

Slope degradation and analysis of Mokattam plateau, Egypt

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ABSTRACT: A newly suburban area called Mokattam City was constructed on the Mokattam high plateau. It overlooks the Nile valley at the site of Cairo. Mokattam high plateau rises above the flood plain of the Nile valley by about 180 meters. Geologically, it belongs to Eocene time and it is mainly covered by thick succession of limestone with thinner beds of shale and marl. Mokattam high plateau suffered occasional landslides at different locations. Frequent rock falls were observed along the southern edge of the plateau. The most significant was an edge failure that occurred in front of a five-storey hotel. The rock mass that slipped reached the edge of this hotel and left the footing of the corner column almost overhanging. Since then the problem was subject to various studies by several workers who attributed the problem to several causes including geological, morphological, physical and human factors. In this present work, thorough investigation and analysis of the problem have been made in order to assess the potential hazards due to rock fall and its causes. The study indicated that the problem occurred due to variety or combination of causes including geological, morphological, physical and human. However, the triggering factor was water infiltration due to rainfall and human activities. Geological and morphological conditions lead to the susceptibility to rock fall caused by water infiltration. Limestone in the area is primarily porous and highly jointed, thus allowing penetration of water that descend and occur on underlying plain. Infiltration and run off of water into cavities due to human activities such as car wash at a near by petrol station provided continuous supply of water over a long time period. Furthermore, although the region is arid, intense rainfall frequently occurs. Well-documented studies have revealed a close relationships between rainfall and activation of rock fall. The study included assessment of present geomorphological and geological characteristics, including faults and fissures at the study area, identification of man made activities and water infiltration and analysis using a cross-sections passing by the hotel and the underlying layers and finally recommendation of economically feasible control measures for the problem.

1 INTRODUCTION

During the last decades, Egypt has experienced accelerated urban development in response to general population growth and associated demand for housing and other services. Therefore, the lands on both sides of the narrow alluvial plain of the Nile Valley were opened up for urban expansion.

Among these new lands was a suburban area called Mokattam City which was constructed on a mountainous region. This region, known as Mokattam High Plateau, overlooks the Nile valley at the site of Cairo and rises above it with steep slopes

to an elevation reaching 180 meters above the flood plain of the Nile valley (Fig.1).

THE PROBLEM

Construction of cities atop rocky hill is uncommon in Egypt. Therefore, in the development of Mokattam High Plateau, landslide hazard potentials were not considered or evaluated. As a result, Mokattam City, after its construction, was threatened by occasional landslides at different locations. Progressive increase in slope movements, tension

