

**Assessment and Monitoring the
groundwater risk using electrical and
shallow refraction seismic measurements
and conservation aspects of Hawara pyramid**

By

B. Ismail* and M. M. Abou Heleika**

Assessment and Monitoring the groundwater risk using electrical and shallow refraction seismic measurements and conservation aspects of Hawara pyramid

By

B. Ismail* and M. M. Abou Heleika**

* Conservation Dept. Faculty of Arts, South vally University
Qena, Egypt.

** Geology Dept. Faculty of Science, El Minia University,
Egypt.

1. Abstract:-

The present research programme concentrated on knowing the physical and chemical properties of mudbrick to identify the characteristics of hawara materials, Various experiments have been selected such as grain size distribution, x-ray diffraction and scanning electron microscopy. Adobe (mudbrick) and salt samples collected from the hawara pyramid were analyzed by XRD method.

The groundwater level is in continuous rising around Hawara pyramid, which is considered one of the valuable monuments in El Fayoum district. Due to the rareness of the hydrogeologic data, two geophysical methods were used in simulating the groundwater aquifer in the area. Simulation is the process of getting more reliable subsurface model from measured data set.

For achieving this purpose, twenty vertical electrical sounding stations and forty-eight seismic shots were conducted in a nearly regular grid around the pyramid. The measured data were processed and inverted by three-computer software. 2 D model was calculated for the area from the interpretation of each stations. As a result of this simulation process ,three layer of different physical properties and thickness can be detected. some engineering

solutions for decreasing the groundwater level were discussed, depending on the result of this simulation.

Introduction:-

Hawara pyramid is considered one of the highly valuable monuments in El Fayoum, Egypt. It is the burial place of the Middle Kingdom pharaoh Amenemhet III. The pyramid was built from the mudbricks and it was covered by limestone, which is completely removed as a result of weathering process. On the other hand, the core of the pyramid is composed of limestone blocks, which is now completely immersed in the groundwater and subjected to deterioration process. The pyramid basis area is square of 100 m side length, while the pyramid's height is 56 m. The inclination angle of the pyramid side is 48 degree.

Mudbricks are the most common construction material employed in ancient Egypt. Mudbricks, also known as adobe which, was the most common bulding material employed throughout the ancient near east (Oates, 1990). It is a building medium well suited to the Egyptian climate (Fathy, 1973). It also has the considerable advantages of adaptability ease of construction and durability (Oates, 1990). Egyptian bricks were mainly produced from Nile alluvium. Nile alluvium is composed of clay, silt and sand in proportions that vary depending upon locations.

It's suitability for brick making in any given region depends upon the particular composition of the local alluvium. If the clay percentage is too high, however, alone will produce mudbricks that dry slowly, shrink, crack and lose their shape (Gurcke, 1987). So Mudbrick is composed of sand, silt, and clay; fibrous organic materials such as straw may also be added. Sand was added to increase workability and molding and minimize crackng when the adobe dried. Non-clay minerals act as internal binder. They reduce contraction and prevent cracking (Torraca, 1982). Sand reduces shrinkage and cracking during drying as well

as excess plasticity (Gurcke, 1989). Chopped straw and animal dung act as mechanical binder and increase both the strength and the plasticity of the clay (Lucas, 1999).

When straw is the main binding agent, the resistance of mudbrick to fracture decreases as the straw decays (Oates, 1990). Fathy (1980) indicated that shrinkage of bricks made of pure alluvium was about 37 percent after drying. These bricks also cracked very badly a short time after molding. The adding of straw and sand as binding agent mimseses this phenomenon.

The fermentation of alluvium and binding material such as sand and straw produces lactic acids that make the bricks stronger and less absorbent and results in a brick with a highly desirable homogeneity of texture not present in an unfermented brick (Fathy, 1980). Bricks were formed with the aid of small hand mold consisting of rectangular frames without top or bottom. The basic design of this mold has remained unchanged for millennia, and both depictions and models of similar molds as well as an actual example from ancient Egypt, (Lucas, 1969). Use of molds produces bricks of more or less identical size and provides a dependable construction unit. Brick dimensions in particular have often been used as chronological indicators. The size of the ancient Egyptian mudbrick varied, some had the same dimensions as the recent ones, while others had a very large size (Helmi, 1990).

The pyramid is surrounded from the western side by big irrigation canal called Bahar Wahbi (Pl.1.Fig.1). All the cultivated land west of this canal is irrigated by flooding technique without any adequate drainage system. Also desert reclamation project was started 20 years ago at the area in the north of the pyramid. All these factors lead to the continuous rising of the groundwater table in the pyramid and affect it in very dangerous way. Decreasing the groundwater level represents the main task for some of the hydrological models studies. But most of these models

assumed that subsurface layers for the model parameters are homogenous and isotropic. This assumption is not true due to the nature of the sediments. The aim of this study is to use two geophysical methods, the vertical electrical resistivity and shallow refraction seismic measurements for seeking the geometry of the subsurface layers around the pyramid such types of studies had been carried by authors e.g. Flathe (1970) and Ackermann (1974). Due to scarcity of the subsurface geologic and hydrogeological data, we used the terminology of simulation process. By this process, the composition and distribution of the groundwater bearing formation can be detected from surface measurements. Since the surface geologic information will help in building the assumption of this process; the geologic setting of the area is summarized in the following:

The stratigraphic sequence in El-Fayoum depression generally ranges in age from Middle Eocene to Recent (Fig. 1) Said, (1981), Tamer (1968) Conco, (1989), and Ibrahim, (1994). Only two formations from the middle Eocene are represented in the area, which are the Observatory and Wadi Rayan formations. The Observatory Formation is formed from shallow marine, dense medium bedded limestone with local chert and few nummulites. The Wadi Rayan Formation is represented by shallow marine limestone intercalated by shale and sandy shale. The Quaternary sediments unconformably overlie the Eocene sediments which they mainly consist of clay, sandy clay and sand intercalated with silt. The Pliocene deposits are also represented in some local sites. They are formed from sandstone beds alternating with shale and conglomerates.

The main objective of the present work is to study the deterioration factors affecting Hawara pyramid structure and deterioration of mudbrick of the site, furthermore, the main aim of this research is to investigate the main source of groundwater recharge.

Mudbrick of the site is essentially of clay, silt, and sand that are mixed with water and shaped in molds, to become bricks. Straw is used as binding material.

Alluvium, which is natural aluminosilicates, has a layered, plate-like structure of linked aluminosilicate tetrahedra contained within layers of magnesium or aluminium hydroxide. Clay both absorbs and adsorbs water and becomes plastic (Spener 1994). This action is accompanied by an expansion in volume that is reversed when water is lost from the clay. Some clay minerals expand more than others as they absorb moisture, eg montmorillonite (an aluminosilicate with variable composition, which has a high cation – exchange capacity). The causes of deterioration of hawara adobe were identified as follows: rain, wind and sun. Climate is certainly one of the most serious causes of adobe structure. The daily temperature changes provide condensation of water vapour on the surface. The high insulation, the daily variations of temperature and relative humidity and the physical action of water condensation and erosion wind action are the most deterioration factors of the site. The rain beating and running on the structure dissolves the clay. The wind exercises mechanical pressure and abrasion, which were particularly damaging to surfaces already weakened by rainwater. The sun heats and dehydrates the adobe, causing the material to cause cracks and break. This is accompanied by crystallization of salt. The degree of the weathering of adobe is closely related to the effects of moisture. Therefore, the durability of adobe is closely related to its porosity. So, adobe, as a composite material, is porous, soft, and wettable; and when it is wet, its compressive strength is reduced, because of absorption – desorption by clay minerals and the consequent swelling – shrinking cycles causes cracking. This will be responsible for much of the weathering. When water penetrates an adobe structure, it permeates the porous material by diffusion (pl.1 fig4), shows the canalization of rainwater over the mudbrick of

hawara pyramid and the natural canalization due to rainwater as in (pl.1 fig.5).

