Subarea 1 (Fig. 4) to outline the near surface features. We developed a model using 2.5D gravity modelling software Gmodel of Lacoste&Romberg Inc. As disturbing bodies we considered a near surface air filled cave with estimated depth of 2 - 3 meters. However, such cave cannot produce the observed signal. We may suggest that the anomaly on the NW side is likely caused by such a void within a cavernous zone strongly fractured up to the surface with decreased bulk density approaching to 2.00 g. cm^{-3}. The SE anomaly with lower amplitude can be the expression of such a zone itself without a bigger void. The tentative model of near subsurface is shown in Fig. 6.

3. Geotechnical properties of the foundation beds

To realize the aim of this paper, studying the rock and soil properties was an important part of our work. The determination of the rock and soil parameters of the area under investigation was performed by field and laboratory work. The field work represented rock sampling in the study area, while the laboratory work was the measurement and determination of various mechanical and petrophysical parameters using various types of analyses.

3.1 Sample collection

The exposed rock section through a small valley in the area under investigations is about 10.7 m in height and the rock formation and layers are illustrated in Tab.1

Tab. 1: Depth and lithology of rock samples under study.

Bed No.	**Sample No.**	**Exposed thickness [cm]**	**Lithology fossiliferous limestone**
1	1 and 2	140	- cavernous
2	3	180	- marly
3	4 and 5	350	- shaly
4	6 and 7	200	- chalky
5	8 and 9	200	- sandy

3.2 Mechanical analysis

The studied samples of soil were obtained from fragments of sand and/or clay existing within the limestone beds. The quantitative data that the engineers need before starting a construction are mainly mechanical properties, such as stiffness and strength of the soil; these properties can be determined by the following mechanical tests:

Grain Size Analysis:

The grain size may be determined as the first significant property of soils. This kind of test is performed using sieves with different opening diameters to distinguish between the different grain sizes. The results of that mechanical analysis showed that the particle size can be defined as gravel (5.56 %), sand (82.95 %) and silt/clay (11.5%). The average grain size diameter of the soil samples for the study area is 0.5 mm. This mechanical analysis is used for the definition of other parameters, as follows:

- ***The Uniformity Coefficient (Cu):*** defines the particle size range of the grains of the soil samples. The classification used is:

Cu < 5 very uniform
Cu = 5 medium uniform
Cu > 5 not uniform
For our samples Cu equals = 0.6/0.1 = 6. That mean grain sizes of the soil in the area under investigation are not uniform.

- ***Coefficient of Gradation or Coefficient of Curvature (Cg):*** defines the shape of the particle, curvature of the grains. This coefficient was calculated from laboratory measurements and the value equals 1.3 for our samples. This value, according to the scale of this coefficient, is considered to be of well graded (for values 1- 3 the sample is well graded).

Grain size analysis defined our samples as coarse grained soil, with not uniform and well graded grains. This type of soil especially the coarse grained soils have good load bearing capacities and good drainage qualities, and their strength volume change characteristics are not significantly affected by change in moisture conditions.

Physical engineering properties of soil:

We performed some principal laboratory tests on clays of the soil on our samples, like Atterberg limits, consistency indices, and swelling pressure.

Atterberg Limits and Consistency of Soil can be defined as the boundary between the states of soil. Atterberg limits are empirically developed but widely used procedures for establishing and describing the consistency of soil:

Tab. 2: Atterberg limits of the studied clay samples from bed No. 3.

Sample No.	Liquid Limit (L.L.)	Plastic Limit (P.L.)	Plasticity Index (P.I.)	Shrinkage Limit (S.L.)	Free Swell [%]
4	63	29	34	11.62	130
4	68	27	41	11.21	120
5	60	23	37	10.91	110
5	62	30	32	11.70	140

- ***Liquid limit (L.L.):*** The values of the liquid limit are ranging from 60% to 73% (average value is 66.5%).
- ***Plastic limit (P.L.):*** The values of the plastic limit for the soil samples are ranging from 23% to 29% (average values is 26%).
- ***Shrinkage Limit (S.L.):*** one of the parameters that can be determined from the following equation:

$$S.L. = \frac{(W_s - W_d) - (V_s - V_d)}{W_d}, \qquad (1)$$

where S.L. = shrinkage limit,

W_s = weight of saturated sample,

W_d = weight of dry sample

V_s = volume of saturated sample and

V_d = volume of dry sample.

The values of this parameter are ranging from 10.9% to 11.7% (average value is 11.3%).

