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Analysis and reinforcement of fissured large roof of a cavern in Mokattam hill at the suburb of Cairo

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ABSTRACT: A natural cavern inside the Mokattam Hill at the outskirt of Cairo is currently being used by the Egyptian Radio as a broadcasting station. The cavern has a length of 120 m, a maximum width of 40m and a maximum height of 10 m. The maximum overburden thickness above the cavern is 90 m. In order to upgrade the broadcasting station, the Egyptian Radio and Television Cooperation requested the stability of the cavern to be ensured. For this purpose, Geotechnical and geophysical investigations on the side and fissured roof were undertaken. The cavern can be divided into three major sectors. The first part extends from the entrance to about 40 m and is characterized by an arched roof consisting of very weak limestone with very closed spaced two set of fissures. The second part extends from 40 m to 90 m and is characterized by an arched roof consisting of weak to medium limestone with fissures further spaced than in the first part of the cavern. The third part of the cavern extends from 90 m to its end. It is characterized by a flat roof of maximum 3 m height and consists of very weak marly limestone with very closely spaced fissures. Thirteen lateral sections were analyzed using the whole rock mass properties as well as some empirical formulas. Based on the results of the analysis, it has been recommended to strengthen the roof of the cavern in the following way:
1- For the first part of the cavern about 500 rock bolts spaced between 1 and 2 m apart.
2- For the second part about 450 rock bolts spaced between 2 and 3 m apart.
3- For the third part about 100 steel posts are needed.
In addition to that, the whole side and roof surfaces of the cavern is needed to shotcrete processing.

1. INTRODUCTION

A natural cavern inside the Mokattam Hill at the outskirt of Cairo is currently being used by the

Egyptian Radio Organization as a broadcasting station. The cavern has a length of 120 m, a maximum width of 40 m and a maximum height of 10 m. The maximum overburden thickness above the cavern is 90 m.

Some powder salt infiltration were observed to perculate to the side walls of cavern as well as some salt foliation occurred at many parts of the cavern's roof. As a result of these observations the Egyptian Radio and Television Cooperation requested the study of the state of stability of the cavern.

In order to study the state of cavern stability, the whole rock mass properties as well as the fissures characteristics and the hydroelectric resistivity were considered.

The whole rock mass properties mean the mechanical properties of the intact rock with the effect of the fissures or discontinuities characteristics as well as the rock quality designation and the state of wetting are considered. These mass properties are:

i- The Rock Mass Rating (RMR) from which the very famous empirical cavern's design called Q-system can be deduced using some empirical charts (Bieniawski, 1979 and 1993, Jorda et al., 1999).

ii- The Geological Strength Index (GSI) from which the effective rock mass compressive strength (σ_{Cm}) as well as the effective rock mass shear strength coefficients (c' & ϕ') can be deduced using some empirical charts (Hoek et al. ,1994) .

From the obtained results of the rock mass properties the state of stability and the stabilization method can be deduced using some empirical chart (Kaiser and Gale, 1985; Kirsten, 1988 and Butler and Franklin, 1990) .

2. GEOLOGY & GEOMORPHOLOGY

Mokattam plateau is located in the east of Cairo. It has characteristic topography features and about 180 m high above the average flood plain of the Nile Valley at the city of Cairo. Its highest point is at an elevation of 213 m above sea level and constitute the chain of hills separating Cairo from eastern desert (Fig. 1).

Geologically, Mokattam formations belong to Eocene age and consist mainly of two units which differ in lithology and colour. The upper unit is red brown sandy limestone, marl and shale refereed to as " Upper Mokattam " or " Maadi " Formations. The lower unit consists of a series of massive gray to white limestone designated as "Lower Mokattam " or "Mokattam Formation".

The predominant rock of Lower Mokattam is relatively homogeneous white and yellowish brown weak to medium limestone. The studied cavern is located inside the lower mokattam formation as shown in Figure 2 (Said, 1962 and El- Shazly and Abdel-Hady,1976).

3. IN-SITU INVESTIGATIONS AND MEASUREMENTS

The following investigations and measurements were be taken through 13 lateral section surveying along the cavern length:

a- The number of fissures system and their spacing.

b- The apparent quantity and quality of the salt powder on the wall sides.

c- The apparent quantity and quality of salt foliation at the roof.

d- Core samples taken from the roof and side wall and their characteristics and the hydraulic electo- resistivity .

