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Erosion in the Foundation of Abshineh Dam (Iran)

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Almost 75% of dams in the world are constructed from soil and rock [1]; and, they can easily be damaged by seepage and piping. Earth fill dams usually suffer from this problem more; and, only a short time after the first impounding several embankment dams have collapsed [1,3, 4].

Abshineh dam, located in the west of Iran, is an earth fill dam with a clay core in which a complicated seepage has appeared through its foundation. Though, insufficient insitu testing and incomplete geotechnical investigations has led this situation, yet the highly weathered rock of foundation, insufficient depth of cut-off wall, and a fault and a Qanat[1] crossing its foundation are the most important elements which must be considered in its seepage analysis.

SEEP2D, a well-known program in the underground seepage analysis, has been used to analyze the seepage flow and find the most eroded areas in the foundation of Abshineh dam. To make seepage model with a two-dimensional program, the dam body and its foundation has been divided into several sections; and, for each section uniform soil properties are assumed. Then, the model has been updated with the insitu data which are mainly drilling, grouting, and piezometric data.

Outcomes of the analysis show a very good agreement between the calculated results and measured data. Moreover, the results prove that a high rate of erosion has been occurred in an extended zone of the dam's foundation. Moreover, the analyses of one line grouting, the method used to get the weathered foundation of Abshineh dam watertight, shows that this method does not provide a permanent remedial pattern.

In fact, the efficiency of (a very condensed) one-line grouting in a limited zone of the foundation of Abshineh dam has been analyzed and estimated maximum 60% (for seepage reduction) by the finite element program; therefore, the past experiences and conclusions[2] declaring that the reliability of one line grouting system is not as much as engineers can trust on it as the only system for seepage's controlling is certainly certified.

Moreover, the conclusions of this research must be considered for the optimized selection of the remedial method.

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[1] Qanat is a continued underground aqueduct (small tunnel without lining) which was invented in Persia and used to transit water from mountains to flat areas. Also, vertical shafts with equal distances were used to access to Qanat and dredge it. More information can be found on www.Qanat.info.

[2] Prof. Terzaghi and Prof. Casagrande, First rankine lecture, Geotechnique, 1961.

FIGURE 1. ABSHINEH DAM AND ITS RESERVOIR, HAMADAN, IRAN

I. INTRODUCTION

The Abshineh dam is a clay core dam located in Hamadan, one of the provinces of Iran, on the Abshineh River and downstream from Ekbatan dam. A picture taken over the crest of Abshineh dam is presented in Fig 1. The Abshineh dam was constructed in 1996 to secure the water supply and irrigation needs of Hamadan city. Moreover, the discharged water of Ekbatan dam accumulates behind Abshineh dam. Table 1 presents the main characteristics of the Abshineh dam.

Fig 2 shows a typical cross section of Abshineh dam, which is comprised by three main parts: rock fill, clay core, and filter. The double filter at the downstream side is used to prevent piping or transportation of clay particles from the core into the rock-fill zone. It is

TABLE 1
THE MAIN CHARACTERISTICS OF ABSHINEH DAM

Abshineh Dam's Characteristics		
1	Maximum height of dam	18 M
2	Abshineh dam's crest level	MSL+1818
3	Maximum water level	MSL+1818
4	Normal water level	MSL+1815
5	Crest length	660 M
6	Crest width	8 M
7	Normal reservoir capacity	5,000,000 M^3
8	Area of reservoir	750,000 M^2
9	Length of reservoir	1200 M

