Groundwater Lowering in Deep Excavation (Case Study: Foundation Excavation of Shahid Madani Dam)

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ABSTRACT

In many big civil constructions, deep excavation is an essential part of project and groundwater control in excavation process is the prominent tasks. In this paper while mentioning the risks of deep excavation, the solutions of underground water control have been explained and different methods of groundwater control in regard to financial conditions, different soil condition and various depths have been investigated.

Groundwater control in foundation excavation of Shahid Madani Dam as a case study is presented. Depth of foundation excavation was about 50 meters in tight valley and excavation was performed under groundwater table. This excavation is one of the deepest excavations in Iran and it has some specific problems related to topographical and geotechnical condition in dam site.
Finally the proper methods for groundwater control are presented and recommended. Measurements in excavation period and in the middle of dam body construction have shown that this design method had a good performance.

INTRODUCTION

In many big civil constructions, exposed deep excavation is risky and unavoidable. In excavation process especially when the depth is high, some attention is necessary. Some of them are:

-The probability of side slope instability and relevant stabilization.
-Increasing instability of cut sides cause by external loads (such as walls, near buildings, other loading)
-Instability of the excavation slopes by material being removed from them by erosion due to seepage. Effective control of groundwater may allow slopes to be steepened and therefore the area of excavation is reduced (Behnia, 1987).

All above problems contribute at the start as well as at the end of excavation. The proper method is a function general plan of project which determines excavation period, subsurface condition, buildings around that impose loads on side slopes and probable problems from settlement, purpose of excavation (permanent or temporary excavation) and financial restrictions.

Referring to ancient documents, it shows that people in that area had encountered some problems in getting water from wells and subterranean canals. The title of one of the most ancient books related to Iranian scientists is "Getting hidden water from earth". In a chapter of this book some problems that arise in soft rock excavation, when a large amount of water has been exist in it, had discussed and some solutions presented. (Xadiv jam 1994)

Nowadays in international projects, underground water control is one of the important aspects in deep excavation and annually some experts present their experimental findings. For instance, Forth (2004) presented his experience in deep excavation in Hong Honk and recommend grouting method for underground water control in there. Ahn et al. (2006) mentioned the different methods of lowering underground water table in tunnel and effectiveness of grouting in reduction of leakage investigated with both experimental and numerical methods was investigated.

Also, (Hideki 2007) presented a report on pumpage for underground water control in Tokyo city. In his design, four pump stations had installed and 200 cubic meters of water was pumped per second. This is unique project in that kind.

In this study, the methods of groundwater control in deep excavation were considered and then as a case study the foundation excavation of Shahid Madani embankment dam has been discussed.

METHODS FOR CONTROL OF UNDERGROUND WATER IN EXCAVATIONS

Generally, two major groups of underground water techniques controls are are exist: Exclusion techniques and dewatering techniques (Cashman et al. 2001).

Exclusion techniques: Those that exclude water from the excavation.
Dewatering techniques: Those that deal with groundwater by pumping.

Exclusion methods

The aim of groundwater control by exclusion techniques is to prevent groundwater from entering the working area. The methods used can be grouped into three broad categories:

A: Methods where a very low permeability wall is physically constructed or inserted in the ground. (Sheet pile, Diaphragm walls…)
B: Methods that reduce the permeability of in situ ground. (Grouting methods, Ground freezing …)
C: Methods which used a fluid pressure in confined chambers such as tunnels to counter balance groundwater pressures. (Compressed air, earth pressure balance tunnel boring machines)

Dewatering methods

In the second group, underground water flow is pumped so the underground water table is lowered below the deepest excavation formation level. For safe and stable excavation it necessary to remind these two important points:

In the excavation period, do not hold back the water table to its first condition. This may cause a build up of pore water pressures that will eventually cause catastrophic movement of soil and groundwater.

Ensure those fine grain soil particles are not continuously migrated around the drainage well. Proper filter design avoids any build up of pore water pressures and prevents transportation of fines.

As a general guide (Cashman et al. 2001) recommended that if the soil permeability is less than about 1e-7 m/s, migration of fines ceases otherwise migration of fines should be considered. Lowering groundwater levels are the basis of the so-called methods such as well pointing, deep wells and ejectors where groundwater levels are lowered in advance of excavation.

In figure 1 two main group of underground water control are presented.