pl.1 (fig.3) shows the weathering process of mudbrick in hawara pyramid. The detachment and loss of the cohesion between the mudbrick blocks with spalling of several blocks as in (pl.2 fig.1). (pl.2 fig.2) shows the wall of the pyramid suffered an enormous loss of its material due to erosion. The most common feature of the above ground remains is deterioration through wind erosion (pl.2 fig.4) which is equivalent to sand blasting. This results in the disintegration of mudbrick. In the last years, the desert land reclamation process was started especially from the eastern side of hawara pyramid. The irrigation water from the Nile water leakage from Whaby canal resulting in the groundwater table started to increase. As a result, groundwater covers the pyramid floor; and its entrance is filled with water. Groundwater inside the pyramid is charged with soluble salts. Interior structures will absorb groundwater, increasing the quantity of salts and humidity. Evaporation takes place as water from the brick and limestone. In which evaporates more slowly from the interior of the structure, as the clay particles and limestone blocks gradually lose both adsorbed and absorbed water and the moisture moves to the surface. The salts crystallize out of solution either at surface or in pores below the surface of the structure. The effect of these two actions cause the surface to crack. (pl.2 fig.3) shows the salt crystallization in the entrance of hawara pyramid.

Materials and Methods:

The present research programme concentrated on knowing the physical and chemical properties of mudbrick to identify the characteristics of hawara materials. Various experiments have been selected such as grain size distribution, x-ray diffraction and scanning electron microscopy. Adobe and salt sample from the hawara pyramid were analyzed by XRD method. A Phillips x-ray

diffraction equipment model PW/1710 with Ni. Fi Lter, cu radiation ($\lambda = 1.542\text{\AA}$) at 40 KV, 30MA and scanning speed 0.02%sc, were used. The reflection peaks between $2\theta=2^{\circ}$ and 60° corresponding spacing (d, A) and relative intensities (I/I°) were obtained. The diffraction charts and relative intensities are obtained and compared with JCPDS files.

The Thermal Analysis (DTA&TGA) was carried for mudbrick samples by means of shimadzu DTA- 5o H, and TGA 50H the powdered samples were heated by $10^{\circ}\text{c}/\text{min}$ up to 900°c with α Al₂ O₃ as a reference material. In order to understand the decay phenomena, the decay aspects were studied by means of scanning electron microscope (SEM) and Energy dispersive x-Ray analysis.

Field work:-

The area around the pyramid was surveyed, and locations of the electrical and seismic stations were selected. By using the GPS, these stations were projected on topographic map of scale 1: 25000. In this manner, twenty vertical electrical sounding, (VES) were conducted around the pyramid by using SAS 300, where the Schlumberger arrays were applied with maximum spacing ranging between 200 and 300 m. Also forty-eight shallow refraction seismic shots along ten profiles were measured beside some selected sounding stations (Fig. 2).

Results:-

Grain-size distribution

A granulometric analysis was made by elutriation method (weaver, 1971) in order to determine the ratio of sand to silt to clay using micromesh sieves. The particle distribution was done by a combination of wet and dry sieving. The ph values were in basic range between 8 to 8.6 . Three adobe samples were analysed and the results are summarized in table (1). The particle size distribution shown in table (1) infer the mudbrick of hawara samples. Sediment of adobe are standard Nile silts dominated by fine

to coarse sub-rounded to sub angular quartz. These muds and silty mud represent Nile sediments. These adobe exhibited moderate tensile fracturing since the linear shrinkage is 1.84.

Table (1) Grain size distribution of hawara adobe .

Sample no.	Grain size distribution			Ph	Shrinkage
	Silt	Clay	Sand		
1	22.2	29.0	48.8	8.4	1.84
2	23.0	28.0	49.0	8.2	1.81
2	24.1	29.2	47.7	8.3	1.79

X- Yay diffraction XRD.

XRD data illustrated in Fig (2) showed that the Hawara adobe is composed of Montmorillonite $\text{Na}_3 (\text{Al Mg})_2 \text{Si}_4 \text{O}_{10} (\text{OH})_2 \cdot x \text{H}_2\text{O}$ (10.07-2.49), Quartz (SiO_2) (3.34-2.23) as a predominant minerals with Albite (Na, Ca) (Si, Al) $_4 \text{O}_8$ (3.19-4.03) and Illite $\text{KA12} (\text{Si}_2 \text{Al O}_{10} (\text{OH})_2$ (3.63-2.45) with small traces of Magnesio-riebeckite $\text{Na}_2 \text{Mg}_2 \text{Fe}_2 \text{Si}_8 \text{O}_{22} (\text{OH})_2$. Montmorillonite shows a high swelling capacity. This capacity depends on the type of ion exchange and on the pressure of water vapor as a highly Hydrophilic materials Na-montmorillonite gives high swelling, a particular absorption and a high value of exchange capacity (Brown, 1979).

X-ray diffraction of salt samples collected from the entrance of the pyramid revealed that the samples are composed of Halite, NaCl (3.25-3.32) as a major constituents with Calcite Ca Co_3 (3.03-1.60). and Thenardite ($\text{Na}_2 \text{So}_4$) (1.93-1.63) as a minor constituents with small traces of magnesium sulphates Fig (3). These salts are characterized by their continous crystallization mechanism as a result of the cyclic variations of air temperature and relative Humidity which lead to serious damage of the mineral constituents of limestone blocks used in the entrance of the pyramid.

Differential thermal analysis:

The data show that the mudbrick consists of montmorillonite and quartz as major minerals. The DTA/TGA measurements Fig (4) prove that the basic material of mudbrick is clay. Montmorillonite exhibits two peaks: the first is a main endothermic peak at temperature 580oC due to the dehydroxylation of clay and the second at temperature 750oC due to the structural changes in montmorillonite. Quartz exhibits a small peak at temperature 575oC due to the transformation of a quartz to β quartz α .

The small shifts in peak positions are probably caused by partial decomposition of individual clay minerals.

Scanning electron microscope (SEM):

SEM micrographs of adobe shows eroded surface with the disintegration of grains (pl3 Fig1). (Pl3 Fig2) shows the loose packing with leaching of clay and silt of adobe. The inherent weakness of adobe, the destruction of cement material of mudbrick and the physical disintegration of adobe are shown in (pl3 Figs3-6). SEM micrographs show an excessive pore spaces and the adobe was characterized by numerous large pores and internal fractures which cause brick failure and adobe collapse. Also, Montmorillonite packs change their position in material and their structure becomes loose and causes cracking, fleeking off and powdering of the adobe. SEM (pl.4 Fig.1) shows the crystalline fluffy and bristly salts which cause spalling and damage of stone.

The growth of megafibrous crystals of Thenardite has been observed in (pl.4. Fig2). The amorphous form of Halite is shown in (pl.4 fig3). (pl4. fig4) shows the whisker growth in the crusts formation in the entrance of the pyramid.

The cubic form of NaCl crystals (pl4. Fig5) produces pulverization where as the needle growth of Nacl tends to produce flaking in the stones as in (pl4. Fig6). SEM

micrographs show the most common habits of efflorescent salts on the surface of the entrance of the pyramid such as prisms, acicular, columnar, hair like crystals, amorphous, hair like crystals and the so called whisker crystals. Idiomorphic cubes of halite showing their specific equilibrium crystal forms as shown in (pl4. Fig5). These salts form bristly efflorescence of individually standing crystals (pl4. Fig2), or losses aggregates of whiskers which forming fluff efflorescence (pl4. Fig1).

Energy dispersive analysis (EDX).

EDX analysis shows that the samples are rich in elements such as Si, Al, Ca, Na, Mg, K, Fe, Cl, S. EDX (fig5) shows that silicon and aluminum with calcium oxides are found to be in high quantities in the samples. EDX analysis of salt samples shows them to be dominated by sulphates and chlorides. High chlorine levels might be from salts such as halite. Crystallization of chlorides, sulphates mainly of sodium, magnesium and calcium have been identified by energy dispersive X-ray analysis Fig (6).

