Designing Mollasadra Dam Right Abutment's Sealing System

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Abstract

Mollasadra dam is located on an alluvium of about 40m thick made up of alluvial sedimentations ranged from fine materials (incl. silt and marl) to coarse ones (coarse rubble particles, gravel, sand with clay paste). Practically, flow line passes through two layers causes high hydraulic gradients at the two layers' border. Due to the above, choosing most suitable sealing system considering execution, technical and economical terms and conditions is one of the main questions to be brought up. To ask this question, first of all using Seep/w software permeability data are analyzed. Then, every sealing method is modeled separately and the results are compared with total quantity of seepage from under dam foundation.

Key Words: *cut off wall, hydraulic gradients, sealing system, Seep/w software*

1. Preface

Issue of seeping through foundation and abutment of dams is of great importance in views of quantity of seeping and wastage of a considerable amount of reserved water behind dam, of technical problems resulted from seepage caused by hydraulic gradients and created interactional forces, as well as of the risks affecting stability of dam and erosion of the foundation. Thus, controlling this issue is one of necessities of each and every dam work.

In this research, we try to introduce usual sealing methods of foundations and abutments of earth dams, present different tricks of seepage control and calculate quantity of seepage through Mollasadra dam foundation in each method with the use of Seep/w software.

2. General Geology of the Area

Geologically, the area under study is located in zone of overthrusted Zagros or high Zagros. Overthrust of Zagros extends northwest– southeast in a direct line which defines a very deep and old joint and distinguishes boundary of Saudi Arabian and Iranian platform. [1]

The most important element of Mollasadra dam's location is Kor anticline where the dam is located on its eastern chord. This anticline with a wavelength and trend of almost northwestern – southeastern is limited to a calcareous layer aged in upper Cretaceous (Sarvak formation).

Of the main faults of the area is Zagros Fault. Zagros main fault is the largest fault in Iran and southeastern Asia.In this area there are two types of faults:transitional faults of Bakan and Ardakan,reverse faults of Sedeh and Sheshpir.

Stratigraphy wise, the project extent ranges age wise (from old to recent) as follows:

Sarvak formation (KL1, KL2 units), Goorpey formation, Neogen sedimentations (alternates between non-homogenous conglomerate with relatively poor cement and red and yellow marl) and current testament sedimentations (incl. alluvial terraces, flood plain sedimentations, alluvial cones and piedmont sedimentations).

The KL1 and the KL2 units are mainly exposed in downstream and upstream of the dam's axis respectively. The most exposure of conglomerate unit is in the right abutment of the dam.

3. Engineering Geology:

3.1 Discontinuities system:

To analyze status of joints in abutments and rock exposures at the flow weir and culvert extents and to study joint setting of each abutment 100 joints were surveyed and then diagram contour and discontinuities plates were set out on Schmitt grid. Rather than layered plates there are three types of main joints (J1 = 45/55, J2 = 170/80 and J3 = 250/73) at the right abutment.

3.2 Quality of Cores (RQD)

RQD is percentage of sound cores of >100mm long to total cores. [4]

Based on these results, average of the rocks' quality index in the left abutment and the foundation is about 70%. The average of the rocks' quality index is about 50% every where in the right abutment where constituted from marl, marl and bituminous limes and lime rock which are classified (Deere & Barton, 1963) as weak to medium rocks except in the weak conglomerate zones which have poor clay cement.

3.3 Permeability

There are several factors contribute in permeability rate of cairns of which the most important ones are: discontinuities (joints, layering), cairn strength, tensile strength of discontinuous levels and strength of filling materials. Among them existence of discontinuities creates transmission routes around bore holes in which multiplicity of routes and their embranchments around boreholes is important. [5]

In the right side of the dam location boreholes C1, DR1, DR2, DR3, DR4, and DR5 were drilled. Permeability status of the right abutment's cairn depends on its lithological conditions. In boreholes DR1-DR5 permeability test in conglomerate rocks was mainly done with Luphrane method. The permeability in the right side conglomerates measured 1.8×10^{-3} to 1.2×10^{-6}.

Boreholes T1, S1, DL1, DL3, DL4, and DL6 were done in the left side of Mollasadra dam.

