Design and Construction of Grout Curtain at karstified Formations With special view on Salman Farsi Dam Project

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Abstract

Construction of a grout curtain in karstic terrains consists of some uncertainties which usually result in money and time consumptions. From the engineering geology point of view, having karst at the grout curtain route can be a disaster. In some cases, the dimension of karst was so big that stopped the work for a certain time or made the whole project uneconomical. In rare cases despite of huge remedial works, little or no results have been achieved.

Case histories of finished projects in karstic terrains show that a great part of problems is related to the lack of investigations during the study phases. Off course there are many limitations to define the problem. For instance, it should be noticed that recognition of small (and big) karsts features is very difficult and sometimes it's even impossible. After recognition of the karst, there are still many problems that should be solved. These problems consist of determining the karst geometry, removing the deposited materials from the bottom of karst, how to fill the karst, how to connect the karst to the grout curtain and so on.

Fortunately, it's possible to consider some arrangements which help to have fewer problems during the execution phase and being ready for quick action. In this paper, we try to explain major criteria for designing the grout curtain in karstic terrains and also consider the problems happened in some big projects and their solutions with special view on Salman Farsi dam project as typical karstic dam.

1-INTRODUCTION

For designing of watertightening system locating of grouting galleries have a important role on future recognition and probable variations specially where the galleries cross large scale caves. In addition the other factors same as appropriate grout mix and pressure led to ideal design.

According to the construction practices in some complicated karstic cases the watertightness element changed from grout curtain to cut off wall or overlap shafts.

In this paper Salman Farsi dam reviewed as a typical karstic dam and a few karstic examples also are explained.

2-GEOLOGICAL SETTING

The geological formations in dam axis from old to young include Pabdeh, Asmari and Razak formations. The formations are from core to north limb of Changal anticline in folded Zagros belt (Figure 1). Since the grout curtain will be executed in Asmari formation the formation is divided into three units as bellow by Mahab Ghodss Company [4]. Figure 3 indicates the location map of structures and grouting galleries. The formations belong to Paleocene-Oligocene, Oligo-Miocene and Miocene age respectively.

Upper Asmari: Includes the sub-units 1 to 15 and occurred from limestone, marl and clayey lenses.

Middle Asmari: Includes the sub-units 16 to 22 and occurred from thick intensely karstified limestones.

Lower Asmari: Includes the sub-units 23 and 24 (transitional zone) which extended to Pabdeh argillaceous formation.

Several studies have been accomplished by Millanovic[6], Nazari[7] and Salehi[8] showing that the extension of karst is mainly related to middle Asmari.

2-1-HYDROGEOLOGY

One of the key designing points in karstic terrains is understanding groundwater situation. Grout curtain extension at banks generally might touch groundwater level. Also the lowest grouting gallery location fully advised to be located near ground water table because the base of karstification determine by groundwater table.

As a famous case deep groundwater location at Lar Dam project around Tehran caused huge water scape.

In the dam axis area, the groundwater table is naturally higher than river level and it is a positive point for watertightening, Bell [1]. Warm artesian groundwater with maximum temperature about 42° in left bank is considered as another groundwater system. According to the artesian pressure, it seems that in left bank the natural groundwater table may be increased about 10-12m. Generally, the river channel is the main drainage of the area.

With some marly layers, the Upper and Lower Asmari have low permeability. The Middle Asmari has much more limestone layers, and also the purity of the limestone increases.

The Changal anticline (figure2) has a key role in dam site hydrogeology. The Pabdeh Formation is in the core of anticline. This formation (together with the bottom part of the Lower Asmari) acts as a thick and deep impervious barrier against underground water filtration from the upper erosion base levels to the lower levels. All springs (including thermal water springs) are upstream from Pabdeh. In other words, the hydrogeological connection between upstream and downstream parts of Pabdeh formation is cut. This is the key for designing the grout curtain toward downstream. The karst aquifer was in constant adjustment to the level of gorge bottom. The bottom of the gorge was cut by a very fast fluvial process. The discharge zone became progressively lower and the hydraulic gradients toward the gorge bottom were increased. The rock mass is fully exposed to the karstification process. This process could only develop down to the bottom of the gorge. It is assumed that the karst conduits exist down to the bottom of gorge level and this is the base level of karst. How ever, deeper karstification may be expected because of hot water upward flows.