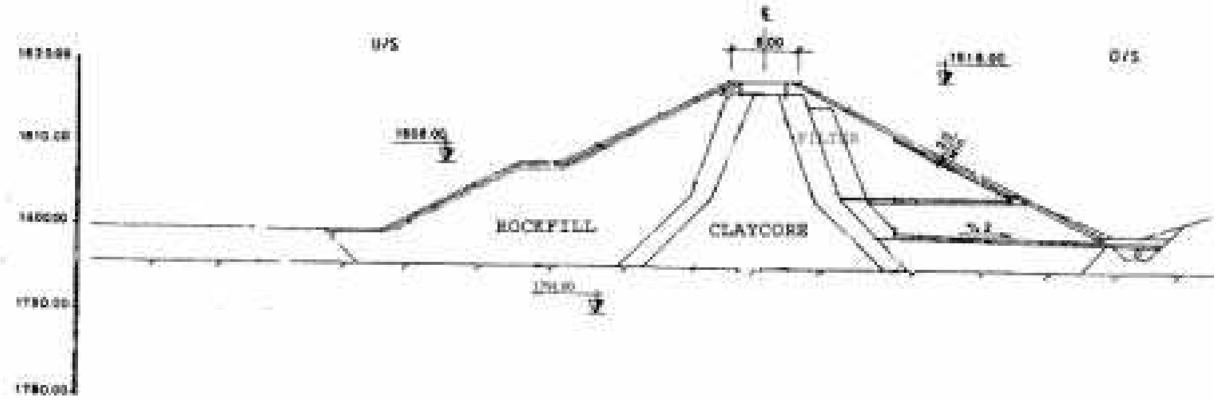

FIGURE 2. TYPICAL CROSS SECTION OF ABSHINE DAM

important to notice that an appropriate design of filter and its material size can perfectly prevent piping through the dam's body [2]. Also, a short cut-off wall with a constant depth of two meters had been designed, yet because of differing depths of the constructed cut-off wall, varying from 0.35 to 2 meters, it is not included in this Figure, neither in the seepage analysis. Nevertheless, it must be considered that in a weathered rock foundation like Abshineh dam's, a cut-off wall is an important element which can change the underground flow path, and especially prevent piping through the contact layer and foundation.

Fig. 3 represents a plan view of the Abshineh dam. Its right embankment is extended to make a higher reservoir capacity. In addition, the concrete structure[3], being used to discharge reservoir water, is displayed in this figure. Letters accompanied with numbers (C38, C37…) over the crest of the dam signify the primary grouted boreholes in an effort to get the foundation watertight; some of them, however, are not grouted.

The interest is focused on the difficult foundation of this dam: a complex site, both in a geological and geotechnical matters. For instance, the combination of karstic limestone and silt in the highly weathered foundation rock is clearly an indicator of a potential seepage problem, and generally cause to wash out the silts and clay particles through the limestone fissures.

It is not possible here to elaborate on the design process of Abshineh dam, but it is important to mention that this project has a lack of basic investigation; only one exploration borehole was drilled at the dam's location [1, 7-9]; in other words, the geological profiles of foundation are schematic. In fact, this case is a clear example that the underground condition cannot be guesstimated, and *geotechnical examinations are a very important part of the design processes of infrastructures* [10]. Accordingly, the Qanat and fault which cross through the foundation of Abshineh dam were not considered in the first design.