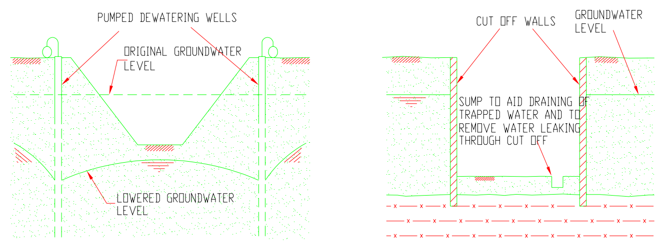

Fig. 1. Different methods of underground water control in foundation excavation (Cashman et al., 2001)

PROPER METHOD SELECTION FOR GROUNDWATER CONTROL

The method most suitable for dewatering of an excavation depends upon the type of excavation, geologic and soil conditions, depth of groundwater lowering, required rate and intermittent of pumping, experience of domestic contractor in recommended method and cost comparison between different methods. The following points are important for selection of proper groundwater control method:

1- The perviousness and drainability of a soil or rock may dictate the general type of a dewatering system to be used for a project. A guide for the selection of a dewatering system related to the grain size of soils is presented in figure 2. (Cashman et al. 2001).

2- The magnitude of the drawdown required is an important consideration in selecting a dewatering system. If the drawdown required is large, deep wells may be the best alternative. Deep wells have an ability to achieve large drawdown from the top of an excavation, whereas many stages of wellpoints would be required to accomplish the same drawdown. Deep wells can be used for a wide range of flows by selecting suitable pumps with appropriate size (Quinon et al. 1987).

3- The required rate of pumping to dewater an excavation may vary from 20 to 100,000 liter per minutes. Thus, flow to a drainage system will have an important effect on the design and selection of the wells, pumps and piping system.

4- In some projects, it needed to mix two or more methods together to find the best way for underground water control.

GENERAL SPECIFICATION OF SHAHID MADANI DAM

Shahid Madani dam is located in 5 km east-north of Tabriz city which is under construction to control the floods and also development in agriculture in vicinity.

Water shed extent of this dam is about 7700 km^2 and has 445 million cubic meters discharge per year. In current situation this volume has missed via floods especially in spring. Total volume of reservoir is about 360 million cubic meters and reservoir area is 37 km2 at normal water level. The type of the dam is rockfill with vertical clay core and its height is about 93 meters from foundation. The crest length is 277 meters and total dam body volume is about 1.7 million cubic meters (GNCE, 2002). In dam design, it has determined to put clay core on proper rock to reduce discharge flow in foundation. The depth of this excavation is about 50 meters (See Fig. 4).

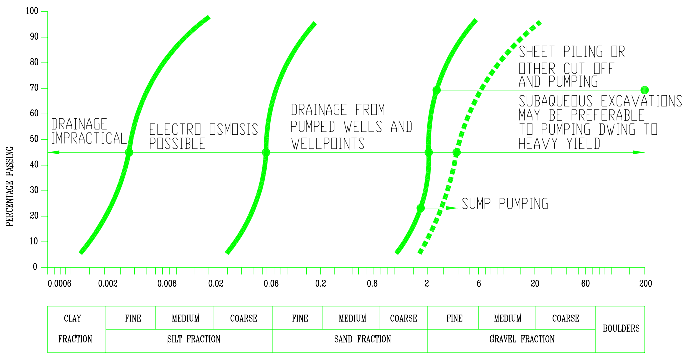

Fig. 2. Experimental Dewatering systems applicable to different soils (Cashman et al., 2001).

For proper foundation treatment and water proofing, several alternatives as cut off wall, grout injection and excavation of slope wash are investigated. In regard to technical and financial condition and available construction method in area, excavation of foundation is selected as a preferred method.

SITE INVESTIGATION

Comprehensive investigations were carried out to find subsurface condition including permeability, layer stratification, groundwater level, type of aquifers and etc. Figure 3 shows the plan of exploratory dam boreholes and dam axis. The related results of those investigations have shown that aquifer is unconfined type. In dam site, foundation consists of thick layer about 50 meters of right slope wash on weathered igneous rock. This part of foundation is covered by a mixture of coarse-grained and fine-grained particle which in some places has large amount of loose sand. After some tests it was cleared that the permeability of local parts in foundation is very high and in some places soil strength is inadequate.

On the basis of borehole samples and insitu permeability test result, the coefficient of permeability in alluvium is between 1e-3 to 1e-4 cm/s and in some cases is about 1e-5 cm/s (GNCE, 2002). So the permeability is in medium range Groundwater table is about five meters below the ground surface.