cracks of magnitude of centimeters, failure of marginal cliff and frequent

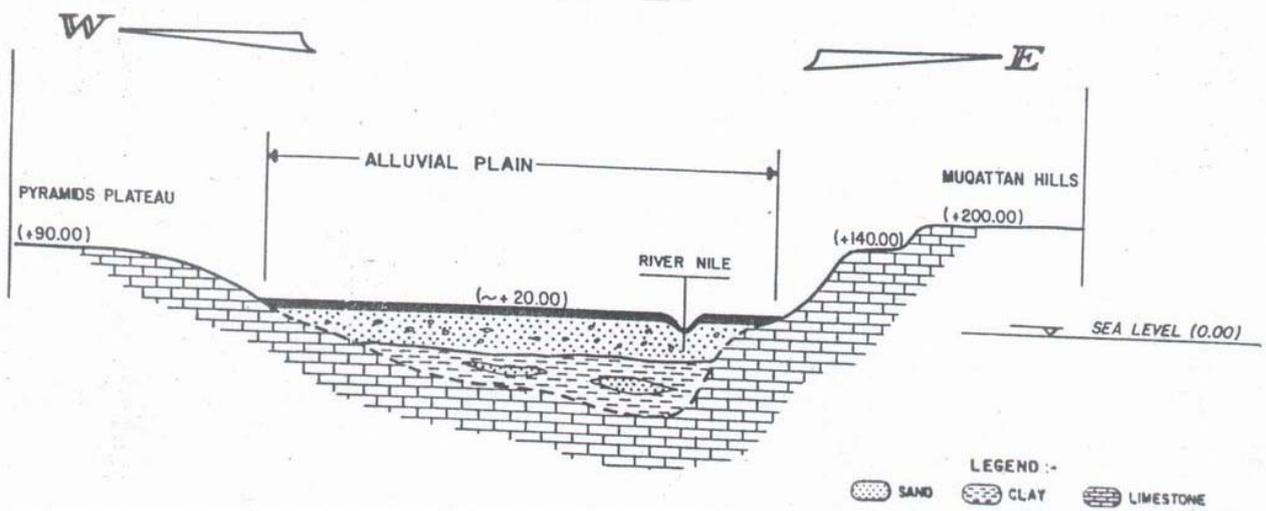
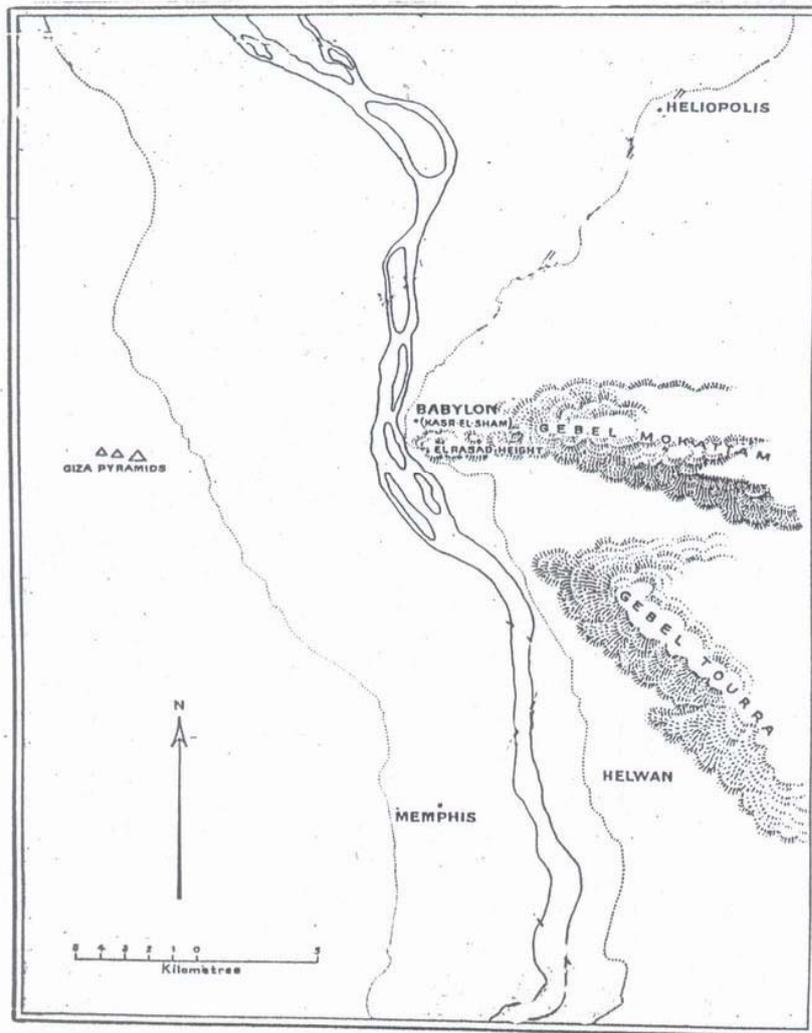


Figure 1. General layout of Mokattam hill (at the site of Cairo)

rock falls were observed. The most significant of this was an edge failure that occurred in front of a five-storey hotel. The rock mass that slipped reached the edge of this hotel and left the corner column almost overhanging (see photos). Since then, several investigations on the incidents were launched to assess the causes, future hazards and probable protective or mitigation measures (EGSMA, 1996; El-sohby and Eleboudy, 1988; El-sohby et al. 1987 and Elleboudy, 1985). However, the studies were usually for particular zones and addressed local failures.

In the present work, the approach is to study the phenomenon in more comprehensive way integrating all the factors involved taking into consideration all previous efforts.