Inversion of the measured data:-

Inversion of geophysical data involves the estimation of the parameters of a postulated earth model from a set of observed data. It may be viewed as an attempt to fit the response of an idealized subsurface earth model to a finite set of observed data. A reliable inversion technique for any geophysical method is essential to meet the requirement for a more detailed delineation of underground media. For doing this, each one of the measured stations was interpreted individually, where one-dimensional model for each site was obtained. These models were combined to produce two-dimensional cross-sections. The interpretation of the electrical data was done along the following steps: The automatic iterative program (ATO) of Zohdy (1989) was applied to the 20 field sounding curves. The multilayer model, which was produced from this program, is manually

grouped to a simplified one. We seek a model, which minimizes both the data misfit and model roughness. So, we have to run the inversion process until the best fit is attained. For this reason, the reduced model was recalculated iteratively by computer software called RESIST of Velpen (1988). Computer software called RESIXP (1993) was used in the final stage of interpretation. In the software the iteration process of the suggested models can be constrained by ground truth driven from wells or any other sources. In this way, the fitness of the models can be attributed to the geological pictures rather than mathematical form. This step was guided, in fact, by the available geological and hydrogeological information summarized by Allam (2001) in table 2.

Table (2): Engineering properties of the soil layers.

Layer No.	1	2	3
Thickness (m)	1 - 2	5 - 7.5	13
Soil classification	Silt + Fine sand	Shall	Fissured limestone
Laboratory hydraulic conductivity (m/day)	7	4	13
Porosity	0.4	0.08	0.04

The inversions of the measured seismic data were conducted through calculation of the seismic velocity for each layer. The intercept time and critical distance techniques were used in this process. Velocities and thickness at each shot point were calculated as shown in table (3).

To come a conclusion regarding the water-bearing rock unit in the area, correlation was made between the results of quantitative interpretation of some VES and the seismic velocity. A careful study was executed to the area, where no other controls are known.

Three geoelectric cross-sections were constructed from the combination of the inverted electrical data for each

VES station (Fig. 8 to 10). These sections represent the main slices of the suggested model; if combined together, they will reflect a quasi three dimensional view for the subsurface. Selection of the data set, which is suitable for the model, is controlled by the general geology and the information extracted from the shallow boreholes around the area. The features of this model can be mentioned in the following:-

- 1- There are shallow thin resistive layer followed by a relatively conductive one, then a resistive limestone bed.
- 2- Surface layer characterized by resistivity range varies from 7374 ohm. m to 5 ohm. m. The relatively high resistivity can be attributed to the remains of debris for some monumental foundations distributed around the pyramid, while the very low resistivity is related to the presence of some clay lenses. If the high and the low values were excluded, the normal resistivity range of this layer would range between 40 and 103 ohm.m, which reflects the sand and gravel deposits of Nile sediment. The thickness of this layer varies from 2 to 9 m. The calculated seismic velocity of this layer is ranged between 250 m/s and 1000 m/s. Except these two low and high values, the normal range of the velocity is 500 m/s. This velocity range reflects unsaturated sand and gravels. The calculated thickness of this layer from seismic measurements ranges between 3.5 m and 9.6 m. There is great coincidence between the results obtained from the electrical and seismic data.
- 3- The second layer, which represents, the main task of our model, is characterized by resistivity ranges varying from 2 ohm.m. to 47 ohm.m. The low resistivity values can be attributed to shale deposits while the higher values in range from 20 ohm.m and above can be explained by the presence of sand

lenses embedded in shale. We refer to it in general as shaley sand layer. The suggested thickness for it from the resistivity model ranges between 14 m and 52 m under the ground surface (Fig. 8 to 10). Most of low thickness value was recorded around the pyramid (Fig. 11 and 12). This will help in choosing the sites of the suggested pumping wells for decreasing the water level. The average resistivity of this layer is represented in a map (Fig. 13). As shown in this map, the low resistivity value is concentrated beside eastern border of Bahr Wahbi canal; and this reflects that this canal acts as a recharge source for this layer. Also seepage from the reclaimed area in the northwestern corner of the area has an effect in decreasing the resistivity value. On the other hand, the seismic velocity for this layer ranges between 1250 m/s and 2500 m/s (Table 3). The high seismic velocity value reflects shale deposits, while the low velocity value is attributed to partially saturated sand. The calculated thickness from the seismic measurements ranges between 14.9 m to 31.2 m (Table 3).

- 4-The third layer which appear in our model as spots rather than a complete layer is due to that their thickness is more than the depth of our probe. This layer exhibits a resistivity raing varies from 41 ohm.m to 404 ohm.m. and velocity ranges between 2000 m/s and 3333 m/s (Table 2). This increasing in resistivity and velocity can be attributed to the presence of Pliocene or Eocene deposits which are varying in lithology from marl to sandstone and limestone.

Engineering solutions:-

As mentioned above, the ground water level is in continuous rising around and under the pyramid itself. This

will cause great damage to its body. So decreasing this level should represent the main task of any suggested solutions. We will discuss the previous solution. Then we will introduce our suggestions. Allam (2001) introduces two engineering solutions for this problem. The first one was the construction of an interceptor drain around the pyramid site from the western and northern boundaries. The second suggested solution was the construction of well point system within and around the pyramid site itself. Many depths of that interceptor drain were tested with the help of the numerical model as shown in table 4.

Table (4): Effect of the drain depth on the groundwater level.

Drain width (m)	Drain depth (m)	Decrease in G.W.L (m)
1	1	0.59
	2	1.15
	3	1.29
2	1	0.67
	2	1.29
	3	1.5

Lowering of the groundwater levels within the pyramid site can be achieved by means of pumped well point system. The radii of influence of the well points should overlap. The method was simulated to the calibrated numerical model with different discharge and spacing as shown in table 5.

Table (5): Effect of well point system on the groundwater level.

Pumping rate (m ³ /day)	Spacing (m)	Decrease in G.W.L (m)
40	5	0.99
	10	0.79
	15	0.55
60	5	1.2
	10	1.0
	15	0.7

All the numerical for these two solutions were suggested according to the geological parameters mentioned in table (3). As a result of our simulations for the electrical and seismic data, the thickness of both the first and the second layer is greater than that mentioned in table 1. This thickness varies from 3.5 to 9.5 and from 14.5 to 45 for the first and second layer respectively. Also there is groundwater seepage from Bahr Wahbi canal, the cultivated land in west and the reclaimed farms in the northwestern corner acting as recharge sources for the pyramid area.

Depending on these facts, our solutions can be summarized in the following:

- 1-Aligning both sides of Bahr Wahbi canal by materials characterized by very low porosity.
- 2- Drilling a number of pumping wells around the pyramid site. The total depth of these wells and their distribution should be controlled by the results represented in figure (11). Any numerical model for the expected pumping rate for these wells can be guided by these results.
- 3- The government should be started in a long-term program for transforming the irrigation system in the area around the pyramid from flood to drip irrigation

techniques as well as changing the direction of Bahar Wahbi canal to be as shown in figure (13).

Conservation Problems of mudbrick:

The problem of conservation of mudbrick is to find a suitable material to restore mechanical strength and increase hydrophobicity. The penetration of resins depends on the chemical make up of the material, the size of the resin molecules and the properties of the solvent solution (Lewin, 1981). The solvent used directly influences the distribution of the resin within the porous structure of mudbrick, many experiments of conservation of mudbrick failed because the resin solutions did not have the right properties for the material to be consolidated. The resins were not deposited evenly within the pores of the mudbrick, but were drawn back to the surface by capillary action as the solvent evaporated. The resin are forming a thick, unsightly film that eventually became detached, taking with it an appreciable amount of the surface. Acrylic resins have been favored in mudbrick because of their stability, solubility in several organic solvents, consolidating ability, reversibility and hydrophobicity, while allowing the passage of water vapour through the film the low viscosity of the monomer making deep penetration of the consolidate more feasible. The process of polymerization in site has proved problematic (Vassallo and Lewin 1981).