3-KARSTIFICATION IN THE AREA

Karst development and understanding of the karstic relations in the dam site depend on defining the hydrogeology and structural geology conditions of the area. The exact evaluation of karst can result in successful grouting. For this project karst will be assessed in two main parts.

Karst along River

The river valley is the largest karstic phenomenon of the area which has been resulted in cutting the Changal anticline (Figure 2). According to the studies, the anticline has 15 degree plunge in northwest- west direction. In plunging folds, the river turns around the plunge, while in this area the river has cute Changal anticline completely and doesn't follow the anticline plunge. The reason is that the Gareh Aghaj River is older than Changal anticline and during the Zagros folding the river reacted to the strata rising and eroded its bed downward and has formed the karstified valley of dam site, Nazari [7]. In another study, Salehi [8], the above phenomenon is called superimposed karst.

Karst in Abutments

The existence of plunging fold has caused water movement along plunge or bedding and dissolving the rocks. This type of karst is a general karstification in both abutments and the entire of Changal anticline. Another principle factor is joint system and tectonic activity. Existence of sub vertical joints (J_1: 135 and J_2: 275) in both abutments and the predominant effect of J_1 especially in right abutment has caused extension of karst in the area. Because of curvature in Changal anticline axis (Figure 2) the joint systems especially J_1 evolved to minor faults with maximum 10m separation which has caused concentration of seepage along them.

The most important karst systems of right and left abutments are: Golshan and Saidi caves with the volume 150,000 m^3 and 5000 m^3 respectively. The karsts are occurred in connection point of joint systems, bedding and subsidiary fractures.

4- GROUT CURTAIN

Curtain geometry includes grouting galleries and boreholes in which galleries are located at elevations: 853, 835, 802 and 769 masl. In left abutment one gallery has been designed at elevation 775 instead 769 because of the existence of diversion tunnel. The central grouting gallery is located at elevation 738 masl. The borehole spacing finally decreased to 0.5m. In figure3 shows the layout of grouting galleries, dam body and other structures.

4-1- KARST DIMENSION AND WATERTIGHTENING METHOD

According to the Ewert idea [3] in reviewing the karstic condition two main types can be considered: One large scale and the second small scale karsts. In this paper the Salman Farsi dam karsts are divided into three groups of: small, medium and large scale karst. For named scales there are different ways of recognition and treatment.

4-1-1- SMALL SCALE KARSTS

This scale of karst can not be defined by the execution of grouting boreholes and galleries. Actually the difficulty of these karsts is their recognition. These caves with irregular geometry and clay fillings can lay in upward to downward direction of grout curtain, provided the grouting hasn't effective penetration to them. Under these conditions however the boreholes may be able to directly cross the small caves but selecting closer spacing of the grouting boreholes lead to more effective grouting.

Nevertheless appropriate watertightening of the small caves is achieved by applying high grouting pressure. In designing the grouting pressure, 40bar has been selected practically with

final borehole spacing of 0.5m to penetrate the cement grout to caves to fracture and squeeze the clay filled materials hydraulically. In this manner and under high grouting pressure the cement replace the filled materials as finger shape veins which lead watertight small caves.
In addition if the saturation pressure is considered to equal 40bar all along the entire the grout curtain, it would be better to add superplasticizer to the extent of %1 of the cement weight for better pentration and overcoming lateral pressures which comes from adjacent fractures which selected primarily by grout because of more aperture and desired cross with borehole Deer & Lombardi [2].

4-1-2- MEDIUM SCALE KARSTS

These groups of karsts are recognized during the drilling of grouting borehole in direct connection to cave by rod fall and lack of wash water return in direct and indirect connection to the medium scale karst. The dimensions of this kind of karst usually are higher than two successive boreholes. Nevertheless because of specific direction of the karst extension it can be unrecognized by adjacent borehole. In crossing this scale of karst, the following points can be considered:
- Drilling of adjacent borehole can be suggested to determine the extension of the caves and primary classification of the size and scale of karts. In other word the probable extension of karst along grouting gallery will be recognized.

- Drilling 1 to 2m after lack of wash water return. In this case extension of karst along borehole and depth will be recognized.

- Preparing specific grouting flowchart, to determine the volume of grout for filling the caves according to the karstic condition of the project and previous experiences.