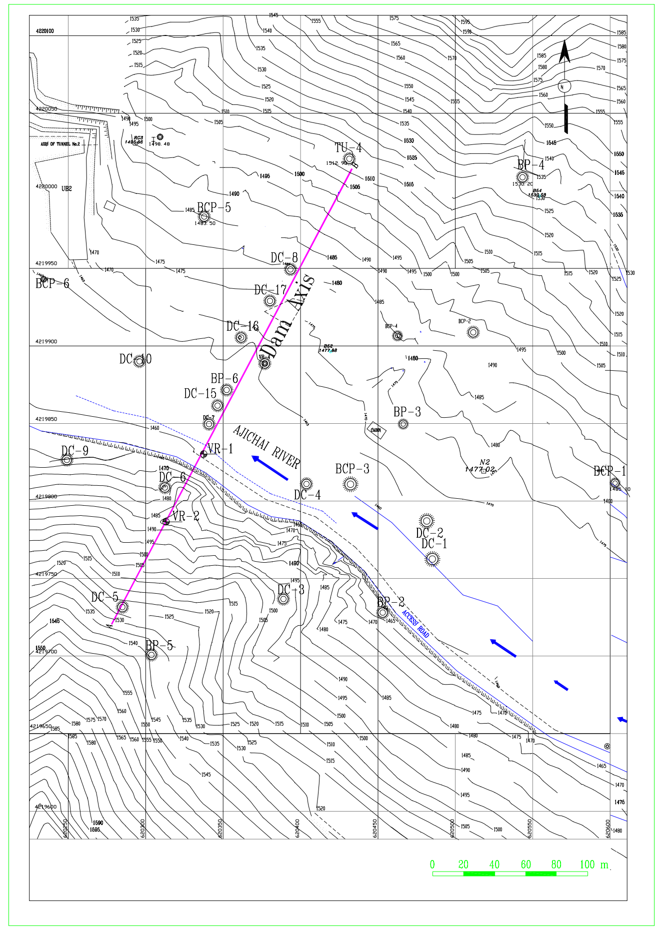

Fig. 3. plan of exploratory dam boreholes (GNCE, 2002).

PROPER METHOD TO CONTROL GROUNDWATER IN DEEP EXCAVATION OF DAM

For groundwater control, the design recommends to mix some methods together. These steps had carried to control water flow:

-On the upstream of cofferdam, the clay blanket was constructed. This blanket cause reduction in hydraulic gradient and as result the discharge flow was reduced.

-Deep well with pump installed in four points. These pumps were lowered the water level up to 40 meters.

-Sewage pumps put in two sumps area, to pump out leaky water into excavation area.

-Drainage channels with 2 meters height and 0.5 meter wide were installed in base of excavation to conveyance the water to sump.

-Some Collector channels were installed in excavation area to prevent the surface water run-off flow into excavated area.

Precise estimation of discharge flow rate is very difficult due to some uncertainty in groundwater table in different season, sandy lenses in some points and diversity in soil and rock conditions and etc. Numerical analyses were carried out to

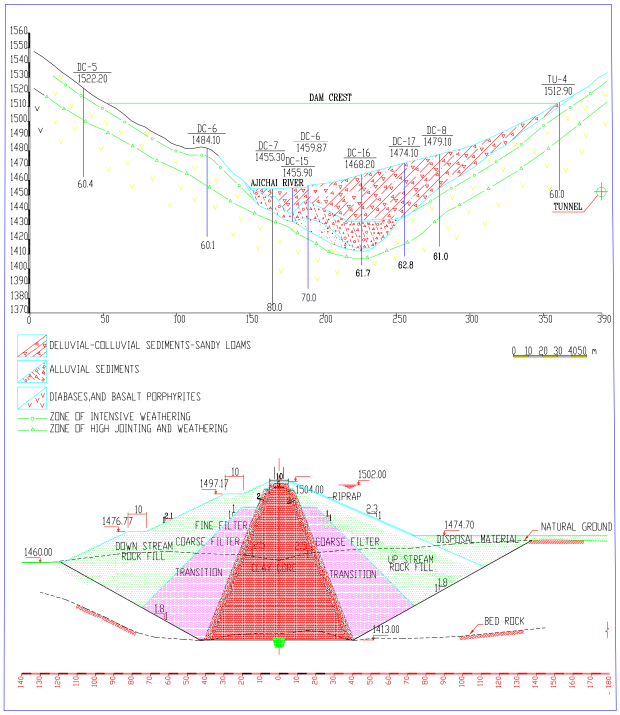

Fig. 4. a: Geological section of dam axis b: Transverse section of dam.

find discharge flow. Results were estimated discharge to be 67 lit/s. By assuming factor of safety be equal to 3, design flow is about 200 lit/s.

Four deep wells have designed. Two wells had drilled between upstream cofferdam and cut edge. The line of these wells is parallel to dam axis. The distance between cut edge and coffer dam is 50 and 200 meters respectively.

The well diameter and depth is 700 mm and 70 meters. The drilling method used to construct these wells is rotary method. Approximate 50 meters of well is in alluvium and the 20 meters is in rock. So, the bottom level of wells is about 20 meters under bottom of excavation. Location and excavation section of cut and drainages well is presented in figure 5.