Figure 3 shows one example for the observed points to represent a lateral section (2 -2).

4. LABORATORY MEASUREMENTS

The following measurements on the core samples were taken (table 1):

a- The intact compressive strength at dry state and at wet state (σ_{ci} & σ'_{ci})

b- The porosity and absorption.

5. ROCK MASS PROPERTIES

The strength of a fissured or jointed rocks with some discontinuities depends not only on the intact strength properties of the core or laboratory samples but also on the characteristics of the fissures or joints and on the conditions of the discontinuities as well as on the wetting conditions of the whole rock mass. Therefore, the rock mass properties mean the mechanical properties of the intact rock including the effect of the fissures characteristics and the discontinuities conditions as well as on the rock quality designation and the state of wetting. The most important parameters of rock mass properties are: The Rock Mass Rating (RMR) and The Geological Strength Index (GSI).

5.1 RMR (Rock Mass Rating):

It is considered as a geomechanical classification based by Bieniawski, 1979 and 1993 and as a very well known and systematically applied to underground excavations. RMR has become a standard for use in tunnels and many professionals apply it to describe any rock mass (Jorda et al., 1999).

RMR is the sum of five ratings corresponding to five properties (table 2): (i) compressive strength of intact rock (σ_{ci}); (ii) rock quality designation (RQD); (iii) spacing of discontinuities; (iv) condition of discontinuities; and (v) state of wetting.

5.2 Q - System (Rock Mass Quality):

It is a quality control based on the rock quality designation and the characteristics and conditions of fissures and discontinuities which apply to an empirical chart based on 212 case histories of underground openings to stabilization and support recommendations. Numerical values of Q range from 0.001 for an exceptionally poor- quality squeezing ground up to 1000 for an exceptionally good - quality rock, which is practically unfissured.

The Q system was developed at the Norwegian Geotechnical Institute by Barton, 1988; Barton et al., 1974 & 1975. Various authors (Kaiser and Gale, 1985; Grimstad & Barton, 1988; Kirsten, 1988 and Butler & Franklin, 1990) give a relationship between the RMR and Q values in the form:

$$\underline{\mathbf{RMR = A \log Q + B}}$$

They found that both RMR and Q systems accurately predicted and the Q system gave a better forecast of support quantities. Recently Barton, 1995 suggested the following relationship between RMR and Q - value:

$$\underline{\mathbf{Q\ value \cong Inv.\log (RMR - 50) / 15}}$$

Table 2 shows the deduced Q values for the different types of investigated rocks. In addition, the Q values at some selected points in the investigated 13 sections were determined on the figures The selected points of each investigated section were applied on a separate sheet of Q- system which indicate the required stabilization and support for each one, as shown in figure 4).

5.3 GSI (Geological Strength Index):

The geological strength index (GSI), introduced by Hoek et al. (1994)provides a system for estimating the reduction in rock mass strength for different geological conditions (table 3).

Once the GSI has been estimated, the effective rock mass compressive strength (σ'_{cm}) as well as the effective rock mass shear strength coefficients (c' & ϕ') can be deduced using some empirical charts. The results of these rock mass properties for the investigated samples are shown in table 2.

To realise the obtained results, it was found that the coefficient of reduction of the intact compressive strength (σ_{ci}) to the rock mass compressive strength (σ'_{cm}) ranged between 0.2 for the medium to strong investigated limestone and 0.1 for the weak to medium limestone and 0.04 for the weak to very weak limestone. These reduction coefficient values are completely agree with the coefficient of weakness of rocks as a function of rock- jointing characteristics according to Jumikis, 1983.

6. ANALYSIS OF RESULTS

From the obtained results of Q values for the selected points applied on the Q- system charts, It can be observed that:

i- The cavern can be divided into three major sectors. The first part extends from the entrance to about 40 m which is characterized by an arched roof consisting of very weak limestone with very closed spaced fissures. The second part extends from 40 m to 90 m which is characterized by an arched roof consisting of weak to medium limestone with fissures further spaced than in the first part of the cavern. The third part of the cavern extends from 90 m to its end. It is characterized by a flat roof of maximum 3 m height and consists of very weak marly limestone with very closely spaced fissures.

ii- Based on the results of the analysis, all the observed lateral sections needed to be reinforced and stabilized by rock bolts and shotcrete processing.

iii- The favorable spacing between the rock bolts must follow the frequent spacing of fissure sets. This means that, the rock bolts spacing for the first part of the cavern ranged between 1 and 2 m apart and it needs about 500 rock bolts. For the second part they ranged between 2 and 3 m apart and it needs about 450 rock bolts. For the third part which is a very critical state of stability because of not yet creating the protective arch zone and not enough height for installation of the rock bolts, it will need about 100 steel posts.