It is probable to cross large scale karst which requires serious exploration, if the suggested volume of cement in grouting flowchart was not enough in which the following problems are taken place: continuing the absorption under limited pressure, lack of increasing the grouting pressure to saturation pressure and etc.

- It is not practical to determine exact boundary of medium and large scale karst before excavating the exploratory adits, shafts and just by coming up with some problems as rod fall, huge grout absorption without pressure and etc.

- The watertightening of medium scale karstic caves is principally achieved by drilling of grouting borehole and filling them. In this case it is necessary to make some changes in grouting mix and adding up other materials.
In grouting diagram of Salman Farsi dam project there have been considered thickening the grout from C: W (weight ratio) 1:1 to 1.5: 1 and 2: 1 and also adding of 01 size sand for filling and increasing the grout volume. Variation of from one mix to thicker mix was taken place when the take reached 12 ton cement. After achieving the maximum thickening (C: W, 2: 1), the procedure was continued to zero absorption by adding of max 6 percent 01 size clean sand. Nevertheless in other grouting projects of Iran the maximum selected sand percent

was 20 percent of cement weight. Generally there have been considered 100 ton of cement as a basis for grouting the medium scale karsts of this project. In this case the condition has been considered as large scale karst.

4-1-3- LARGE SCALE KARSTS

The most important problem for investigation of this scale of karst and huge caves is to determine the dimensions and directions of karts extension. For achieving such information, it is necessary to prepare appropriate maps and profiles which are basis for selecting the best treatment according to the exact investigation.

For preparing the above mentioned documents it is necessary to evacuate and explore the caves in grout curtain zone. Investigation of karstic caves in curtain zone is adequate because the karst may be extended in a specific direction. For evacuation and having access to large caves, enough space and proper access is very important. The role of grouting galleries in connection with the above purposes is discussed as following.

- The grouting galleries extension is toward lower Asmari and Pabdeh formation (as watertight strata) in downstream which is more or less as a horse shoe shape. The Grouting galleries of right abutment, except for the gallery at ele. 835 and grouting gallery at ele. 802 and 853 in left abutment were extended to downstream.
- In the most developed karst, the extension and geometry of the caves need to have access to caves at different elevations same as Golshan cave in right abutment of Salman Farsi dam. The accesses are prepared via galleries at elevations 802 and 769. In other words in the study phases which karstic evidences and features are observed on the surface of the earth and boreholes, the vertical distance of grouting galleries should be short as far as possible. In this case, while crossing the karst, complete recognition is obtained. In figure 4.A, B and C plan and selected profiles of Golshan caves in right abutment are observed.
- With respect to work interference of dam body with evacuation of karstic caves in concrete dams because of close relation of dam body and grouting galleries, it is probable that the dam body activities to be interrupted. In this case, the work interference is decreased to the minimum amount provided that the access to karstic media is possible through different elevation or different grouting galleries.
- The location of karst has an important role in a satisfactory watertightening. In the karsts which are extended in abutments same as Salman Farsi project, the appropriate method of watertightening will be defined by exploratory shafts, galleries and adits. In deep karsts located under the foundation, investigation activities have frequent difficulties as having access and the groundwater pressure. Practically the method of watertightening of the deep karst is filling the cave by grouting borehole no matter if it is large or medium scale. The Lar project is a well known dam with deep karsts in Iran. In this project some caves were located more than 300m under the foundation level. Filling and grouting of the caves by 146mm size grouting boreholes did not lead to complete watertightening.

In Salman Farsi project with respect to the exploratory works three main methods were discussed for watertightening the huge Golshan cave as following:

4-1-3-1- Filling the Large Cave by Concrete

In the first step, filling the caves seems to be a common method of watertightening. However, because of following difficulties this method was not selected for watertightening of Golshan cave in right abutment.

As mentioned before, in concrete dams because of work interference the elevation of construction of dam body is limited by selecting the filling manner. In this case as opposite to the exploration and evacuation time, the filling condition was possible only through one gallery at ele. 802. The rate of filling isn't high and will appear some problems as huge volume of karst and uncertainty of complete filling, lack of readiness of contractor for execution of this method, financial dependency of contractor to proceeding with the main dam and etc. With respect to performed investigations of karstic caves some uncertainties will appear as: settlement of caves floor, because of presence of dislocated blocks and interfiling materials, piping and erosion of fine grained material between blocks, very irregular geometry of caves which finally leads to mitigate the watertightening role of filling method.