3 GEOLOGICAL CHARACTERISTICS

3.1 Site geology

Site geology was subjected to the study, since long time, by a large numbers of workers. The more significant of whom are (El-Shazly and Abdel-Hady, 1976; Said, 1962 ; Cuvillier, 1924; Barron, 1907; Foutau, 1897 and Zittel, 1883). These studies may be summarized in the following:

Mokattam cliffs constitute a chain of hills forming a continuous scarp that extend from Cairo southwards for about 200 kilometers separating the Nile valley from the eastern desert. This formations which belong to Middle and Upper Eocene is a succession of sedimentary carbonates and less abundant argillaceous rocks. They were classified into two distinct rock units which differ in lithology and colour. Zittel (1883) originally referred to these beds as “ Mokattam Stuff “ and subdivided them into a lower (Unter) an Upper (Ober) Mokattam. At that time both units were considered to be of Middle Eocene age. However, subsequent work (Said, 1962) demonstrated that the Lower Mokattam (now designated as Mokattam formation) is of Middle and Upper Eocene age, whereas the Upper (now designated as Maadi formation) is of Upper Eocene age.

Upper unit (Maadi formation) is made up of a series of easily identified well-developed brownish beds of fissured limestone, marl and shale. The underlying unit (Mokattam formation) is made up of white to gray massive limestone. The latter formation is more resistant than Maadi formation and as a result a step or erosion surface separates the two.

3.2 Lithological setting

According to (Aboushook and Sherif, 2000; EGSMA, 1996 and Said, 1962) and as seen in Fig. 2. Maadi formation include the following (from top to bottom):

- 1- Medium to strong yellowish white dolomitic limestone becoming sandy towards the base, some fissures & caverns, traces of gypsum pockets) and is denoted by “ IV “ - (6 m average thickness).
- 2- Alternating yellowish sandy and grayish shale beds with minor intercalation of marls & salts, some fissures & caverns and is denoted by “ III “ - (40 m average thickness).
- 3- Fissured and cavernous weak to medium yellowish brown limestone, some marl and gypsum pockets and is denoted by “ II “ - (20 m average thickness).
- 4- Alternating yellowish sandy and grayish shale beds with minor intercalation of marls & salts, some fissures & caverns and is denoted by “ I “ - (10 m average thickness).

The underlying Mokattam formation consists of four members: the Giushi member; the upper building stone member; the Gizehensis member and the Lower building stone member. The top member of Mokattam formation (Giushi) is a thinly bedded white limestone 60 m thick. Upon the plateau of this member lies the largest part of the new – development of Mokattam city.

At the site of Cairo both units (Maadi and Mokattam formations) have a cumulative thickness of about 166 meters.

4 ENVIRONMENTAL EVALUATION

The study of geological, geomorphological, hydrological and geotechnical evidence indicate that geological and geomorphological features make this hill highly susceptible to degradation. Bedding and stratification of all strata in Mokattam plateau is nearly horizontal with a small dip angle of 5 – 8 degree in the northern direction. Thoroughgoing bedding, two families of parallel joints occur at spacing of 5 – 8 m. Also inclined discontinuities occur. Two major fault systems at irregular spacing spread through the whole area and have a remarkable extension.

Worsening of the situation stated above, is probably the presence of man and changes brought about by him. Therefore, there is wide combination of