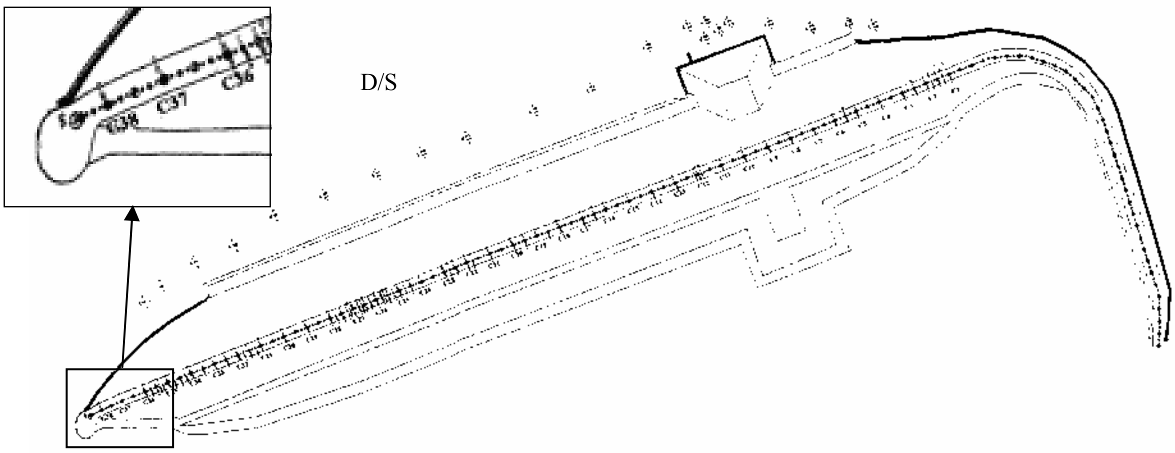

FIGURE 3. PLAN VIEW OF ABSHINEH DAM, *STATION E, WHICH IS MAGNIFIED, IS LOCATED ON* THE LEFT BANK WERE THE HEIGHT OF CLAYCORE IS ZERO

[3] Because of the probability of piping, it is suggested avoiding design of a (concrete) structure passing through the clay core; and, in the case of Abshineh dam regarding the highly weathered foundation, presence of this structure means an *unacceptable risk of failure*.

II. Dam Site Geology

The valley of Abshineh dam is almost symmetrical. The left abutment has a slope of around 4.5%, and the right abutment has a 13.6% slope below 1814 +MSL and 3.3% above that level. The site is located at Sanandaj-Sirjan[4] zone, expanding overall the northeast of Hamadan, one of the provinces of Iran.

The formations under dam are a composite of shale, marl-shale and sand-shale in the color of gray-dark to gray-light blue followed by layers of lime sand-stone with medium sand size; and, the main composite is marl-shale. The mineral combination of the main bedrock is marl-shale, clay-silicate, quartz, and carbonate combination. In addition, some metal minerals such as Fe_2O_3 can be found in the field. Shale is highly weathered, and sandstone layers are in better situation [7].

The insitu data which includes boring, testing, and grouting displays a highly cracked zone within 2 to 3 meters depth under the base of Abshineh dam, and its uniaxial strength is close to 12 MPa. Medium and high weathered rocks are at a depth of 2-6 meters below the base. And, in deeper places, there are usually better rocks, and the uniaxial strength gets up to 32 MPa or more. On the other hand, all samples of surface rock saturated in a limewater solution for 48 hours changed to clay phase.

III. History of Problems and Grouting

During the construction of Abshineh dam, a high rate of water flow passing through the foundation was detected when the rain water accumulated behind Abshineh dam could easily flow through the foundation; therefore the consultant[5] company tried to suggest a cure pattern for sealing the foundation; to evaluate one line grouting as a cure method, a grouting test was proposed and accomplished in a limited region over the half-constructed clay core (the height of the dam was maximum 5m from its base). The grouting test was applied at 0+430m from station E, located in the left abutment as it is presented in Fig. 3. In the grouting pattern, boreholes A1 and A2 (with distance of 6 meters) were drilled and grouted first; then A3, and in the next step A4 and A5 were drilled and grouted. Finally, two checking boreholes, named CH1 and CH2, were drilled to evaluate the performance of grouting in seepage reduction. A schematic draw of this pattern is shown in Fig. 4.

The main conclusions of this (grouting) test were: 1- Permeability of clay core was acceptable. 2- The highest permeable zone was under the cut-off wall. 3- Grouted cement decreased permeability of the foundation. 4- Contact zone between clay core and its foundation had a permeability of 10^{-4} cm/s [11].