In addition to that, the whole side and roof surfaces of the cavern need to shotcrete processing.

7. CONCLUSIONS

From the previous analysis we can conduct to the followings points:

1- The state of stability of the broadcasting station existing in a natural cavern in the Mokattam Hill and suite to the Egyptian Radio Organization is stable at dry state conditions only. However, at the wet conditions the state of stability is very critical and need to be strengthened.

2- Application of the rock mass properties coefficients such as the RMR and Q systems are very useful and accurate prediction tools to give a forecast of support and stabilization quantities for our study case.

3- It was recommended to strengthen the roof of the cavern in the following way:

(i)- For the first part of the cavern about 500 rock bolts spaced between 1 and 2 m apart.

(ii)- For the second part about 450 rock bolts spaced between 2 and 3 m apart

(iii)- For the third part about 100 steel posts are needed.

4- It was recommended to use a rock bolt of length of 5 m and capable to carry out of 15 tons.

5- In addition to that, the whole side and roof surfaces of the cavern need shotcrete.

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Table 1. Physical & mechanical properties of core samples taken from the cave sections (2 - 2 ; 6 - 6 & 12- 12)

Properties / Section No.	Section 2 - 2			Section 6 - 6			Section 12-12		
	Left side	Right side	Roof	Left side	Right side	Roof	Left side	Right side	Roof
σci (Mpa)	6.55	23.5	30.25	14.25	22.35	34.25	3.45	3.15	2.85
σci ' (Mpa)	2.52	12.45	16.50	5.85	12.45	16.85	1.05	1.00	0.85
γ (ton / m3)	2.20	2.42	2.45	2.30	2.40	2.47	2.10	2.05	2.00
A (%)	8.55	1.63	1.46	4.22	1.65	1.25	10.0	10.45	11.55

σci = Intact Compressive Strength - $\sigma ci'$ = Water Soaked Compressive Strength - γ= Intact Density - A= Water absorption

Table 2. Quality properties of investigated rock masses

Bed No.	Description	RMR	Q value	SMR	GSI	σ_{ci} Mpa	$\sigma_{cm'}$ Mpa	c' Mpa	ϕ'
1	Medium to Strong Limestone, traces of fissures & pores within some marly fissures	50-60	1.0-5.0	40-50	60-75	35-45	5.0-10	1.0-2.0	35-40°
2	Weak to Medium Limestone, some pores & fissures within marly fissures	40-50	0.5-1.0	30-40	50-60	25-35	2.5-5.0	0.5-1.0	30-35°
3	Weak to Very Weak porous & fissured Limeston	30-40	0.05-0.5	20-30	40-50	15-25	1.5-2.5	0.1-0.5	25-30°

	within marly fissures								
4	Very Weak porous & fissured Marly Limestone within thin marly fissures	20-30	0.01-0.05	10-20	25-40	5.0-15	0.5-1.5	0.05-0.1	20-25°
5	Shaley Marl- hard in dry state and soft& swelling in wet state	10-20	0.005-0.01	0.0-10	15-25	2.5-5.0	0.1-0.5	0.01-0.05	15-20°
6	Clayey Shale- hard in dry state and soft& swelling in wet state	< 10	< 0.005	0.0	< 15	< 2.5	< 0.1	< 0.01	< 15°

- RMR= Rock Mass Rating = Sum of rating values depending on : strength of intact rock (σ_{ci}) ; rock quality designation (RQD) ; spacing and condition of discontinuities and ground water in joints
- Q value = Rock mass quality depending on RQD and joint characteristics ≡ Inv log { RMR - 50 } / 15
- SMR= Slop Mass Rating= RMR + adjustement factors depending on the joints- slopes relationships
- GSI= Geological Strength Index to estimate the reduction in rock mass properties for different geological conditions