Using a low percentage-solution in a solvent that has a slow evaporation rate and consists of a relatively small molecules stimulates deep penetration, and creates a resin film coat on the surface of the pores. This prevents the moisture from the atmosphere to penetrate into the outer fabric of the wall. (Havola, 1985).

Due to their low viscosity, silicore esters and alkoxy silanes penetrate easily and improve cohesion. However, structural strength does not change dramatically. Hence, an acrylic silane can be used, or one may add an acrylic polymer to a silane solution to enhance the change. Good

results have been recorded using ethyl silicate to treat mudbrick.

Helmi, 1990, Found that TEOS is the most suitable consolidant for the Egyptian adobe because it has low viscosity and penetrates well through adobe structure.

Consolidation:

The mudbricks were cut into tested samples. The tested sample of adobe measured 5 x 5 x 5 cm. All samples were treated by total immersion. The efficacy of products were evaluated by scanning electron microscopy.

The four consolidant products have been tested; Ethyl silicate (Ethyl Ester of Siliceous acid) as consolidant and water Repellent.

Rc70 (Ethyl Ester of siliceous acid) as consolidant (70% in white spirit).

Paraloid B72 10% W/V with 1, 1,1- trichlorethane or xylenel.

Methylcrylate and Ethylmetha crylate copolymer).

Wacker H (methyltrimethoxy silane). SEM micrographs of the samples after treatment with wacker H show penetration through porous and around grains. But there are still large areas where little precipitation of the polymer occurred and there are no links between the grains as in plate (5-2). Paraloid B72 shows thin coating of polymer between grains with unhomogenous resin links (plate 5-1). Rc70 shows a weakness of links between grains and there are still large cavities between them (plate 5-3). Ethylsilicate shows that the links were formed between grains and the success of the polymer in forming network links and the porosity is greatly reduced and giving cohesion to the adobe (plate 5-4).

TEOS without silane groups is more suitable for adobe treatments. According to Helmi, (1990) and Fielden (1982). TEOS has low viscosity and it can penetrate well through adobe structure. The hydrolysis takes place by moisture in air and in adobe itself forming a network Si-O polymer in its structure; and ethanol is evaporated.

Discussion:

It can be seen that the materials used in the adobe can be affected by climate, the daily temperature changes, such as rains and wind. Water can interface with grain adhesion and cause brick failure and collapse with swelling of clay minerals; Evaporation will lead to shrinkage, cracking and breaking. The wind exercises will give rise to mechanical pressure and abrasion, which were particularly damaging to surfaces. Daily temperature changes heats and dehydrates the adobe, causing the material to shrink, crack and break. Sediments of Hawara adobe are standard Nile silts dominated by fine to coarse sub-rounded to sub angular quartz. XRD data show that Montmorillonite and Quartz with Albite and Illite are the mineral constituents of adobe. DTA analysis shows that the mudbrick consists of Montmorillonite and quartz. SEM micrographs show the loose packing and the inherent weakness of adobe with the disintegration of grains. Groundwater covers the pyramid floor and its entrance, leading to the crystallization of salt crusts in the blocks of the entrance of the pyramid. SEM micrographs show different forms of salts such as bristly efflorescence, individually standing crystals and loose aggregates of whiskers forming fluffy efflorescence. The scanning microscopy technique showed that Hawara adobe has been successfully consolidated. The most suitable consolidant was found to be Ethyl silicate due to its ability to penetrate well the adobe structure it has low viscosity and the polymer has succeeded forming network links.

Decreasing the groundwater level represents the main task for some of the hydrogeological studied models. Due to the scarcity of the data, most of these models are built on wrong assumptions about the factors related to the distribution and thickness of the subsurface layer. The electrical and shallow refraction seismic measurements help us in getting the geometry of these subsurface layers which are called simulations processes.

In this study, the measured electrical and seismic data around Hawara pyramid were inverted by iteration and compared with the general geology to simulate a two dimensional subsurface model for the groundwater aquifer in the area.

The main features of this model can be summarized as:-

- 1-Relatively high resistivity value and low seismic velocity were recorded at shallow depth, which represent the gravel and sand deposits of the surface layer.
- 2-It is followed by low resistivity and moderate velocity values for layers of moderate thickness, which reflect the groundwater aquifer in the area.
- 3-High resistivity and seismic velocity values were recorded for the third layer which may represent a marly limestone or limestone deposits.
- 4-The seepage from Bahar Wahbi canal and the cultivated lands around the pyramid can be considered the source for increasing the groundwater level in the area.

Some engineering solutions for decreasing the groundwater level were discussed and others were suggested. Any future numerical hydrogeological models for lowering the water level should depend on the result of this model or any one similar to it.

References

- Ackermann, H. D., 1974.** Shallow seismic compression and shear wave refraction and electrical resistivity investigations at Rocky Flats – Jefferson Country, Colorado. U.S.A. J. Res. U.S. Geolog. Survey, v.2, p. 421- 430.
- Allam, A. R., 2001.** Groundwater via Hawara pyramid degradation, Fayoum conference, Cairo Univ.
- Bradley, S. 1985.** “Evaluation of organosilanes for use in consolidation of sculptures displayed indoors.” Fifth International Congress on Deterioration and conservation of Stone. Lausanne.
- Brown, P. robins, O and cliffon, J, 1979,** Adobe II. Factors affecting the durability of adobe structures. Studies in conservation, vol. 23 P 23-39.
- Brown, W. R. and Clifton, 1978.** “Adobe 1-The properties of adobe”. Studies in conservation 23.
- Butterbaugh, D. and Pigott, V. 1980.** “Masca mudbrick/adobe conservation. Third International Symposium on Mudbrick (adobe) preservation Ankara.
- Charola, A. Laurenzi Tabasso, and U. Santamaria 1985.** “the effect of water on the hydrophobic properties of an acrylic resin.” Fifth International congress on Deterioration and Conservation of Stone. Lausanne.
- Chiari G, 1987,** Consolidation of Adobe with EhyI silicate, control of long-term effes using SEM.5th intern. Metting on conservation of Earthen Architecture, Rome, P 25-32.
- Chiaria, 1990,** chemical surface treatments sand capping techniques of earthen structure, long term evaluation; inter conf adobe “90”, 105 Angeles, pp 267-273.
- Conoco Coral Egypt, 1989.** Geologic map of Egypt (scale 1: 500000).

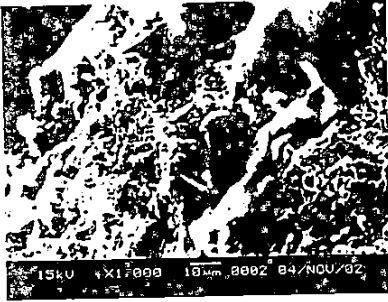
- Fathy, Hasson, 1969;** gourn. A tale of Two villages, Cairo, P63.
- Feilden, B., 1982,** Conservation of Historic Buildings (Butterworth, London, P75.
- Flathe, H. 1970.** Interpretation of Geoelectrical resistivity measurements for solving hydrogeological problems. In Morely, E. W. (ed.), Mining and Groundwater Geophysics: Geological Survey of Canada Economic Geologica Report, no. 26, pp. 580-597.
- Gurcke, Karl, 1987,** Bricks and Brickmaking. A hand book for Historical Idaho Archaeology, Moscow, P 12.
- Hassan Fathy, 1973,** Architecture for the poor, London, the university of Chicago press.
- Helmi, F., 1990,** Deterioration and conservation of some mudbrick in Egypt Adobe 90 6th internation conference on the conservation of earthen Architecture, the Getty conservation institute, los Angeles.
- Ibrahim A. Sh., 1994.** Geological and hydrogeological studies for El Faiyum and their surrounding with the possibility of the groundwater pollution for the area. Ph. D. Thesis, Fac. Sci. Monofeia Un. 322 pp.
- Lewin, S and Papadimitriou 1981.** "Investigation of polymer impregnation of stone: Solvent transport of pre-polymerized methacrylate". The conservation of stone II International Symposium, Bologna.
- Lewin, S. and Wheeler, 1985.** "Alkoxy silane chemistry and stone conservation." Fifth International Congress on Deterioration and conservation of Stone. Lausanne.
- Lucas, A., 1962.** Ancient Egyptian Materialsand industries. 4th edition revised by JR Harris, London, Edward Arnold.
- Oates, Daivd, 1990,** Innovations in mud-brick. Decorative and structural techniques in Ancient Mesopotamia, world Archaeology, P388.