Some photos showing land slide activity

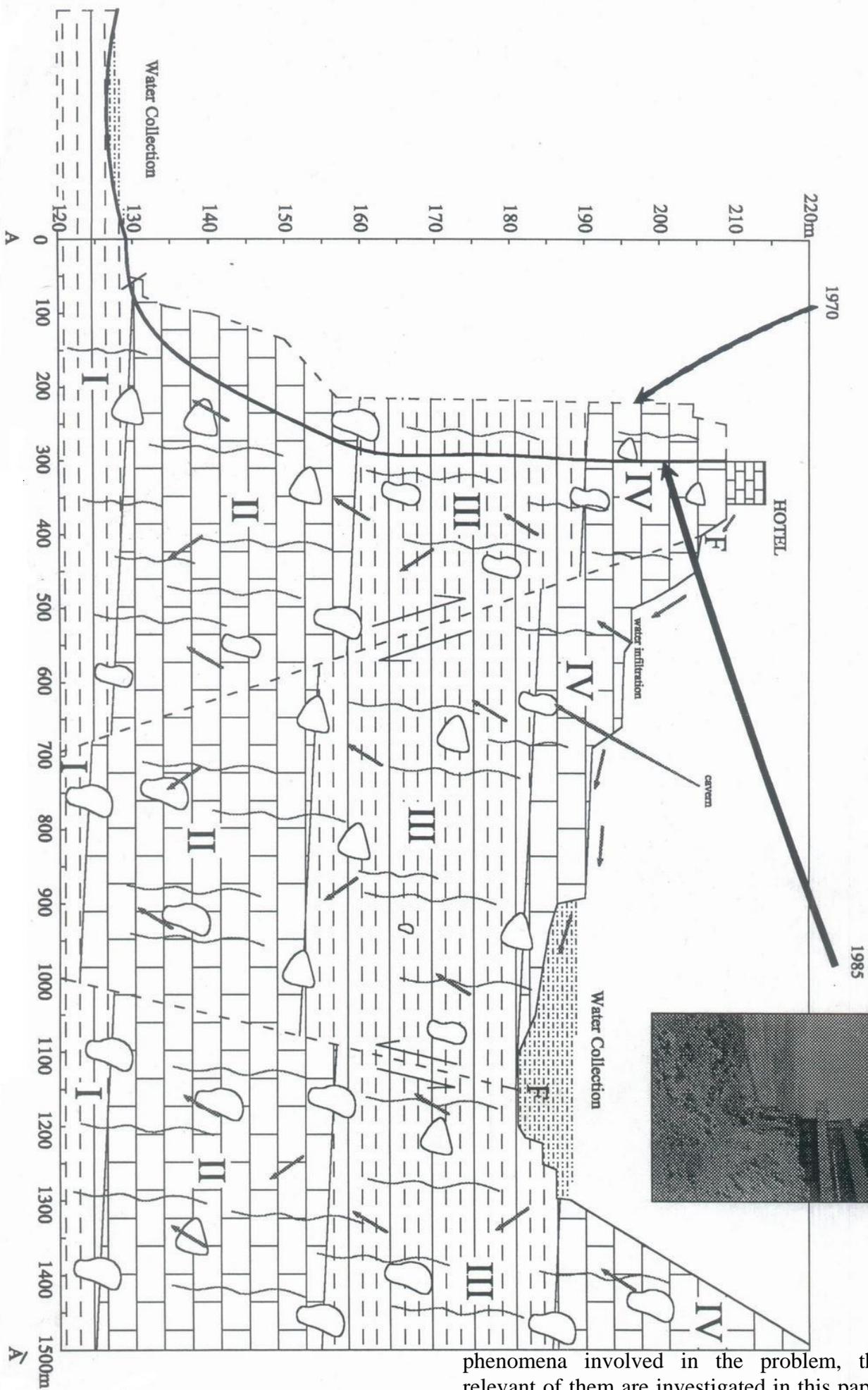


Figure 2. Geological cross section through the studied area

phenomena involved in the problem, the most relevant of them are investigated in this paper. They include lithological characteristics, jointing and faulting systems, topographical features, hydrological conditions and geotechnical properties.

5 PROBLEM ANALYSIS

5.1 *Effect of discontinuities*

The first problem is the influence of jointing, faulting and fissures of the limestone being a result of an intense tectonic action of the area. This tectonic action was of horizontal and perpendicular directions and as a result, many clastic phenomena showed up leading to the movement of limestone blocks (Aboushook and Sherif, 2000 and Moustafa et al., 1991).

As the hill is dissected by systems of vertical and horizontal joints, they inevitably combine on the outer perimeter to form wedge prone to move apart. This situation favours the development of rock fall phenomems. Furthermore, due to fractures in the rock mass, water can percolate through the open joints, thus creating seepage path.

5.2 *Effect of water infiltration*

Another very serious problem is water infiltration. Infiltration and run off of water into cavities and fissures is due to natural cause as rainfall accumulation as well as due to human activities such as irrigation and sanitary installation failures.