In left abutment because of limited volume ($\approx$5000 m^3) and lack of above uncertainties of Saidi cave however, the method of filling by concrete have been selected.

4-1-3-2- Building a Concrete Wall in Caves

Building a concrete wall between right abutment galleries of 769 and 802 in Golshan cave is complicated and expensive with numerous uncertainties. In this case, a concrete wall with more than 30m height in a limited space might be constructed that serious problems will be appeared as transport of material, equipping and carrying special instrument, instabilities related to settlement of dislocated blocks and seismic loads and seepage and erosion of fine grained materials between the dislocated blocks.

In this case, actually there is a 30m height concrete dam in the underground space. Eventually the method was not selected because of the above mentioned problems.

4-1-3-3- Change in Azimuth of Grouting Galleries and by passing the Karst

In design of grouting galleries in karstic media, it is necessary to consider appropriate azimuth in addition to their elevations. The grout curtain of Salman Farsi project as a classic design extended downward in horse shoe shape geometry to connect lower Asmari watertight strata (Figure 3). The galleries cross the karstified thick layered middle Asmari limestone before the connection is taken place. In design phase, the grouting galleries are designed in parallel to karst extension with the minimum interference with karst, provided that the investigations are completed.

According to the investigations made on Golshan cave and the plan view of the caves and its channels (Figure 4A), finally turning around the karst and installation of grout curtain upward the cave have been executed. In this case, all the huge karsts are located downstream of the curtain and actually after turning (figure 5), the limited karstic space in new azimuth was filled by concrete. The modified location of grouting galleries after turning is shown by figure 5.

In this case, the above mentioned problems, uncertainties and risks of watertightening are decreased to some extent and finally the curtain is extended to lower Asmari formation.

As a other practice in the Sklope dam in Croatia during the execution of grout curtain in both aboutments large caves were crossed by grout curtain in which by passing method selected for installation of grout curtain between reservoir and caves.

5- EFFICIENCY OF GROUT CURTAIN IN KARSTIC TERRAINS

The efficiency of grouting depends to the grouting technology from one hand and ground condition from the other hand. In complicated karstic geology condition generally watertightening doesn't achieve by grouting and there are some cases in which cut off walls or overlap shafts have been done as an antifiltration barrier. In fact the difficulty of grouting is related to the micro karstic features of rock which filtrate water while grouting penetration is limited. The best example of cut off wall in fault zone of Asmari limestone is Karun I in Iran. In this case (figure6) connection of reservoir to downstream was made possible by clay filled fault zone and the leakage prevented by concrete cut off wall exceeding 100m in height and about 30m width.

In groutable rocks same as Salman Farsi dam the efficiency of grout curtain can be assessed by piezometric holes.

5-1- Evaluating the curtain performance based on the piezometric data-Golshan Cacve section

It was decided to impound the reservoir in different phases to control the possible seepages. The first phase of impounding started in March 2007. During this phase, the reservoir impounded up to 60 meter above the dam foundation.

So far, more than 640,000 meter boreholes are drilled to improve the water tightness of the dam. The average cement take of boreholes is about 103 kg/m. All karsts at the curtain route are filled with concrete. The check holes and permeability tests show good results. An intensive net of piezometers and drainage holes has been installed to monitor the behavior of the curtain. Piezometric data, drainage holes measurements and visual inspection of abutments and downstream area, show very low amount of seepage through the curtain. At the end of the first phase of impounding the behavior of curtain could be considered satisfying. As an example the piezometric data for Golshan Cave section interpreted here. Golshan's cave is about 250 meter far from the valley cliff at right abutment. It has two big karstic channels. Piezometers No. 769RY2-5U and 769RY2-6D are installed in this part. Similar to the previous section, piezometer5U is installed upstream and piezometer 6D is installed at the same section but downstream of the curtain.

Before impounding, the ground water level in 5U was 757.97 masl.(fig7) Then, at the maximum reservoir level it reaches to 759.73 masl and it's maximum piezometric level is 763.45 masl.

On the other hand, before impounding the ground water level in 6d was 748.07 masl. During the impounding and at the maximum reservoir level it reached to 747.01 masl and its maximum piezometric level is 748.87 masl.

6- CONCLUSION

1- In karstic dam project the karsts can classified in three group of small, medium and large scale.