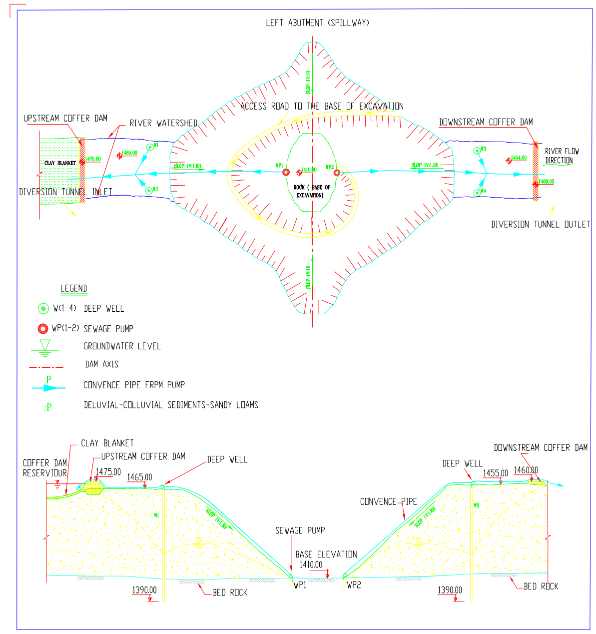

Fig. 5: Foundation excavation plan and section.

In excavation period, some times the pumps were off for some hours. In the beginning of excavation pumps was on in about 5 hours of 24 hours. As the excavation was going on, the work time of pumps were increased. At the end of excavation the pumps was on in 20 hours of 24 hours. At this time discharge flow was about 60 liters per second from 4 wells.

Also when the excavation depth increased, water flow from abutments and up /down stream increased, so to dry the trench base and providing the movement of excavation machines and trucks, inflow water were conveyed to two excavated pits at up/down stream ends through temporary channels and pumped out with two sewage pumps.

This two sewage pumps in upstream and downstream of excavation had great influence in water flow control. When the pumps were temporary become out of work or turn off, the discharge flow increased up to 4 times. The sewage pumps in excavated pits were lowered as the excavation depth increased. So the pumps level was about 3 to 5 meters below the bottom of excavation. The mean discharge flow from these pumps was about 10 lit/s.

Fig. 6: Foundation excavation pictures at start, middle and end of excavation.

The slope of this open cut excavation was analyzed in two directions by equilibrium method. Slop of excavation perpendicular to dam axis in regard to stratification and shear strength of foundation in upstream and downstream is assumed to be 1.8H:1V and along dam axis is 1H:1V due to presence of rock.

To access in excavated area the spiral road had designed to provide access of trucks and excavation machines.

Foundation excavation of Shahid Madani dam started from and lasted in 12 months and after that dam construction started. Total volume of excavation is about 0.7 million cubic meters. In practice this scheme of underground water control had good performance.

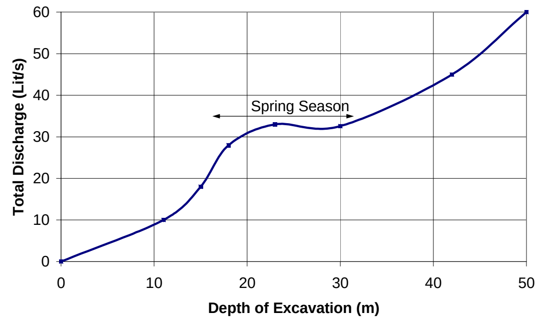

Fig. 6. Variation of leaky water in different depth of excavation.

SUMMARY AND RESULTS

Underground water control in deep foundation excavation is one of the important problems. In dam foundation construction, preparation of the ground water management plan and correct selection of phases for managing the district's ground water resources is an essential challenge in the projects. To solve this problem, two major ways exist. The first is to construct cut off wall or clay blanket to reduce hydraulic gradient and as a result the leaky water reduced. In second method groundwater problems can be solved by dewatering methods.

Shahid Madani dam is a rockfill dam with a vertical clay core where located in west-north of Iran. This dam has been under construction to control the floods and also development in agriculture in vicinity. In dam design, it has determined to put clay core on proper rock to reduce discharge flow in foundation. For proper foundation treatment and water proofing, several alternatives as cut-off wall, grout injection and excavation of slope wash are investigated. In regard to technical and financial condition and available construction method in area, excavation of foundation is selected as preferred method. Depth of foundation excavation was about 50 meters in tight valley and excavation was under groundwater table.

For groundwater control, the design recommends to mix some methods together. The elements of designed system are a clay blanket on the upstream of cofferdam, four deep wells with pump station, two sewage pumps, drainage channels and some collector channels. To access in excavated area the spiral road had designed to provide access of trucks and excavation machines. Variation of leaky water in different depth of excavation is monitored. Measurements had shown that this system was suitable for underground water control in foundation.

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