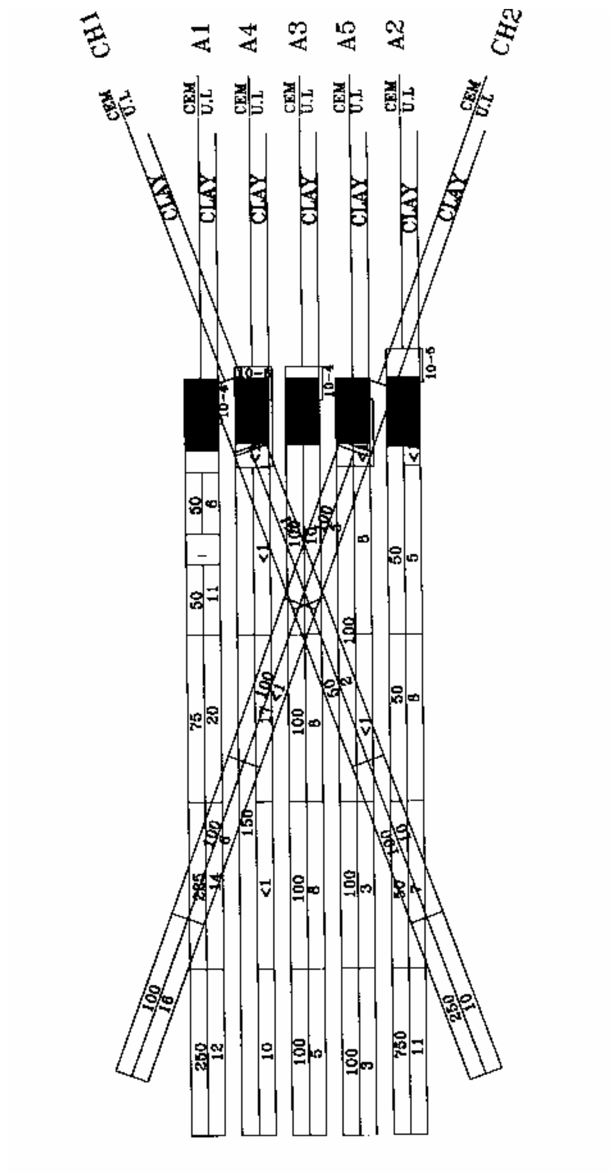

FIGURE 4. DETAILS OF TRIAL GROUTING IN 0+430 FROM LEFT OF THE DAM

Then, one-line grouting of mixed cement[6] along the top of the crest in permeable areas of foundation was suggested as a remedial plan, in which at first the distance between boreholes was 16 m and this could reduce to 2 meters by the dividing method. In this manner, the permeable boreholes were grouted, and the low permeable ones were filled with cement.

However, considering the fact that only one-line grouting was possible because of limited width of the clay core on the top and bearing in mind the past experiences of one line grouting, [1, 3, 4, 12], and conclusions of some experts[7] that *the maximum efficiency of a grout curtain can usually cause a reduction of seepage by maximum 30%,* some questions about the

[4] Sanandaj-Sirjan is one of the most dynamic (seismic) zones of Iran; and, this zone has registered diverse phases of magmatism, metamorphism and deformation. More information about this zone can be found in: http://www.ngdir.ir/States/

[5] Mahabe Ghods engineering company.

[6] Combination of cement, bentonite, and water.

[7] Prof. Terzaghi and Prof. Casagrande, First Rankine Lecture, Geotechnique, 1961.

capability of this curative method come to the mind: How effective is this method? Or, is this a permanent remedial scheme?

After first impounding in 1996, seepage was observed at the downstream side, and so was grouting restarted in the areas that had not been grouted before (low permeable boreholes). Then, at second impounding in 1999 when water depth behind the dam was not more than 6 meters, water flow was observed at three locations of downstream side: right, center, and left. The rates of discharges flowing over the downstream were estimated 20 lit/s at right and almost 4 lit/s at left; yet, the seepage rate in central part was low. As a matter of fact, development of seepage faced Abshineh dam with internal erosion; and, in as much as it might cause instability of dam, the impounding was interrupted, the reservoir water was completely discharged, and grouting was seriously restarted.

It is important to notice that the reservoir was discharged in a dry season and caused economic damages especially for the farmers of downstream side.

In this time, even grouting more than 7.5 tons mixed cement in C1, a borehole at the right abutment of dam, it did not fill, so was a shaft with diameter of 70 cm bored from the crest, and the excavation exposed a fault under the foundation. Fig 5 shows some pictures related to this borehole and fault. To close this fault, it was filled with concrete and rock in one-meter thickness, and then it was grouted with mixed cement.