- Resix, I.P. 1993.** Resistivity and induced polarisation data interpretation software. Copyright by Interpex Limited Golden Company.
- Rossi-Manaresi, G. and Chiari, G 1980.** "Effectiveness of conservation treatment of volcanic tuff very similar to adobe", Third International Symposium on Mudbrick (Adobe) preservation. Ankara.
- Said, R., 1981.** The Geological Evolution of the River Nile. Springer-Verlag, New York, 181 pp.
- Spencer, J; 1979,** Brick Architecture in Ancient Egypt, Arts of Philips ltd, Warminster. Wilts plates 1-20.
- Spener, E., 1994,** Mudbrick; its Decay and deterioration in upper and lower Egypt. Studies in the culture and Heritage of Ancient Egypt, London, P 315-320.
- Tamer, M. A., 1968.** Subsurface geology of the Faiyum region. M. Sc. Thesis, Fac. Sci. Alex, Uni. 89 pp.
- Torraca, G., 1982,** Porous Building Material-Materials science for Architectural conservation 2nd ed., icrom PP 95-104.
- Vassallo, and Lewin, Z 1981.** "Investigation of polymer impregnation of stone II. In situ polymerization of methyl methacrylate." The conservation of Stone II. International symposium. Bologna.
- Velpen, V.D.B.P.A., 1988.** "RESIST", a computer program for the interpretation of resistivity sounding curves. An ITC. M. Sc. Research Project. ITC, Delft, The Netherlands.
- Weaver, M, 1971,** A new water separation process for soil from Archaeological excavations, Anatolian studies, vol xx1, 1971.
- Weaver, M. 1973.** "The use of an inflatable airdome to produce controlled conditions for an archaeological site." Studies in Conservation 18.
- Zohdy, A. A. R., 1989.** A new method for automatic interpretation of Schlumberger and Wenner sounding curves. Geophys., v. 54, p. 245-253.

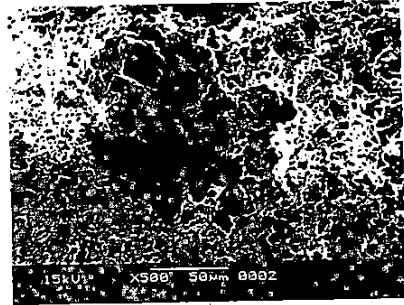
Table. (3). The calculated velocity and depth for the measured seismic profiles.

No.	Shot No.	V1	V2	V3	D1	D2	No.	V1	V2	V3	D1	D2	
1	0	500	1666	2142	4.7	15.3	2	500	1587	3636	6.5	25.2	
	1	500	1666	3000	3.9	19.9		500	1500	3409	5.0	26.8	
	3	1000						786					
	3	971	2500		9.5			625	1724	3500	6.7	26.7	
	6	833	1666		6.8			666	1724		7.6		
	6	625						666	1266	2666	8.2	20.2	
	9	926	2000		9.4								
9	833												
3	0	666	1250	2000	8.2	22.6	4	555	1750	2333	9.6	22.8	
	1	500	1250	2000	4.6	16.6		555	1666	2380	7.9	22.6	
	3	500						500					
	3	500	1250	2000	6.2	15.8		495	1428	2500	4.2	17.2	
	6	500	1500		6.3			500	1250		7.4		
	6	500	1250	2500	6.5			413	1333	2439	4.7	15.5	
	9	500	1250		6.5			357	1886		4.9		
9	400	1250		5.0		250	1250		4.3				
5	0	500	1270	2083	6.5	23.7	6	416	1666	2500	5.3	20.6	
	1	500	2403		4.8			416	1904	2500	4.3	19.0	
	3	500						357					
	3	500	2625		5.0			416	1250	2500	4.0	21.3	
	6	555	1270		3.7			510	1571		4.9		
	6	400	2500		5.5			500	1268		4.9		
	9							714	1666		5.9		
9						833							
7	0	555	1278	2143	7.0	29.6	8	555	2000	2162	9.2	18.1	
	1	500	1351	2286	4.0	19.2		555	1754	2307	7.6	24.2	
	3	500						555					
	3	500	1524	2000	3.9	14.9		500	1754		6.2		
	6	500	1190		3.6			416	1803		4.2		
	6	357	1500		4.2			500	1619		6.5		
	9	500	1250	2538	3.9	21.4		500	2439		7.1		
9	500	1250		3.9		500	1500		7.1				
9	0	500	1666	2631	6.8	28.1	10	600	1666	2750	7.7	31.2	
	1	500	1428	3333	6.4	26.9		500	1666	2750	3.6	25.9	
	3	625						500					
	3	625	1400		3.5			500	1587	2500	4.2	20.7	
	6	500	1250		7.6			500	1562		4.2		
	6	294	1666		4.2			357	1666	2400	5.8	20.2	
	6	555	1600		6.2			500	1666		3.9		
6	555					500	1339	2512	4.0	17.4			

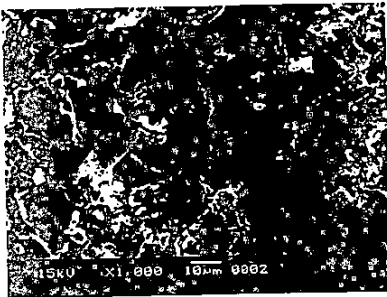
Plate (5)



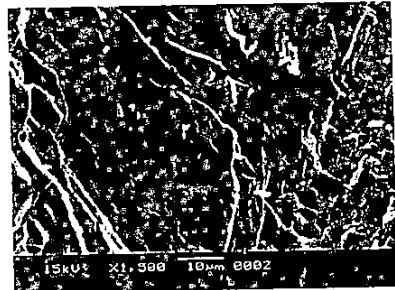
1- mud brick sample after treatment with paraloid B 72 showing the thin coating between grains



2- mud brick sample after treatment with Wacker H and showing penetration through pores and around grains



3- mud brick sample after treatment with RC 70 which shows that the weakness of links and there still large cavities



4- The mud brick sample after treatment with Ethyl silicat showed that links were formed between grains