1- The practical method of watertightening the small scale karsts and caves is to apply high grouting pressure and closer spacing of grouting boreholes.
2- The best method of watertightening the medium scale karsts is to change the grout mix to thicker grouts and add fine sands.
3- The appropriate method of exploration of large scale karsts is to have grouting galleries at specific elevations and to construct exploratory shafts and adits in grout curtain zone.
4-one of best methods of watertightening of large scale karst, is by passing the karst
5- In intense karstified system the watertightening element could vary from grout curtain to cut off wall or overlap shafts.

REFRENCES

1- Bell.F.G.1990. Engineering geology p.359

2- Deer. D & Lombardi. G. 1993. Grouting designe and control using GIN principle. International water power and dam construction. Pp 15-22

3- Ewert. F. K.1995. Consideration on grouting of karstic limestones of dam sites. Dam engineering. Issues 1. Pp3-30

4- Mahab Ghodss consulting engineering. 1991. Geology of Salman Farsi dam site(in farsi).

5- Milanovic,P,2000, Geological engineering in karst, Zebra publishing,Belgrade

6- Millanivic. P. 2001. Report on hydrogeology for Salman Farsi dam. Fars water regional company. P28

7- Nazari. M.H. 2002, Evaluation of effective engineering geology parameters in designing of grout curtain of Salman Farsi dam. M.Sc thesis(in farsi). Tarbiat Modares university (TMU).

8- Salehi. M. 2001, Considering of engineering geology problems of Salman Farsi dam with emphasis on karst(in farsi). M.Sc thesis. Isfahan university

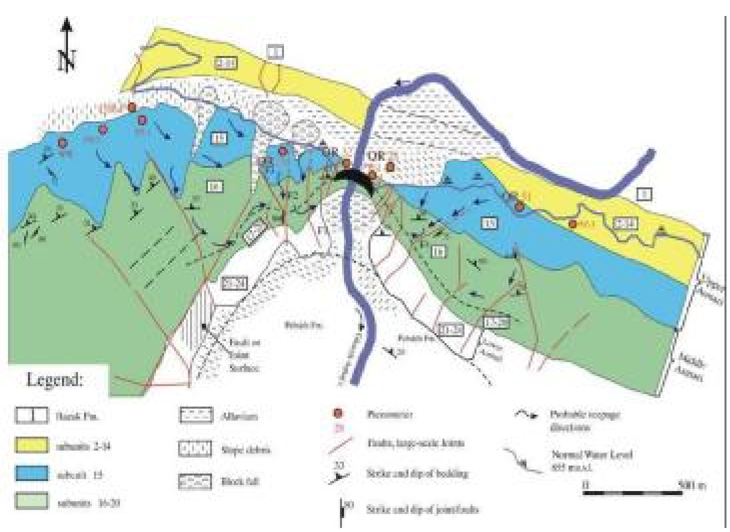

Fig. 1 Geological sketch of dam site

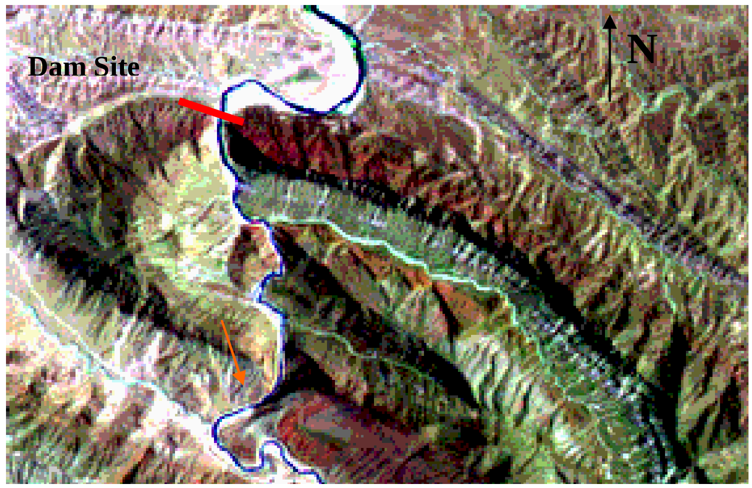

Figure 2- Satellite Image of the Area and Cutting the Changal Anticline by Ghareh Aghaj River.