Meanwhile, the primary boreholes, C11, C12, C13, C14, C27, and C34, intersected with cavities under the concrete cut-off wall; these cavities clearly show the karstic nature of the foundation. In addition, close to left abutment, borehole C27 crossed an old Qanat, (Qanat term is explained in the first page).

IV. MODELING

Seepage of Abshineh dam has been analyzed using SEEP2D, a two dimensional (2D) finite element program produced by Fred Tracy. Seep2D is a valid program for seepage analysis; and, many international projects have been analyzed by this program.

Nevertheless, using a two dimensional program provides some restrictions. For instance, making a model including different zones of a foundation, Qanat, or fault is not possible. To overcome the limitations, the dam is divided into eight different zones by length, and each zone is modeled separately; 8 zones totally have been defined, and information of these zones are summed up in Table 4. In addition, the analyses have been done for two reservoir water levels: 1809 and 1818 which represent the water level of existing data and full supply level, respectively.

Figure 6 shows the basic model used for seepage analysis of Abshineh dam. The main elements constructing the model are a clay core, grout curtain, weathered rock, and fresh rock. The cut-off wall, with varying depth, and rock-fills are not included in the model.

FIGURE 5. BORING A MANHOLE OVER THE CREST, C1 CROSSED THE FAULT THROUGH THE FOUNDATION

The grout curtain, being a zone with lower permeability, is modeled by low permeable elements, and its permeability and thickness is estimated by using the information of grouted boreholes and some checking boreholes. Furthermore, the Qanat which passes through the foundation of Abshineh dam is modeled as a small tunnel. Figure 8 presents the results of the analyses of the full reservoir water level. In this case, the outcomes of the analyses have been used for evaluation of the sealing approach used in the Qanat and fault passing through the foundation of Abshineh dam.

The data which are used for updating the model can be divided into two categories: the data of drilling boreholes including insitu testing and grouting, and the piezometric data. The first group of data, in this case, is used as a base of modeling, and the second group is used for controlling and updating the model.

In other words, the average of insitu testing and grouting data in each zone defines the permeability of the clay core, weathered rock, fresh rock, and grouted area.

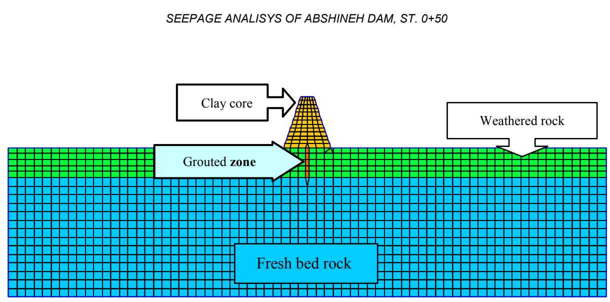

FIGURE 6. ABSHINEH DAM'S BASIC MODEL USED FOR SEEPAGE ANALYSIS

Therefore, this is a practical modeling that is completely based on the insitu data. Meanwhile, the piezometric data can effectively help updating the model; every piezometer, moreover, can act like an alarm announcing the internal erosion or increasing seepage energy. Unfortunately, at the first impounding of Abshineh dam, no pizometer was installed; although, it had been designed. However, at the second impounding in 1999 several piezometers were installed in three typical areas: clay core, contact zone, and foundation rock to measure local pore pressures. The 5th column of Table 4 presents the name of piezometers.

V. Analysis Results

As it is previously explained, in order to utilize the SEEP2D, the dam body and its foundation is divided to eight zones, and the average properties of each zone is applied to the model. The information of defined zones and the analysis results are summarized in this Table 4.

A. The Fist Zone

The first zone, is the first 40 meters of dam's length from left bank (station E), where the height of clay core is zero, as it is depicted in figure 3. The first row of the Table 4 presents the information of this zone.