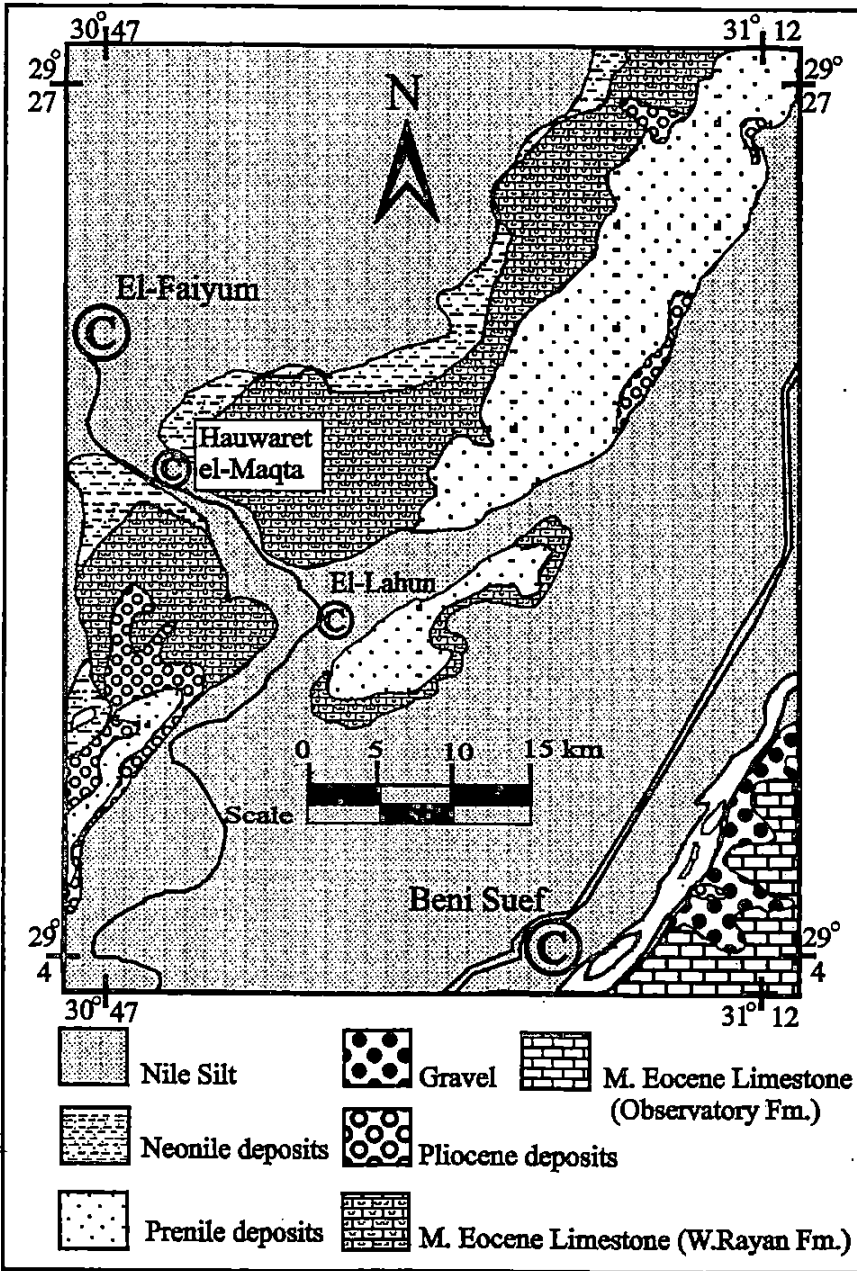


Fig. (1) Geologic map for the study area modified after Conoco, 1989.

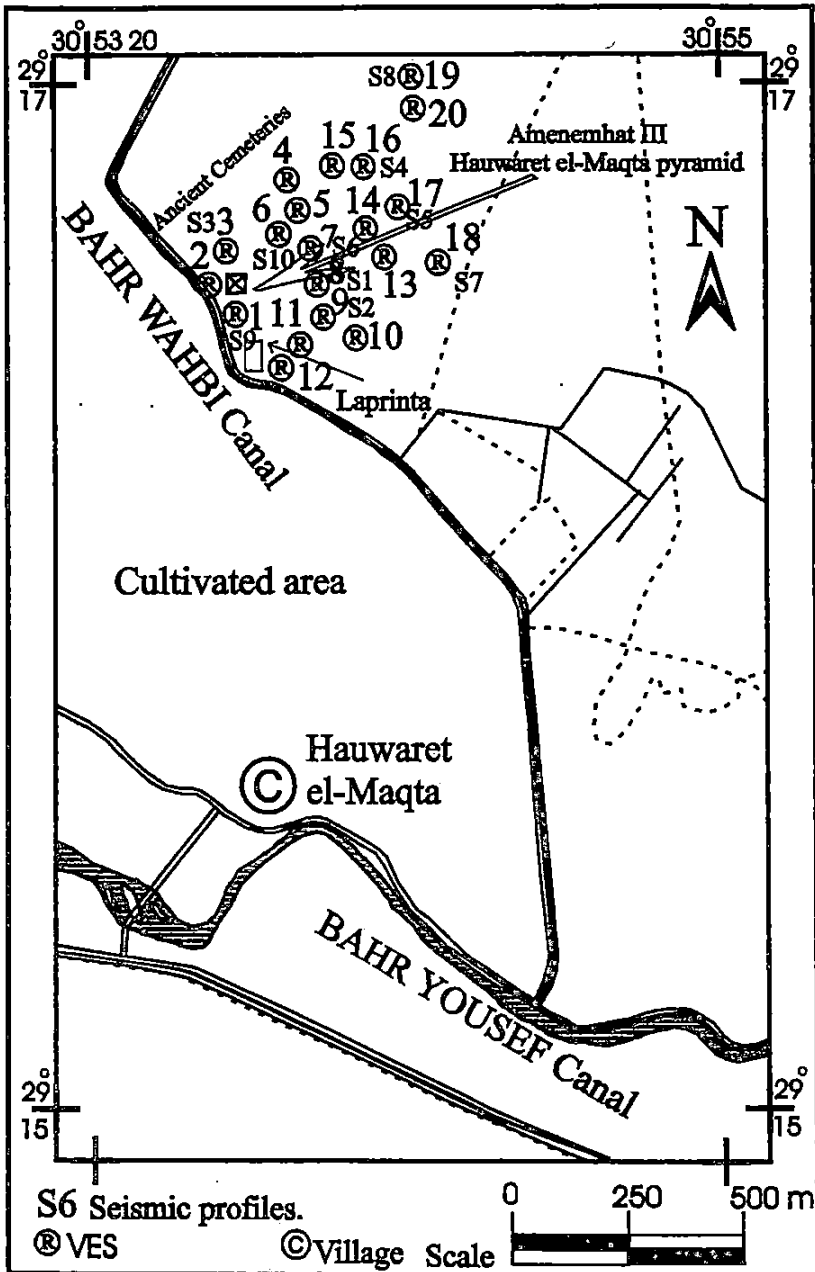


Fig. (2) Location map and layout of the VES stations and seismic profiles.