Rainfall accumulation, in the course of time, percolates into deeper strata at the contact between limestone and clay shale. Water percolation is evidenced by the occurrence of ditches down the hill in combination with significant growth of weeds.

Irrigation and sanitary installation failures provide more continuous supply of moisture over a long time period compared with the usual duration of infiltration from rain. However, the supply of both meteoric and sewage water continues as no equilibrium profile or hydrological balance is reached.

Worsening the situation, detected in the last decades was probably due to growing occupation that increased water infiltration as well as due to uncontrolled building construction. Subsequent urban development increased water consumption without improving the sanitary network. Usually conduits suffer opening joints, cracking and increasing leakage, leading to piping and internal erosion of the surrounding soil. This phenomenon usually occurs unattended. As a result, infiltration develops until reaching the lower downhill or the weak zones of clayey shale and marly beds causing saturation, softening and deterioration in the geomechanical conditions of these clayey beds. As a result, subsequent degradation of bearing condition

occurs and subsidence by bending and fracture of the overlying strata. Also, concentrated seepage through poorly cemented sand and siltstones causes a progressive erosion of these layers.

Effect of material characteristics

Limestone of the area is primarily porous and susceptible to chemical reaction with water rich in sulphates and chlorides. Pores allow water to be stored within the rock formation forming a good environment for chemical reaction. Part of soluble carbonates constituent's dissolve in the stored water resulting in a continuous process of void creation and expansion of already existing voids. This process continues leading eventually to the formation of large pores, cavities and pits; eventually reducing the rock into porous weak formation of remarkably deteriorated low strength. As a result, subsidence, bending and fracture of overlying strata occurs.

Fractured portions of rock mass are then separated from parent rock . At the border of the cliff, instability is thus triggered and rock topples. Furthermore, at the bottom of the cliff deterioration in the geomechanical conditions of the clayey strata due to water infiltration affects the overlying limestone complex such that traction fractures together with the existing fractures, determine favourable conditions for failure.

Remedial and Mitigation Measures

Urgent Stabilization Work

Urgent stabilization work recommended included grouting, drainage and strengthening.

Grouting

To provide water tightness of the hill top at the areas where water escapes into the limestone mass, grouting of the hard rock slab to reunite the fractured parts and sealing of the various cavities, sinkholes, etc.

6.1.2 *Drainage*

Construction of a suitable drainage system (including drainage by horizontal borings) for the catchment and diversion of the rainwater.

6.1.3 *Strengthening*

Stabilization or removal of the unstable limestone blocks, and protection of certain parts of the slopes against furthers deterioration and weathering; reduction of the overall angle of slope by excavating benches and flattening the upper part of the slope;

reinforcement of rock walls by means of passive tendons and increase of shearing resistance by backfill at the toe of the slopes.

6.2 *Integrated Long Term Stabilization Work*

The most evident signs of instability are the rock falls occurring on the cliff edges. However, due to the presence of clayey layers which form intermediate elements on the stratigraphical series, a more serious instability condition exist. It is due to the interaction between upper rock formation and the underlying deformable (clayey) substratum. Therefore, stabilization work aiming at reinforcing the rock slopes cannot be a complete solution of the instability problem. It may only be considered sufficient if the upper rock layer overlies a competent substratum.

As a result, to solve the problem in a more comprehensive way, remedial measures must take into account the overall geotechnical conditions rather than remedy of local failures. This should be done on the basis of suitable geological and geotechnical investigation taking into account the various aspects of the problem.

6.3 *Maintenance*

Further to the previously mentioned stabilization measures, a continual maintenance program should be made and followed to ensure that all the executed work is always in a good working order. If this is not done, remedial measures are subject to deterioration and instability phenomena would be reactivated.

6.4 *Monitoring*

Monitoring program must be made to study the effectiveness of remedial measures and to predict future rock fall hazards by:

- Measurements of displacement at joints (joint widths) at different intervals of time to get a general idea of particular endangered areas.
- As slope inclination is connected with the conditions for the occurrence of landslides, regional measurements of slope angles can predict landslide areas.