However, there are no data to calibrate model for this zone; yet, the high permeability of C34, located in the border of this zone, and flowing water at the downstream side after grouting of the second zone signifies high permeability of this zone. In other words, the water flow in the left part of downstream side comes from this zone.

B. The Second Zone

In the second zone, including main boreholes, C35, C36, and several intermediate boreholes, no grouting had been done before first impounding. Yet, after seepage flow at the downstream side, this zone was completely grouted. The seepage has been analyzed on the base of data coming from drilling boreholes, insitu testing, and grouting; and the results show that both highest velocity of underground water flow and the volume of seepage have been reduced by nearly 60%. Table 2 presents the results of the analysis of seepage before and after grouting. Meanwhile, the area of high velocity seepage has been decreased as it is shown in Figure 7; so grouting does reduce seepage through the foundation and the contact layer.

TABLE 2.
Results of The Seepage Analysis Before and After Grouting in The Second Zone

MSL +	Before grouting		After grouting	
	Seepage (lit/day)	Max. velocity (m/day)	Seepage (lit/day)	Max. velocity (m/day)
1809	430	0.092	143	0.026
1815	1436	0.031	480	0.089

C. The Third Zone

The main boreholes of the *third zone*, also, had divulged a low permeability before impounding. However, the piezometric data revealed a higher permeability. In fact, backward analysis of seepage shows that erosion has been occurred in the foundation of Abshineh dam.

In order to find the rate of erosion, backward analyses were done; in this case different value of permeability has been tested as input data for the analysis. A brief of this process is summed up in Table 3; and it results a higher permeability almost 5.5 times more than the time before impounding (for duration of near two years) which proves a high rate of erosion. The total seepage volume estimated for entire of this zone is presented in Table 4.

TABLE 3.
To Get Equivalent Pore Pressure (water-level), Backward Analysis Has Been Done With The Assumed Permeabilities

MSL +1809	Piezometer A4		Piezometer A5	
	measured water level	calculated water level	measured water level	calculated water level
1ST	70.1807	1805.4	1802	1802.5
2ND	70.1807	1807.63	1802	1800.75
3RD	70.1807	1807.17	1802	1801.67

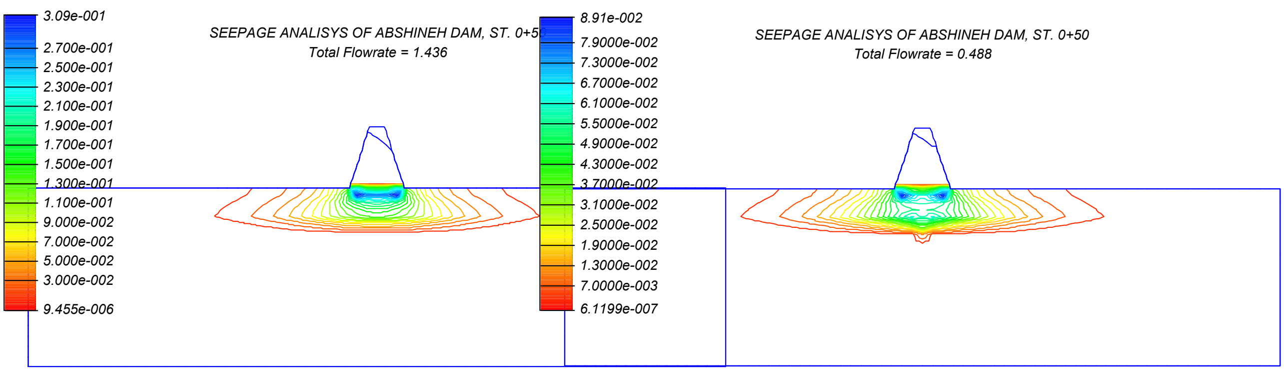

FIGURE 7. GROUTING HAS REDUCED BOTH VOLUME AND VELOCITY OF SEEPAGE; LEFT PICTURE SHOWS CO-VELOCITY CONTOURS BEFORE GROUTING AND RIGHT PICTURE PRESENTS THE SAME CONTOURS AFTER GROUTING