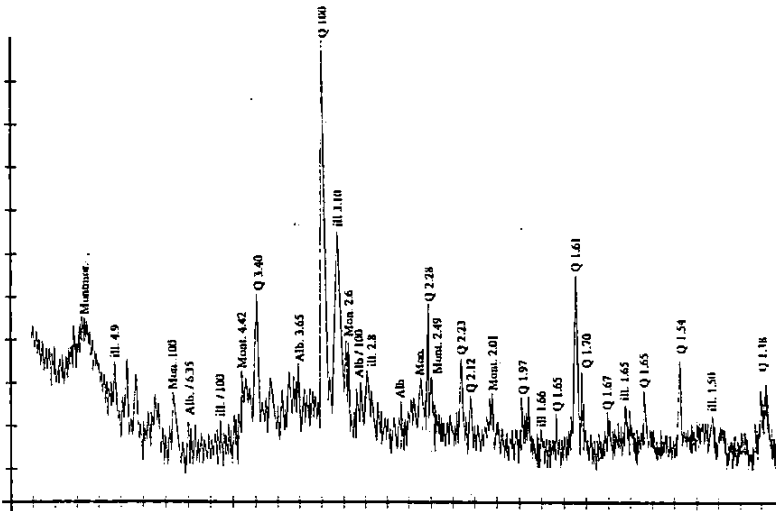


Fig (2) x - ray diffraction of adobe, Hawara Pyramid

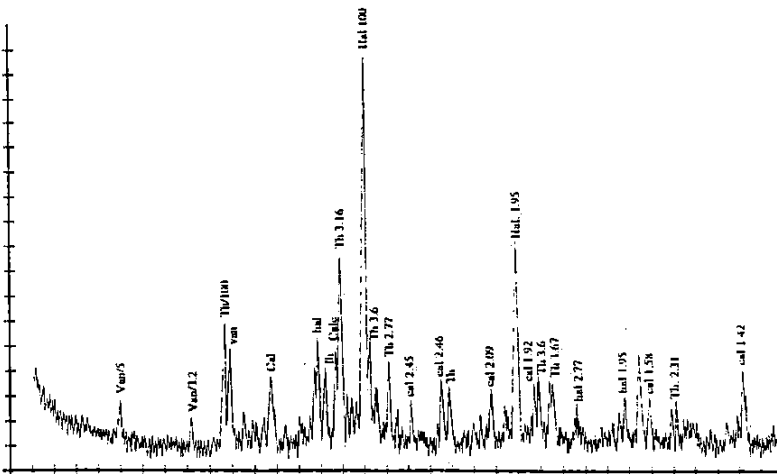
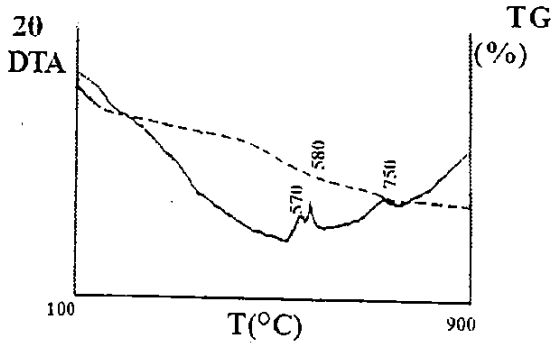


Fig (3) x - ray diffraction of salt - Hawara Pyramid



Fig(4) DTA/TG analysis of mud brick Hawara Pyramid

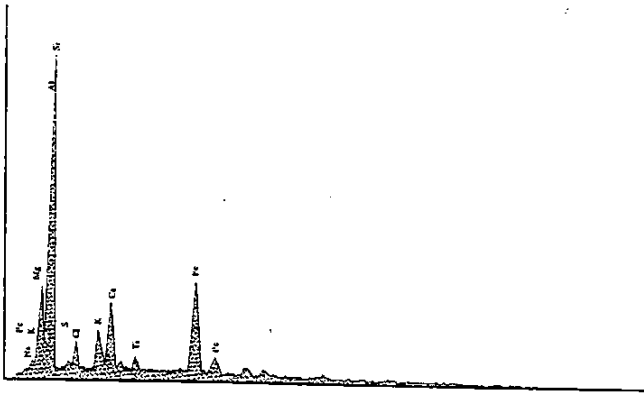


Fig (5) Energy Dispersive X-ray analysis of mudbrick from Hawara

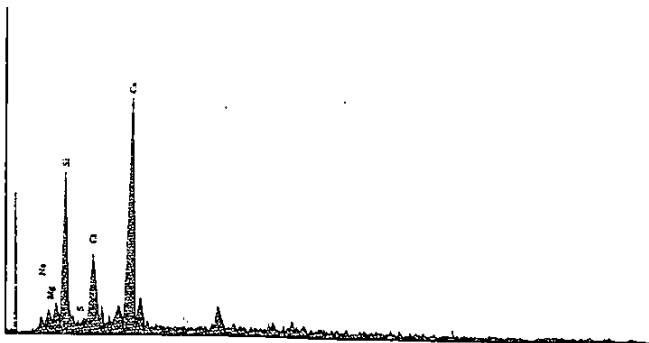


Fig (6) EDx of Hawara shows the constituting elements of mudbrick

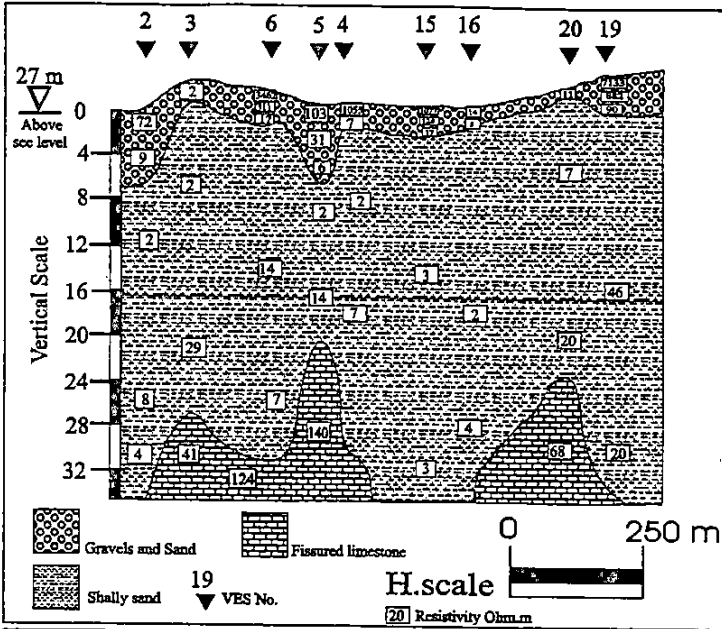


Fig. (8): Geoelectric cross section A - A'.

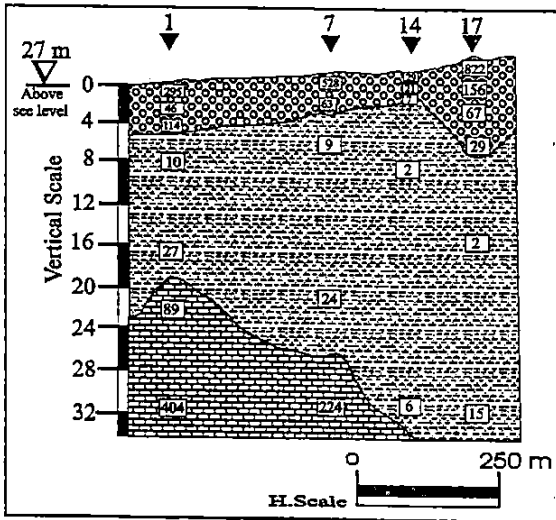


Fig. (9): Geoelectric cross section B - B'.

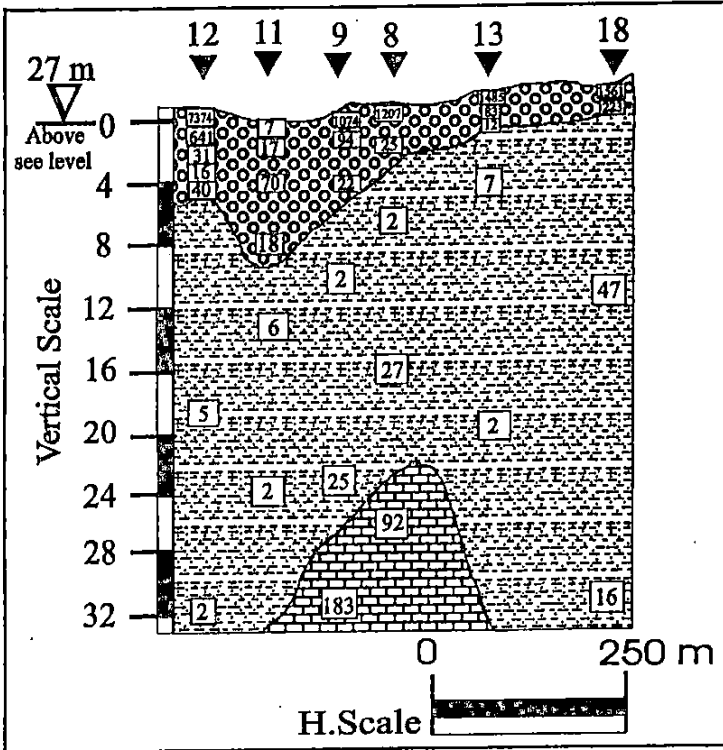


Fig. (10): Goelectric cross section C- C'.