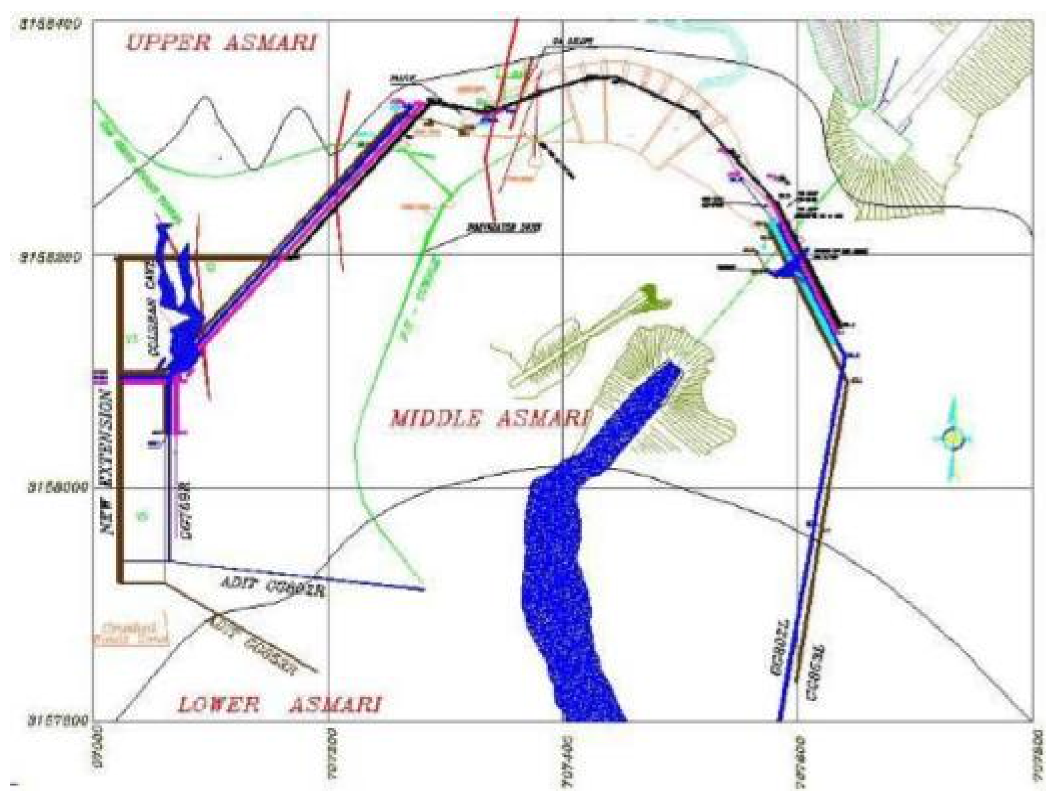

Figure 3- Plan Location of Grouting Galleries, Dam Body, Geological Formations and Units