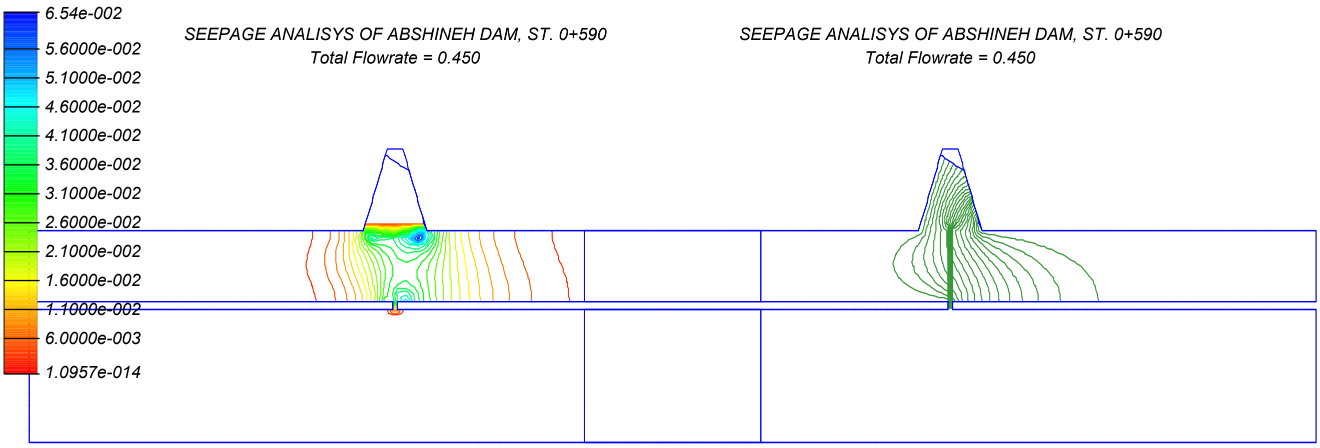

FIGURE 8. THE MODEL OF QANAT IN FOUNDATION OF ABSHINEH DAM. THE LEFT PICTURE SHOWS THE CO-VELOCITY CONTOUR, AND THE RIGHT ONE PRESENTS CO-POTENTIAL CONTOURS.

D. The Fourth Zone

In the fourth zone, half of the drilled boreholes had disclosed a permeability of 10^{-3} cm/s during insitu testing. In C27, one of the most permeable boreholes, a manhole was bored, and met an old Qanat. To close the Qanat flow path, it was filled with concrete and rock in one-meter thickness, and then it was grouted with mixed cement. This method is, also, was used to close C1 (see Fig. 5).

In order to check the performance of this closing method and its effects on the surrounded areas, a separate modeling is done. Fig 8 shows the results of model analysis used for Qanat and closing approach. As shown in this figure, concentration of high velocity seepage is an undesirable consequence of this closing method; as a result a high rate of erosion over the full length of grout curtain especially in weathered rock near the contact layer will be happened, and this case can seriously encourage piping; *so this closing approach does not provide a permanent remedial method at all!*

E. The Fifth Zone

In the fifth zone, no grouting had been done before the first impounding because of the fact that permeability of this area was reported very low by drilling of boreholes and insitu testing; nevertheless, after impounding, the out flow of water at the downstream side showed a high permeability. Meanwhile, the piezometers of this zone had many things to tell; in other words, analysis of the data of piezometers A7d and A10, located at the weathered rock of foundation, showed that a high rate of erosion has occurred after impounding. In fact, there is a big difference between the data before and after impounding. As a matter of fact, the backward seepage analysis demonstrates that if $K_x = K_y = 10^{-4}$ cm/s, the pore pressure is in agreement with the data of piezometers which do very well correspond with each other; so has high rate of erosion occurred in this zone. This fact confirms the result of the other zones, and proves the erosion-able nature of the Abshineh dam's foundation. Accordingly, three important conclusions can be drawn from the analysis of this zone: *first, no grouting in this zone caused fast erosion in the foundation. Second, a high rate of erosion is expected in weathered foundation of Abshineh dam; so will not grouting have a long lasting effect. The third conclusion is a high probability of piping in the contact layer.* The estimated seepage volume of this zone is presented in Table 4.