- ***Free swelling of soil:*** This test is performed by putting 10 cm^3 of dry soil into a 100 cm^3 of water filled into a graduated cylinder. After 24 hours the volume of the settled and swell soil is read on the cylinder.

Tab. 2 shows the Atterberg limits of the studied clay samples from the area under investigation. The plasticity determination according to Casagrande (1948) showed that the clay samples of our study area can be classified and defined as inorganic clay of intermediate plastic soil.

Tab. 3: Strength classification of the samples from the uppermost formation

Sample No.	Compressive Strength [kg/cm^2]	Rock Type	R.Q.D. [%]	Description
1	68.8	Medium weak	36	Poor
2	52.2	Medium weak	26	Poor
3	166.4	Medium weak	39	Poor

- ***Compressive Strength*** was determined from mechanical tests and is presented in Tab. 3. The results of this test indicated that starting from the sample No. 3 which represents the third bed layer in the study area; the beds can bear a big construction or inhabitancies. The first and second beds are of weak rock type and they cannot bear a big construction; rather they have to be removed before constructing. However, rock quality designation R.Q.D. assigns all samples, including sample 3, to rock type group "poor".

3.3 Petrophysical Parameters the collected core samples.

Petrophysical laboratory investigation was performed in order to determine porosity, permeability, rigidity and bulk modulus. These rock properties indicate the ability of the bed rock to bear big constructions or possibly other engineering developments.

The study of these dynamic parameters (Tab. 4) showed that the bed rock is suitable engineering purposes, especially when the rocks are in dry state.

Tab. 4: Overview of petrophysical parameters of rock samples

Sample No.	Porosity Φ[%]	Grain density ρ_g [g/cc.]	Bulk density ρ_b [g/cc.]	Permeability K [md]
1	21.85	2.71	2.12	30.77
2	19.90	2.70	2.17	18.68
3	16.10	2.63	2.21	8.84
4	15.60	2.68	2.26	0.80
5	14.10	2.67	2.29	1.10
6	19.90	2.66	2.13	8.50
7	21.10	2.56	2.09	8.00
8	10.40	2.66	2.38	0.02
9	9.70	2.68	2.42	0.03

The water saturated rocks exhibit lower rigidity and elastic dynamic characteristics. The upper most layers (samples No.1, 2 and 3) in the studied succession are characterized by high porosity, high permeability and low rigidity. This is obviously due to the highest rate of erosion and weathering, but possibly also due to the presence of caverns and a lot of fossil shells within the limestone. These results should be considered in all engineering plans on site.

4. Conclusion

The study of the near surface features using microgravity survey and soil/rock mechanics in parallel was performed in the area of Al-Amal, SE of Cairo. It turned out that the application of such combined investigation can bring complex information on geomechanical composition of the near subsurface. This is crucial in places with high degree of weathering, karstic phenomena, fractured rocks and other sources of rock massif deterioration, especially if big engineering developments are planned.

We present below the principal results of the study:

- Microgravity survey indicates the presence of some shallow near sub-surface features in the form of caves with different dimensions and depths ranging from 2 to 4 meters. The caves are located within zones of weathered cavernous limestone with estimated decrease of bulk density by 0.20 to 0.25 gcm^{-3} compared to normal (average) density of investigated limestone about 2.20 g cm^{-3}.
- The grain size analysis showed the coarse grained soil, not uniform and with well graded grains. This type of soil has good load bearing capacities and good drainage qualities, and their strength volume change characteristics are not significantly affected by change in moisture conditions.
- The study of the clay properties based on the plasticity chart according to Casagrand´s (1948) shows that the clay of our testing site is defined as inorganic clay with intermediate plasticity.
- The quantitative mechanical tests of rock stiffness and strength were applied. The results show that starting from the third bed layer in the study area (from depth of about 3 meters or more) the beds can bear a big construction or inhabitancies. The first and second beds are of weak rock type and must be removed before constructions.
- The study of porosity, permeability, rigidity and bulk modulus indicates that the bed rock is suitable for buildings and other engineering purposes especially when the rocks are in dry state. The upper most layers (sample No.1, 2 and 3) are characterized by high porosity, high permeability and low rigidity. This is due to the presence of fractures and caverns and a lot of fossil shells in limestone; these technical and scientific notifications must be considered during the constructions.

- The results from engineering and petrophysical properties investigation are in accordance with the results of microgravity survey showing low stability in the first 3 – 4 m of the uppermost layers in some zones.
- All the geophysical and engineering parameters of the study were collected in one packet and became in hand for the decision makers and for the engineers during the construction planning process.

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