Permeability rate in boreholes DL1 and DL2 in the left side was great in -25 to -65m deep and larger than 100 Lugeon that demonstrates an impermeable zone. Studies on the drilled cores also show small and big solubility holes and vuggy joints.

3.4 Controlling behavior of water flow in the joints

Out of 46 Lugeon tests, about 4% have laminar, 4% turbulent, 11% dilation, 16% washing out of joints and 65% impermeable behaviors.

4. Analyzing Seepage Status Using Seep/w Software

To analyze the above, a geology cross section was prepared in parallel to the dam axis. Then, the boreholes and their relevant data were set out in the sections. Since 8 boreholes were done in the dam axis, the axis length was divided into 8 areas with different lengths accordingly. (Pic. 1)

5. Parameters Used in the Analysis

To analyze the seepage relation of water flow in soil is bound to water level status and its changes as well as to the environment's permeability conditions. [2]
Based on the measurements, water level in downstream of the dam is 2050m from sea level. Normal water level in the upstream is 2115m from sea level. 17 boreholes were drilled in the extent of the dam. 8 of them were in the axis of the dam and data of which was used for seepage analysis in this paper.. Permeability values gained from Luphrane tests equal to Darcy permeability ratio with the unit of cm/s went directly under analysis. It is while the Lugeon test results which were in LU converted to Darcy permeability ratio using experimental charts and are used in the seepage analysis. [3]

6. Analysis Results

6.1 Seepage Analysis with No Sealing

Water passing value from the location of Mollasadra dam without any sealing and only based on placement of the dam on the location was analyzed with the here below results (pic. 2)
$Q = 2.71\ E - 1 \quad m^3/s/m$
Daily seepage rate equals:
$Q = 2.71\ E - 1 \quad m^3/s/m \times 86400 = 23427\ m^3/day$

6.2 Seepage Analysis Using Sealing Methods

Different sealing methods used are:

- Grouting
- Cut off wall
- Grouting + cut off wall
- Upstream impermeable clay blanket
- Upstream impermeable clay blanket + grouting

- Grouting

There is no scheme in this stage for sealing of the alluvium and only grouting in to bed rocks with Lugeon 1, 3 and 5 was done. Seepage rate of flow described in 6.1 i.e. with no sealing method reduced from 23427 to 941m^3/day by grouting down to depth of -65m and Lugeon 1. From this depth downward no sensible reduction in the rate of flow was seen. (Table 1) and (Pic. 3)

- Cut off wall

A cut off wall with permeability ratio of 1× 10-6 cm/s, 200m ling and 80cm thick was considered.
Seepage rate of flow in the right abutment without using any sealing method reduced from 12031 to 287m^3/day by construction of a 40m deep cut off wall. This reduction proves efficiency of this method.

- Grouting + cut off wall

In this method a cut off wall with different depths for sealing off in alluvial material and grouting into different depths and with a selected Lugeon (3 unit) for sealing off rock materials were used. Best results were achieved using grouting down to maximum 65m in calcareous rocks of the left side and constructing a cut off wall down to 40m in conglomerates of the right abutment. In this method, seepage rate of flow reduces from 23427 to 1547 m^3/day.

- Upstream impermeable clay blanket

The upstream impermeable clay blanket thickness is 1m and coverage lengths are 0, 38m, 60m, 120m, and 150m. The aforesaid lengths are regardless of extending length of the dam's crust in the upstream (152m). Permeability value of this impermeable clay blanket is also considered just like a clay core.

- Upstream impermeable clay blanket + grouting

In this method, an upstream impermeable clay blanket + grouting in to depths of 55m, 45m and 65m and Lugeon 3 were used.

7. Presenting the Optimum Sealing Method

Yearly inlet volume of water into the dam reservoir is 415,000,000$m^{3.}$ Total capacity of the reservoir is 440,000,000 m^3. Based on the calculation results of the seepage rate of flow in the last section, quantity of seepage from foundation and abutments of Mollasadra dam is 23427m3/day and 8551×10^3 m^3/year.

Regarding the above results in the last section, in reduction of seepage rate: effect of grouting > the cut off wall > the upstream impermeable clay blanket.