F. The Sixth Zone

The sixth zone spreads over 75m along the dam axis whereas the last 30 meters is located on the right abutment. This zone, also, was reported to be a low

TABLE 4.
CALCULATED RATE AND VOLUME OF SEEPAGE FOR DIFFERENT ZONES OF ABSHINEH DAM IN 1818 +MSL

Zone number	Start from	End to	Boreholes	Piezometers	Max. Velocity (cm/day)	Seepage (lit/m/day)	Seepage (lit/day)
1	0+0 (station E)	0+40	----		---	---	---
2	0+40	0+60	C29 to C36		8.90	480	9600
3	0+ 60	0+170	C26 to C33	A1u, A1d, A2, A4, A5	1.76	93	10،230
4	0+170	0+230	C24 to C28		4.69	247	14،820
5	0+230	0+410		A7u, A7d, A10, A11	4.68	316	56،880
6	0+410	0+585	C2 to C12	A13u, A13d, A14	2.10	121	21،175
7	0+585	0+600	C1		9.47	865	12،975
8	0+600	0+678		A21u, A21d	---	---	---
Total calculated seepage from Abshineh dam and it's foundation							125،680

permeable area before impounding, and it includes boreholes C2 to C12. Piezometers, named A13u, A13d, and A14 are located in this zone, and the model was updated with the piezometric data. The backward analysis of this zone, also, demonstrated internal erosion in the foundation. The estimated seepage volume of this zone is presented in Table 4.

G. The Seventh Zone

The seventh zone contains borehole C1, having a permeability of more than 100 Lugeon (1 Lugeon unit = 1 litre/m/minute at 150 psi) over its full length. This borehole intersected a fault crossing dam axis through the foundation. In order to make this borehole watertight, more than 7.5 tons of mixed cement was grouted without getting any result. Then, boring a manhole from the crest, it crossed a horizontal highly cracked fault with north to south direction. Therefore, it was closed in the same manner as C27; so can the analysis approach of Qanat (see Figure 8) also be applied for this zone. The analysis results of this zone are presented in table 4.

H. The Eighth Zone

There is a lack of data in the last zone, *eighth zone*. However, some piezometers have been installed, yet the fault can act like a drainage system; it easily affects on the piezometric data. Meanwhile, the possibility of erosion must also be considered.

CONCLUSIONS

1. The efficiency of (a very condensed) one-line grouting in a limited zone of the foundation of Abshineh dam has been estimated maximum of 60% of seepage reduction by a finite element program, and regarding the past experiences [1, 3, 4, 12] and conclusions[8], it is concluded that the reliability of one-line grouting system is not as much as engineers can rely on it as the only system for seepage's controlling.
2. The in-situ and piezometric data proves that a high rate of erosion has been occurred in the foundation of Abshineh dam estimated almost 5.5 times more than the time before impounding for the two years period.
3. Since concentration of seepage with higher velocity occurs in the grouted zones, its performance in the grouted zones will be reduced by seepage; so the one-line grouting does not prepare a permanent remedial method.
4. The analysis of method which was used to seal the Qanat and fault shows that the surrounding area of the Qanat (or fault), grouted zone, and especially the contact layer are faced with a high probability of erosion. It means that there is a high risk of piping for that area; in this case, the repairing procedure will be a very difficult task.

[8] Prof. Terzaghi and Prof. Casagrande, First rankine lecture, Geotechnique, 1961.

RECOMMENDATIONS

1. It is recommended that *engineers do not rely on the one-line grouting system as the only system for seepage's controlling.*
2. Evaluation of *the reliability of one line grouting* is an important research subject for dam engineers.
3. As far as a reliable remedial method has not been applied, developing a risk assessment system for this project, including the economical model of downstream fields is recommended.
5. The results of this research should be considered for the selection of the optimized remedial method.

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