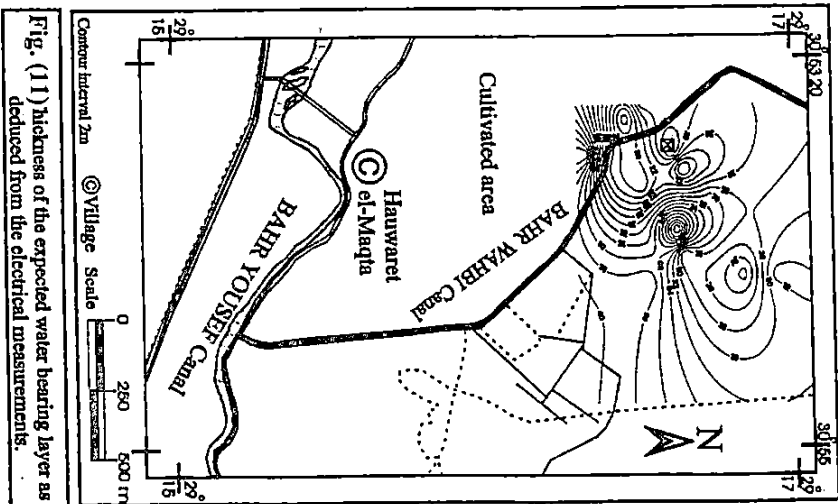
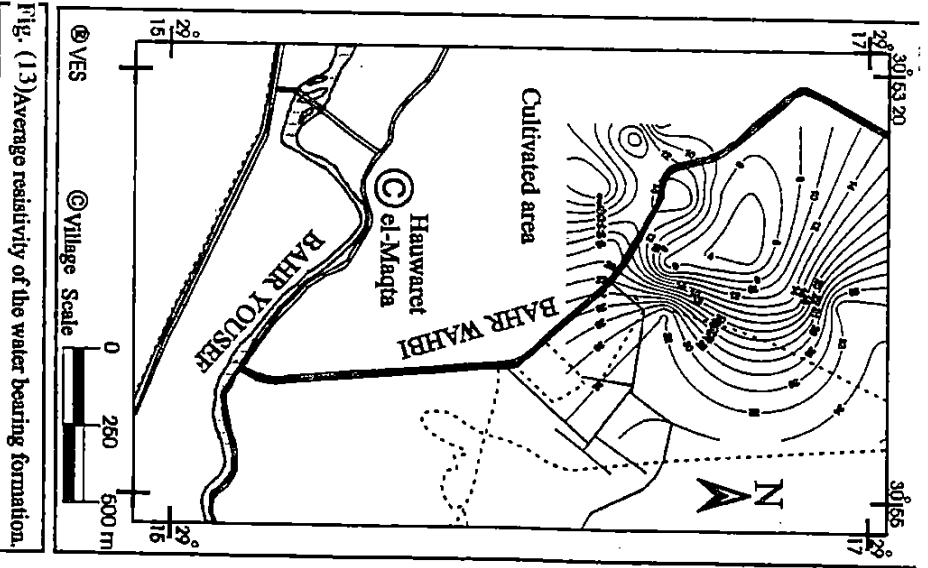
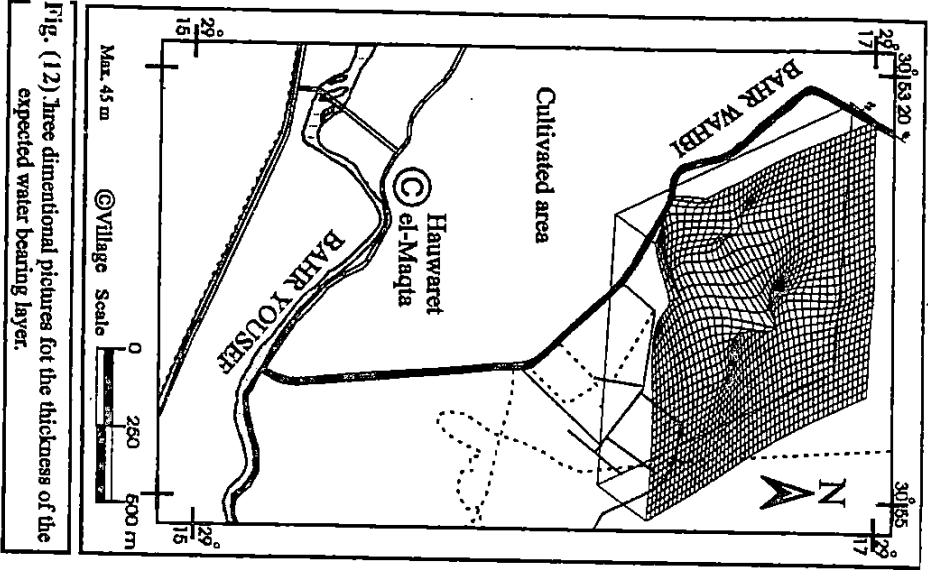


Fig. (11) Thickness of the expected water bearing layer as deduced from the electrical measurements.



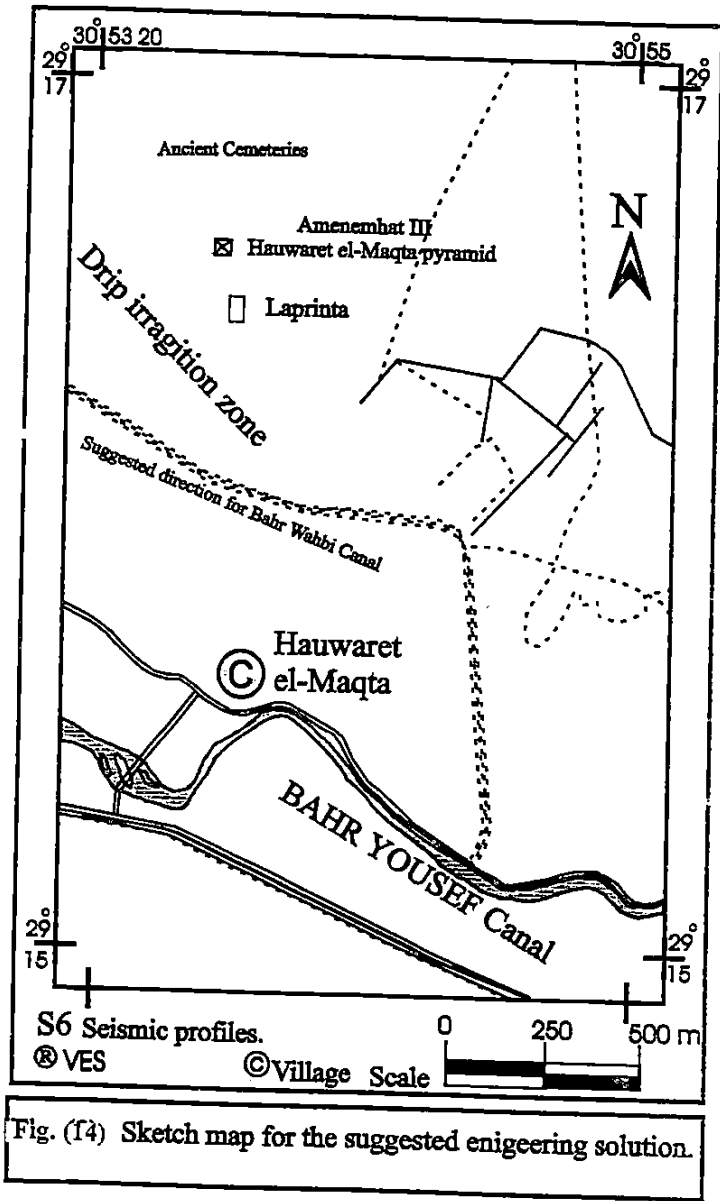


Fig. (14) Sketch map for the suggested engineering solution.