Proposed solutions for sealing of the dam are:

- 1st solution: grouting down to -65m with Lugeon 3+ cut off wall of 200m long and 20m deep in the right abutment alluvium.
- 2nd solution: grouting down to -65m with Lugeon 3+ upstream impermeable clay blanket of 60m long.
- 3rd solution: grouting down to -65m with Lugeon 3 + cut off wall of 200m long and 40m deep in the right abutment alluvium + continuation of grouting under the wall to reach to suitable bed rock.

The first solution has the least seepage rate, but due to the very high volume of required materials, difficulty construction of a 40m wall this method is not economical and therefore not proposed. Hydraulic gradient surrounding the wall in this method is 22 although the materials of the cut off wall are designed in way to be able to bear this gradient. However, erosion wise their safety is less than the other sealing methods. This solution is also not proposed due to unexpected seepage which occurs sometimes in poorly constructed areas – that is more probable in this solution due to extensive depth of the wall.

In the second solution, an upstream impermeable clay blanket is used. Due to existence of alluvial terraces and extensive spread and thickness and specific grading (incl. clay and silt) of the in situ soil in the dam reservoir, a type of natural clay blanket is performed on the bed of the dam’s lake. Therefore, replacing the above said sedimentations with this materials is not only illogical but also non-economical.

Finally, the third solution is proposed as the suitable option for easy construction of a 20m cut off wall and solidity of grouting until reaching suitable bed rocks in all sub layers of the dam location and also due to controlling of hydraulic gradients caused by construction of the cut off wall (by reduction of the wall length and continuation of grouting).

8. Final Results of the Research

Due to the above, construction of a partial cut off wall down to approximate depth of 20m, continuation of grouting with Lugeon 3 under the wall until a suitable depth at the right abutment and grouting in rock materials of the middle part and the left abutment down to approximate depth of 65m is proposed as the optimum method of sealing.

9. References:

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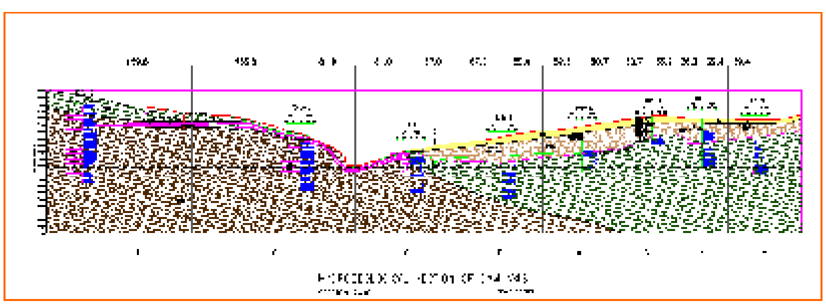
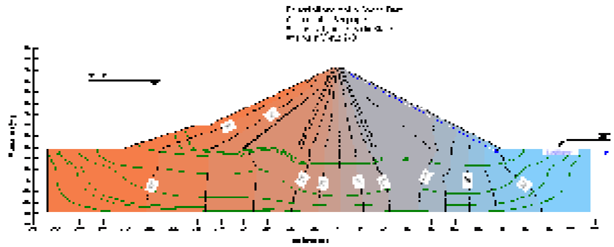
Table1 – Changes in seepage rate of flow (m^3/day) in lieu of changes in grouting depth with Lugeons 1, 3 and 5

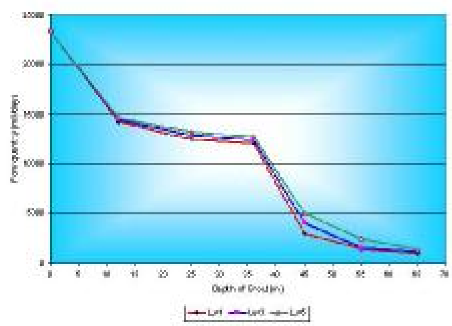
Depth of grouting	0	12	25	36	45	55	65
Lu = 1	23427	14269	12469	12049	2956	1474	941
Lu = 3	23427	14490	12918	12394	4042	1499	1221
Lu = 5	23427	14684	13278	12740	4967	2450	1380



Picture 1- Hydrogeological section of dam axis



Picture2 – Co-potential contour lines in Mollasadra dam's body and foundation with no sealing



Picture 3- Chart showing changes in seepage rate of flow (m^3/day) in lieu of changes in grouting depth with Lugeons 1, 3 and 5