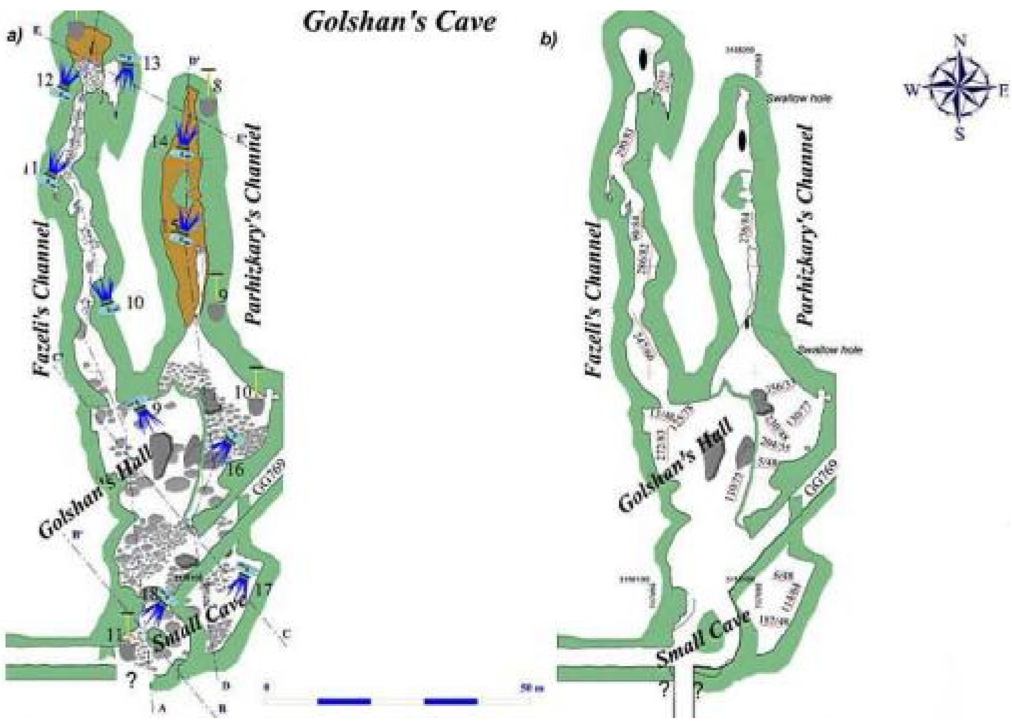

Figure 4.A- Plan View of Golshan Cave and Karstic Channels of Right Abutment.

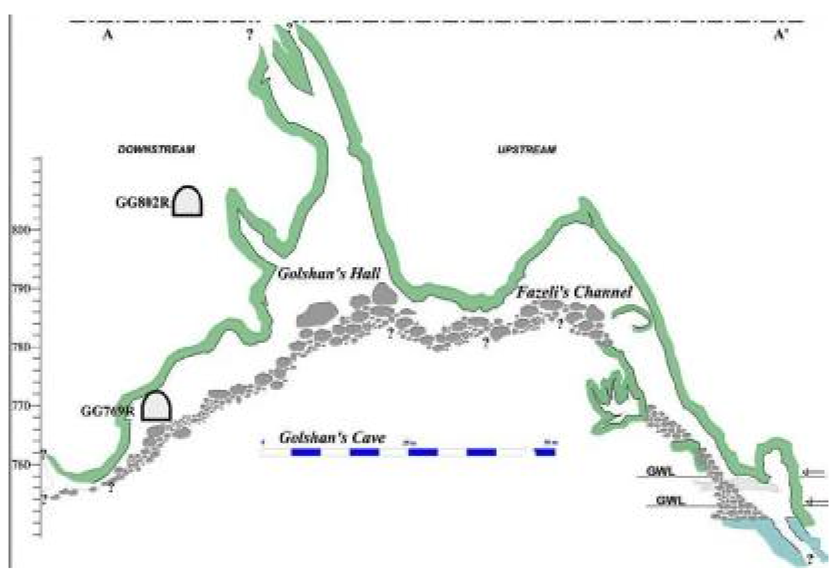

Figure 4B- Section A-A of Grouting Galleries, Karstic Channels and Golshan Cave in Right Abutment.