7 CONCLUSIONS

- i- The Mokattam hill is dissected by systems of vertical and horizontal joints, they inevitably combine on the outer perimeter to form wedge prone to move apart. This situation favours the

development of rock fall phenomena. Furthermore, due to these fractures in the rock mass, water can percolate through the open joints, thus creating seepage path.

- ii- Rainfall accumulation, in the course of time, percolates into deeper strata at the contact between limestone and clay shale. Water percolation is evidenced by the occurrence of ditches down the hill in combination with significant growth weeds.
- iii- Irrigation and sanitary installation failures provide more continuous supply of moisture over a long time period compared with the usual duration of infiltration from rain.
- iv- The supply of both meteoric and sewage water continues as no equilibrium profile or hydrological balance is reached.
- v- Worsening the situation, detected in the last decades was probably due to growing occupation that increased water infiltration as well as due to uncontrolled building construction. Subsequent urban development increased water consumption without improving the sanitary network. Usually conduits suffer opening joints, cracking and increasing leakage, leading to piping and internal erosion of the surrounding soil.
- vi- Infiltration develops until reaching the lower downhill or the weak zones of clayey shale and marly beds causing saturation, softening and deterioration in the geomechanical conditions of these clayey beds. As a result, subsequent degradation of bearing condition occurs.
- vii- Concentrated seepage through poorly cemented sand and siltstones causes a progressive erosion of these layers and subsidence by bending and fracture of the overlying strata.
- viii- At the bottom of the cliff deterioration in the geomechanical conditions of the clayey strata due to water infiltration affects the overlying limestone complex such that traction fractures together with the existing fractures, determine favourable conditions for failure.
- ix- Remedial measures recommended were divided into two stages: urgent and integrated long term stabilization work in addition to maintenance and monitoring.
- x- Urgent stabilization work included grouting, drainage and strengthening.
- xi- Integrated long term stabilization work included the consideration of overall geotechnical conditions on the basis of suitable geological and geotechnical investigation.

- xii- Maintenance program was recommended to ensure that the executed work will be always in a good working order.
- xiii- Monitoring program was also recommended including measurement of displacement at joints and slope inclination.

- El- Shazly, E.M. and Abdel- Hady, M.A., 1976. *Geological investigations on Gebel El- Mokattam. Report*, Academy of Scientific Research and Technology, Egypt, 1-25.
- Fourtau, R., 1897. Note sur la stratigraphie du Mokattam. *Bull. Soc. Geol. France*, 25: 208-211.
- Moustafa, A.R.; El- Nahhas, F. and Abdel- Tawab, S., 1991. Engineering geology of Mokattam city and vicinity, eastern Greater Cairo, Egypt. *Engineering Geology*, 31: 327-344.
- Said, R., 1962. *The geology of Egypt*. Elsevier, Amsterdam, 348pp.
- Zittel, A.K., 1883. Beitrage zur geologie und palaeontologie der Libschen Wust und der angrenzenden Gebiete von Aegypten. *Paleontographica*, 30(1), 1-112.

REFERENCES

- Aboushook, M.I. and Sherif,A., 2000. Reinforcement of fissured large roof of the Egyptian broadcasting cavern in Mokattam hill. *Proc. Of ISRM. Sym. Eurock 2001. Finland*, 401-408.
- Barron, T., 1907. *The topography and geology of the district between Cairo and Suez. Eyp. Survey Dept.*, Cairo, 133pp.
- Cuvillier, J., 1924. Contribution a l' etude geologique du Mokattam. *Bull. Inst., Egypt*, 6: 93-102.

- EGSMA.(Geological Survey of Egypt), 1996. *Engineering geological report on Mokattam upper hill*.
- Elleboudy, A.M., 1985. Analysis of Mokattam rockfalls. *Proc. Of 11 th Int. Conf. On SMFE, San Francisco*, 2321-2324.
- El- Sohby,M.A. and Elleboudy, A.M., 1988. Instability of natural slope in interbedded limestone and shale. *Proc. Of 15th Int. Symp. On Landslides, Lausanne*, 121-123.
- El-Sohby, M.A.; Elleboudy,A.M. and Aboushook, M., 1987. Swelling and shear strength characteristics of Mokattam shale. *9th African Regional Conference of ISSMFE, Lagos*, 143-146.