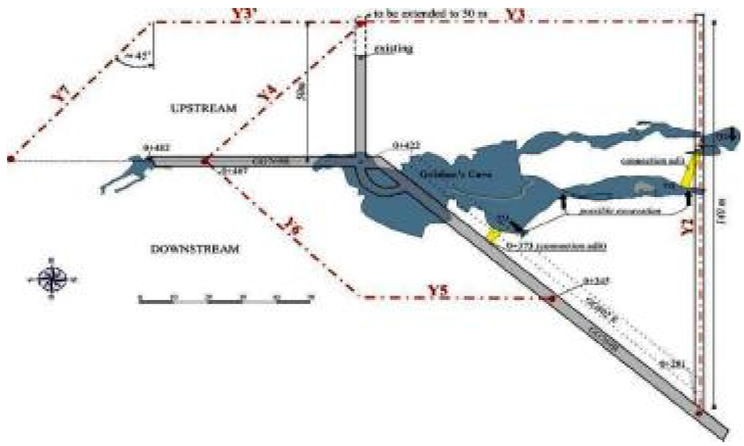

Figure 5- Grout curtain by pass the Golshan's Cave. From Stucky-Electrowatt

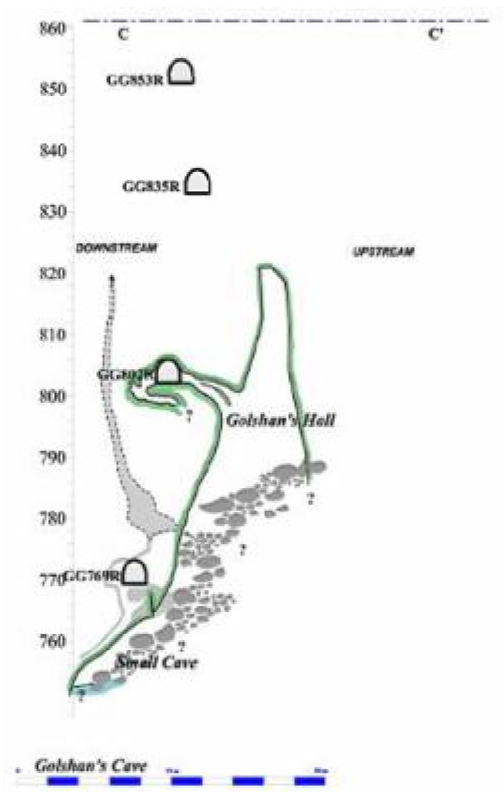

Figure 4C- Section C-C of Grouting Galleries, Karstic Channels and Golshan Cave in Right Abutment.

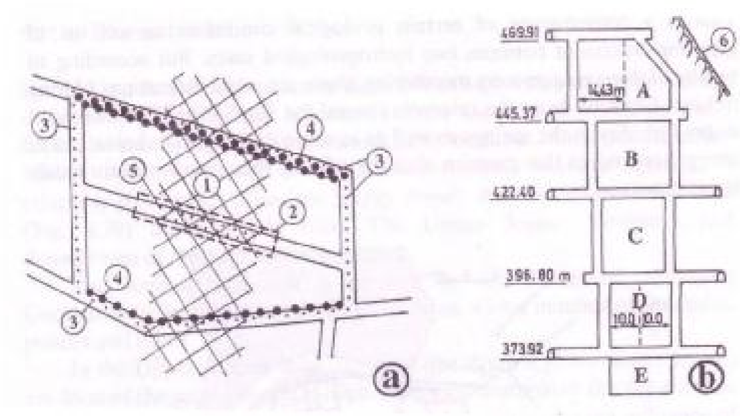

Figure6-Karun I cut off wall. a) Grouting borehole layout b) vertical lay out of cut off wall. 1- fault zone 2- cut off wall 3- primary grout holes 4- secondary grout holes 5- tertiary grout holes 6- Dam foundation(after Millanovic[5])

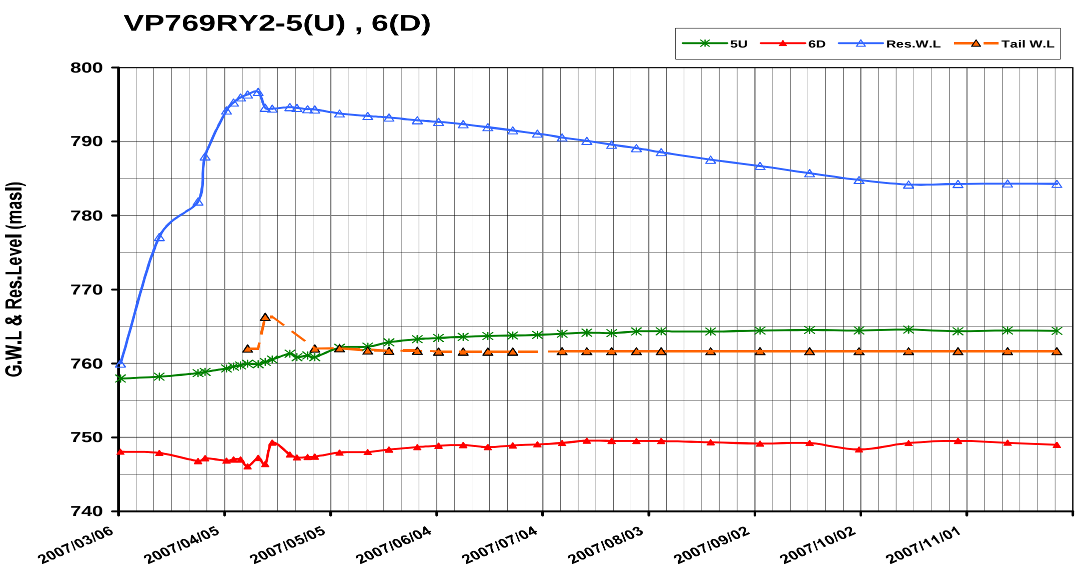

Figure7- piezometric data for Golshan Cave section